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Par

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Recyclage des eaux grises : Etude de nouvelles filières de traitement

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Dedication

Facing a window in a residence in Lille 1 campus on a vacation

You began dreaming of what your future will be

Today, I wanted to dedicate this thesis for you

Because no one deserve it but you

You stood up, alone, with no one's help

You never gave up on your self

To my little me, I say, you first dream came true

And to myself I say! Baby keep on dreaming

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Abstract

We can't deny that our world is suffering from a major water crisis, with climate change, everything is changing. Countries must take actions toward alleviating stress on water resource and start realizing the importance of a resource that be easily recycled but instead is thrown in vain. Greywater constitutes 61% of the total wastewater stream that includes bathroom waters, kitchen water and washing machines. When treated, this source can be easily reused in wide options excluding potable uses. Our thesis explores the opportunities to treat greywater and will try to choose the most efficient yet cheap treatment systems.

First we did an overall view of different types of treatment systems, then we chose which systems can deliver both efficiency and feasibility for a certain type of greywater (low load greywater). After selecting two types of treatment systems, we wanted to merge both of them into one system that will enhance the treatment efficiency. These two system rely tightly on adsorption that is why we wanted to identify which adsorbent can offer the best percentage of pollutants elimination but still fit in the low budget of low income countries. Different type of adsorbent were tested: bricks residus, bricks risidus activated with HCl, brick activated with a deposit of FeOOH, activated carbon and different granulometry of sand. Chemical oxygen demand, turbidity and the percentage of elimination of active agents were used to judge their effectiveness.

After selecting fine sand and coarse sand we jumped into the phytoremediation concept and wanted to test different type of plants. Lavender was then selected to be part of our system. Chemical oxygen demand and turbidity were used to judge whether or not our system could deliver good results. After running these two tests, our pilot showed great results and recovered great amount of water that could be then used in different reuse options like toilet flushing or irrigation. Because user's opinion and social acceptance is a threat to any new treatment system, we visited some of the nearest hotels and resorts to see their willingness to engage in such treatment path. In addition, cost is always a major throwback to any new treatment system, therefore, cost benefit analysis was used to ensure the feasibility of our pilot.

Keywords: Chemical oxygen demand, greywater, pilot, reuse, turbidity, treatment systems.

Résume

Nous ne pouvons pas nier que notre monde souffre actuellement d'une crise majeure de l'eau en particulier avec le changement climatique, tout change. Les pays doivent prendre des mesures pour réduire le stress sur la ressource en eau. Le recyclage constitue une bonne option pour une majeure partie des eaux usées qui est rejetée en vain. L'eau grise constitue 61% du flux total des eaux usées, elle provient essentiellement de l'usage en salle de bain, en cuisine et machines à laver. Une fois traitée, cette source peut être facilement réutilisée dans de larges options, à l'exclusion de l'utilisation comme eau potable. Notre travail de recherche explore les possibilités de traitement des eaux grises et de choisir les techniques de traitement les plus efficaces et les moins coûteuses. D'abord, nous avons identifié des différents types de systèmes de traitement, puis nous avons choisi les systèmes qui peuvent fournir à la fois de l'efficacité et la faisabilité pour un certain type d'eaux grises (eaux grises à faible charge). Après avoir sélectionné deux types de systèmes de traitement, nous avons voulu les fusionner en un seul système qui améliorera l'efficacité du traitement. Ces deux systèmes s'appuient fortement sur les procédés d'adsorption, c'est pourquoi nous avons voulu identifier quel adsorbant peut offrir le meilleur pourcentage d'élimination des polluants à faible coût et adapté au budget des pays à faible revenu. Différents types d'adsorbants ont été testés : résidus de briques, briques activées avec l'acide chlorhydrique (HCl, 6M), résidus de briques activées avec un dépôt de ferrihydrite (FeOOH), du charbon actif et différentes granulométries de sable. La demande chimique en oxygène, la turbidité et le pourcentage d'élimination des agents actifs ont été utilisés pour juger leur efficacité. Après avoir sélectionné le sable fin et le sable grossier, nous voulons se concentrer sur le concept de phytoremédiation et tester différents types de plantes. La Lavande a été sélectionnée pour les expérimentations avec notre système. Deux paramètres ont été suivis, la demande chimique en oxygène et la turbidité, pour juger l'efficacité de notre système. Les résultats obtenus montrent que le pilote est opérationnel et permet de récupérer une grande quantité d'eau qui pourrait être réutilisée dans les toilettes ou l'irrigation. La dimension sociétale est un élément très important dans le succès de tout nouveau système de traitement destiné à une large utilisation par la population ou la collectivité. En fonction de l'opinion choisie, des enquêtes d'utilisateurs sont indispensables pour examiner l'intérêt suscité et l'acceptation de tout nouveau système de traitement. Dans ce but, nous avons réalisé un questionnaire qui a été utilisé lors de certaines visites d'hôtels pour percevoir la volonté d'engagement dans une telle voie de traitement. En outre, le coût est toujours le retour majeur des résultats des enquêtes, par conséquent, l'analyse coûts-avantages a été utilisée pour assurer la faisabilité de notre pilote.

Mots-clés: Demande chimique en oxygène, eaux grises, pilote, réutilisation, systèmes de traitement, turbidité.

ملخص

لا يمكننا أن ننكر أن عالمنا يعاني من أزمة مياه كبيرة ، مع تغير المناخ ، كل شيء يتغير. يجب على الدول اتخاذ إجراءات لتخفيف الضغط على مياه الشرب والبدء في إدراك أهمية المورد الذي يمكن إعادة تدويره بسهولة ولكن بدلاً من ذلك يتم طرحه بلا جدوى. تشكل المياه الرمادية 61٪ من مجمل مياه الصرف الصحي التي تشمل مياه الحمام ، مياه المطبخ والغسالات. عند المعالجة ، يمكن إعادة استخدام هذا المصدر بسهولة في خيارات واسعة باستثناء الاستخدامات الصالحة للشرب. هذه الأطروحة يتكشف الفرص لمعالجة المياه الرمادية وسيحاول اختيار تقنيات العلاج الأكثر كفاءة.

أولاً ، قمنا بتغطية شاملة لأنواع مختلفة من أنظمة المعالجة ، ثم اخترنا الأنظمة التي يمكن أن توفر كفاءة لنوع معين من المياه الرمادية (المياه الرمادية منخفضة الحمولة). بعد اختيار نوعين من أنظمة المعالجة ، أردنا دمج كليهما في نظام واحد سيعزز كفاءة المعالجة. هذان النظامان يعتمدان بإحكام على الامتزاز ، لذلك أردنا تحديد أي الممتزات يمكن أن تقدم أفضل نسبة من القضاء على الملوثات وفي الوقت عينه تراعي الميزانية المنخفضة للبلدان منخفضة الدخل. تم اختبار نوع مختلف من الممتز ؛ من الطوب الطبيعي إلى الطوب المنشط مع حمض الهيدروكلوريك ، إلى الكربون المنشط ومختلف أحجام من حبيبات الرمل. تم استخدام الطلب على الأكسجين الكيميائي ، التعكر ونسبة التخلص من العوامل النشطة للحكم على فعاليتهم.

بعد اختيار الرمال الناعمة والرمل الخشن إنتقلنا إلى مفهوم المعالجة النباتية وأردنا اختبار أنواع مختلفة من النباتات. ثم تم اختيار الخزامى لتكون جزءا من نظامنا. تم استخدام الطلب على الأكسجين الكيميائي والتعكر للحكم على ما إذا كان نظامنا يمكن أن يحقق نتائج جيدة أم لا. بعد إجراء هذين الاختبارين ، أظهر النظام نتائج رائعة واستعاد كمية كبيرة من المياه التي يمكن إعادة استخدامها بعد ذلك في خيارات مختلفة مثل تنظيف المرحاض أو الري. نظرًا لأن رأي المستخدمين والقبول الاجتماعي يشكلان تهديدًا لأي نظام جديد للعلاج ، فقد زرنا بعضًا من الفنادق والمنتجعات لمعرفة استعدادها للمشاركة في مسار العلاج هذا. أيضا ، التكلفة هي دائما الارتداد الكبير لأي نظام علاج جديد ، وبالتالي ، تم استخدام تحليل التكلفة و المنفعة لضمان قبول المستخدم.

الكلمات المفتاحية: التعكر , الطلب الأكسجين الكيميائي , المياه الرمادية , أنظمة المعالجة , إعادة الاستخدام.

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List of acronyms

- µm: Micrometer
- AM: *Achillea millefolium*
- B+Fe: Activated bricks with a deposit of FeOOH
- BAF: Biological Aerated Filter
- BC: Before Christ
- BET: Brunauer–Emmett–Teller
- B-Fe: Activated bricks but without a deposit of FeOOH
- BOD: Biological Oxygen Demand
- BSF: BioSand Filter
- CAR: Central African Republic
- CC: *Celosia argentea cristata*
- CIRIA: Construction Industry Research and Information Association
- CO: *Calendula officinalis*
- COD: Chemical Oxygen Demand
- CP: *Celosia argentea plumose*
- DOC: Dissolved Organic Carbon
- E.Coli: Escherichia Coli
- EC: Electrocoagulation
- GAC: Granular Activated Carbon
- GW: Greywater
- ISO: International Standards Organization
- LA: *Lavendula angustifolia vera*
- LU: *Linum usitatissimum*
- MENA: Middle East and North Africa
- MIEX: Magnetic Ion Exchange Resin
- N: nitrogen
- NB: Natural Bricks
- OM: Organic Matter
- P: Phosphorus
- PAC: Powdered Activated Carbon
- RSF: Rapid Sand Filter
- SBR: Sequencing Batch Reactor
- SSF: Slow Sand Filtration
- TDS: Total Dissolved Solids
- TOC: Total Organic Carbon
- Tot-N: Total Azote
- Tot-P: Total Phosphorus
- TSS: Total Suspended Solids
- UASB: Upflow Anaerobic Sludge Blanket
- UN: United Nations
- US: United States
- WHO: World Health Organization

General Introduction

1.1. Background

Everyone fears the depletion of oil resources, but these people do not realize that a much important issue can threat our future is happening: the depletion of underground water and freshwater resources.

Water is the source of life, as we know it. Difficult to purify, expensive to transport and impossible to substitute; water is the vain of food production, energy generation, economic development, our daily rituals and life itself. This vital source has its limits of approximately 1.4 billion cubic kilometers but only 2.5% are considered as fresh water **(Xercavins, 1999)**, which can be used for drinking, irrigation and for industrial uses. Population growth is a major factor in water availability. Our nation nowadays is around 7 billion and is expected to increase to reach about 9 billion in the year 2050 according to the UN **(Dubois, 2011)**. This huge number will boost the demands for water sources that are already extreme in so many countries and will worsen through the years that come, due to global warming. With this growing population rate, the income per capita will also increase, which will raise the demands on water and food. This exponential growth is pressuring many cities that are trying to satisfy the needs for water in urban areas. Therefore, all this evolution, prosperity and population growth, mismanagement, the overconsumption and pollution of water leads to one thing: Water scarcity.

With an increasing water demands and without any possibility for an increase in water supplies, water scarcity, is one of the most significant problems facing most parts of the world. Within 50 years, more than 40% of the world's population will face water stress **(WHO, 2006)**. It is estimated that 48 and 54 countries will be classified as water-scarce or water-stressed countries by 2025 and 2050 respectively.

To protect these finite resources two approaches can be taken. The first is to increase water supplies and the second is to reduce potable water demands. The first option has different strategies. Countries can increase their water supplies by constructing dams, reservoirs or can desalinate seawater, upgrade water treatment and pipe systems and finally, they can improve in operational methods such as pressure reduction of flow restrictions **(Hunt et al., 2008; Surendran & Wheatley, 1998)**. Unfortunately, these solutions will have extremely high direct and indirect costs or can threat the environment (construction of dams and desalination and seawater). The second approach will be by optimizing the existing water supply system (reducing leakage), by reducing the demand and losses by installing water-saving devices or changing public behavior, by water re-use and recycling or by looking for alternative sustainable local sources of water (rainwater harvesting and greywater recycling) **(Hunt et al., 2008)**. In many countries, the reduction in water consumption alone is not enough as the water sources are already stressed even with sustainable water consumption. The mounting need of this limited resource has inspired creative technics for freshwater management. Usually, municipal wastewater is reused following different types of treatment at large-scale plants. This kind of reuse/recycling was quickly spread in both developing and developed countries. However, a new water management alternative has started to emerge in an effort to minimize the effects of water scarcity using low-cost solution: reuse of greywater. Greywater reuse is one strategy that can be considered useful to satisfy non-potable water needs.

To summarize, population growth and economic prosperity coupled with climate change are triggering water scarcity. With water resources worsen every single day we have to take action to save our world and to sustain this vital source for our next generation. Thence, reusing and recycling blackwater is not the only solution; greywater can also be a part of overarching urban water management plan.

Not only numerous pipes mix between blackwater and greywater, also some of us do not understand the difference between them. Simply and without any complexity, greywater combines water flowing from sources such as showers, washing machines, bathroom sinks, dishwashers and kitchen sinks. These sources together with toilet wastewater form what we call blackwater. Greywater represents approximatively 60 to 80% of household wastewater. This continually and consistently produced water can be considered a readily available and reliable source that can be easily reused. Unfortunately, most conductive pipes mix black and grey water together; otherwise, by excluding toilet water, greywater is less polluted **(Almeida et al., 1999)**. By reusing/recycling this available source, freshwater demand can be reduced; consequently, we can rescue the water levels in countries from dropping, prices of rising and introduce the knowledge of conserving water in our communities.

Generally, to reuse or recycle blackwater, well equipped wastewater plants are constructed and millions of dollars are spent on equipment's and maintenance. For greywater, many studies and technologies were placed to remove pollutants, but if we want to implement this concept in every facility, we should take into consideration the ration of cost/efficiency. Although irrigation takes over 70% of freshwater consumption **(FAO, 2008)**, plants maybe the solution for water treatments. With different studies done by using plants for the remediation, the term of phytoremediation began to grow in every part of the world.

1.2. Aim and Objectives of this study

This thesis aims to identify greywater treatment systems and highlight the most efficient and easiest method to implement it in different type of facilities. In addition, this work will investigate different types of plants and see their behavior towards greywater. The global objective is to provide a new efficient concept for greywater reuse. Toward this objective, a pilot study was conducted to try to eliminate the major pollutants of greywater with low cost equipment's and maintenance.

1.3. Outline of the thesis

According to the following objectives, we will try to find a proper functioning small-scale, low-cost greywater reuse and disposal systems for urban areas. This is an important part in future waste management plans and a step along the path to alleviating scarce water problems.

This thesis will begin with a general introduction about greywater characteristic and chemical, physical composition then will illustrates the most popular technics used for treating greywater, guidelines and finally reuse possibilities. In this chapter, a review was submitted and accepted in Desalination and Water Treatment (DESWATER) journal. Chapter 2 will cover the first technical content of our thesis. This chapter first goes through basic knowledge of adsorption and adsorbent characteristics then investigates the ability of different types of adsorbent (residual bricks, activated carbon and sand) to eliminate pollutants found in greywater. Two articles concerning residual bricks and activated carbon are intended for submission in Water treatment scientific journal. Chapter 4 explores the pilot that we have constructed and shows how we chose the dimensions, what plants we decide to use and base on what analysis must be followed. Plus in this chapter we studied different aspects of our pilot like social acceptance and financial approach. The Final chapter draws a conclusion with suggestions for further work and what were the limitations in our work.

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Chapter 1 – Literature review

1.1. Introduction

On August 1989, Santa Barbara was the first district in the United States that legalized greywater. As a response to a letter from the water district conservation office, Santa Barbara Board of supervisors approves residential use of greywater. As a result, greywater and blackwater were separated. Appendix 1, is a copy of the Title 24, Part 5, of the California Administrative Code “greywater systems for single family dwellings”, commonly called the California Greywater Standards. After two year, on spring 1991, the first edition of “Create an Oasis with Greywater” was published and in the same year, five other cities adopted the concept of greywater. In 1992 California was part of the State plumbing code making it legal to use greywater everywhere in California.

As years went by, the concept of greywater was growing and spreading in every part of the world. This new resource seemed to be the answer to water scarcity, whereas countries were concerned for their huge water consumption.

Australia followed the United States, and conducted studies that concluded later on that significant water savings could be made from the responsible reuse of greywater **(Anda et al., 1997)**. In addition, Australia developed guidelines for greywater reuse **“Australian Guidelines for Water Recycling: Managing Health and Environmental Risks”** .Cyprus then initiated a program for households in order to reuse greywater for domestic landscaping and toilet flushing. Cyprus as well as Korea and Japan had incentive programs for installation of greywater systems **(Soroczan, 2008)**. For example in Tokyo, greywater systems are obligatory for buildings with an area of over 30,000 square meters **(Hanson, 1997)**. Studies were published from two agencies in the United Kingdom (Environment Agency **(Agency, 2008)** and CIRIA **(Leggett et al., 2001)**) concerning greywater treatment and reuse. Due to the high quality water available in Germany from rainwater collection, the use of greywater recycling systems has been limited. Several municipalities in Spain and Catalonia, have passed regulations to promote greywater reuse in buildings **(Domènech & Saurí, 2010)**. As for Norway and Sweden greywater reuse systems were implemented in some student dormitories and apartment buildings **(Jenssen, 2002)**.

Concerning the Middle East and North Africa (MENA) region, 5% of the world’s population inhabits this region with 1% of accessible water resources. The Gulf States has no surface water that can be taken into consideration and are relying principally on desalination or groundwater.

Saudi Arabia conducted studies in order to improve public awareness and greywater reuse system **(Al-Jasser, 2012)**. Kuwait reuses a significant portion of treated ordinary domestic wastewater but the reuse of greywater is not common yet **(Abusam, 2008)**. The United Arab Emirates, and especially Abu Dhabi, rely on reusing treated wastewater but still not familiar with reusing greywater. Yemen is the least advanced country regarding reusing any wastewater or greywater because of its predominantly rural setting, limited sewer connection and wastewater treatment plants which do not meet national quality requirement. Jordan, has a scarce resources with no major rivers and minimal rainfall. Therefore, Jordan is considered as an Arab leader in greywater studies. Although Lebanon has numerous amount of rivers, but with climate change everything is in danger. Therefore, some projects were conducted in Lebanon to enhance the idea of greywater reuse **(El-Hajj, 2010),** but unfortunately, the reuse has no high priority in the governmental action plans.

In order to use and experiment on greywater, we should understand its composition, physical, chemical and microbial characteristics, what are the most systems used in greywater treatment and what are the guidelines and reuse options.

1.2. Greywater Composition

Depending on personal hygiene habits, socio-economic status, cultural practices and lifestyle of each resident, products and chemicals used at home for bathing and laundry, frequency of cleaning, cooking habits and length of showers all these factors affect the composition and quality of greywater. For example, longer showers contributes to diluted, lighter greywater. Or, water softeners, reduce the hardness of incoming municipal water. Each human produces slightly different greywater composition, because of varying amount of dead skin cells, dirt, body oils and fecal coliforms in their intestines that vary according to age **(Nolde, 2000), (Rose et al., 1991)**.

Greywater represents 50 to 80% of total water uses **(Al-Jayyousi, 2003; Christova-Boal et al., 1996).** Because this water source come from washing hands, body, clothes, hair and other; greywater contains often high concentrations of oils, residues from soap, detergents, cleaning agents and low content of metals or organic pollutants depending on usage of substances like paints and other solvents **(Ridderstolpe, 2004).**

Greywater have different origins, therefore, each type has its own composition and characteristics. Water generating from bathrooms (hand washing and bathing) constitutes 50-60% of greywater. It contains, soap, shampoo, hair dye, toothpaste and cleaning products; therefore, it is considered as the least contaminated type of greywater. Micro-organisms could also have their origin from urine and feces washed away during bathing and washing of hands and diapers.

Kitchen greywater contributes 10% of the total greywater volume. Seriously polluted with food particles, oils, fats, other wastes, detergents and cleaning agents; this type is not suited for reuse in all greywater treatment systems. In addition, usually the temperature of kitchen greywater is higher than other types. The large amounts of organic matter present in kitchen greywater promotes the growth of microorganisms.

The third type originates from washing machines, generates 25-35% and contain large amount of soap and detergent. The quality of this type of greywater varies from wash to wash, and can contain harmful substances such as paint, solvents, pesticides and herbicide due to clothes residues.

1.3. Greywater Characteristics

In the purpose of treating greywater, we should have more knowledge of the characteristics of raw water entering any treatment system. The acquaintance of chemical, physical and microbial characteristics will be our reference in the next several chapters to identify whether or not this system is efficient. We should note that the characteristics of greywater highly depend on the volumes produced. High strength greywater are produced, when little water are used and vice versa, when high water is consumed greywater becomes more diluted.

1.3.1. Physical and Chemical greywater characteristics

To monitor the efficiency of each system, chemical and physical characteristics of greywater should be known. Mostly, greywater is taken as any other regular water in testing and no further tests are imposed. As said earlier, most of the greywater, according to their type, can contain soap, shampoo, cleaning products and could contain some solvents; therefore we can find high chemical concentrations especially of sodium, phosphate, boron, surfactants, ammonia, chlorine and nitrogen as well as high suspended solids, turbidity and oxygen demand.

As basic water quality parameters, total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and turbidity should be tested. Physical characteristics combine temperature, suspended solids. For the temperature of greywater, it is higher than water supply within 18 to 30°C, because of the use of warm water for personal hygiene and cooking water. This high temperature will enhance the growth of bacteria and decrease the solubility of $CaCO_3$, which can produce precipitation in storage tanks and pipes. Suspended solids, foods, oils, hair, powdered detergents and soaps can cause turbidity in water, clogging of pipes, pumps and filters used. Containing a variety of solids and dissolved impurities, we test suspended solids to be able to quantify particles present in a certain water column. TSS can differ from study to study even though water is originates from the same type. For example, in greywater originated from bath, 76 mg/L of TSS has been determined in greywater of university residence **(Surendran & Wheatley, 1998)**. While greywater of residential housing in urban area collected from 28 households, between 54 and 200 mg/L of TSS has been determined **(Almeida et al., 1999)**. For turbidity, greywater contains much lower turbidity than sewage or potable water systems **(Franklin, 1991)**.

The pH indicated whether a liquid is acidic or basic or natural, because this indicator can affect soil and plants if reused water is used in irrigation. This indicator in greywater is dependent strongly on the pH of the original water supply. The pH of greywater range between 7 and 8 because of the alkalinity of soaps and detergents **(Jefferson et al., 2004)**.

As said earlier greywater contains salts (sodium, calcium, chlorine etc.), in this purpose electrical conductivity is measured to know salinity of this resource. The salinity of greywater is normally not problematic, but can become a hazard if used for irrigation since it could reduce yield potential. With the revolution in agricultural studies to overcome this problem, we could choose salt-tolerant plants. According to, **(Surendran & Wheatley, 1998)** and **(Jefferson et al., 2004)**, greywater have low concentrations of nitrogen, phosphorus and potassium that rarely exceed 5 mg/L, because urine are excluded from greywater the only origine for these 2 componunt are products used. And to prove our saying that each greywater differs with used products and practices, residences that uses phosphate-free detergent will have low phosphate than other households. The phosphate-free detergents are important regarding the problems that they can indure such as the algae growth in receiving water; but, nitrogen and phosphorus are important for the plant growth also. In countries where phosphorous-containing detergents is not banned yet, the main sources for these compounds are the dishwasher and laundry detergents and could be found with a concentration ranging from 4 to 14 mg/L **(Eriksson et al.,**

2007). A deficiency in nitrogen and phosphorus can be noted because these 2 compounds are excreted into toilet bowl, which is not included in greywater and this can be illustrated in the ratio of COD:N:P in previous studies. Between 100:20:1 of COD:N:P in **(Franklin, 1991)**, 250:7:1 **(Franta et al., 1994)** and 100:10:1 **(Beardsley & Coffey, 1985)** these 3 studies prove that greywater has a significant lower concentration of inorganic nutrients. According to **(Jefferson et al., 2000)** this deficiency could limit biological treatment.

BOD refers to the amount of oxygen that would be consumed if all the organics in one liter of water were oxidized by bacteria and protozoa. Usually by using bacteria within a certain time span (5 days normally) BOD could be measured. In addition BOD can differ from study to study and type to type of greywater. For example, in greywater obtained from university residence, water coming from baths had 216 mg/L, hand washing 252 mg/L, kitchen sink 536 mg/L and washing machines had 472 mg/L of BOD (**Surendran & Wheatley 1998)**. And COD refers to the measure the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD of greywater varied strongly depend on the type of source. For example, greywater from baths, hand wash, kitchen sink, washing machines and dishwashers contain 645, 95-386, 1340, 1339 and 1296 mg/L of COD respectively (**Friedler, 2004)**. The **Table 1.1** is a compilation of the value of principal parameters of greywater obtained from various studies. COD and BOD in greywater are higher than domestic sewage because of the poorly biodegradable materials such as soap and greases **(Sayers, 1998)**. Discharging high BOD and COD into surface water can cause oxygen depletion, which later can affect the aquatic life.

Although, greywater may be contaminated by chemical and physical pollutants, risks are minimal as those pollutants are typically human hygiene products in low concentrations **(Beveridge et al., 2007)**.

The main components in any household cleaning products are: Surfactants. These surface-active agents, consist of a hydrophilic head and a hydrophobic tail and by lowering the surface tension of water, they allow the cleaning solution to wet a surface more rapidly. Of course, laundry and automatic dishwashing detergents are the main source of surfactants in greywater, also personal cleansing products and household cleaners can be considered as a source. Depending on the type and quantity of detergents used, the amount of surfactants present in greywater can vary. The concentration of these surfactants can range from 1 to 60 mg/L **(Friedler, 2004).** Surfactants can endure one problem, because detergents are a main source of boron in greywater and although this compound is essential for plants but an excessive amounts become toxic.

PARAMETERS	WC	BATH	HAND WASH	KITCHEN SINK	WASHING MACHINE	DISHWASHER
TURBIDITY (NTU)	60-240[1]	92[2] 28-96[3] 49-69[4]	102[2]		50-210[1] 108[2] 14-296[3]	
TOTAL SOLIDS (mg/L)		631[2] 777-1090[5] 250[6]	558[2] 835[5]	1272-2410[5] 2410[6]	350-2091[5] 410-1340[6]	45-2810[5] 1500[6]
TOTAL VOLATILE SOLIDS (mg/L)		318[2] 533[5] 190[6]	240[2] 316[5]	661-720[5] 1710[6]	330[2] 125-765[5] 180-520[6]	30-1045[5] 870[6]
pH	6.4-8.1 [1] 7.1[5]	7.6[2] 6.7-7.4[4,5]	8.1[2] 7.0-8.1[5]	6.5[5] 6.3-7.4[8]	8.1[2] 7.5-10.0[5]	9.3-10.0[1]
CHEMICAL OXYGEN DEMAND (mg/L)	210-230[5]	645[5] 210-501[7] 100-633[9]	95-386[5] 298[7]	644-1340[5] 1079[7]	725[2] 1339[5] 1815[7]	1296[5]

BIOCHEMICAL OXYGEN DEMAND (mg/L)	173[5]	216[2] 170[6] 424[5]	252[2] 33-236[5]	536[2] 530-1450[5] 1460[6]	48-290[1] 472[2] 280-470[5] 150-380[6] 282[10]	390-699[5]
TOTAL ORGANIC CARBON (mg/L)	91[5]	104[2] 30-120[5] 100[6]	40[2] 119[5]	582[5] 880[6]	381[5] 100-280[6]	234[5] 600[6]
TOTAL NITROGEN	4.6[1]	5-10[9]		15.4-42.5[8]	1-40[1] 6-21[6]	40[6]
TOTAL PHOSPHORUS	0.11-1.8[1]	2.0[6]			0.06-42[1]	68[6]

Table 1. 1. Values for physical-chemical parameters and nutrients in greywater

(1) Christova-Boal et al. (1996); (2) Surendran& Wheatley (1998); (3) Rose et al. (1991);
(4) Burrows et al. (1991); (5) Friedler (2004); (6) Siegrist et al. (1976); (7) Almeida et al. (1999); (8) Shin et al. (1998); (9) Nolde (1999).

1.3.2. Microbial Characteristics

Through inhalation, ingestion or simple contact with reused water anyone can be infected with a variety of bacterial, protozoan and viral pathogens. Although some will find that toilet flushing has no effect and can easily be reused even without treatment, **Gerba et al., (1995)** showed that it could produce aerosols (bacteria and viruses) that can settle and spread up to 83 cm from the toilet seat **(Barker & Jones, 2005)**. Not only toilet flushing, all aerosol-producing activities such as car washing or spray irrigation could cause risk of infection by inhalation or typical contact of *Pseudomonas aeruginosa* **(Evans et al., 2006)**, *Staphylococcus aureus* **(Wertheim et al., 2005)**, *Legionella pneumophilia* **(Atlas, 1999)** and more. If we mistreated water used in these activities, consequences could range from respiratory tract infection to skin infections especially for elderly, very young and immunocompromised members of society.

Greywater can be divided into two groups, light and dark greywater. Generally dark greywater is considered more polluted then light greywater from a chemical and microbial point of view because it includes kitchen water **(Friedler, 2004)**. Dark greywater can cause more human illness if not treated correctly because of the high organic matter and high temperature present in these waters that favors the growth of microbes **(Denis, 2007)**. When treating greywater, our aim is to eliminate all kind of pollution and none desirable compounds. Consequently, the chemical composition and microbes present in greywater that could affect the quality of our output should be determined.

The primary concern for any user of a reused water is risks of pathogens especially fecal transmitted bacteria, viruses and protozoa. The concentration of organisms is affected the most by the source of greywater. Also family members especially small children and adults can affect the total and fecal coliforms found in greywater **(Rose et al., 1991).**

Total coliforms in greywater can range from 1.7 $log_{10}.100mL^{-1}$ **(Rose et al., 1991)** up to 8.8 $log_{10}.100mL^{-1}$ **(Gerba et al., 1995)**. Fecal coliforms, *E.coli* and Enterococci have a concentration of 4.2, 3.3 and 2.8 $log_{10}.100mL^{-1}$, respectively.
Total coliforms group both fecal coliforms (example: *Escherichia*) and non-fecal coliforms (example: *Enterobacter*). This type of bacteria is rod-shaped, gram-negative can be found in soil, water and the digestive system of animals and humans. Some of these bacteria are pathogenic and can cause typhoid fever and cholera **(Jefferson et al., 2004)**. Generally to be

able to test the microbial quality of water, we use indicator organisms to have a rapid test and in many cases we use coliform bacteria.

Fecal contamination of greywater is not an occasional occurrence. Fecal coliforms, *E.coli* and Enterococci are reported in several studies and enteric pathogens may be present. Enteric pathogens could be present throw washing of raw meat or vegetables which can also contain *Campylobacter* and *Salmonella* **(Cogan et al., 1999), (Rose et al., 2001)**. *E.coli* can be found in large numbers in the intestine of humans and warm-blooded animals and can live longer than enteric pathogens therefore it is used also as an indicator of water quality. Fecal coliform is also used as an indicator because it indicates the presence of other pathogenic bacteria like *Salmonella*, *Shigella* and *Vibrio* **(Cogan et al., 1999)**. The presence of such type can cause typhoid fever, hepatitis and gastroenteritis. A pathogen is defined as an organism which benefits from the suffering of another organism, and the most concerned pathogens include *Cryptosporidium* and *Pseudomonas* sp. **(Craun et al., 2005)**.

P.aeruginosa and *Staphylococcus aureus* were found in 20 greywater samples from a single household. High number of *Staphylococcus aureus* ranging from 7.0 – 7.7 $log_{10}.100mL^{-1}$ have been found in shower greywater from military camp. *P.aeruginosa* and *Staphylococcus aureus* can be found in mouth, nose and throat of humans **(Eriksson et al., 2007)**.
Legionella pneumophilia is a bacteria that grow in high water temperature. Water originating from baths usually have high temperature, therefore it was important to discover whether or not there was any trace of *Legionella pneumophilia* in previous studies. Only one study focusing on greywater collected from a military camp has reported their present with the concentrations between 2.2 and 2.9 $log_{10}.100mL^{-1}$ **(Birks et al., 2004)**. And the same study has reported the concentration of *Cryptosporidium* at 8.3 $log_{10}.100L^{-1}$.

Greywater storage can increase the concentration of pathogens, excluding *Salmonella* sp., *Shigella* sp., and *Campylobacter* sp.; therefore it is more likely to store these water until 24 maximum 48 hours **(Rose et al., 2001)**. More details about each bacteria will be illustrated in **Table 1.2**.

GREYWATER SOURCE	TOTAL COLIFORMS (LOG_{10}.100 mL^{-1})	FECAL COLIFORMS (LOG_{10}.100 ML^{-1})	ESCHERICHIA COLI (LOG_{10}.100ML^{-1})	ENTEROCOCCI/ FECAL STREPTOCOCCI (LOG_{10}.100 ML^{-1})	REFERENCES
WASH BASIN	4.7-5.8	1.5-3.5	3.8	>2.3	Birks et al. (2004); Friedler (2004) ; Surendran and Wheatley (1998)
SHOWER	3.0-5.0	1.0-6.6	2.8-3.2	1.5-3.3	Rose et al. (1991); Nolde (2000); Friedler (2004) ; Jefferson et al. (2004)
BATH	1.7-4.4	6.6	1.9-4.3	1.0-1.6	Dixon et al. (2000); Friedler (2004) ; Jefferson et al. (2004)
LAUNDRY	1.7-5.8	1.4-6.6	No Data	1.4-3.4	Rose et al. (1991);Christova-Boal et al. (1996); Surendran and Wheatley (1998); Dixon et al. (2000); Friedler (2004)

Table 1. 2. Indicator bacteria in different greywater types

1.4. The most popular systems used in treating greywater (Published in Desalination and Water treatment (DESWATER) journal)

1.4.1. Abstract

With the scientific evidence of climate change is occurring, water conservation is extremely import, thus every drop of water counts, whereas 61% of the domestic wastewater stream a by-product of households, municipal wastewater from communities (also called sewage system) and or industrial wastewater from industrial activities. Known as greywater, can be easily recycled but is discarded. Countries, municipalities, and communities realized the importance of graywater recycling and reuse. Studies and practices were started to remove and or eliminate major pollutants so that the recycled water can be used for irrigation, toilet flushing, and many other uses. The use of different types of filtration systems such as slow sand filtration, rapid sand filtration, slanted soil, and others common l systems techniques like sequencing batch reactor, upflow anaerobic sludge blanket reactor used in wetlands . This review aims to discuss the most efficient systems for the treatment of greywater, by comparing more than 20 systems for their biological, chemical and physical removal of pollutants.

Keywords: constructed wetlands, filtration, greywater treatment, slanted soil and technics.

1.4.2. Introduction

The reuse of wastewater is becoming more and more a necessity around the world, this is due to the growing concern over the shortage of available freshwater supply. Low amounts of rainfall, drought conditions, high evaporation, and large demands for freshwater, growing population, higher standards of living, and economic considerations. These issues are forcing countries to search for alternative solutions as a substitute to freshwater consumption and resources. Reusing and recycling greywater is receiving increasing attention as a key to overcome high urban water demand. Recycling Greywater (GW) studies has increased from 38 studies in 2008 to 110 studies in 2017, and continuing. GW is domestic wastewater excluding toilet waste and can be classified as either low-load GW (excluding water from kitchen) or high-load GW (including water from kitchen) and constitutes 61% of the total domestic wastewater stream[1]. Hence, we can conclude that this source have different origins: bathroom that constitutes 50 to 60% of greywater, kitchen greywater with 10% and washing machines with 25-35%. Greywater can be reused for toilet flushing, irrigation of lawns, athletic fields, cemeteries, parks, golf courses and domestic garden, washing of vehicles and windows, concrete production, and groundwater recharge [2]. Different studies were conducted to address challenges of different type of greywater, taken into considerations the personal hygiene habits, socio-economic status, cultural practices, the lifestyle of residents, the products and chemicals used at homes for bathing and laundry, the frequency of cleaning, cooking habits, and length of showers. All of these factors affect the quantity, composition, and the quality of greywater generated. This is critical to select the best appropriate treatment method of greywater when dealing with chemicals, solid, and microbial characteristics of greywater. High concentration of sodium, phosphate, boron, surfactants, ammonia, chlorine, nitrogen as well as high suspended solids and oxygen demand; originated from soap, shampoo and cleaning products could be found in greywater. Nitrogen and phosphorus concentration can change from user to user, because some countries ban the use of these two components in detergents and other do not. From study to study and from type to type; physical, chemical and microbial characteristics of greywater can vary. Factors effecting such variations of water sources are temperature from hand basin, kitchen sinks, and bathtubs. Other factors are, user's age, microbial characteristics, human with of dead skin cells, dirt, body oils and fecal coliforms.

In this review we will list and compare several popular methods that are used to treat greywater that's can deliver high efficiency based on the input, the type of wastewater and the quality of greywater. Because of the numerous studies made in this subject, only studies that provide results for at least one chemical, physical or microbial parameters were mentioned.

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A review of the most popular systems for greywater treatment

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ABSTRACT

With the scientific evidence of climate change is occurring, water conservation has now become extremely important and every drop of water counts. More than 60% of the domestic wastewater is a by-product of households, municipal wastewater. Known as greywater, it can be easily recycled but has historically been discarded instead. However, countries, municipalities, and communities have now realized the importance of graywater recycling and reuse. Studies and practices have been started to remove and or eliminate major pollutants so that the recycled water can be used for irrigation, toilet flushing, and many other uses. Different types of filtration systems can be used, such as slow sand filtration, rapid sand filtration, slanted soil, and others common systems techniques like sequencing batch reactor, upflow anaerobic sludge blanket reactor used in wetlands. This review aims to discuss the most efficient systems for greywater treatment, by comparing more than 20 systems for their biological, chemical and physical removal of pollutants.

1.4.3. Treatment systems

As discussed earlier, greywater is divided into 2 main categories, low load and high load, and it will be more suited to differ between treatment methods that can overcome each type. Below will discuss the most popular methods used for treating low greywater load, then high greywater load.

1.4.3.1. Low load greywater treatment systems

Slow sand filtration (SSF) is the most studied method, because it's well suited for rural communities since it does not require a high degree of operator skill or attention. This technic that has been used for hundred years is simple to use, reduce protozoa, operate for up to 10 years and the materials are available [1]. But slow sand requires large surface, maintenance and is not effective on viruses. Plus the major problem that slow sand face is clogging and that it cannot be used on high turbid water. This filter consists of layer of sand supported on a layer of graded gravel [3].Previous studies [4,5,6,7] reported the efficiency of SSF in water treatment, in which the average of COD, BOD, DOC, Tot-N, turbidity, OM, TOC, *E.coli*, total coliform and fecal coliform removal. Zipf et al, (2016) [4], took the water in this study from lavatory sinks in a university campus and had 35.8 ± 45.1 NTU for turbidity, 7.7 pH, 56.0 ± 15.9 mg/L for BOD, 145.8 ± 79.1 for COD, 8.3 ± 3.5 mg/L of surfactants and1.8 x 105 ± 4.4 x 105 NMP/100 mL of total coliforms. By using slow sand filtration, the average removal efficiency was 61%, 56%, 56% 70% and 61% for turbidity, BOD, COD, surfactants and total coliforms respectively. Li et al. (2010) [5] used landscape water to prove if slow sand filtration could eliminate pollutants. In this study, raw water had 3±11.4 NTU for turbidity, 22±50 mg/L for COD, 2.4±9.9 mg/L for BOD and 1.1±3.9 for total nitrogen (Tot-N). After 46 days of test, the average removal of turbidity, BOD, COD and Tot-N of 86%, 67%,34% and 59%. The third study [6] founded the typical removal efficiencies for slow sand filter when operating in Colombia. Raw water was monitored for over 2 years and then a mean of each parameter was calculated. The mean of turbidity was 64 NTU, fecal coliforms was 63.3 CFU/100ml,DOC had 18 mg/L. Working with a filtration rates between 0.04 and 0.2 m/h; the removal efficiency of turbidity, coliforms, DOC and BOD were 99%, 90 to 99%, 5 to 40%, 46 to 75% respectively. The forth study monitored [7] COD, turbidity and total bacterial counts for more than one year using slow sand filtration and had 43.9% removal of COD, 89.5% for turbidity and 73.5% for total bacterial count. One study done by Kader Yettefti et al, (2013)[8], reported higher percentages when used river sand from morocco with 88% for COD, 72% for Tot-N, 65% for Tot-P and 86% for TSS. Therefore we can conclude that changing conditions of media can increase the percentage of elimination.

The rapid sand filters (RSF) is also commonly used for light load greywater but also can be used for high load. This filter is a large sand grains (1 - 2 mm) supported by gravel (5 - 20 mm) and capture particles throughout the bed [9].The advantages of rapid sand filters, that it treats a broad range of water, effectively removes colors, requires smaller land and lower labor cost. Moreover, it is a simple and low cost technology. It is moderately effective on guinea worm larvae, iron, manganese and turbidity; a little effective on bacteria, odor, taste and organic matter (OM). However, similar to the SSF, the RSF can disturb by the clogging problem and it requires chemicals addition and a high level of operator skills. Numerous studies have focused on the influence of certain parameters on the efficiency of RSF [10,11,12,13]. Yousaf et al. (2013)[10] have reported the efficiency of RSF to eliminate 25% of COD when they 80mg/L as input water from canal water near Peshawar. Higher efficiency of elimination has been reported by Van Haute et al. (2012)[13] with 70.4% because of the use of coagulation flocculation before RSF. Low elimination was reported for BOD with only 14% [10].RSF is not appropriate to eliminate DOC and TOC with only 2.7% and 20% respectively [11,12]. However, turbidity can be eliminated satisfactory by RSF with > 98% of removal [13,14].Previous works were also interested in studying the **roughing filter**, which can be classified according to flow as vertical or horizontal. The horizontal flow-roughing filter is more commonly used because of its unlimited filter length and its simplicity layout. In this type of flow solids settle on top of the filter medium surface and then grow into aggregates. Part of these aggregates will drift towards the bottom as soon as they become unstable[15]. Comparing to other technics the roughing filter is the cheapest and it doesn't require chemical addition sand large amount of space. Nkwonta and Ochieng (2009)[16]has repported the modifications impact to roughing filtration technology. Different case studies have been done in Iran, Malysia, Africa, India and Sri-Lankain which each study used different type of medium (*local Iranian sand and gravel* with decreasing sizes: 25mm- 4mm, *limestone* with ranging particulate sizes: 1.91mm – 16.3mm, *broken burnt bricks and charcoal, fiber glass sheeting* filed with gravel and coarse). Limestone roughing filter achieved the best removing efficiency with 51 to 67% % of BOD, 79 to 88%% of TSS, 75 to 92%% of turbidity, and 67 to

96%of total coliform. The filtration rate depends on the type of the filter. The efficiency increase with the decreasing of flow rate and optimal flow rate was obtained at 0.5 m^3/h [17,18, 19].

Another technique is **Slanted soil**, it is simple to implement with low cost and can perform during 3 years without maintenance and is known to treat low load greywater [20]. This slanted soil system consists of several chambers containing soil that can be stacked vertically, which require only smaller space. Two studies used the Kanuma soil (Japan) which consists of alumina and hydrated silica, this system could remove organic pollutants, total nitrogen, total phosphorus and suspended solids [21,22]. In Iyatama et al. (2006) study [21], influent COD, BOD, SS, Tot-N and the Tot-P were reduced from 271 mg/l, 477 mg/l, 105 mg/l, 20.7 mg/l and 3.8 mg/l in the influent to 40.6 mg/l, 81 mg/l, 23 mg/l, 4.4 mg/l and 0.6 mg/l, respectively, in the effluent. Same results were showed when using the same media [22].Another study done by Ushijima et al. (2015) [23], used crushed baked mud brick, with different sizes ranging from 1mm to 9.5mm and with synthetic greywater and were divided into 2 groups shower, laundry. During the days these 2 types were feed according to 3 periods of the day (Morning and noon) and with different quantities. The average removal of COD and suspended solids were approximately -equal to the previous studies with 94% and 80% respectively. Crushed baked mud brick eliminated more than granite and gravel that felled behind for the COD, BOD and suspended solids average removal. Based on two studies done in the international institute of water and environmental engineering in Burkina Faso, using granite (1 to 6mm) in slanted soil system [24,25]. Collecting water from 5 different families, results showed that granite can remove 67.6% COD, 95.6% BOD and 90% suspended solids; gravel removed even lower percentages with 33%, 78% and 46% for COD, BOD and suspended solids respectively. Finally, we can conclude that the concept of this system is innovative and showed great results. However, slanted soil presents some disadvantages such as it throws out the water volume and temperature of the treatment system.

Silica filter issued for both single and dual filtration. However, there are only very few studies have focused on this technique. Soyer et al., (2010) [26] have reported that single filtration can eliminate 98% of turbidity when raw water coming from 3 different greywater sources in Istanbul had between 6 to 14 NTU.

The **BioSand Filter (BSF)** is a filtration system adapted from the slow sand filters. It’s a combination of biological and physical processes that take place in a sand column covered with a biofilm. This new technology has been applied in the developing countries either constructed with concrete or plastic filled with gravel, followed by coarse sand and then fine graded quartz sand[27].Duke et al., [27] used a biosand provided by Prostar Industries in Victoria, B.C. and water samples were collected from seven Victoria areas. As reported 62% of DOC, a range of 60 to 94% of turbidity and 70% of TOC can be removed by BSF.BSF can eliminate 76% and 83% of COD and BOD respectively when using 1m of sand diameter according to Abudi study when they took water from the college campus in Mustansiryiah University and used 3 sets of experiments each has different sand diameter (1m, 0.75mm and 0.35mm) [28]. This filtration technique is also appropriate to treat the TSS, turbidity and TDS with the efficiency respectively 66.6%, 60% and 48.6% and an absence of *E.Coli,* if we used a filter with crushed rocks with 10mm in diameter [29].

The **Greensand** also known as manganese greensand is an oxidizing medium used generally for iron, manganese and for turbidity removal. Greensand is a clay mineral that comes from glauconite, a sedimentary rock that typically has a green color [30]. It is manufactured by coating small particles of iron silicate mineral with manganese sulfate and potassium permanganate [31]. Therefore, iron and manganese oxides fixed on the sand grains adsorb soluble iron and manganese. Because this medium is quite new there is a lack of information regarding its ability to remove pollutants.

Wetlands ecosystems were used as sinks, sources or used to transform nutrients and carbon [32]. Therefore, the idea of using this concept for greywater treatment grown all over the world. Constructed wetlands will use wetland hydrology, soils microbes and plants to assist in treating greywater [33]. This man-made system is combining three mechanisms: biological by transformation of nutrients using anaerobic and aerobic bacteria and by plant root metabolism, physical by filtration and sedimentation, and chemical by absorption and decomposition that will help purify waste water. Constructed wetlands are used in small communities for its cheap and efficient water treatment. This technique is basically divided into two major group based on water flow regime: surface flow and sub-surface flow. Commonly only vertical and horizontal sub-surface flow are well studied. According to Lavrova and Koumanova (2013) [34], and after doing a laboratory subsurface vertical-flow wetlands system using *Phragmitesaustralis* as a plant concluded that this system can eliminate 93.1% of COD, 43.3% of BOD and 53.7% of nitrogen.

In the same study, constructed wetland system was joined by aerobic activated sludge reactor and results increased with this combination to attend 97.1% for COD elimination, 54.2% for BOD and 93.7% for nitrogen removal. Ammari et al, (2014) [35] constructed a subsurface flow constructed wetlands pilot plant planted with *Typhalatifolia* and filled with gravel and fine gravel and was fed with raw domestic wastewater. Good removal yield has been reported for BOD, Tot-N and TSS with the removal of 97%, 86% and 76.5% respectively. Because of the importance and efficiency of this system, many studies tried to modify this concept. We have the modified constructed wetlands called "EvaTAC" that combine evapotranspiration and treatment tank with anaerobic digestion chamber followed by a horizontal subsurface flow-constructed wetland. Using different plants, different strategies, numerous case studies were made all over the world in order to enhance constructed wetlands knowledge.

Although **gravel** is a low cost media, easy to obtain and to install and is used as a media in most water treatment technique; few are focused on its removal efficiency. Galvis,(1999)[36] conducted a study on the four gravel process namely dynamic gravel filters, horizontal flow gravel filters, downflow gravel filters in series and upflow gravel filters in layers. A dynamic gravel filter consists of two or more parallel units packed with 3 layers of gravel of different sizes ranging from coarse at the bottom to fine at the surface. In this study, raw water had 64 NTU for turbidity, 172 mg/L for total solids, 14.3 mg/L for COD, and 63.3 CFU/100ml for fecal coliforms. After testing the different types of gravel; dynamic gravel filter offers the best efficiency to remove COD (44%), TSS (80%), turbidity (79%) and fecal coliforms (52.5%).

Anthracite filter media is a series of anthracite coal products designed for water filtration. Anthracite is characterized by a higher service flow, longer filter runs and lighter than sand filters. Jiang et al.,(2014) [37] have conducted their study on eight filter media (gravel, zeolites, anthracite, shale, vermiculite, ceramic filter media, blast furnace steel slag and round ceramic). Comparing these media, and depending on the nature of the substrate and the adsorption mechanism; the highest removal rates of BOD, Tot-N, Tot-P and TOC were obtained with anthracite media filter. Zhang et al.,(2015) [38]studied the removal efficiency of Tot-N and COD for 3 anthracite particle size(1-3 mm, 3-5 mm and 0.5-1 mm) in vertical flow constructed wetland columns. The best efficiency was obtained with 1-3 mm with 88.3% and 73% of removal for COD and Tot-N respectively. In the study [39, 40], a dual media filter with anthracite coupled with silica sand was compared with a single layer system. With the intervention of anthracite results were increased and the removal of TOC was 65.6% and COD was 63.9%.

Recently, Lava rocks has been selected as a new medium for greywater treatment. In a laboratory scale, Katukiza et al.,(2014)[41] investigated the efficiency of lava rocks in treating greywater by implementing 2 uPVC (unplasticized polyvinyl chloride) columns with an exact dimensions and hydraulic loading rate (HLR) in 10 Kampala city households. Both columns were packed differently. The first was filled with 60 cm of lava rock while the second was filled with 30 cm lava rock and silica sand. With a 20cm/day HLR, the first column had 90% COD removal, 77% TOC and DOC, whereas the second column had 84% elimination of COD, 72% of TOC and 67% of DOC. Another study done by the same group showed better results when working with two step crushed lava rocks filter [41]. A pilot was set in the same city, was composed of 2 identical filters made of plastic material. Those filters were composed of 10 cm of crushed gravel, 30 cm of graded crushed lava rock. Results showed 90% of COD removal, 59.5% of Tot-N, 69% of Tot-N, 3.9 log removal of E.coli, 3.5 log removal of Salmonella species and 3.9 log removal of total coliforms [41].

Cotton, silk, polyester, burlap and many other **fabric materials** are found in every house. Therefore it's very important to study the efficiency of using these fabrics to eliminate water pollutants and nutrients, unfortunately, not many researchers have. Tammisetti and Padmanabhan (2010) [42] have reported the use of cotton, silk, polyester and burlap to remove the turbidity from water collected from pond in Shrewsbury. The impact of folds (0, 1, 2 and 3 folds) has been study and the results show that folding the material into 3 folds offer the best efficiency with the removal of turbidity of 48.2% for cotton, 43.4% for silk, 57.3% for the burlap and the polyester was not applicable. A next study, Colwell et al., (2003) [43] used as the base this result and compared burlap and nylon fabric to see the elimination of cholera and resulted that burlap was the most effective in eliminating cholera. The removal of COD, BOD and other nutrients, hasn't been studied.

Ceramic and **Clay** are considered as a porous medium to treat water. Most of Asian countries use ceramic filter because they are easy to manufacture and inexpensive [44, 45].A theory was posed by Erhuanga et al,. (2014) [45], if ceramic filters can be modified in order to eliminate more and more microbial, physical and chemical pollutants. The new ceramic filter included clay, laterite, charred cattle bones and charcoal, then all materials were crushed and processed to dry powdered forms to create a ceramic pot filter. Results showed in improvement in TDS and TSS and lead treatment and as for bacterial removal 78% of bacterial count were eliminated and 99% of coliforms were reduced. The removal of total coliform was equal to another study that indicated that ceramic filter can remove 98% of E. coli and total coliforms [46].A new system that combine, aquatic plant filter, bio-zerolite filter, bio-ceramic filter and gravel bed filter was built in an artificial landscape pond to monitor its efficiency [47]. The whole system can remove an average of38.7% of COD, 57.2% of Tot-N and 45.6% of Tot-P. But we have to mention that the bio-ceramic filter accounted for the primary COD removal. Another technique is clay vessels. Indeed, clay can be used as a substitute to zeolite in water treatment. As proved in the study [48], clay aggregates were used instead of zeolite in different indoor tests and had a removal yield of 70% for COD, 88% for Tot-N, 98% for Tot-P and 70.5% for TSS. Clay can be also used in combination with sawdust to remove the E.coli, total coliform and turbidity [49].The grain size of clay pots had an influence on the removal yield; clay pots of 600 µm outperform the 900 µm pots. The removal yield was as the following, 99.9% for E.coli, 99.3% for total coliform and 86% for turbidity in pots with 600 µm. Using clay pipes, Naddafi et al., (2005)[50] wanted to analyze it performance. Water entering clay pipes was then collected and studied. The removal yield of turbidity was more than 90%

Methods	COD	BOD	DOC	TOC	Tot-N	Tot-P	TSS	Turbidity	E.coli	Total coliform	Fecal coliform	References
Slow sand	55.4%	61%	22.5%	ND	68.5%	65%	86%	84%	ND	78%	ND	[4], [5], [6], [7], [8]
Rapid sand	47.70%	14%	2.70%	20%	ND	ND	ND	98%	ND	ND	ND	[10], [11], [12], [13], [14]
Roughing	59%	ND	ND	ND	ND	ND	83.5%	83.5%	ND	81.5%	ND	[16]
Slanted soil	82.2%	85.5%	ND	ND	78.7%	84.2%	82.6%	ND	ND	ND	ND	[21], [22] , [23] ,[24], [25]
Silica	ND	ND	ND	ND	ND	ND	ND	98%	ND	ND	ND	[26]
Biosand	76%	83%	62%	70%	ND	ND	66.6%	68.5%	100%	ND	ND	[27], [28], [29]
Constructed wetlands	95.1%	64.8%	ND	ND	77.8%	ND	76.5%	ND	ND	ND	ND	[32], [33], [34], [35]
Gravel	44%	ND	ND	ND	ND	ND	80%	79%	ND	ND	52.5	[36]
Anthracite	76%	ND	ND	65.6%	73%	ND	ND	ND	ND	ND	ND	[38], [39]
Lava rocks	88%	ND	72%	74.5%	59.5%	69%	ND	ND	99.9%	99.9%	ND	[40], [41]
Fabric	ND	ND	ND	ND	ND	ND	ND	49.6%	ND	ND	ND	[42], [43]
Ceramic	38.7%	ND	ND	ND	57.2%	45.6%	ND	ND	98%	99%	78%	[45], [46]
Clay	70%	ND	ND	ND	88%	98%	70.5%	88%	99.9%	99.3%	ND	[48], [49], [50]

Table 1. 3. Average percentage of physical chemical and biological elimination of low load greywater pollutants

1.4.3.2. High load greywater treatment systems

Bacteria are usually used to eliminate the organic matter substances from municipal wastewater. This mechanism requires constant oxygen therefore requires lot of expertise, manpower and huge amount of money. However, algae release oxygen in the process of photosynthesis and this continuous supply emerged to be the solution as an alternative to bacteria [51].With low energy requirement, reduction in sludge formation, reduction in greenhouse gas and a production of useful algal biomass, many countries such as Australia, USA, Thailand, Taiwan and Mexico are interested in using algae treatment technique[52, 53,54, 55,56,57]. Colak and Kaya,(1988)[58]have reported the efficiency of algae to eliminate 67.2% of COD from wastewater and 68.4% of BOD. Krishnan and Neera,(2013)[59]have obtained lower elimination yield with 58.1% of BOD and 54% of COD when using a combination of 2 algae ***Oedogonium***and ***Chara***. The elimination can be improved from 68.4% to 90% of BOD elimination by adding activated sludge [60].For the Tot-N and Tot-P respectively 56.4% and 71.6% can be eliminated with the combination of ***Oedogonium*** **and** ***Chara*** [59]. And, ***Oedogonium*** **and** ***Chara***seems to be not appropriate for the elimination of turbiditywith only 13.1% [59].In comparison, ***Chlorella vulgaris*** showed better results with 86% for Tot-N and 78% for Tot-P [61]. Activated sludge may also increase the elimination of Tot-P with 80% when added to the algae system, but with extra light the percentage will even increase more as the Wang et al.,(2016)[62],showed that the elimination of Tot-N will increase to 99.2% and Tot-P to 83.9%.

The **activated carbon** is a common media used for water treatment due to its excellent adsorption capacity. In the study done by Al-Jlil (2009) [63], water was collected from a technical college in Riyadh with a raw BOD of 128.5 mg/L, a COD of 130.3 mg/L, a Tot-N of 1.8mg/L and a Tot-P of 1.9 mg/L. After using activated carbon for treatment we had an efficiency of 97.6% BOD, 92.1% COD, 89.7% of Tot-N and 67.8% of Tot-P. After collecting greywater from different houses, and passing it throw a bed of granular activated carbon, Siong et al. (2013)[64], had an average pH of 7.13, a turbidity of 0.79 NTU, a TSS of 7 mg/L, a COD of 258 mg/L, a BOD of 26.1 mg/L as in input. After treatment turbidity decreased to 0.23 NTU, TSS to 1mg/L, and COD to 5 mg/L also BOD 5 mg/L. Even in removing color and odour, activated carbon can easily do the task [65]. Even though this media effectively removes also bad odors and taste and significantly reduces hydrogen sulfide and heavy metals, the activation of carbon is expensive and has thus limited its use in water treatment [66]. Therefore, biochar was getting the attention for the mutual similarity with activated carbon. Biochar is obtained when biomass, such as wood, manure or leaves is thermally decomposed with little or no available oxygen and at relatively low temperatures (<700°C). Therefore, this carbon-rich product incorporate both charcoal and biocarbon [67]. It is used generally for soil improvement, waste management, climate change mitigation, energy production and of course pollutant removal [68]. Biochar offer similar and sometimes better efficiency than the activated carbon. In a 50 cm columns activated carbon and biochar were packed and fed with artificial greywater in order to evaluate their efficiency [68]. Over 10 weeks, chemical parameters were analyzed. Biochar and activated carbon delivered good results with 99% removal efficiency for COD. Biochar removed Tot-P more than activated carbon with 89%. As for Tot-N activated carbon eliminated 96.6%; a value higher then biochar with 90.9% [68]. In another perspective, a study done by Lobo et al., (2016) [69], powdered electrocoagulation was integrated with granular biochar to assure higher treatment efficiency. Water samples had a turbidity of 400 NTU and total suspended solids of 514 mg/L. Results showed that this combination can achieve 99% turbidity and total suspended solids removal 90% [68, 70]. In order to investigate the efficiency of biochar in eliminating E.Coli [71, 72]. Synthetic water was applied and E.coli were cultured, centrifuged and suspended in the synthetic water. Results showed that biochar can eliminate 96% of E.coli.

Moving bed biofilm reactor (MBBR), is a combination of the process of activated sludge and the biofilter process. These biofilm provide a large protected area and optimum conditions for bacterial culture to grow. The MBBR has many advantages: it takes smaller footprint, uses the whole tank volume for biomass, produces less sludge and an ease of operation. This system is commonly used for treating wastewater and showed over the year's great removal for most of the pollutants. A case done in Morocoo, greywater was taken from a sports club. Merz et al., (2007)[73]have reported good results with the elimination yield of 98% for turbidity, 85% for COD, 94% for BOD, and 99% for fecal coliforms except for Tot-N with 19% has been removed with an influent composed of 29 NTU turbidity, 109 mg/L COD, 59 mg/L BOD and 100/mL fecal coliforms Another study conducted in Belgium showed similar results for turbidity, COD and BOD with 98%, 93.5%, 97% and better results were obtained for Tot-N and Tot-P with 58%, and 79.5%

respectively when operating with submerged MBR[74]. Although the MBBR offer great results but this technique is costly.

Coagulation is a major step in water or wastewater treatment; coupled with flocculation these 2 techniques are widely used for their simplicity and cost-effectiveness. Used as a pre or post treatment coagulation-flocculation can affect the overall treatment performance. Coagulation is a chemical reaction, which occurs when a chemical called coagulant is added to the water. This coagulant encourage the destabilization of a given colloidal material present in the solution to join together into flocs [75].With the use of appropriate chemicals so-called coagulant agents: usually aluminum or iron salts water is then gently stirred to allow the particles to come together and form larger particles for better sedimentation. Through the years the concept of coagulation has evolved, and was combined with energy to create the new electrocoagulation method. This evolution was based on the principle that iron and aluminum anodes can produce cations, which can increase the coagulation of contaminants in water. According to Moreno-Casillas et al., (1990)[76], electrocoagulation (EC) can remove metals, anions, organic matters (BOD, COD), suspended solid matters, colloids and even arsenic.

Aluminum sulfate can be used for greywater treatment [77], with average removal of 60% for COD which was lower than electrocoagulation 88.5%[78,79,80].

Long life, cheap maintenance, ion exchange resins are polymers that have the ability to exchange particular ions within the polymer within the solution. Water that usually contains calcium and magnesium will pass through a sodium resin and ions will be exchanged; this will then decrease the hardness of water. Although this treatment system seems easy and suitable, only few studies have reported the efficiency of this system to remove the physical, biological and chemical pollutants. A new system emerged from the concept of ion exchange resin, magnetic ion exchange resin (MIEX). The MIEX has a magnetic component in its structure, which facilitates agglomeration and settling. It is 2 to 5 times smaller than traditional ion exchange resin and has a high surface area for adsorption. Pidou et al.,(2008)[79]carried out a study that compares MIEX and coagulation for the treatment of greywater. This study showed that MIEX could decrease the COD, BOD, turbidity and Tot-N by 65.6%, 83.9%, 82.53% and 15% respectively, after collecting greywater samples from baths, shower and hand basin of 18 flats within Cranfield University residence. The magnetic ion exchange resin process failed to reduce the turbidity and the BOD to the levels required for both unrestricted and restricted reuses. In the same study a combination of MIEX and coagulation resulted in 64% COD and 53% BOD removal [79].

The Upflow anaerobic sludge blanket reactor (UASB) is considered to be the most used technique in anaerobic treatment [81].The waste are introduced in the bottom of the reactor and greywater flows upward through a sludge blanket composed of biologically formed granules or particles [82].First, a study compared different hydraulic retention time of 16, 10 and 6 h using an UASB reactor feed with collected greywater from a settlement in Luebeck, Germany [83]. The results showed that with HRT equal to 16 h COD can be 64% removed and 30% of Tot-N, 21% of Tot-P. The low percentage of elimination of both azote and phosphorus is due to the 3 processes of physical sedimentation, filtration and incorporation into biomass. In the same spirit as the last study, another HRT were tested (20, 12 and 8h) [84]. The HRT equal to 12h had better results in the elimination of COD with 41%, a value lower then the previous study with HRT equal to 16h. As for Tot-P HRT of 20h and 12h had the approximately the same elimination percentage with 21.6-24%. For Tot-N HRT with 12h had the highest elimiation with 35.6%.A case study was done in the airport in Brazil in order to test the efficiency of this anaerobic process [85]. The efficiency of this case study was 73% BOD elimination, 72% COD, 77% TSS and 88% turbidity. In another proof that UASB is not appropriate to remove Tot-N and Tot-P, a study collected greywater from 32 houses in Sneek, Netherlands, and 5 L were feed to the UASB system [86]. Results were as the following, 51% elimination of COD, 15% for Tot-N and 11% for Tot-P.

The sequencing batch reactor (SBR) is an alternative of conventional biological treatments due to its simplicity and flexibility [87]. Consisting of 5 stages operating in a septic tank, it can adapt to various volumetric flows and pollutants concentrations [88, 89, 90]. The SBR have been proved to be efficient for treating different kinds of effluents. Even with one of the most difficult wastewater types to treat, SBR can eliminate 85.3% of COD, 63.7% TSS and 39.2% Tot-N from dairy wastewater treatment[91]. With the same type of wastewater, another study choose also the SBR system to treat industrial milk factory wastewater and had slightly higher percentage of elimination of COD with 90% [92].Combined with coagulation, SBR can treat up to 94% of COD from municipal sewage using poly aluminum chloride as a coagulant[93]. As for greywater SBR can remove the COD up to 90% according to Pidou et al., (2008) study [79] biological aerated filter (BAF) because they are both aerobic techniques. BAF can remove COD similarly to SBR with the elimination yield from 85% to more than 96% [94,95]. The BAF is a biological treatment technology that can provide secondary treatment for wastewater and is now popular in Europe for its compactness and easy to implement [96]. Concerning BOD removal, BAF can eliminate 93% from a paint production factory wastewater with 1711 mg/L COD as raw water [95].However, for Tot-N, BAF can be more efficient with removal yield up to 72% than SBR that can only remove 37%[86].The efficiency can be improved by adding of an anoxic cycle for denitrification of Tot-N; the removal can be thus up to 93.5% for Tot-N and Tot-P can reach up to 70% [87, 97, 98].

Methods	COD	BOD	Tot-N	Tot-P	TSS	Turbidity	E.coli	Fecal coliform	References
Algae	66.8%	63.2%	71.2%	74.8%	No Data	No Data	No Data	No Data	[58], [59], [60], [61]
Activated carbon	95%	89.2%	89.7%	67.8	85.7	70.8	No Data	No Data	[63], [64], [65]
Biochar	98%	No Data	90.94%	89%	90%	99%	96%	No Data	[68], [69], [70], [71]
MBBR	89.2%	95.5%	39%	79.5%	No Data	98%	No Data	99%	[73], [74]
MIEX	64.8%	68.4%	15%	No Data	No Data	82.5%	No Data	No Data	[81]
UASB	57%	73%	26.9%	18.2%	77%	88%	No Data	No Data	[84], [85], [86], [87]
SBR	89.8%	No Data	39.2%	No Data	63.7%	No Data	No Data	No Data	[81], [92], [93], [94]
BAF	90.5%	93%	82.7%	70%	No Data	No Data	No Data	No Data	[87], [95], [96], [98]

Table 1. 4. Average percentage of physical chemical and biological elimination of high lowed greywater pollutants

1.4.4. Discussion

From this review we can see that there is a large variation and evolution in the greywater treatment systems. Greywater is an important source that we can't let it go in vain and it is clear now that each type of technology perform differently because of the variation of raw greywater. Comparing and choosing between this numbers of treatment systems is difficult but to simplify the task the average of each parameter from each system will be taken and will be then compared. Table 1.3 will illustrate low load greywater treatment systems and their average parameter value and Table 2.4 will illustrate high load greywater treatment systems and their average parameters.

Constructed wetland showed good results concerning the elimination of major parameters and because of its advantages we can see how this system is growing all over the world. But also, choosing certain plants can affect the output of this system. Concerning different media that were illustrated in this review (silica, biosand, gravel, anthracite, lava rocks) most of them were used in low load greywater. Every media has its own characteristics and because lava rocks comparing to other has the best porosity and filtration capacity, this medium showed great results comparing to other concerning the elimination of COD, DOC and bacteria. Although slanted soil system can be considered as a simple and easy to modify system; even when using different types of medium (kanuma soil, crushed baked mud) elimination percentages of COD, BOD, Tot-N, Tot-P and TSS were amazingly removed compared to slow sand, rapid sand and roughing sand system. About porous and fabrics filters, these systems are considered as primitive although clay can offer good elimination percentages.

Activated carbon and biochar are known for their amazing removal of pollutants that why they are used in eliminating different pesticides, heavy metals and a lot of other unwanted pollutants. Also in treating greywater, they both had high percentages of elimination in all parameters studied. Algae capacity of treatment is always related to the type of algae used, but the overall efficiency can be used in treating high lowed greywater. Using algae alone to treat greywater is not the most accurate one to choose, same as MIEX system that had approximately similar results as algae. BAF is more efficient than SBR and UASB in most of the pollutants elimination.

1.4.5. Conclusion

As discussed above the greywater offers environmental and economic benefits, but in order to have efficient results each case demands special media and special technique depending on the water input and reuse guidelines. The study of various literatures concluded that the performance and efficiency of some techniques were more interesting than others. Constructed wetlands, slanted soil, activated carbon and Biochar were the most efficient compared to others. To deal with the environmental changes, reusing greywater is the answer to decreasing water consumption; and when choosing a treatment system we need to take into consideration the economic situation and the budget allocation , how the recycled water will be used , as well the source of the raw water and characteristics.

1.4.6. References

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1.5. Greywater guideline and reuse possibilities

1.5.1. Reuse advantages

Growing urbanization coupled with increasing population in water-scarce areas, exacerbates the water demand, therefore some changes should be taken into consideration. Reusing greywater can offer different advantages. First, this greywater can minimize the use of potable water thus, decrease the water stress in some countries. Second, the price range of treatment system is very wide, therefore, anyone can find a suitable system for his budget. Plus when treating greywater and then using it for toilet flushing for example; we will have less microbial growth than a typical toilet flushed with potable water. Nowadays the majority of countries are just reusing blackwater but when they will be reusing both water sources this can improve financial benefits not to forget community awareness and education on water conservation practices.

1.5.2. Reuse possibilities

In view of reducing the demand for treated potable water for non-potable application, greywater can be collected, treated and reused. Depending on the quality of output water and referring to the guidelines, the reuse application must be determined. Reuse application types can include urban, industrial, agricultural, environmental and recreational, groundwater recharge, augmentation of potable supplies and many more.

In urban reuse greywater is recycled in irrigation of public parks and recreation centers, athletics fields, school yards, playing fields, highway medians, landscape areas surrounding public buildings and facilities, landscape areas surrounding family residences, areas surrounding commercial, office and industrial developments. Also water can be reused in vehicle washing facilities, laundry facilities, window washing, mixing water for pesticides, herbicides and liquid fertilizers. Ornamental landscape uses and decorative water features such as fountains, reflecting pools and water falls. Another urban uses we can find, concrete production, fire protection, toilet and urinal flushing.

Many studies throughout the world chose to use treated greywater in irrigation, because of the great water consumption of this application especially in water scarce countries. Before a formal building code was introduced in Arizona, and by the year 2000, using greywater to irrigate lawns and garden was spread. A huge controversy was brought whether or not greywater is affecting soil, and human health in indirect way. The first group saw that greywater composition can deteriorate soil by increasing soil alkalinity and salinity, reduce the ability to absorb and retain of water and thereby affect the growth and health of vegetation. In addition, some concerns were brought about the harmful microorganisms and chemicals that greywater harbor and can affect the environment and human health **(Jeppesen, 1996)**. Others found that greywater can help in the growth of plants due to the presence of nitrogen and phosphorous compounds. To end this debate, a study done by **(Jackson et al., 2006)**, used greywater to irrigate vegetable plants for home consumption. However, the microbiological safety should be taken into consideration. This study concludes that using greywater will provide nutritional and economic benefits and probably not cause any additional diseases. Another study took 3 different sites in the United States (California, Colorado and Texas) and measured for over 5 years the pathogen indicator and found in the results that the concentration of those were not higher than controls irrigated with freshwater (**Sharvelle et al., 2009)**.

The second popular use for recycled greywater is toilet flushing since this activity take a great proportion of potable water. By using greywater for toilet flushing, from 9.3 to 21.5% of total domestic water consumption can be reduced (**De Luca, 2012)**. Similar result has been reported by **Jefferson et al. (2000)**, from 3.4% to 33.4% of domestic water consumption are saved.

As for industrial reuse, greywater can be used as a cooling water and for boiler make-up water. In addition in some industries like pulp and paper, chemical and textile industries, greywater can be used in the process. The environmental and recreational reuse sectors includes, wetlands enhancement and restoration, recreational and aesthetic impoundments, creation of wetlands to serve as wildlife habitat and refuges. Therefore, the reuse of greywater can serve in these purposes: landscape impoundments, water-based recreational impoundments.

Although practices such as irrigation can indirectly recharge groundwater, but with the excessive use of this resource, some actions should be taken in consideration. The major cause for ground water recharge lays in establishing saltwater intrusion barriers to coastal aquifers, in proving further treatment for future reuse, in increasing potable or non-potable aquifers and in controlling and preventing groundwater subsidence (WHO., 2006).

The reuse of greywater can be jeopardize for several reasons. First, the quality of greywater can be affected by different factors as cited in the section 2.2, therefore the treatment system have to be modified in each case. Water regulation if found are kind of ideal and usually doesn't match output from treatment systems. Users should have a total knowledge on system maintenance requirements because the lack of communication and public dialogue between the treating facility and users and stakeholders can cause major problems. In addition, financial incentive should be taken from governments to encourage the reuse of greywater. In the lack of knowledge concerning greywater, people fears it reuse and some can be disgusted and concerned for their health. Even though greywater systems have economical asset but the real cost of recycled water, operational and maintenance should be determined clearly and this remains challenging because each case differ from the other depending in the greywater quality.

1.5.3. Greywater guidelines

After the US Marine corps base camp Lejeune disaster left 500000 people infected with chemicals found in water that caused fatal diseases like cancer, reproduction disorders, and birth defects; to the Walkerton event, when drinking water system became contaminated with deadly bacteria leaving seven people died, and more than 2,300 ill **(O'Connor, 2002)**; water was under increased scrutiny from safety and health regulation and induced quality guidelines.

With time, greywater is increasingly being considered as a resource, because of this evolution, ensuring public safety, minimizing any chemical and microbial risk, public awareness, regulating managing treatment systems at users houses should be taken into consideration. In order to ensure safety of users, each country that integrated greywater into their building codes are forced to follow a certain guideline.

In order to plan the appropriate treatment system, all applicable regulations should be understood. The difference between a regulation and a guideline, is that the first is an enforced rule by

government agency, the second is not enforced but can be used in the development of a reuse program. Concerning the US, in November 2002, 25 states had regulation covering the reuse water and 16 states had their own guidelines. The most important guideline is the WHO guideline with the objective to maximize the protection of human health and the beneficial use of water resources (greywater, wastewater) targeting policy makers, people who enforce standards, scientists, educators, researchers and engineers. The first greywater guideline of the WHO was set in 1989 and a new more detailed guideline was published in 2006. This new guideline offered a set of numerical guidelines with evidence-based health risk assessment, guidance for managing risk adapted with cultural social economic and environmental context, guidelines in implementation and mentioned the importance of modifying each case according to the local area. So this guideline eradicated the concept of sticking to a certain water quality standards because incidence of disease is related to the degree of exposure, the health and age of those affected.
The most important statement regarding greywater in the WHO 2006 guideline is that the risks associated with greywater are not as severe as those related to combined wastewater.

Other then WHO, two international standards organizations, NSF International and the International Standards Organization (ISO) have been developing water reuse standards over the past few years. In the national scale, Canada updated the national plumbing code in 2010 to include greywater reuse in the standard.

1.6. Conclusion

Greywater may not eradicate water crisis but it is a recognized vital supply source for countries suffering from potable water scarcity. Scientists from all over the word are working hard each day to find a new efficient technic or medium because given up is not an option and we came a significant distance from the days when greywater use was forbidden. In the next chapter we will be testing different type of medium using the most common and affordable technic: adsorption.

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Chapter 2 – Adsorption and adsorbents

2.1. Adsorption

Adsorption is a surface treating phenomenon that do not have any limitations. It can be used on both organic and inorganic pollutants found in a solution and on any phase (liquid-gas, liquid-liquid, liquid-solid and solid-gas). The major evolution of adsorption is mainly focused on gas-solid and liquid-solid interfaces. Liquid-solid intermolecular forces attract absorbable solute molecules found in the solution and then these molecules will be concentrated and deposited at the solid surface. The solute retained is called adsorbate and the retained solid is called adsorbent. The importance of adsorption either in the environmental or biological field can never be in doubt. Between the boundaries of two phases, the magic of physics, chemistry and biology takes place. From more than 100 years ago, Gibbs was the first scientist that introduced the concept of adsorption and his studies are considered as a reference regarding its importance for describing adsorption in various types of interfaces **(Gibbs, 1906)**. However, the Egyptians first used the adsorption in 3750 years BC when they used charcoal to reduce copper and zinc in the manufacture purpose of bronze. And then in 1550 BC they also used adsorption for medicinal purposes. It was Phoenicians in 460 BC who used first charcoal filters to purify drinking water.

2.1.1. Adsorption types

Adsorption can be divided into two types: physical adsorption or physisorption and chemical adsorption or chemisorption. In physisorption, forces involved can be either hydrogen bonding or intermolecular forces (Van der waals force). We should note that the physical adsorption can be reversible and time needed for the interaction is short. Generally, the physical adsorption can be found the most in the gas-solid phase because gas molecules adhering to a surface without the formation of a chemical bond at a pressure less than the vapor pressure **(Lawrence & Jiang, 2017)**. Physisorption is an exothermic process but with low energy value (20-40 kJ mol^{-1}). To measure physical adsorption, we have to measure the adsorption isotherm because it indicates the amount of adsorbed versus the adsorption pressure at constant temperature **(Gibbs, 1906)**. The slightest change in the shape of these isotherm can indicate a surface changes. The analyses of isotherm can expose data regarding the total surface area, mesopore and micropore volume and area, total pore volume, the distribution of pore volume and pore area by pore size and surface energy distribution

(Lawrence & Jiang, 2017). Another type of measurement that can be taken into consideration is the calorimetry but this measurement is more difficult to perform. Physisorption occurs on all surfaces and have the ability to form multiple layers under certain conditions **(Sing, 1985)**.

As for chemisorption, it is based in the chemical link therefore, forces involved in this types are valence forces and chemical bonds. Because having a chemical bond requires sharing electrons between adsorbate and the adsorbent it is difficult to reverse **(Webb, 2003)**. This type is limited to monolayer coverage and is highly selective and depend on direct contact with the surface only **(Sing, 1985)**.

2.1.2. Factors affecting adsorption and adsorbent

The efficiency of this phenomenon is related to different characteristics of the adsorbent and the most important one is pores sizes. Because adsorption is a surface phenomenon thus the importance of specific surface area meaning the available area for adsorption. Therefore, the amount of adsorption will be greater if solid is finely divided and have more pores. Pores can take different sizes and shapes; mostly they can be found as slit shaped or cylindrical. As we said earlier total porosity can be used to identify physisorption and to understand more what total porosity is, we should have a total knowledge about its classification. Total porosity can be divided into 3 groups. Micropores are small pores that have maximum 2 nm width, mesopores have width between 2 and 50 nm and macropores are pores which have more than 50 nm **(Everett, 1972)**. Nanopores is used nowadays to combine both micropores and mesopores. Figure 3.1 illustrates more the difference between the 3 types. Adsorption is strongly related to pores because it depends highly on their size and whereas it is compatible with the adsorbate molecules **(Dąbrowski, 2001)**. After knowing the total porosity all characteristics related to pores must be taken into consideration.

The nature of the adsorbate, places a major role in adsorption, its functional groups, pKa, polarity, aqueous solubility, molecular size and weight **(Terzyk, 2004).** Adsorption increase with the decrease of the solubility of the solvent and vice versa because the strong solute-solvent bond can be present only when there is great solubility.

The nature of adsorbent can also affect the capacity of adsorption because of its physiochemical nature. Surface functional groups and structural details can play a major role in adsorption. In addition, the pH of the solution also influence adsorption. Indeed, hydrogen and hydroxide ions can be adsorbed easily but the problem occurs with other ions and especially negatively charged ones and carbons. These elements will give great de-colorization only in acidic solutions this may alter the pH of the liquid.

Although the effect of temperature is not significant but we should take this parameter in consideration. Also mixing adsorbent can have in impact on adsorption because compounds may mutually enhance the efficiency of adsorption or may interfere with each other.

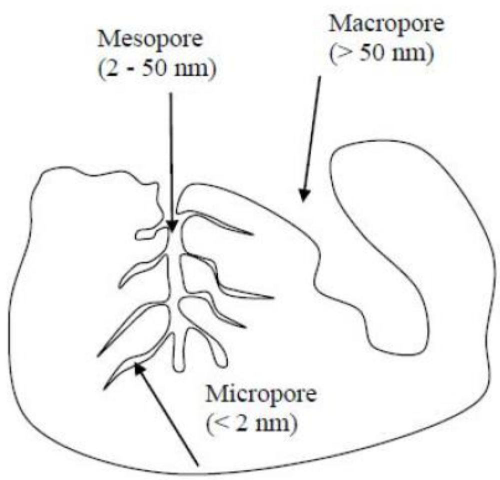

Figure 2. 1. Schematic representation of different types of pores

2.2. Adsorbent

The evolution of adsorption should always be coupled with the evolution of adsorbent. These adsorbent can have different geometrical surface structures and numerous chemical forms according to their application either in industries, in wastewater plants or in laboratory. That is reasonable because of the wide variety of adsorbents found in our nature and environmental applications **(Cohen & Peters, 1995)**. From carbon adsorbents such as active carbons to mineral adsorbents such as silica gels, activated alumina, zeolites, clay minerals and much more types can be listed **(Gibbs, 1906)**. As presented earlier, charcoal was the first adsorbent used, and till now, this amazing adsorbent is still widespread. This wide range of adsorbent let us choose between hundreds of types when building a water treatment system. In the next section we will examine the efficiency of several adsorbent whereas they could eliminate greywater pollutants or not. First we will begin by examining 3 types of residual bricks, then we will test 3 types of activated carbon and finally we will analyze 4 different particle sizes of sand.

2.3. Performance of 3 types of residual bricks in treating greywater pollutants

2.3.1. Introduction

In order to minimize potable water demand, growing search for additional water sources were prompted. One of these sources is the reuse of greywater for non-potable applications, which can account 61% approximately of the total water usage in households. Greywater is wastewater drained from showers, bathtubs and washing machines. When treated greywater can be used for many purposes like toilet flushing, irrigation of parks and many other uses. The water quality requirements for each application contain criteria based on organic, solids and microbiological content in water. In order to eliminate major pollutants and surfactants found in greywater, many technics and systems were tested but mostly adsorption technic was used. Activated carbon **(Ademiluyi et al., 2009; Siong et al., 2013)**, bark **(Dalahmeh et al., 2014; Dalahmeh et al., 2012)**, sand **(Abudi, 2017; Zhang et al., 2016)** and many other adsorbents were used to treat water. In most of these studies, great results were showed: with 96% of elimination of COD by using biochar **(Berger, 2012; Lobo et al., 2016)**, 93.2% with activated carbon **(Ademiluyi et al., 2009; Siong et al., 2013)** and 90% with lava rocks **(Katukiza et al., 2014)**.

All over the word, countries are suffering from water crisis. Each day, studies from all continents try to find a new efficient technics or adsorbents, simple solutions, to solve water pollution. Adsorption on solid supports is among the less aggressive processes in the water treatment field. The advantages of this concept is the simplicity, efficiency and low cost energy. Various materials were used in order to reduce organic, inorganic and metallic pollutants like activated alumina **(Do, 1998)**, zeolites **(Motsi et al., 2009; Qiu & Zheng, 2009; Rios et al., 2008)**, activated carbon **(Brasquet et al., 1996; Métivier-Pignon et al., 2003; Smíšek & Černý, 1970)**, clay minerals **(Jiang et al., 2010; Novaković et al., 2008)** and others. Many criteria such as porosity, specific surface area and ion exchange capacity, judge the capacity for a filter or adsorbent to remove pollutants.

When tested, bricks were found to have more interesting characteristics than sand with its sorption **(Arias et al., 2006; Boujelben et al., 2009; Han et al., 2006; Selvaraju & Pushpavanam, 2009)** and physical characteristics **(Selvaraju & Pushpavanam, 2009).** With three time's greater specific area, 63 times higher specific pore volumes and lower average pore diameter compared to sand; bricks can be easily used as an adsorbent.

Crushed bricks originated from the Central African Republic (CAR) can remove soluble toxic metal contaminants from wastewater **(Aziz et al., 2008; Djeribi & Hamdaoui, 2008)**. To enhance the capacity of adsorption of this materiel a study done by **(Dehou, 2011)** was made to improve the chemical nature, crystalline structures and surface properties of CAR natural bricks. This modified brick was then used to study the removal efficiency of Fe(II) and other metallic pollutants such as Cd^{2+}, Cu^{2+}, Zn^{2+}, Ni^{2+},Fe^{2+} and Pb^{2+} **(Allahdin, 2014; Dehou, 2011)**. In addition, the modified brick can also eliminate some endocrine disrupting compounds **(Ben Sghaier, 2017)**.

In this study we used residual bricks originated from Central African Republic, to test their efficiency to eliminate pollutants and surfactants from our synthetic greywater. We tested natural bricks and two types of activated bricks. After the great results that were shown in a study conducted by **(Allahdin, 2014)** with the use of these activated bricks and their capacity to eliminate heavy metals such as Cd^{2+}, Cu^{2+}, Zn^{2+}, Ni^{2+}, Fe^{2+} and Pb^{2+} from CAR water, we were curious to see if this same adsorbent could clear greywater from its impurities.

2.3.2. Materials and methods

2.3.2.1. Adsorbent preparation

African craftsmen in Bangui region (Central African Republic) use bricks in their construction. These bricks were extracted at ≥0.2 m below ground, then were mixed with water until they obtain mud materiel which is shaped afterwards in molds. After 48 hours air-dried, bricks were then treated in a heat oven at 500 - 900°C for 3 days. To be able to use these bricks as an adsorbent, the materiel was broken in grains by using a hammer until particles sizes reached 0.7 to 1 mm. These particles are washed with Milli-Q water, decanted then dried at 105°C. In order to activate natural bricks, **(Dehou, 2011),** used first the acid HCl and then the iron oxy-hydroxide for its high capacity to immobilize contaminants especially metallic contaminants in aqueous solutions. To characterize the mineralogical composition of bricks before treatment, an X-Ray diffraction was made by **(Dehou et al., 2012a)** by using a Bruker Endeavor D4 diffractometer at a scan speed of 1°2θ in 2 min and a step size of 0.02° using a Ni-filtered Cu-Kα radiation. Bricks was composed of 61% quartz, 21% metakaolinite, 3 to 4% illite, ≤ 4% iron oxides / hydroxides; and ≤ 2 % feldspar + mica + biotite. After understanding the composition of little bricks particles, two activation methods were used. The first was based on leaching particles with a 6M HCl solution at 90°C for 3 hours. Afterwards, a deposition of FeOOH onto brick grains was performed by the precipitation of a 0.25M ferric nitrate solution in the presence of a 6M NaOH solution, followed by the addition of a 1M NaOH solution in order to adjust pH at 6-7. And finally, the resulting pellets were washed several times with Milli-Q water in order to eliminate the excess of FeOOH not attached to grains **(Dehou et al., 2012b)**.

In this study we used natural bricks residue (NB), bricks leached with 6M HCl solution but not activated by FeOOH (B-Fe), bricks leached and fully activated (B+Fe). The preparations of bricks were conducted in the LASIR laboratory (Université de Lille).

Figure 2. 4. Natural residual bricks (NB)

Figure 2. 3. Brick activated with HCl (B-Fe)

Figure 2. 2. Brick activated with HCl and FeOOH (B+Fe)

2.3.2.2. Physical and chemical characteristics of bricks residue

In order to understand the efficiency of the adsorbent, physical and chemical characteristics should be known. First, the total contents of brick elements were determined with Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES model: Varian Vista Pro axial view) by **(Dehou et al., 2012a; Dehou et al., 2012b)**. Nine elements were found in the brick: SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and TiO_2. The dominant component was SiO_2 with 67.33± 2.88% of the total composition. With nitrogen adsorption isotherm analyses (BET: Brunauer, Emmet and Teller) using Sorptomatic 1990 Carlo Erbaat 77°K, the specific surface area, the specific volume and pore size distribution were determined. The specific surface area of bricks varied between 0.5 and 3.5 mm^2. The environmental scanning electron microscope (ESEM, QUANTA 200 FEI) was used to obtain a microphotography of the representative brick grain surface before and after acid treatment.

2.3.2.3. Feed characteristics

Columns containing bricks were feed with a synthetic greywater prepared every morning, by dissolving 7.7g of MIR dishwashing gel (Henkel, France), 3.1g of Persil washing powder (Henkel, Germany), 0.75g of Colgate (Colgate-Palmolive, United States of America), 1.25g of Dettol liquid hand washing (Dettol, United Kingdom) and 1.25g of Garnier ultra doux shampoo (Garnier, France). All products were chosen based on the list of voted product of the year 2016 in Lebanon and France. For this study, kitchen greywater was excluded from our tests. These proportions were mixed together to establish a composition similar to natural greywater **(Jefferson et al., 2004)**, and were inspired by **Huelgas et al. (2009)**. The prepared solutions were mixed with 10 L of tap water and stored in a glass container. The COD of this synthetic greywater ranged from 281 to 369 mg/L and the average of turbidity was 11.3 NTU. Due to the ban of phosphates by the European Union in 2011, no phosphates or nitrogen were detected in our synthetic greywater. The columns were fed manually the whole day (from 9:00am to 17:00pm) from the top surface of the bricks to minimize any loss. Samples were taken directly from the columns for chemical and physical analysis.

2.3.2.4. Chemical and physical analysis

The COD and turbidity are considered as global parameters used to analyze urban, potable or even naturel water. The COD is the quantity of oxygen consumed by the organic substances present in the water and oxidable oxydable under defined operating conditions. To determine this important parameter, the AFNOR (French norm): NF T90-101(ISO 6060:1989) has been used. The turbidity reflects the effectiveness of the filtration, because it is related to the presence of various organic particles in water. The turbidity was determined by using a turbidimeter according to the AFNOR NF EN ISO 7027. The turbidimeter comprises a light beam, which passes through the measuring vessel. The light scattered laterally by the suspended particles is received by a measuring cell. Our target in this study is to minimize the surfactants present in the greywater due to detergents, shampoo and other ingredients. Therefore, we had to take into consideration the quantity of surfactants in the samples, for that purpose, we used the AFNOR NF EN 903 and measured the anionic surfactants by spectrometry. For the flow rate of each type of brick was determined by using the chronometer. Each time, 20 ml of water is recuperated.

2.3.3. Results

2.3.3.1. Chemical oxygen demand

The elimination yield of COD by the different types of bricks residues are presented in Figure 2.5. In the first day of analysis, B-Fe had the highest elimination of COD with 28% comparing to other types of bricks. Within three days this value strongly decreased to reach 11%, then for the rest of the analysis this value continued to decrease and reach 2.8% after 9 days. . For B+Fe, the elimination yield was determined at 20.7% for the first day of experiment butdecreased quickly to 7.1% at the second day and reach 1.4% after 9 days of experiment. For the natural bricks residues, the removal began with 23.1% then increased slowly to 17.84, 13.39 at the second and third days and then to reach 2.8% after 9 days of experiment. A histogram of the comparison of the elimination yield obtained from different types of bricks were illustrated in Appendix 2.The average elimination rates were 13.3%, 11.9% and 6.2% for B-Fe, neutral bricks and B+Fe respectively. In average, the highest elimination rate was obtained with bricks activated with HCl (13.3%) follow by natural residual bricks and then the bricks activated with HCl and FeOOH.

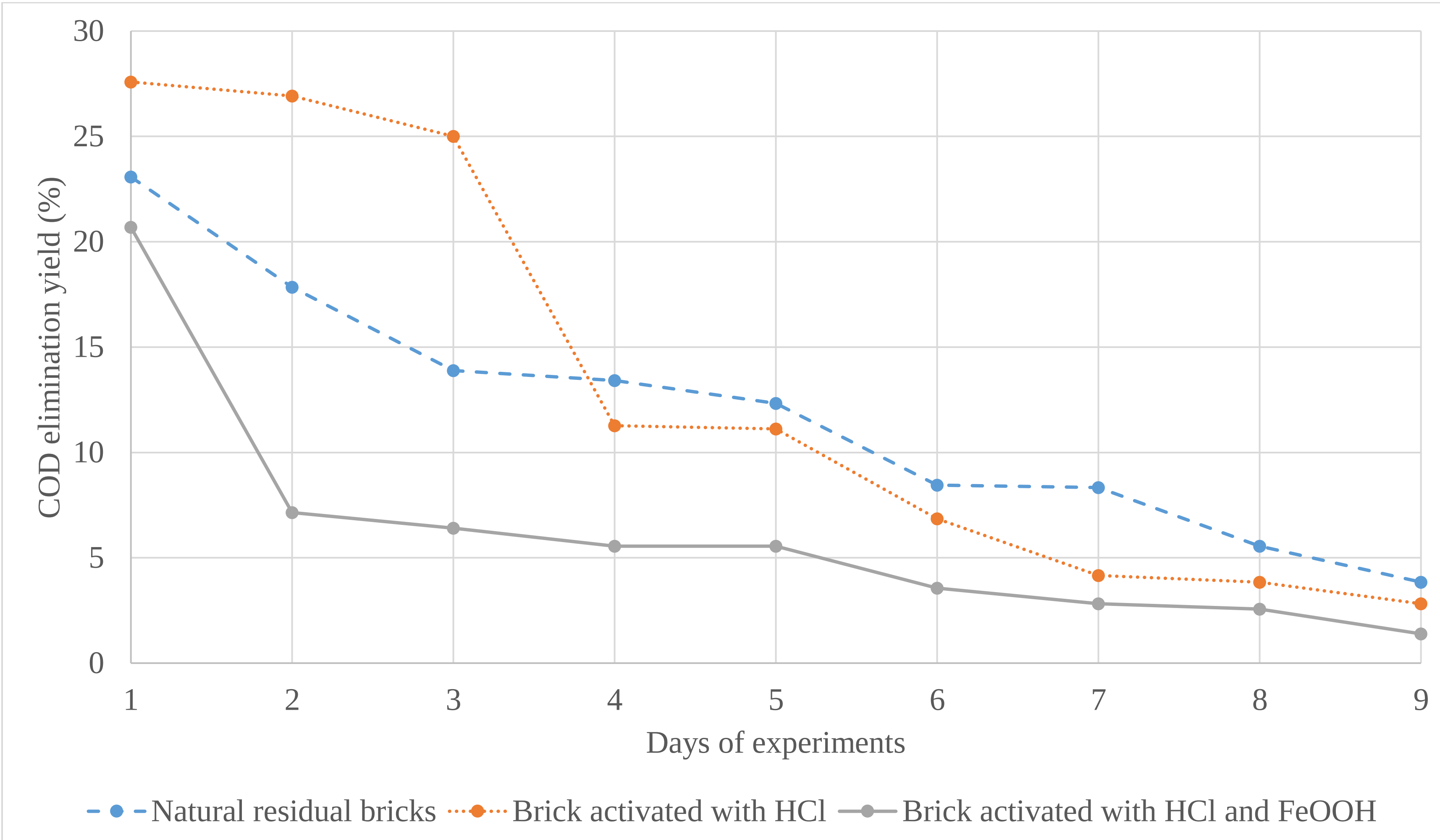

Figure 2. 5. The elimination yield (%) of COD for the 3 types of residual bricks

2.3.3.2. Turbidity

Figure 2.6 showed the removal rate of turbidity of the 3 types of bricks used in this study. During the first 2 days of experiment, the B-Fe gave the highest removal rate with 77.6%, follow by B+Fe with 75.4% and natural residual bricks 72.3%. For the first days of experiment, the turbidity were well eliminated with the elimination >72% for the three types of brick. However, lower elimination yields were obtained at the third day with58%, 58% and 50% respectively for B-Fe, B+Fe and NB. The efficiencies decreased with the days of experiment. The bricks activated with HCl showed the intense decrease of elimination at the end of experiment which the elimination yields were decreased from 32.4% at the ninth to 6.9% at the tenth days of the experiments. Whereas, the 2 other types of bricks, the elimination yield decreased slowly to reach 19.4% and 24.5% respectively for natural residual bricks and the activated bricks with HCl and FeOOH at the tenth days of experiment.

Appendix 3 shows a histogram with the elimination yield and a standard deviation interval of the three types of bricks. For turbidity, bricks activated with HCl and FeOOH had the highest average elimination with 47% followed by the bricks activated with HCl and FeOOH and thennatural residual bricks.

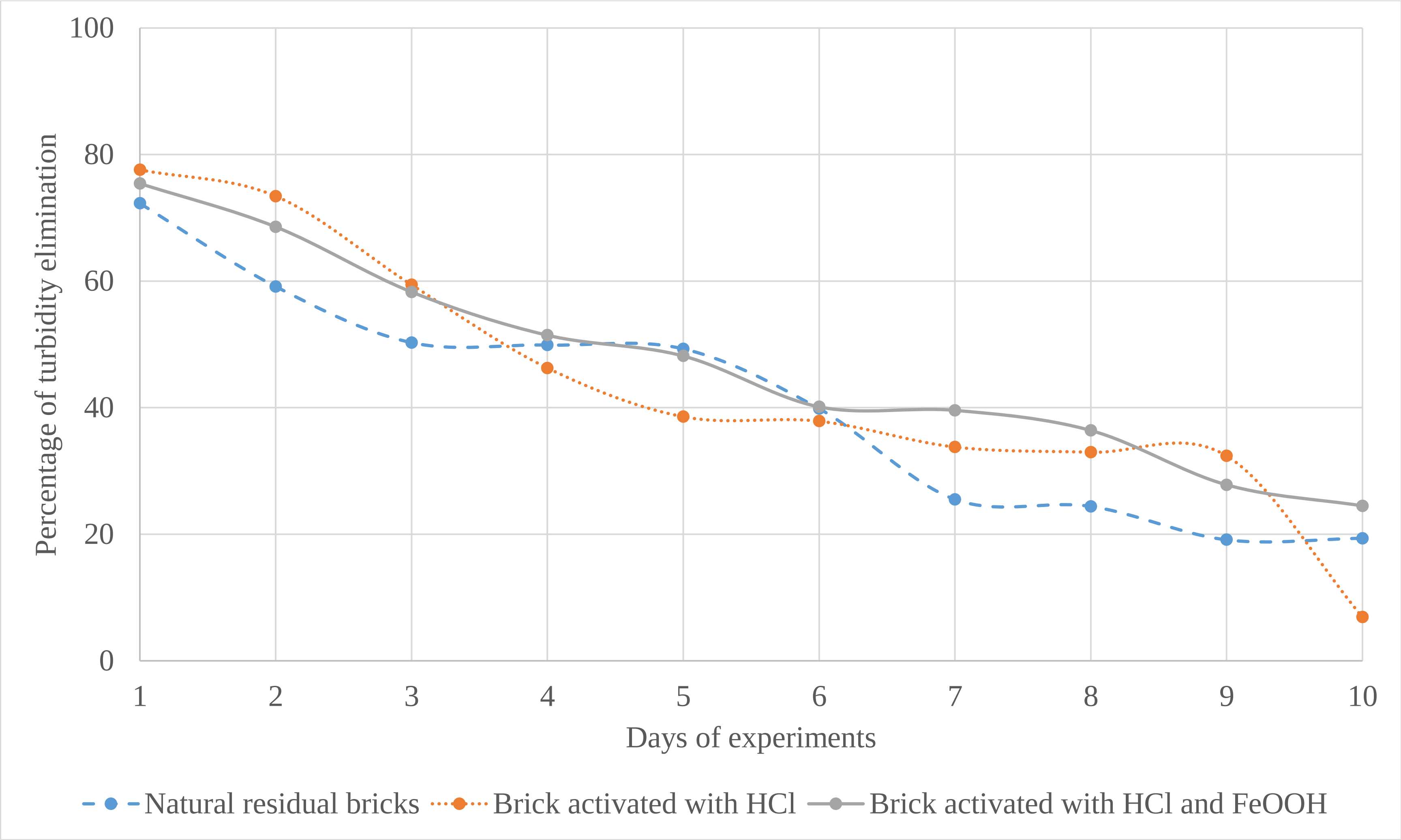

Figure 2. 6. The percentage of elimination of turbidity for the 3 types of residual bricks

2.3.3.3. Active agent: surfactant

The removal efficiencies of surfactant were presented in Figure 2.7. B-Fe showed the highest removal rate of surfactant for the first day with 57.5%. The efficiency decreased slowly to reach 20.8% in the fifth day of the experiment. After the fifth day, the elimination yield decreased quickly to reach 9% at the sixth day and to 6.4% at seventh day. Similarly, B+Fe the elimination yield decrease with time. It started with 45.9%, then decreased to reach 24.5% in the fourth day and only 9.3% and 2.1% of surfactant were eliminated respectively at the sixth and the seventh days of experiment. Natural residual bricks could eliminated 57.8% of surfactant for the first days of experiment then decreased to 37.4% in the fifth day. And only 2.3% of surfactant were eliminated at the seventh days of the experiment

For the removal of active agents, low efficiencies of elimination were determined. In average, only 31.9%, 30.2% and 24.4% were eliminated with the natural residual bricks, bricks activated with HCl and bricks activated with HCl and FeOOH respectively. A histogram in appendix 4 showed the elimination rate of active agent with its standard deviation interval of the three types of bricks used in this study.

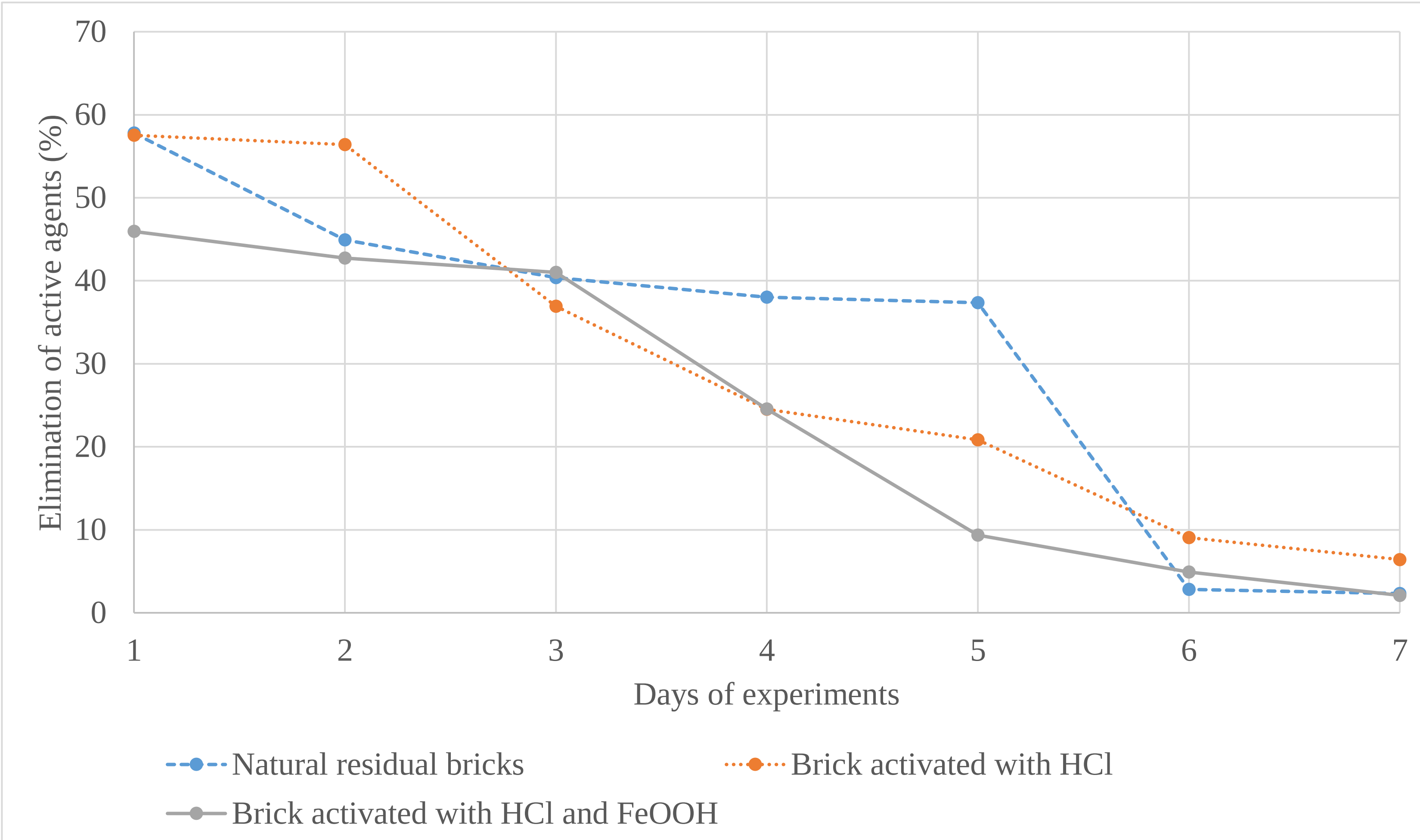

Figure 2. 7. The percentage of elimination of active agents for the 3 types of residual bricks

2.3.4. Conclusion

With population growth, climate change and limited water resources, searching for alternative resources become a necessity. Reuse of treated greywater can be one of the good alternative. Finding local high performant adsorbent to reduce pollutants from used water will have a major impact on economic statement of countries, especially those in need like Central African Republic. Natural bricks of CAR had the privilege of having fascinating specific area and surface to attract scientists to try it as an adsorbent. The research described in this thesis aimed to study the feasibility to treat greywater using 3 types of bricks as adsorbent. Adsorption is defined as the attachment of a molecule or atom to the surface of a solid or liquid. Based on the nature of bonds between the adsorbed substrate and the solid, an adsorption can be physisorption or chemisorption.

According to **(Benjamin et al., 1996; Billon et al., 2002; Genç-Fuhrman et al., 2007)** the structure of iron oxy-hydroxide have the ability to substitute the sodium with another metallic cation. For synthetic greywater, the major element found in the chemical composition is sodium (Sodium Sulfate, Sodium Chloride, Sodium Benzoate, Sodium Hydroxide, Sodium Silicate, Sodium Carbonate, Sodium Bicarbonate, ect..). Therefore, when reviewing the results, bricks activated with HCl only (B-Fe) offered the highest elimination yield for the COD and the surfactant. The natural bricks also offered similar results compared to B-Fe. Iron oxy-hydroxide could not make any substitution with our synthetic water because of the similarity between the brick surface and our greywater. Nor the acid activation could make much difference in the elimination of surfactants found in greywater. Consequently, we can conclude that activating natural bricks with HCl only, or with iron oxy-hydroxide, did not have a major impact on the capacity of elimination of pollutants in greywater. Although, these bricks were efficient in the elimination of endocrine disrupting compounds and some heavy metals, but they were not efficient in the elimination the chemical composition of greywater.

2.4. Ability of three different activated carbons to eliminate greywater pollutants

2.4.1. Introduction

Whereas each and every country is searching for an alternative source of potable water to overcome the problem of increasing water demand, 61% of domestic wastewater that can be reused is thrown in vain. Produced in large quantities from baths, showers, bathroom sinks, laundry (known as light greywater) or kitchen sinks and dishwashers (known as dark greywater), greywater can be treated and reused in different sectors that do not require drinking water quality. Most of studies that concerns water treatment aim for potable reuse, however people use water for a diverse variety of activities. Personal washing, washing clothes, cleaning home, irrigation ect.., all these activities can use recycled non potable water. If managed, greywater can be a major component of water resources supply to meet growing economy needs. In order to implement this new resource treatment strategy, a low cost treatment technology with high removal efficiency should be adopted to ensure compliance of all health and safety standards. Financially wise, adsorption come first in mind comparing to other treatment technologies like advanced oxidation processes, nanofiltration, reverse osmosis membrane **(Grassi et al., 2012)**. In addition, this process, do not add undesirable by-products, can apply at very low concentration, medium can be regenerated, is simple to use and operate and can adjust for every toxic substance according to the adsorbent type and characteristics. The concept of adsorption is to accumulate substances at the interface of two phases which can be liquid-liquid, gas-liquid, gas-solid or liquid-solid **(Grassi et al., 2012)**. Among the variety of adsorbent, activated carbon has been proved its removal capacity to eliminate a multitude of legally restricted compounds presence in aqueous effluents like pharmaceuticals and endocrine disruptors **(Baccar et al., 2012; Dickenson & Drewes, 2010; Katsigiannis et al., 2015; Margot et al., 2013; Marques et al., 2017; Torrellas et al., 2015; Yu et al., 2008)**, natural organic compounds **(Ando et al., 2010; Ho et al., 2011; Martínez-Gallegos et al., 2017)**, phenols **(Akl et al., 2014; Daifullah & Girgis, 1998; Moreno-Castilla et al., 1995; Streat et al., 1995)**, chromium **(Aggarwal et al., 1999; Pérez-Candela et al., 1995; Rai et al., 2016)** and many other. Activated carbon is considered as the most important commercial adsorbents. This porous solid, black carbonaceous materiel, is known for their high surface area with their surface chemical structure that allow them to be used in water purification and industrial water cleaning **(Gonzalez-Serrano et al., 2004)**. Generally, this medium has a very porous structure with a large surface area ranging from 600 to 2000 m^2/g **(Grassi et al., 2012)**. The use of activated carbon is described first in the Sanskrit writing dating from 2000 BC **(Grassi et al., 2012)**. These writings described how charcoal can be used as a filter in purifying water after boiling water in copper vessels and exposing it to sunlight. Even in India and Egypt from 1500 BC, charcoal and carbonized wood have been used in the same purpose **(Mohamed, 2011)**. Then with time scientists discovered the production process of activated carbon. Produced from any carbonaceous solid, activated carbon can be produced with pyrolysing raw material first followed by activation with oxidizing gases. The only disadvantage of activated carbon is their high cost and for that reason some research attempts to prepare alternative natural carbon to minimize the cost. Plus, for the same reason, some industries try to regenerate the activated carbon although this regeneration can lower the adsorption capacity comparing to virgin ones. Alternative low cost activated carbon can be grouped in two categories, either based on their availability like natural materials (wood, coal), industrial, agricultural and domestic wastes, by products like sludge, fly ash and synthetic products either depending on their nature (organic or inorganic material) **(Grassi et al., 2012; Moreno-Castilla et al., 1995; Munoz-Guillena et al., 1992)**.

Activated carbon are versatile adsorbents that can take different forms depending on their application, but the most common forms are granular activated carbon (GAC) and powdered activated carbon (PAC) used in columns adsorption and in batch adsorption respectively **(Allen & Koumanova, 2005; Dąbrowski, 2001).** The PAC was born in the early 19th century in Europe. With smaller diameter comparing to GAC, PAC can be added during coagulation treatment process as dry powder or slurry.

In this study, the aim is to study the removal efficiency of greywater pollutants by using 3 types of activated carbon. To serve this purpose, three types of granular activated carbon have been tested: Norit ROW supra 0.8, Norit ROX and Norit C Gran. The feasibility of these activated carbons in eliminating pollutants present in greywater have been studied. Three parameters which are the mains composition of greywater were taken into consideration: COD, turbidity and anionic surfactants .

2.4.2. Materials and methods

2.4.2.1. Adsorbent used

The main adsorbent used in water treatment plants and industries is activated carbon due to the wide range of amorphous based material that exhibit a high degree of porosity and an extended inter particulate surface area **(Bansal & Goyal, 2005)**. Activated carbon is used previously in the treatment of greywater. Although activated carbon can be either powdered or granular, GAC can be used in columns or beds, so it can be easily analyzed and manipulated. The 3 materials chosen for this study are a commercial activated carbons supplied by Norit Company located in France. Each activated carbon was granular and differ from each other by form and origin. The characteristics of the activated carbon were illustrated in the **Table 2.1**.

2.4.2.1.1. ROW 0.8 Supra

The Norit ROW 0.8 Supra (ROW) is produced by using peat charcoal, therefore, it is considered as a vegetal origin activated carbon. Due to the extrusion process used to produce it, ROW has a well-defined cylindrical shape **(Haist-Gulde et al., 1995)**. To ensure the cylindrical form, **Haist-Gulde et al. (1995)** conducted a static image analysis with a video camera CCD 728x572 pixels and images were analyzed using the Optimas 6, Bioscan software. Also, using the same images they confirmed that the effective size of ROW is 0.8mm as told by the manufacturer. One of the most essential propriety for activated carbon is the total surface area. It can be calculated by using the Brunauer–Emmett–Teller (BET). According to the Norit company, ROW has 1150 m^2/g BET, but this value varied in different studies from 1715 m^2/g **(Grzegorczuk-Nowacka & Anielak, 2017)**, 1150 m^2/g **(Haist-Gulde et al., 1995)**, 950 m^2/g, 849.39 m^2/g **(Ban et al., 1998; Ismadji & Bhatia, 2001)**, and 782 m^2/g **(Fischer, 2001).** Because porosity can affect adsorption, for that, different studies calculated the external and internal porosity, micropore surface and volume. **Mauguet et al. (2005)**, calculated the external porosity by using an equation that combines particle density and had 0.38. For the internal porosity, based on the equation used by **Mauguet et al. (2005),** the internal porosity of ROW has been determined at 0.67.. The micropore surface and volume have been reported respectively at 718 m^2/g and 0.314 cm^3/g **(Ismadji & Bhatia, 2001)**. On the surface, ROW has 0.3 mmol/g acidic and 0.2 mmol/g basic groups. The solid density and particle density were respectively 1950 kg/m^3 and 642 kg/m^3**(Haist-Gulde et al., 1995)**. In the

Norit sheet the electrical resistance of dry ROW was 1-5 Ω. The point of zero charge is reported at 4.9**(Citraningrum et al., 2007)**.

2.4.2.1.2. Norit ROX 0.8

Another activated carbon used in this study was Norit ROX 0.8 (ROX). Itis a coal based activated carbon, with 0.8 mm diameter and has a pellets form. The total surface area (BET) was reported at 959 m^2/g in **Zarubina (2011)** and 1100 m^2/g in **Kwon (2008).** The mesopore surface, micropore surface, micropore volume and the total pore volume were respectively 847 m^2/g, 0.365 cm^3/g and 0.467 cm^3/g (**Ismadji and Bhatia, 2001)**. On its surface ROX has 270 µmol/g acidic sites and 510

Figure 2. 8. Norit RAW 0.8 Supra

µmol/g basic sites **(Gomes et al., 2010).** The point of zero charge is 7.6 according to **Gomes et al. (2010).** The bulk density of ROX is between 350 and 450 kg/m^3.

For the elemental analysis, ROX ROX contains 93.21% of Carbon, 0.28% of Hydrogen, 0.56% of Nitrogen, 0.84 of Sulfur and 5.11% of Oxygen **(CALY & LR, 1994; Figueiredo et al., 1999)**.

Figure 2. 9. Norit ROX 0.8

2.4.2.1.3. Norit C Gran

The third activated carbon used in this study is C Gran. It is a granular activated carbon with 0.8 mm diameter **(Choi et al., 2014).** The total surface area (BET) has been reported differently depend on the study. The BET of Norit C Granhas been reported at 1361 m^2/g in **Plaza et al. (2010)**, 1400 m^2/g in **Choi et al. (2014),** 1545 m^2/g in **Byrne (2012)** and 1813 m^2/g in **Liu (2017).** The point zero charge is between 2.8 and 4.6 **(Liu, 2017; Plaza et al., 2010)**. According to the elemental analysis, C Gran has 82.9% of Carbon, 3% of Hydrogen, 0.4% of Nitrogen and 13.7% of Oxygen **(Plaza et al., 2010)**. The total pore volume, the micropore volume and the mesopore volume were reported respectively at 0.97 cm^3/g, 0.51 cm^3/g (**Plaza et al. (2010)** and 0.89cm^3/g **(Liu, 2017)**. The density of C Gran is 1.51 g/cm^3 **(Plaza et al., 2010)**.

Figure 2. 10. Norit C Gran

2.4.2.2. Feed characteristics

For the study of efficiency of these three types the activated carbon, columns previously filed with activated carbon were feed with a synthetic greywater. This last was prepared every morning, by dissolving 7.68g of MIR dishwashing gel (Henkel, France), 3.125g of Persil washing powder (Henkel, Germany), 0.75g of Colgate (Colgate-Palmolive, United States of America), 1.25g of Dettol liquid hand washing (Dettol, United Kingdom) and 1.25g of Garnier ultra doux shampoo (Garnier, France). All products were chosen based on the list of voted product of the year 2016 in Lebanon. For this study, kitchen greywater was excluded from our tests. These proportions were mixed together to establish a composition similar to natural greywater **(Jefferson et al., 2004)**, and were inspired by **Huelgas et al. (2009)**. The components were mixed with 10 L of tap water and stored in a glass container. The COD of this synthetic greywater ranged from 281.2 mg/L to 369.6 mg/L and the average of turbidity was 11.3 NTU. Due to the ban of phosphates by the European Union in 2011, no phosphates or nitrogen were detected in our synthetic greywater. The columns were fed manually the whole day from 9:00am to 17:00pm from the top surface of the carbon to minimize any loss. Samples taken from the columns were analyzed directly for chemical and physical analysis.

2.4.2.3. Chemical and physical analysis

The COD and turbidity are considered as global parameters used to analyze urban, potable or even naturel water. The COD is the quantity of oxygen consumed by the substances existing in the water and oxidizable under defined operating conditions. To determine COD, the AFNOR (French norm): NF T90-101(ISO 6060:1989) has been used. The turbidity reflects the effectiveness of the filtration, because it is related to the presence of various organic particles in water. The turbidity was measured by a turbid-meter that comprises a light beam which passes through the measuring vessel. The light scattered laterally by the suspended particles is received by a measuring cell. The method AFNOR NF EN ISO 7027 was used for turbidity. Our target in this study is to minimize the surfactants present in the greywater due to detergents, shampoo and other ingredients. Therefore, we had to take into consideration the quantity of surfactants in the samples, for that purpose, we used the AFNOR NF EN 903 and measured the anionic surfactants by spectrometry.

2.4.3. Results

2.4.3.1. Chemical Oxygen Demand (COD)

In the first day of analysis, ROW had the highest elimination rate with 98.7% versus 94.1 % for pellets activated carbon and 82.7% for granular activated carbon. The efficiency of ROW decreased slightly to 64.9% in the sixth day of experiments and only 22.7% of elimination was obtained tenth day of experiment. The decrease of efficiency with time was also observed for the two others activated carbon. However, the efficiency obtained by ROX decreased slightly from 94.1% at the first day to 84.3% the eighth day of experiments. In the last 2 days of experiments, we noticed a decrease of elimination rate and only 41.7% of COD were eliminated at the tenth day of experiment. For the C Gran, its general elimination rate was lower than the two other carbons selected in this study. However, the efficiency rate were relatively stable with time (Figure 2.12). The first 4 days had a minimum of 74.7 and a maximum of 82.7% then a small decrease occurred after the fourth day and reached 40.6% in the last day of experiments. In average, the elimination rate of the COD were 81.3%, 66.5% and 65.4% respectively for Norit ROX, Norit C Gran and Norit ROW. Appendix 5 shows a histogram with the highest percentage of COD elimination and a standard deviation interval of the three types of activated carbon used.

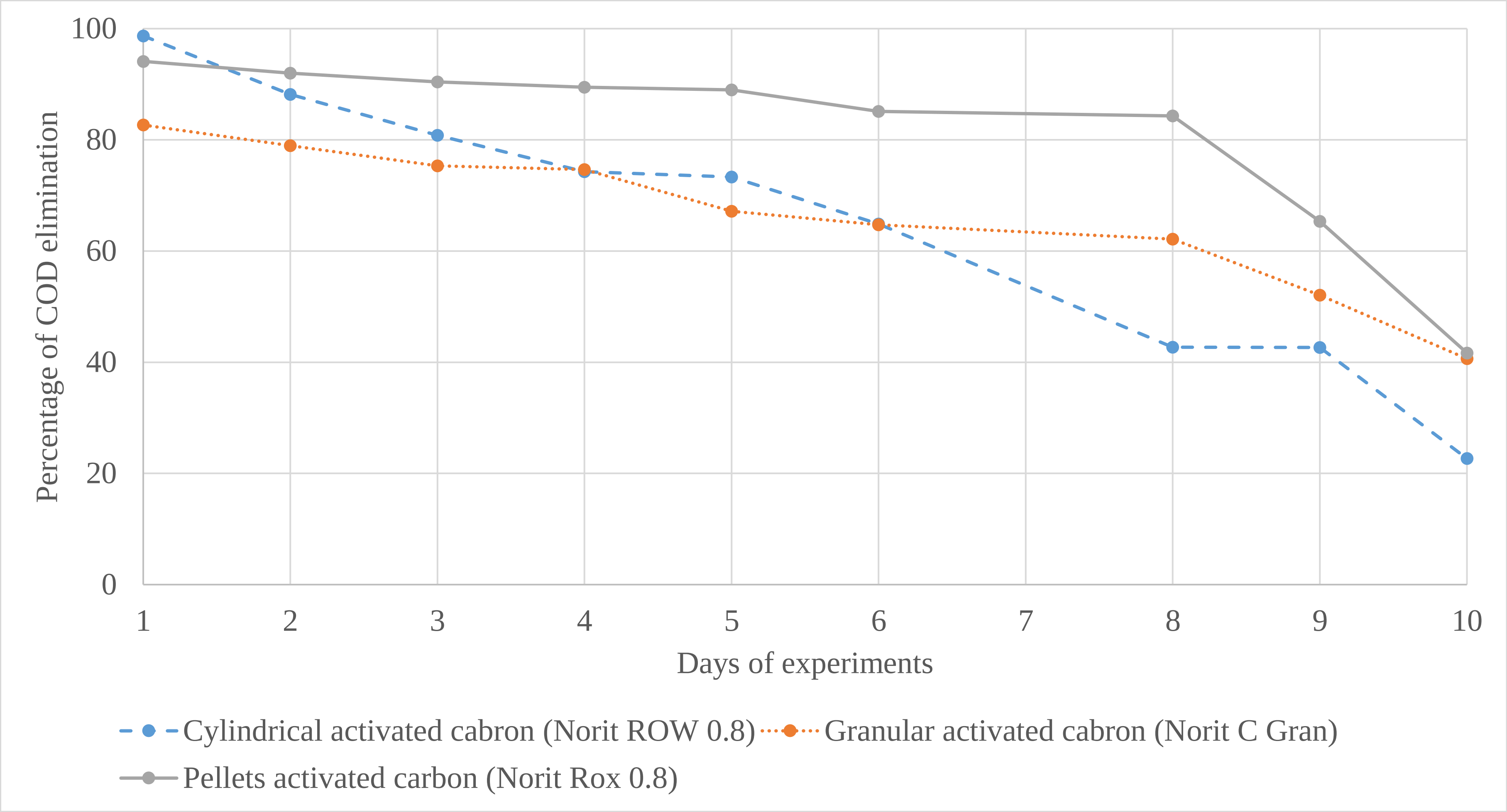

Figure 2. 11. The percentage of elimination of COD for the 3 types of activated carbon

2.4.3.2. Turbidity

Concerning turbidity, the average removal obtained from ROX carbon was 81.3% and was the highest. The elimination yield was stable for the three activated carbon from day 1 to day 5 of the experiment. For the first day of experiment, cylindrical activated carbon (Norite ROW) had the highest elimination rate and follow by Norit ROX; 98.7% of turbidity was eliminated with ROW. The elimination yield decreased slowly to reach 73.3% for the fifth day of experiment. After five day, the efficiency decreased quickly and 22.7% of turbidity was eliminated at the tenth day of experiment. With Norit ROX94.1% of turbidity was eliminated for the first days of experiemnt. The efficiency decreased with time to reach the minimum of removal of 41.7% in the tenth day of experiment. The granular activated carbon could eliminated 82.7% of turbidity for the first day of analysis. The elimination yield decreased slowly to reach 40.6% in the tenth day of experiments.

Judging on the approximately equal average removal of each type of activated carbon used in this study (had 65.4% for cylindrical activated carbon, 66.5% for Norit C Gran and 81.3% for Norit ROX) we can’t choose is the best carbon to use in order to eliminate greywater turbidity. Figure 2.13 shows the results concerning the turbidity elimination efficiency of the 3 tested activated carbon. Appendix 6 shows a histogram with the highest percentage of turbidity elimination and a standard deviation interval of the three types of activated carbon used.

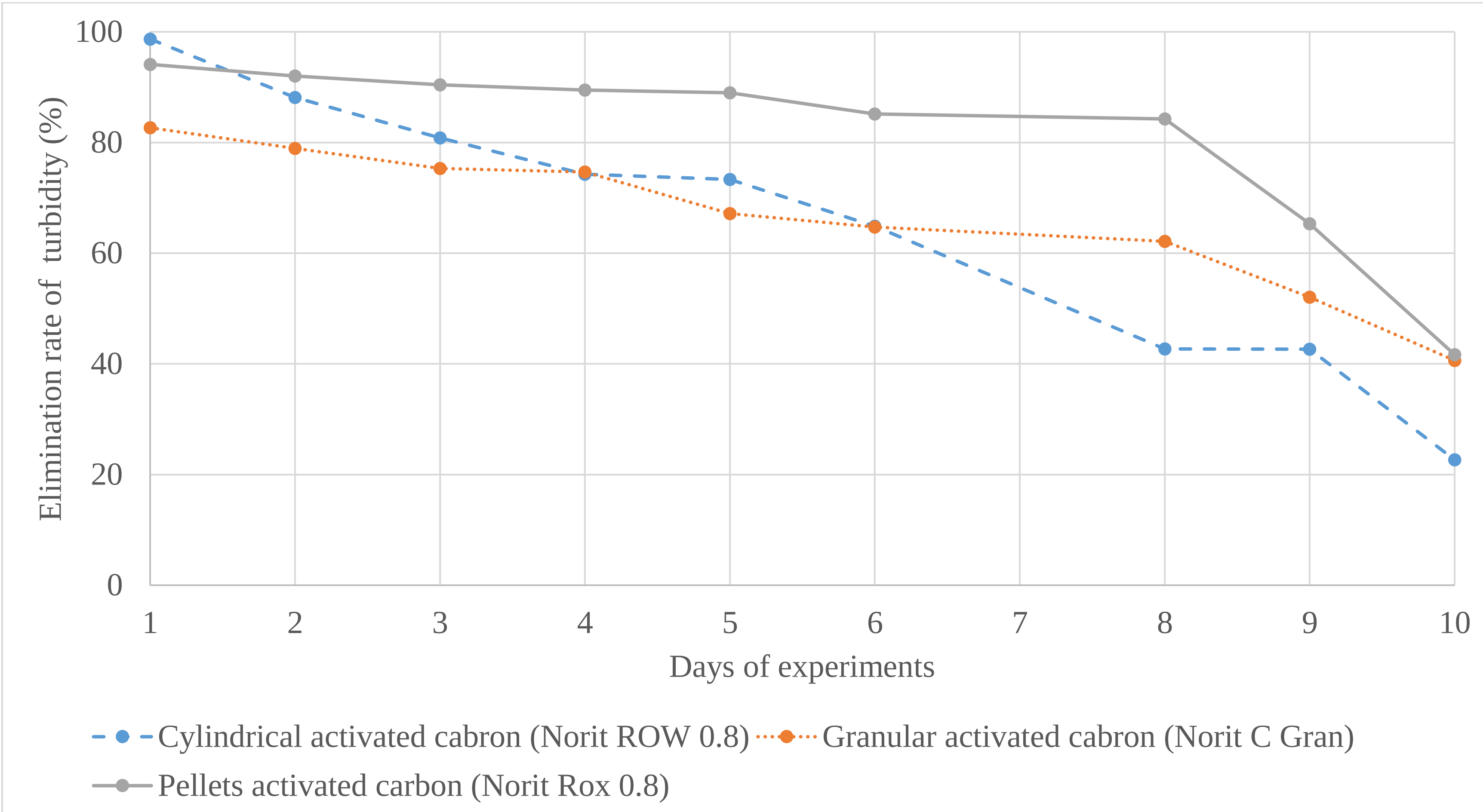

Figure 2. 12. The percentage of elimination of turbidity for the 3 types of activated carbon

2.4.3.3. Active agent

The active agent can be eliminated with good efficiency with the 3 activated carbon (C Gran, ROX and ROW) and similar elimination yields were obtained for the first five days of experiment. Around 91% of active agent was eliminated for the first five days of experiment (Figure 2.14). Afterwards, ROW carbon decreased slowly to reach 60.9% in the ninth day and only 38.3% of active gent was eliminated the tenth day of experiment. While ROX and C Gran offered similar efficiency along the duration of experiment but starting from day five, C Gran offered slightly higher elimination rate, for example 91.8% for C Gran versus 88.4% for ROX at day five and 84.6% for C Gran versus 80.7% for ROX at day ten. Appendix 7 shows a histogram with the highest percentage of active agent elimination and a standard deviation interval of the three types of activated carbon used. For the elimination of surfactants, Norit C Gran showed the highest elimination rate with 91.1% and follow by Norit ROX with 88.1% and Norit Row with 78.3%.

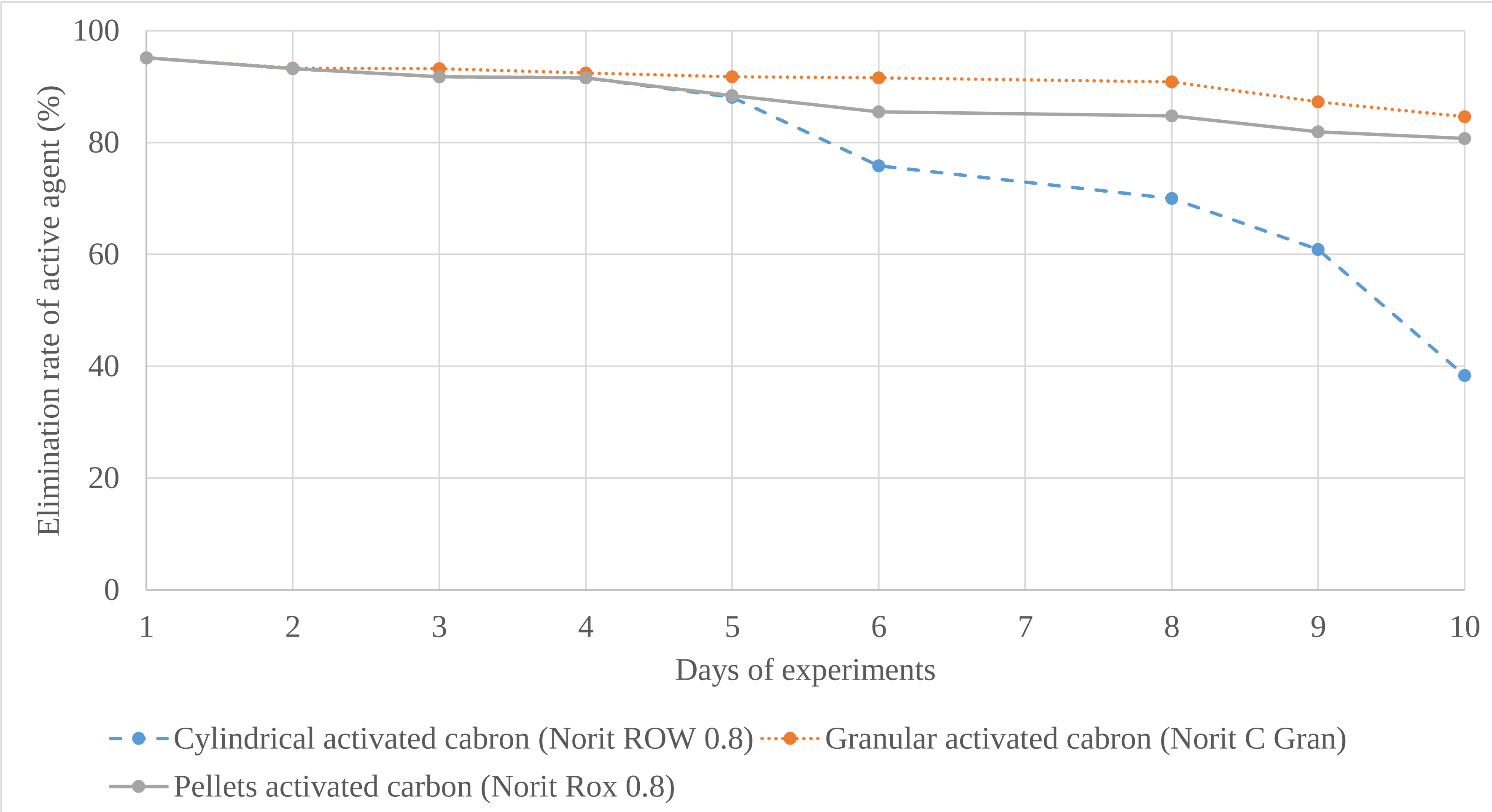

Figure 2. 13. The percentage of elimination of active agent for the 3 types of activated carbon

2.4.4. Conclusion

The word is thirsty for a new way to conserve water and be able to reuse any drop that can be reusable. Greywater can solve many global problems, if used in a correct way and directed in the right path. All we need to ensure is the quality of the outlet water needed for non-potable uses. Our study used activated carbon as adsorbent in order to evaluate their elimination capacity of greywater pollutants. In order to compare the 3 used activated carbon we calculated the average of the 3 tests. The results demonstrated that ROX had the greatest results for carbon oxygen demand and turbidity elimination with 80.61% and 70.48% in average. ROX had slightly lower efficiency in eliminating surfactants comparing to C Gran that took the first place in this category. If we examine in depth ROX proprieties, the mesopore surface and micropore surface in ROX is higher than C Gran. Plus, the carbon percentage in ROX is much higher than C Gran. ROW has the smallest total surface area comparing to ROX and C Gran and it offered the lowest efficiency among the three type selected. Therefore, the results from this study show that the granular activated carbon, originated from coal and with pellets form: ROX, has higher adsorption efficiency due to its incomparable proprieties. It was confirmed due to this study the importance of knowing the proprieties of activated carbon that we are working with.

Characteristics	ROW 0.8 Supra	ROX	C Gran
Type of activated carbon	Granular activated carbon	Granular activated carbon	Granular activated carbon
Origin	Vegetal : Peat charcoal	Coal	Wood
Form	Cylindrical	Pellets	
Total surface area BET (m^2/g)	1150	1225	1400
Methylene blue adsorption (cm^3)	24	24	30
Effective size (mm)	0.8	0.8	0.85-1.7
External porosity	0.382	No Data	No Data
Internal porosity (Kg/m^3)	0.67	No Data	No Data
Solid density (Kg/m^3)	1950	350-450	1510
Point of zero charge	4.9	No Data	2.8 to 4.6
Electrical resistance (W)	1 to 5	No Data	No Data
Mesopore surface	No Data	126 m2/g	0.89 cm3/g
Micropore surface	No Data	847 m2/g	0.52 cm3/g
Micropore volume (cm^3/g)	No Data	0.365	0.51
Total pore volume (cm^3/g)	No Data	0.467	0.97
Acidic sites	No Data	270 µmol/g	No Data
Basic sites (µmol/g)	No Data	510 µmol/g	No Data
Carbon (%)	No Data	93.21	82.9
Hydrogen (%)	No Data	0.28	3
Nitrogen (%)	No Data	0.56	0.4
Sulfur (%)	No Data	0.84	No Data
Oxygen (%)	No Data	5.11	13.7

Table 2. 1. Characteristics of the 3 activated carbon used in the study

2.5. Performance of sand in eliminating greywater pollutants

2.5.1. Introduction

Sand, an international adsorbent, used usually in major treatment technics in order to trap pollutants found in water. The efficiency of sand in treating water depends mostly on its type, size and the quality of influent. When using sand as a medium, it must be fine enough to ensure biological analyses but also coarse enough to minimize clogging and maintain aeration.

Usually the efficiency of sand is measured within the system and not alone in a column. The elimination rate for most sand treatment technics (slow sand filter, rapid sand filter, roughing filter, slanted soil) is attributed to the technic mostly and not the medium. Therefore, there is a difficulty to have an idea about which type of sand is the most efficient. In this section, after analyzing residual bricks and activated carbon we wanted to compare the removal ability of different types and sizes of sand.

2.5.2. Materials and methods

2.5.2.1. Adsorbent

A serial of sieves with different sizes were stacked vertically with smallest opening at the bottom and the largest at the top in order to have a size distribution for the sand material. With circular motion shake, material placed on the top of sieves will percolate throw gaps until each sand particle reaches the right size category. The efficiencies of 4 categories of sand have been studied. They are gravel with particles size higher than 3.5mm, coarse sand with particles between 1 and 2 mm, medium sand with particles between 0.5 and 1 mm and finally fine sand with particles lower than 1 mm. The microsand has the ability to treat wastewater as well as industrial water in different treatment plants like Veolia and particularly in the ACTIFLO process found in 900 installations worldwide; their efficiency was alsostudied in parallel with the 4 sand adsorbent.

Figure 2. 15. Gravel

Figure 2. 14. Coarse sand

Figure 2. 16. Medium sand

Figure 2. 18. Fine sand

Figure 2. 17. Microsand

2.5.2.2. Feed characteristics and analysis

Same as residual bricks and carbon, sand was feed with artificial greywater prepared from dishwasher gel, washing powder, toothpaste, liquid hand washing and shampoo mixed with tap water. All adsorbents were placed in the same columns which were fed manually from the top surface of the adsorbent and samples were taken directly from the bottom and were taken for analysis. COD, turbidity and surfactants were determined for all samples according to the AFNOR norms.

2.5.3. Results

2.5.3.1. Chemical oxygen demand

The Figure 2.20 present the results of elimination yield obtained by the five types of sand. Comparing to other adsorbents, sands represented the less efficiencies for treating he COD from greywater. On the first day of experiment, the elimination yield vary from 22% to 62% depending on the type of sand. The results showed that the efficiency by using sand as filter media depend on the particles size. For the first day, fine sand and microsand offered the higher elimination yield than other type of sand with particles size bigger. 62.1% of COD was eliminated with fine sand and 58.6% with microsand (Figure 2.20). Gravel, coarse sand and medium sand could eliminate less thansame 23% of COD for the first day. After the fifth day of experiment, the elimination yield did not exceed 18%. And the tenth day of experiment, the elimination yield were lower than 6% for all the type of sand selected in this study.

Additionally, microsand can causeclogging easily as we observed at the tenth day of experiment which caused no elimination yield of COD. To judge which sand type eliminated the most the COD from greywater, we calculated the average percentage of removal and had, 19.7% for fine sand, 18.5% for microsand, 11.6% for medium sand, 9.2% for coarse sand and 8.6% for gravel. Appendix 8 shows a histogram with the highest percentage of elimination and the standard deviation of each sand type.

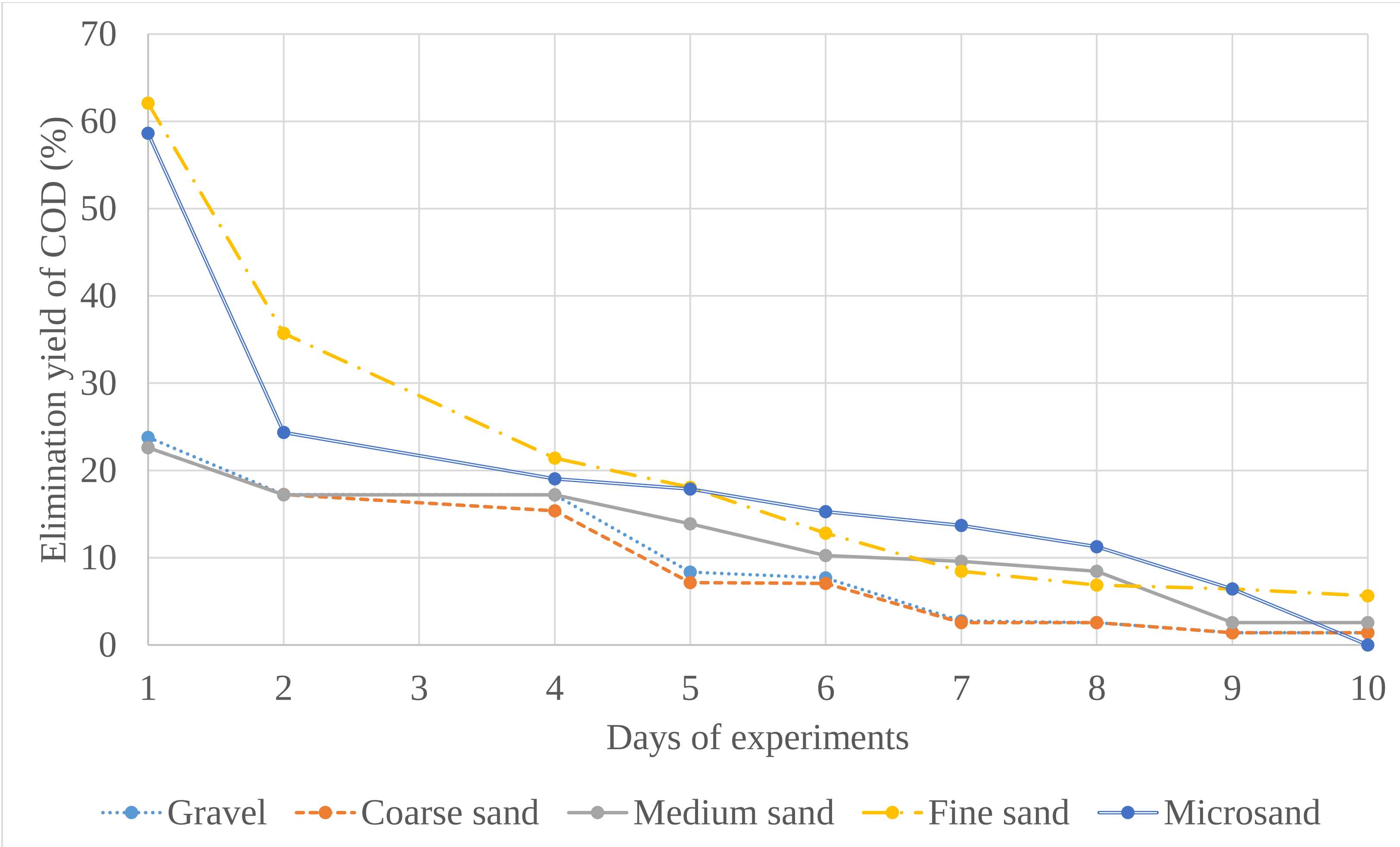

Figure 2. 19. The elimination percentage of COD for sand type

2.5.3.2. Turbidity

Different from the COD, turbidity was easier to eliminate by sand. For the first day of experiment, all type of sand offered the elimination yield with satisfaction. The elimination rate at the first days of experiement varied from 71% obtained with gravel to 100% obtained with medium sand (Figure 2.21). In the next day the 2 highest adsorbent decreased till 84 %, fine sand and gravel stayed stable and microsand. After that, all adsorbent decreased slowly to reach in the final day of experiments 35.3% for medium sand, 34.6% for medium sand, 27.6% for fine sand, 22.4% for microsand and 9.8% for gravel.

As an average removal for turbidity, fine sand and medium sand had the same average percentage with 59%, then comes microsand with 58%, coarse sand with 51.4% and gravel with 31.7%. Figure 2.21 illustrate the result given for the removal of turbidity. Appendix 9 shows a histogram with the highest percentage removal of turbidity with a standard deviation.

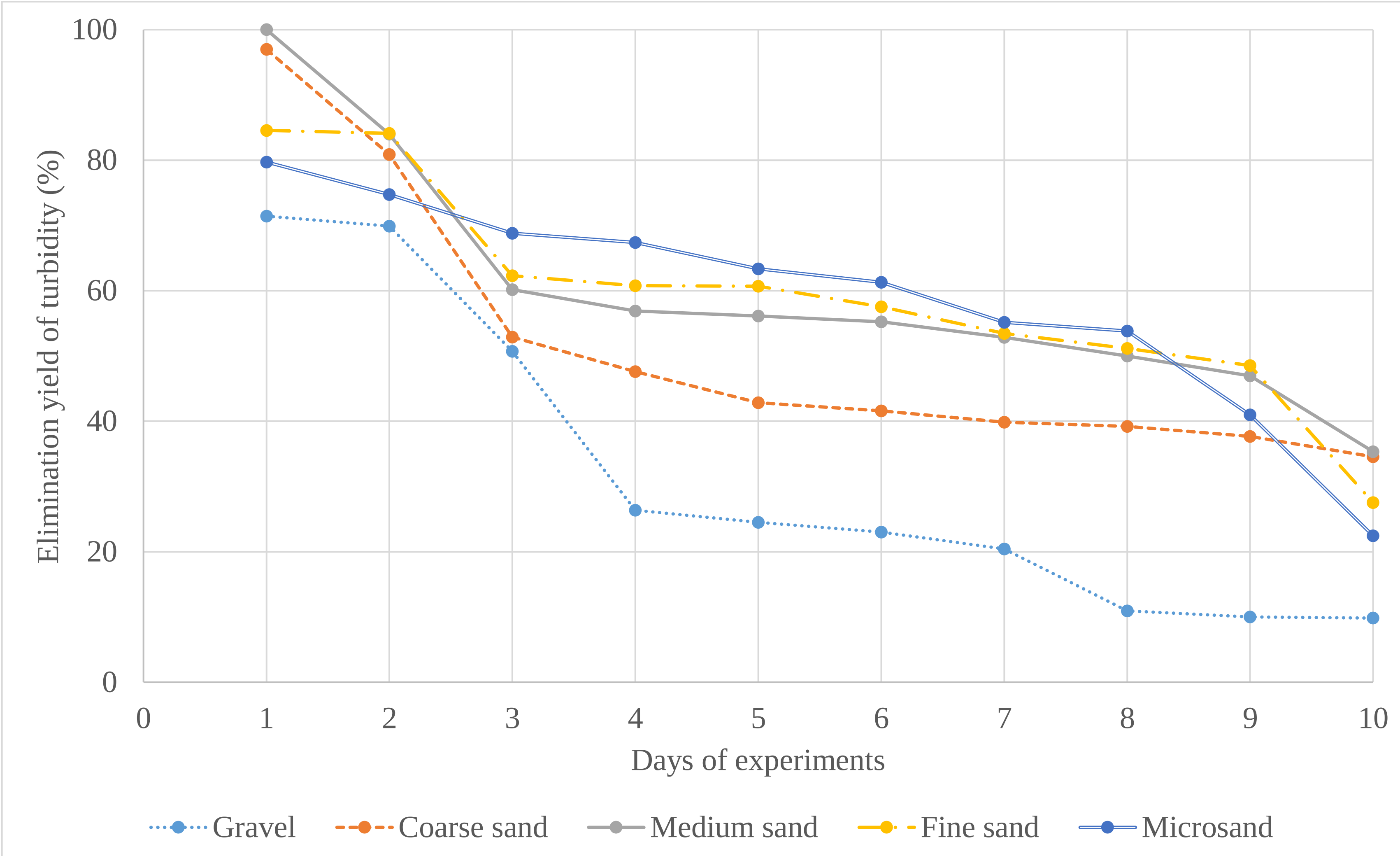

Figure 2. 20. The elimination percentage of turbidity **for different sand type**

2.5.3.3. Surfactants agent

For the removal of surfactants agents, a clear fluctuation in the results was observed between the adsorbents. The medium sand had the highest removal rate in day 1 with 66.5% of elimination but the efficiency decreased with time to reach 41.5% in the day forth and to 10.2% in day 5^{th} and only 3.3% of surfactant agent was eliminated the day tenth of experiment. Fine sand, began with 63.9% then decreased to reach 48.5% in the third day of experiment. At day 4 fine sand reached 18.7% and stayed at this level till the last day of experiment and had 125%. Coarse sand started at 48% but in day 2 this percentage decreased to reach 25.5 and stayed stable till the last day of experiment and reached 6.6%. For gravel, it started with 47.7% then decreased rapidly to reach in day 2 25%. This percentage kept on decreasing to reach finally 4.6%. Last we have microsand with 28.5% in the first day then after day 2 we had a decrease in the removal percentage with 17%. The percentage of elimination kept on decreasing to reach in day 7 0% caused by clogging of this adsorbent. Figure 2.22 illustrates the result of surfactants agent removal.

As for the average removal percentage, fine sand had the highest average with 33.1%, medium sand had 27.1%, coarse sand had 22.3%, gravel had 20% and microsand had 11.6%.

Appendix 10 shows a histogram with the highest percentage of elimination and the standard deviation.

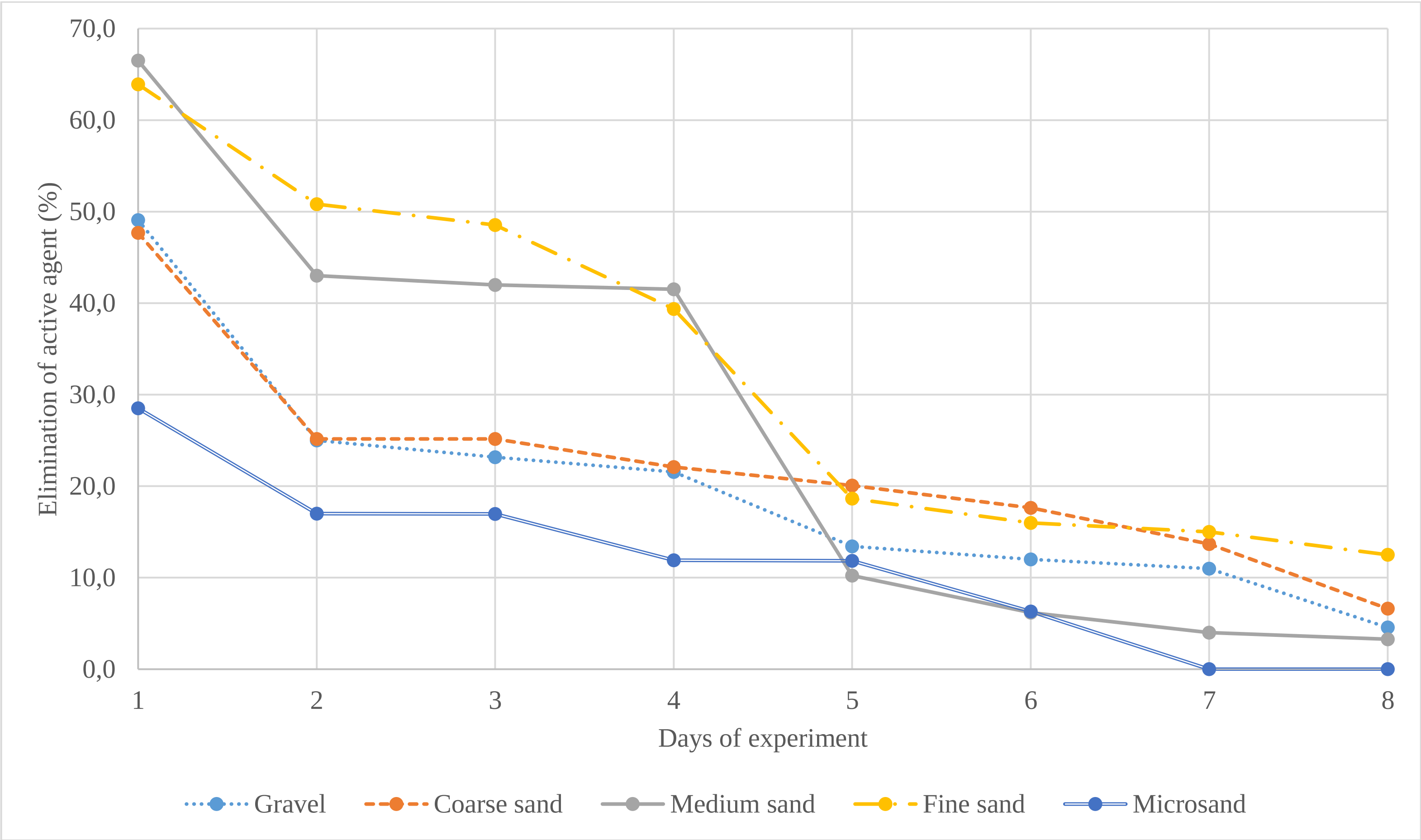

Figure 2. 21. The elimination percentage of active agent for different sand type

2.5.4. Combination of fine sand

The efficiency of different shapes of activated carbon has been presented previously. Fine sand was added to the activated carbon so study if the mixture of these two adsorbents can improve the efficiency of treatment of greywater.The fine sand was chosen because of its great results comparing to other types. In the experiment, the fine sand was mixed with the three types of activated carbon. The results are illustrated in the figure 2.24. We noticed a great improvement of the elimination for all activated carbon types. Norit ROX 0.8 eliminated 100% of the pollutants found in greywater with the addition of fine sand. Results concerning this improvement are shown in the figures 2.23, 2.24 and 2.25. The combination of fine sand with activated carbon improve the efficiency.

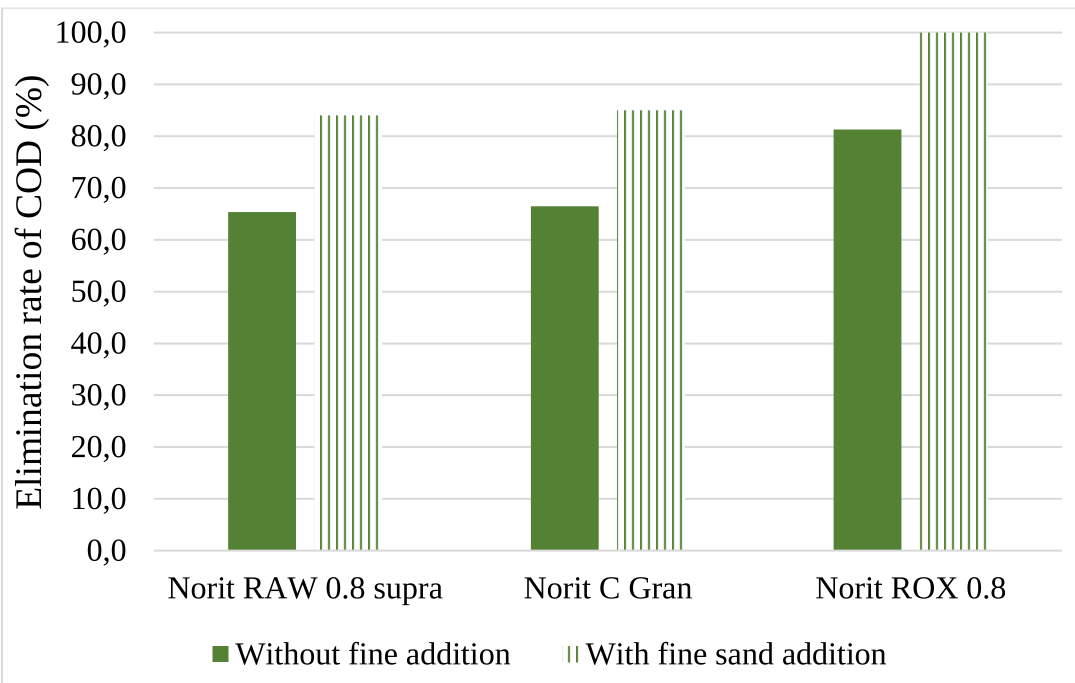

Figure 2. 22. Effect of combining fine sand to activated carbon in the elimination of COD

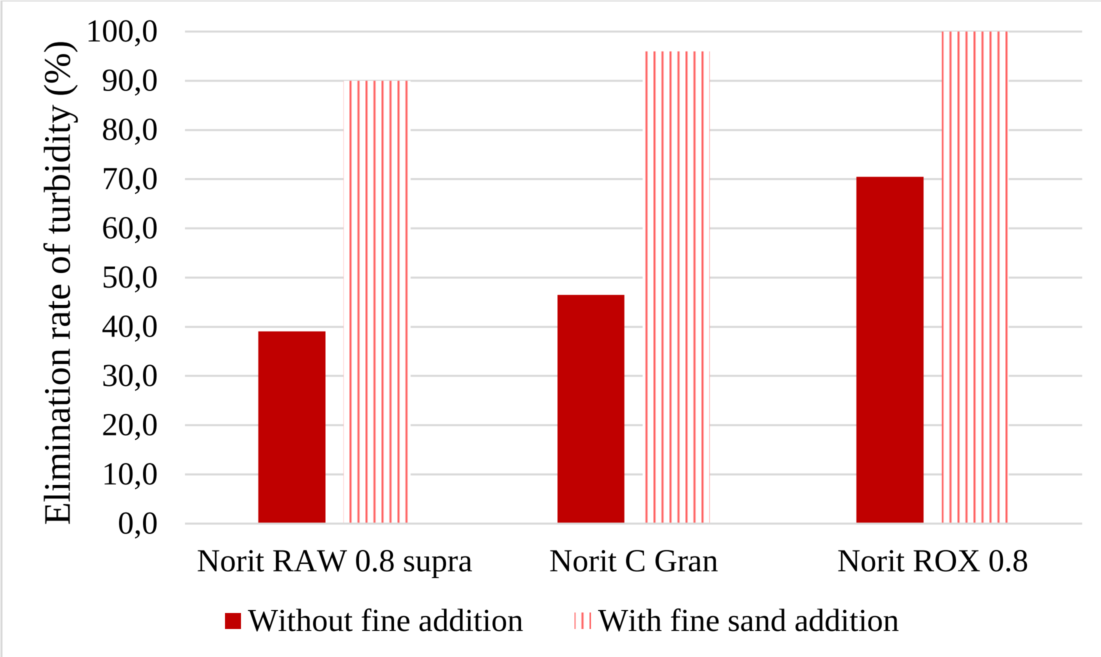

Figure 2. 23. Effect of combining fine sand to activated carbon in the elimination of turbidity

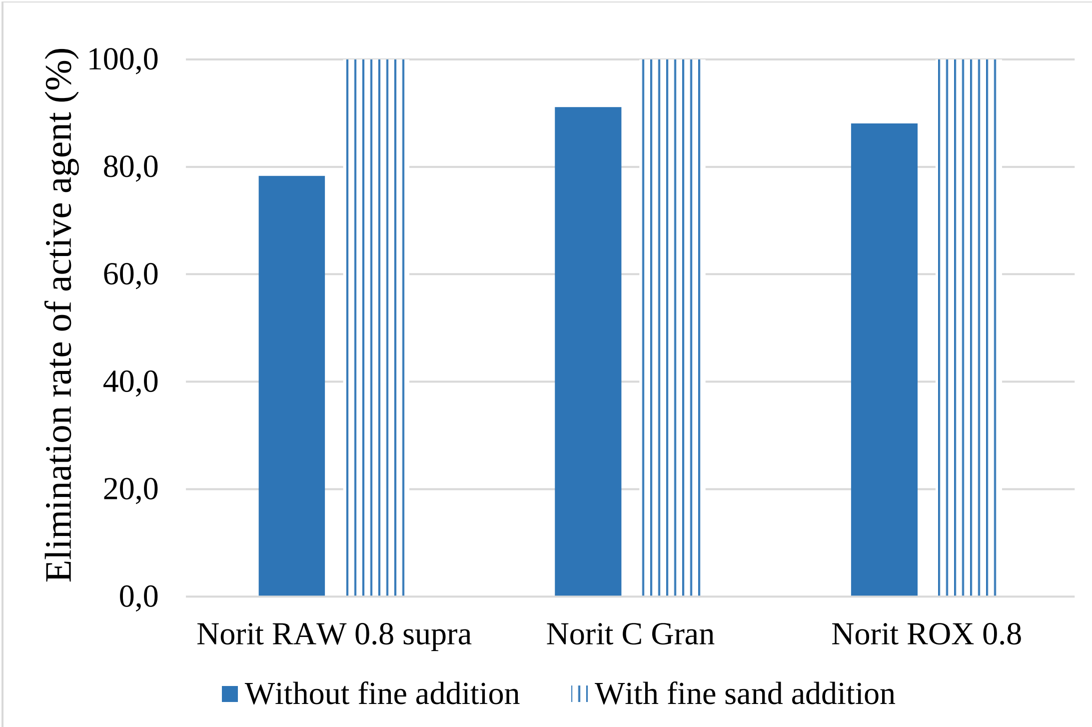

Figure 2. 24. Effect of combining fine sand to activated carbon in the elimination of active agents

2.5.5. Experimental design

Because one of our targets is having a low cost system, therefore we wanted to use the experimental design to try as much as possible to keep high efficiency and minimize the quantity of activated carbon used. Because Norit ROX 0.8 showed great results when combined with fine, these two adsorbents have been selected for the study. Their quantities measured in volume form to put into the column were selected as a variable. The table 2.2 showed the condition of operational of the experiment. The level -1 represent the level minimal and Level +1 represent the maximum quantity acceptable to use. The level of fine sand was higher because of the lower cost of this adsorbent comparing to the other. We had 4 probabilities that are shown in the table 2.3 along with the results of COD and turbidity elimination. We can't deny the difference that fine sand can add for the removal of turbidity and the impact that this adsorbent can have on the results. Thus, it would be suitable to add fine sand to other sand type and both combined together can deliver great results.

Variables	Variables codes	Level -1	Level +1
Volume of fine sand (ml)	X1	75	150
Volume of Norit Rox 0.8 (ml)	X2	50	100

Table 2. 2. Experimental design variables

X1	X2	Elimination rate of turbidity (%)	Elimination rate of COD (%)
-1	-1	48.5 %	74 %
+1	-1	85 %	75.5 %
+1	+1	90 %	96 %
-1	+1	60 %	82 %

Table 2. 3. Experimental design and the percentage of elimination of turbidity and COD

2.5.6. Conclusion

Comparing different type of sand is an important thing for further studies because as we said earlier, it is used in most filtration technics in water treatment. To have an overview of all results of the analysis done in this section we calculated the average removal percentage of each adsorbent in each analysis. Because chemical oxygen demand is the most important parameter concerning water treatment usually, choosing the most efficient adsorbent have a major impact. The most efficient adsorbent was fine sand with 19.7% as an average for the removal percentage. In the second place comes microsand with 18.5% but microsand can cause clogging problem due to its granulometry. For the other type of sand, the elimination yield were 11.3% 9.1% and 8.3% respectively for medium sand, gravel and coarse. For the turbidity, this parameter can be eliminated more easily than COD. The medium sand, fine sand, microsand and coarse can eliminate 59.7%, 59%, 58.7% and 51.4% respectively. The gravel offered the less efficiency with 31.7% of turbidity can be eliminated. However, the five type of sand seem to be not efficient for eliminate the surfactants, only 33%, 28%, 22.2%, 20% and 11,5% of surfactants were eliminated respectively by fine sand, medium sand, medium sand, gravel and by microsand.

In brief, and to conclude this section, fine sand with particles size lower then 1mm is the most efficient sand adsorbent for removing the most pollutants in greywater. In addition, medium sand with 0.5 to 1 mm particle size offered also great results comparing to other adsorbent. If we ignored the problem of clogging, microsand had higher removal percentages than coarse and gravel. Before we end, we have to take always into consideration that each sand has particle characteristics and can differ from origins of sand.

2.6. Conclusion

The main purpose of this chapter was to study the feasibility of greywater treatment using different types of adsorbents. Numerous adsorbents have been studied; there are 3 residual bricks, 3 carbon types and 4 types of sand. The average removal rate of each adsorbent in each test have been determined. Graph 3.10 illustrates the results overview. Maybe it's not fair to compare carbons with residual bricks or sand because of the obvious results that this adsorbent can offer, and that can be seen clearly in the graph. For COD, Norit ROX 0.8 offered the highest removal rate and follow by Norit C Gran and Norit ROW 0.8. After carbon comes fine sand. For the turbidity parameter, the highest elimination yield was obtained with Norit ROX 0.8 and follow by the medium sand, fine sand then microsand. For the sufactant, the highest elimination rate was obtained with Norit C Gran and follow by Norit ROX 0.8 and Norit ROW 0.8.

All the world is suffering from water scarcity but also we should consider economic feasibility of a system. Countries suffering from water stress usually are those also having troubles financially, therefore even though activated carbon can offer great results but using the treatment system with activated carbon is expensive. Because we are kind of targeting countries with low income we will take the challenge to build a system that can benefit from, as much adsorbent as we can. In the next chapter we will try to combine the result from our review of the most popular and efficient treatment system that can treat light lowed greywater and the results of the work done in analyzing the capability of adsorbent to treat also same type without forgetting the economic aspect. Chapter 2 concluded that slanted soil and constructed wetlands both can offer great treatment results. Usually greywater is reused in agricultural fields but in our study we wanted to benefit from the capabilities of plants to treat water, therefore we will have the concept of slanted soil and the concept of using plants in constructed wetlands and combining them into one system. In the chambers of the slanted soil system, based on our results, medium and fine sand have been used in this chapter.

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Chapter 3 – Pilot design and analysis

3.1. Introduction

In order for a country to grow and expand proper sanitation and clean water source must be present. In this purpose and to alleviate stress from potable water, each drop of water that is thrown must be seen as a reusable opportunity. Harvesting rainwater, treating wastewater and treating greywater are the alternative solution for water supply. Our study was focusing on greywater treatment, that source that is growing all over the word. First we saw the most popular treatment technics whereas for high load greywater or for light load and which one of each category was the most efficient based on literature studies. We concluded, that slanted soil and constructed wetlands had great results in removing pollutants from low load greywater. In our study, we excluded kitchen greywater and only light load greywater was taken into consideration. Therefore we were interested in only these results from the review done. We directly planned that our future pilot will combine both systems and will be mostly be based on the concept of adsorption. As presented in chapter 3, there is a tight relation between adsorption phenomenon and adsorbent. For that reason, we tested different types of adsorbent to see also which one will give the most efficient results concerning the removal of light greywater pollutants. In our study condition, activated carbon in its 3 forms showed great results. However, these types of adsorbents were not selected for our pilot due to their expensive cost. Indeed, we want to develop a pilot system with the affordable price. Consequently, sand was chosen for this pilot study because our consumer target were countries without high income. In this chapter, we designed a pilot which can treat light greywater combining the concept of slanted soil (chambers stacked vertically with an incline) and phytoremediation from constructed wetlands. Physical and chemical parameters were determined to study the feasibility of designed pilot. Our main goal is to have a functioning, reliable system with minimal clogging, leakage and easy to implement and maintenance, which successfully treats greywater without increasing the risk to human health or the environment.

3.2. Design of the pilot

To determine the performance of any treatment system, we should first set up and operate on a small-scale system before moving to full-scale. Setting a pilot will give us the opportunity to modify and confirm the performance ability, have valuable data and save money. When designing a pilot there are a serial steps to ensure before heading to analyzing and testing. First we should confirm the process selection and as we reviewed in chapter 2 the most efficient treatment technics to be used for light greywater were slanted soil and constructed wetlands. We will combine the concept of these 2 processes. Slanted soil benefits from using 3 to 4 chambers placed vertically to be able to filter water from one chamber to the other without using energy. This concept will be the base to our pilot. We used 3 chambers but with a twist: the first chamber will contain plants that have the phytoremediation ability taken from the concept of constructed wetlands and the other 2 chambers will contain medium and fine sand adsorbent. The medium sand will be prior to the fine sand. The second parameter to ensure is water input. Because in Lebanon we don't have any separation for blackwater and greywater, we will be using the same formula of synthetic greywater done in chapter 3.

For a quick process description, slanted soil is a technology that was created first time in Japan, consists of several chambers containing soil stacked vertically. This system doesn't require energy because water will infiltrate in each medium and then with the help of a gradient found in each chamber, water will pass to the next chamber. Constructed wetlands depend mostly on the ability of a plant to eliminate pollutants found in water and use also the physical and microbial characteristics of the soil.

3.2.1. Dimensions of the pilot

Slanted soil system is the base of our pilot, therefore, the main layout will be formed of three boxes stacked vertically. In that purpose we took into consideration the dimension of previous slanted soil system studies. The majority of the studies had the same dimension 0.94 m to 1m length, 0.1 m to 0.3 m depth, 0.1 to 0.5 m height and with a gradient of 1/20. The material of the pilot is one of the important criteria and aluminum was chosen because of its ease manufactured and it can support water input without deforming like wood. We decided to build the pilot with 1m length, 0.25m depth, 0.15 height and a gradient of 1/20. To ensure the pass of water from box to box we alternated 29 holes in one side of each box; the first chamber has holes on the right, second on the left and the third on the right again. The stand that cares the 3 boxes was 1.2 m is too able to remove the boxes freely for any soil modification. Each box was paced with large space between one box and the other. As for the gradient we have put an aluminum board to ensure water flow in 1/20 incline. Figure 3.1 illustrates the pilot and figure 3.2 illustrate the interior of a box.

Figure 3. 1. The pilot constructed

Figure 3. 2. One of the chamber interior

3.2.2. Plants choice

Because of the wide use of constructed wetlands in treating either greywater or wastewater we had a variety of plants to choose from. *Typha latifolia* and *Scirpus sp* **(Mancilla Villalobos et al., 2013)**, *Lepironia Articulata* **(Wurochekke et al., 2014)**, *Heliconia angusta* **(Saumya et al., 2015)**, *Canna Indica* **(Husnabilah & Tangahu, 2017)**, *Heliconia psittacorum* , *Bromelia sp* and *Cyperus papyrus* **(Paulo et al., 2007)** are commonly used in treating water. But two criteria were taken into consideration. The first was the presence of the plant in Lebanon and its ability to live in the climate condition and the second most important criteria was the maximum height of the plant. Our target users were at first hotels and universities campuses therefore we wanted an added value from our pilot for that reason we preferred choosing between ornamental flowers. With these limitations we narrowed the selection to ornamental flowers with a maximum height of 30 cm. At first we selected 6 types of plants: *Achillea millefolium*, *Calendula officinalis*, *Celosia argentea plumosa*, *Celosia* *argentea cristata, Lavandula angustifolia vera* and *Linum usitatissimum*. Seeds were brought from "Les graines de France" to have a certified and high germination percentage seeds. **Figures 3.3 to 3.8** shows the packages of seeds bought.

3.2.2.1. *Achillea millefolium*

Achillea millefolium, is used as a medicinal plant in treating fever, asthma, bronchitis, cough, skin inflammation, jaundice, diabetes, hepatobiliary diseases, healing wounds, menstrual regulation, flatulence, dyspepsia, hemorrhoids, dysmenorrhea and gastritis and also consumed for its antitumor, antimicrobial, anti-inflammatory and antioxidant properties **(Cavalcanti et al., 2006; Yassa et al., 2007)**. This plant belongs to Asteraceae family and is represented by about 85 species found mostly in Europe and Asia **(Assyov & Dimitrov, 2002)**. But we choose to test this plant not because of it medicinal properties but because of its phytoremediation capabilities. **Wang et al. (2011)** have reported that *Achillea millefolium* offer great results in accumulating of mercury. This plant can also reduce total petroleum hydrocarbons **(Masu et al., 2014)**. In addition, *Achillea millefolium* can eliminated efficiently heavy-metal such as lead, cadmium, arsenic, molybdenum, nickel, and zinc **(Roodi et al., 2012)**.

3.2.2.2. *Calendula officinalis*

With high Cadmium and lead tolerance **(Chun-hui et al., 2016; Jung et al., 2002; Liu et al., 2008)**, *Calendula officinalis* was chosen. It is also tolerance to copper also **(Afrousheh et al., 2015; Goswami & Das, 2016),** lead and potassium **(Tabrizi et al., 2015)**. Moreover, *Calendula officinalis* has a clinical utilities. It can be used in treating minor skin wounds, skin infections, burns, bee stings, sunburn, warts and cancer **(Hamburger et al., 2003)**. This plant is an annual flower and is native to Asia and southern Europe.

3.2.2.3. *Celosia argentea plumosa and Celosia argentea cristata*

Celosia hashigh health values: high in vitamin E, medium in folic acid, high in ascorbic acid, medium calcium and many other. Moreover, it is one of 33 plant species that is used to treat heavy metals contaminated soils in Taiwan **(Lai et al., 2011)**. Celosia family shown its phytoremediation capacity for lead (**Cui et al., 2013).** It could also accumulate azote and potassium **(Friedman et al., 2007)**. The Celosia belongs to the Amaranthaceae family and commonly known as cockscomb **(Rubini et al., 2012)**.

3.2.2.4. *Linum usitatissimum*

Linum usitatissimum, also known as flax, is very popular for its seeds that contain 36-40% oil rich in fatty acids **(El-Beltagi et al., 2007)**. This plant is an annual plant that belong to the Linaceae family. Flax is considered as an excellent candidate for phytoremediation especially for heavy metal polluted soil **(Broadley et al., 2001; Havel et al., 2010; Kos et al., 2003; Malik et al., 2014).** It can accumulate with good efficiency the cadmium **(Bjelková et al., 2011; Hancock et al., 2012; Szalata et al., 2009)**,lead, nickel, copper and zinc in sewage sludge **(Amna et al., 2015; Bjelkova et al., 2011; Jasiewicz & Antonkiewicz, 2003)**.

3.2.2.5. *Lavandula angustifolia vera*

We wanted to test the *Lavandula angustifolia vera* because unlike all 5 other plants it's the only perennial plant and previous studies showed that this plant like other repellent plants (*Vetiveria zizanioides, Cymbopogon martini, Cymbopogon elexuosus, Cymbopogon winterianus, Mentha sp, Ocimum basilicum*), could be used for phytoremediation. Lavender can accumulate heavy metals such as lead, zinc and cadmium thanks to its essential oil **(Angelova et al., 2015; Bağdat & Eid, 2007; Zheljazkov & Nielsen, 1996; Ziarati et al., 2014).** We were fascinated by the lavender plant because it can overcome hydric and nutrient stress **(Peñuelas & Munné-Bosch, 2005)** without forgetting its importance in regulating soil erosion and enhancing soil physico-chemical parameters **(Ouahmane et al., 2006; Zuazo et al., 2008)**.

3.2.3. Plant testing

We began testing these 6 types of plants, in greenhouses belonging to "Université Lille 1". First we left seeds to grow in a humus trays as shown in **figure 3.9**. Twenty five holes were planted for

Figure 3. 3. Achillea millefolium

Figure 3. 4. Calendula officinalis

Figure 3. 5. Celosia argentea cristata

Figure 3. 6. Celosia argentea plumosa

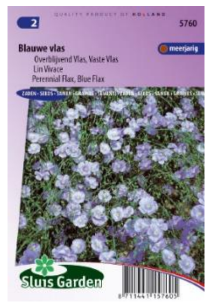

Figure 3. 7. Linum usitatissimum

Figure 3. 8. Lavandula angustifolia vera

each type of plants and each hole contained 2 seeds. To compare the reaction of seeds growth in function of quality of irrigated water; we planted 2 trays in parallel, the first irrigated with tap water and the second with synthetic greywater. But, within 3 days from sowing seeds, 4 types of plants (*Celosia argentea cristata*, *Celodia argentea plumose*, *Linum usitatissimum* and *Lavandula angustifolia vera*) grown faster with irrigated tap water. The comparison is illustrated in **table 4.1.**

Irrigated with tap water, seeds grown in the first tray were transplanted to larger pots filled with different types of soils as shown in figure 4.2. Different mixtures were used: sand, humus, French coffee dregs, sand and humus (1:1), sand and coffee dregs (1:1), humus and coffee dregs (1:1) and the mixtures of sand, humus and coffee dregs (1:1:1). We had 2 repetition for each type of soil mixture and irrigated water. For example, 2 pots of celosia argentea plumosa planted in humus irrigated with synthetic greywater and 2 pots of celosia argentea plumosa planted in humus irrigated with tap water. Plants were irrigated each day in the afternoon with 50ml. To differentiate plants irrigated with tap water and with greywater, yellow and orange tags were used respectively (**figure 3.10**).

Calendula officinalis (CO), *Celosia argentea cristata (CC)* and *Celosia argentea plumose* (CP) had fast growth, then comes *Linum usitatissimum (LU)* and *Lavendula angustifolia vera (LA)*. *Achillea millefolium (AM)* took approximately 4 weeks to grow and didn't even reach the stage where we had to transplant it. Although, coffee dregs has many advantages for plants but we faced a major problem with clogging and water adsorption. More experiences is necessary to optimize the ideal condition of mixture of coffee dregs with other soil types.

To judge if a plant is healthy or no, the first criteria is foliage growth, and for CO, CC, LA and CP we noticed during the tests that they had plenty of healthy new growth. Leaves were bright green and no signs of yellow or brown leaves was spotted. Second criteria is the presence of pests or diseases. Because we were working in the greenhouses it was easy to detect the presence of any undesirable bugs or flies thanks to the high protection and display of yellow sticky trap pads that can detect them. Plus, the undersides of leaves and the joint between steam and leaves were healthy. And last, roots were white for the 4 types which indicated a healthy growing plant. We noted that plants planted in coffee dregs either alone or mixture with sand had some burns maybe because of the pH of this mixture affected these kind of plants. Because all 4 plants had excellent growth even with synthetic greywater irrigation we decide to use LA for our pilot because it is perineal and belong to the repellent family which can give an added value to the system.

Figure 3. 9. Plants growth after 17 days of sowing seeds

	Tray irrigated with tap water	Tray irrigated with synthetic greywater
First day of sowing seeds		
After 3 days of sowing seeds		

Table 3. 1 . Comparison between the plant growths between trays irrigated with tap water and synthetic greywater

Figure 3. 10. Celosia argentea plumosa after transplanting to different pots with different mixtures

3.2.4. Sand used in the pilot

To fill the chambers of our pilot we used 4 types of sand. The first type of sand was brought from a local land and was chosen because of the redness in it which indicate that it contains high iron. This sand was mixed with humus brought from the agriculture store. Mixed together, they formed the first chamber ready to be used for plants. The second type was brought from a crusher in Bhanin- Akkar then was sieved between 3 and 1mm and formed the second chamber. The third was fine sand sieved bellow 1mm brought from the river of al Bared –Akkar and formed the third chamber.

The basic characteristics and proprieties of these adsorbents were studied. The soil particle size, the pH and the electrical conductivity, the total limestone, the activated limestone, nitrogen, phosphorous, potassium oxide, sodium, magnesium, calcium and iron were determined.

3.2.4.1. Soil particle size analysis

The principle of granulometric analysis is relying on the mineral particles that constitutes a soil that can be isolated, sorted and classified according to their size. This test is the most important to characterize the soil ground and understand its operation. The distribution of the various grain size fractions classifies the soil in a texture class which defines certain parameters of physical behavior, useful water retention, ability to store nutrients or risks of leaching losses. The particle size analysis is carried out according to the standardized method AFNOR NF X31-107. In this test we should first separate fraction smaller than 2 mm from coarse elements. Then water was added to the sieved material. The particles will then slowly sediment depending on their size in function of time. After this step it is time for the determination of the texture class and for that we will be using the texture triangle of GEPPA illustrated in Figure 3.11. This triangle give an idea about the texture of our soil because it is composed of 16 classes, grouped into 3 predominantly: clay, silty or sandy groups. The textural class of the analyzed sample is determined according to the positioning of the values in clays and total silts.

For our first chamber the percentages were: sand 35.28%, silt 17.28% and clay 47.44% therefore, the texture was clay. For the second chamber the percentages were: sand 33.28% silt 25.28% and clay 41.44% for that the texture was clay. For the last chamber the percentages were: sand 73.28%, silt 9.28% and clay 17.44% as a result the texture was sandy loam.

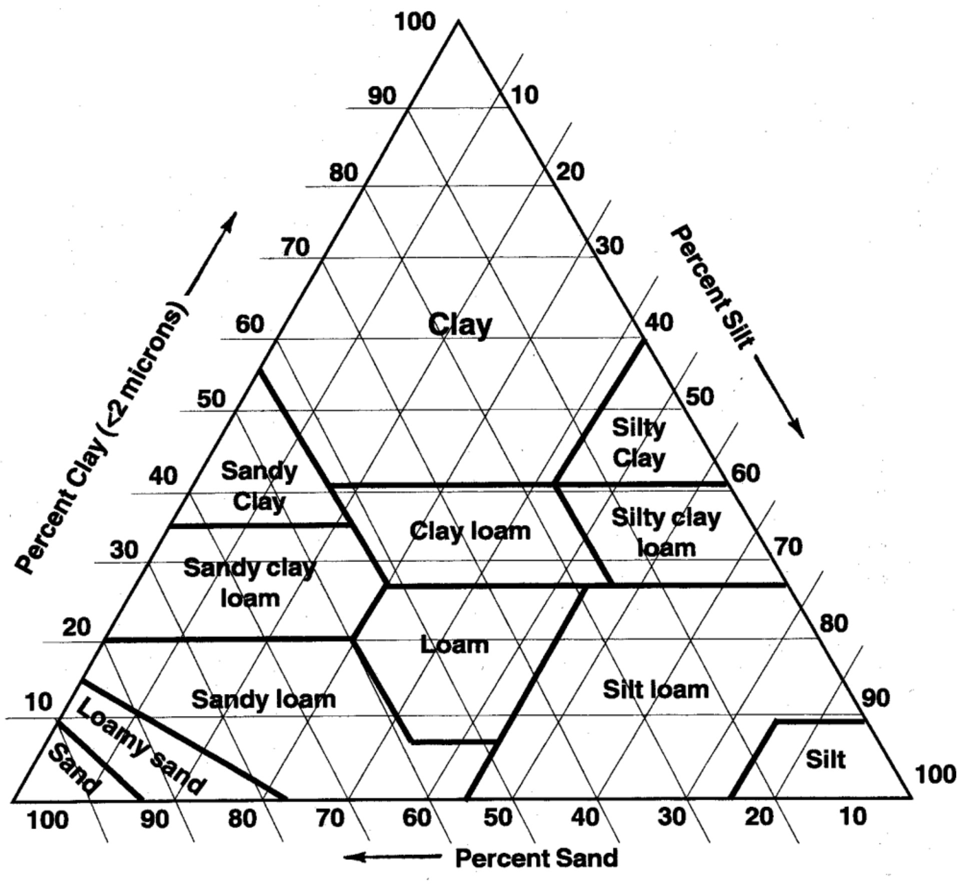

Figure 3. 11. The texture triangle of GEPPA

3.2.4.2. pH and electrical conductivity

The measurement of the pH soil allows to define its state of acidity or alkalinity. With a pH lower than 5.5 soil is considered with high acidity, between 5.5 and 6.0 soil is acid, between 6.0 and 6.5 soil is slightly acidic, between 6.5 and 7.0 soil in neutral, between 7.0 and 7.5 soil is slightly alkaline and with pH higher than 7.5 soil is considered alkaline. Indeed, the pH value should be taken into consideration because it determine the stability of structure, function of cation exchange capacity, assimilability of phosphorous, bioavailability of oligo elements and micro elements and mineralization of organic matter of the ground. Especially with our plants hanging in the first chamber we should know what is the pH because the best pH for agricultural uses is 8. Generally, soil is best to be either natural, slightly acidic or slightly alkaline.

To measure pH soil, the methods described in the international standards NF ISO 10390 was used. After adding deionized water to the soil we can take the pH value. For our soils the first chamber had a pH at 8.20 which could be used in planting. For the second and third, the pH value were determined at9.08 and 8.75 respectively.

The electrical conductivity of a soil is the measure of the amount of ions present and which could dissolve in the presence of water. This method allows to determine the salinity of soils. The conductivity of a solution is the measurement of the capacity of the ions to carry the electric current. This passage of the electric current is effected by the migration of the ions in an electric field produced by an alternating current. Using the ISO 11265 to determine the electrical conductivity, the first chamber had 0.17 ms/cm (between the ranges for agriculture), the second chamber had 0.11 ms/cm and the third one had 0.13 ms/cm.

3.2.4.3. Total limestone and active limestone

Total limestone is one of the components inherited from the soil. The presence of limestone gives the soil specific characteristics in terms of physical and chemical behavior and influences its biological activity. Its total absence results in a gradual acidification. The analysis of total limestone is necessary to refine the characterization of soil constituents and improve strategic choices in terms of liming. Soil is put in contact with a strong acid which dissolves the limestone, in a closed medium. The attack of limestone ($CaCO_3$) results in a gaseous release of CO_2 whose volume is measured. This current analysis method is described in the international standard NF ISO 10693. To qualify the sample we take the percentage of total limestone; if the value is less than 5% it’s a non-limestone soil, between 5 and 12.5% it’s a low soil limestone, between 12.5 and 25% it’s a moderate limestone soil, between 25 and 50% it’s highly limestone soil and if it’s higher than 50% it’s very highly limestone soil. For the first chamber total limestone was 29%; the agricultural range is between 0 and 30%. The second and third chambers weredetermined at 46% and 40% respectively.

Active limestone is the fraction of total limestone that can dissolve easily and quickly in the soil solution. It corresponds more or less to the fine particle size (clay size). It allows to maintain a stable basic pH. The presence of active limestone can induce, in some soils with low iron, a risk to which some productions are sensitive. The soil is brought into contact with a ammonium oxalate, which attacks a fraction of total limestone only. The extracted calcium is then measured. This current analysis method is described in the AFNOR NF X31-106 standard. The risk for sensitive plants can only be shown if the active limestone is higher than 7% and is very serious if it exceeds 10%. For our chambers, the active limestone was measured at 6%, 12.5 2.87% respectively for the first, second and third chamber. The active limestone measured in the second chamber was higher than 10 but this chamber is not used for plants.

3.2.4.4. Available nitrogen

Nitrogen is the most important nutrient for the growth of the plant and it could determine the development of plants and roots and stimulates the optimal adsorption of other nutrients in the soil. To determine available nitrogen, we used the Kjeldahl method in soil. First step in this analysis is the digestion of the organic material to convert nitrogen into HNO_3, then the distillation of the released ammonia with excess NaOH into an adsorbing surface usually HCl and last the volumetric analysis of the ammonia formed during the digestion process. For our samples the first chamber had 0.1% of available nitrogen, the second 0.008% and the last 0.02%.

3.2.4.5. Phosphorus

Phosphorus is one of the major elements essential for the growth and development of plants. In particular, it plays a key role in setting up the root system, photosynthesis and plant reproduction. It is a naturally occurring element in our soils. The extraction technique used in this method is internationally recognized as the most representative of soil-root exchanges and the most universal, which is reliable and interpretable in the vast majority of soil situations. The earth is brought into contact with a solution of sodium hydrogencarbonate. The extract obtained is determined by spectrophotocolorimetry. In our samples the phosphorous in the first and second chamber were under limit of detection and in the third chamber was 0.64 ppm. We should note that the range for agricultural practices should be between 35 to 92 ppm.

3.2.4.6. Potassium oxide

Potassium, like phosphorus, is one of the major elements essential for the growth and development of plants. It plays a multiple role in the plant: ion exchange in the cell, activation of photosynthesis, protein synthesis. It is a naturally occurring element in our soils, with the exception of some calcareous or clay soils. Knowing the soil content of exchangeable potassium is essential to optimize agronomically, according to the needs of soil and crops and sustainably maintain its potassic fertility. Soil is brought into contact with an ammonium acetate solution, according to the AFNOR NF X31-108 standard. The extract obtained is determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). In our samples, 220 ppm84 ppm and 55.2 ppm were determined respectively for the first chamber, second and the third chamber. For the range for agricultural use, the value should be between 216 and 360 ppm.

3.2.4.7. Magnesium, calcium and iron

Magnesium is a minor but essential element as an active constituent of chlorophyll. It is found mainly in the leaves. Secondarily, it plays a similar role as calcium on the physical fertility of soils. Knowing the magnesium content is essential to check the advisability of adding magnesia (preventing a risk of deficiency) and to optimize the magnesian fertilization strategy. Iron plays a significant role in biological processes and its deficiency causes anaemia and disturbed adsorption of nutrients.

To analyze magnesium and calcium, soil is brought into contact with an extraction solution containing a chelate (EDTA), according to the AFNOR NF X31-120 standard. The extract obtained is assayed, for the 4 elements, in atomic absorption spectrophotometry. The first chamber had 290.4 ppm for magnesium (range between 240-400 ppm for agricultural practices) and 4000 ppm for calcium (range 700-4500ppm). The second chamber had 484 ppm and 1840 ppm for magnesium and calcium respectively and the third had 145.2 ppm and 1120 ppm.

For iron, its concentration was determined at 27.9 ppm, 46.6 ppm and 48 ppm respectively for the first chamber, the second and the third chamber. We should note that the marge of iron presence in the soil for agricultural practices should be 10 ppm.

3.2.4.8. Available sodium

Sodium is a secondary element and its natural content in our soils is low, but sufficient for crop needs. On the other hand, an excess of sodium carries a risk of degradation of the structure of the soil. In case of high content, the growth of plants is strongly disturbed and the soil pH rises significantly. Sodium analysis indicates the soil salinity. In the case of massive and repeated spreading of sodium effluents, the monitoring of the sodium content is essential to avoid the risks of structural destabilization. The soil is brought into contact with an ammonium acetate solution, according to the AFNOR NF X31-108 standard. The extract obtained is determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). Sodium available was 71 ppm, 43 ppm and 52 ppm respectively in the first, second and third chamber. The range for agricultural practice is bellow 300ppm.

3.2.5. Pilot water input

As described in the chapter 3.3.2, 3.4.2 and 3.5.2, we used the same recipe for synthetic water by dissolving 23 g of MIR dishwashing gel (Henkel, France), 9.36 g of Persil washing powder (Henkel, Germany), 2.25 g of Colgate (Colgate-Palmolive, United States of America), 3.75 g of Dettol liquid hand washing (Dettol, United Kingdom) and 3.75 g of Garnier ultra doux shampoo (Garnier, France). All products were chosen based on the list of voted product of the year 2016 in Lebanon and France. The kitchen greywater was excluded from our tests. These proportions were mixed together to establish a composition similar to natural greywater **Jefferson et al. (2004)**. The components were mixed with 30 liters of tap water and stored in a glass containers. The among of 30L has been chosen based on the study of **Ushijima et al. (2013)**. **Ushijima et al. (2013)** have reported that they dint not have the problem of clogging when using this amount. This mixture was discharged from the first chamber 3 times per day with a 5 hours intervals at the morning, noon and the evening **(Ushijima et al., 2013)**. The morning discharge was 10L, noon was 3L and the evening discharge was 17L. These numbers were taken based on the practice of water consumption in the morning, noon and in the evening. People consume higher quantity of water at the morning and evening than at noon. As for sampling, water was taken from the holes of each chamber and were put in glass tubes. The COD and turbidity of the pilot were analyzed 2 times per week (Tuesday and Friday) for a period of 5 weeks.

3.2.6. Pilot testing

3.2.6.1. Chemical oxygen demand and turbidity tests

COD and turbidity were analyzed with the methods NF T90-101(ISO 6060:1989) for COD and AFNOR NF EN ISO 7027 for turbidity as described previously. The COD of synthetic greywater was between 281.2 mg/L and 369.5 mg/L. The first day of analysis, SGW had 313.7 mg/L, after passing throw the first chamber the COD decreased to 119.2 mg/L, then the concentration decreased to reach in the second chamber 101.3 mg/L and 81 mg/L in the third. The elimination rate of COD for the first and second day was 97%. The elimination yield was very satisfied during the five weeks of experiment. The elimination yield varied from 94% to 97% and stable during the five week of study. The average elimination yield of COD during 5 weeks was xxxx.

For the turbidity, the treatment of our pilot was very satisfied with the five weeks average removal rate of 97%. In day 1, the SGW had 10.2 NTU passing through the first chamber turbidity decreased slightly to reach 9.89 NTU then decreased in the third chamber to 5.64 NTU and finally was 2.82 in the third chamber. If we studied the efficiency of each chamber separately, the first chamber could eliminate only 3% and the second and third chamber could eliminated 43% and 50% of turbidity respectively. The elimination yield seem stable during the duration of the experiment. The elimination rate obtained from the first chamber varied from 3 to 5% during the duration of experiment. The elimination rate of the second and third chamber were from 40% to43% for the second chamber and from 50 to 54% for the third chamber. The tables 4.2, 4.3 illustrates the concentrations of COD and turbidity values and elimination rate during five weeksof experiment.

To summarize, the first, second and the third chamber removed an average of 60%, 15% and 20% of COD respectively. To study the added value of plants, plants were added into the pilot. And to study the capacity of plants to eliminate the pollution, the results obtained before and after adding plants were compared. In general, the disposition of the chamber can influence the efficiency of the treatment. By changing the slope from 5% to 2% for example, lower efficiency was obtained with 86.75% of the elimination of COD and 89.79% for the elimination of turbidity. To really illustrate the advantages for our system, **(Kondo et al., 2011)** used the same dimension of our pilot and filled the chambers with pumice stone and kanuma soil but also didn't had the same great results as we had. The system only eliminated 70% of turbidity. As for COD **(Ushijima et al., 2013)** filled the chambers with kanuma soil and crushed bricks and fed the system 3 times per day with an interval of 5 hours but only had 58 to 68% of COD elimination. And last but not least, **(Maiga et al., 2014)** used coarse and fine granite gravel and had an elimination of 47 to 50% for COD and 75 to 87% elimination of turbidity. With all further ado, our system proved its capability to treat greywater.

3.2.6.2. Water holding capacity of soil

To know the water holding capacity of each chamber, a graduated cylinder, beaker contain 100 ml water, funnel and filter papers. First we take the graduated cylinder and put on them funnel. Then we put filter papers in the funnel. We weight 25 g of each soil chamber and lace them in funnel. After that we add 100 ml of water into each of the soil samples. We now wait for 15 min until water can run down. The amount of water found in the graduated cylinder can help us determine the water holding capacity of each soil. Our results showed that first, second and third chamber could holds 17%, 15% and 10% respectively.

3.2.6.3. Hydraulic Retention Time

The hydraulic loading rates (HLR) is the amount of water applied per hour over a surface area. The hydraulic loading rates can be calculated as the equation bellow:

$$HLR = {}^{Q}/_{L \text{ x } W}$$

With:

- HLR : hydraulic loading rate (L/m^2/day)
- Q : greywater generation flow (L/day)
- L: Length (m)
- W : Width (m)

This equation was used before, but it became questioned because of the lack of information concerning the volume of the basin this is why a new formula was created: Hydraulic Retention time (HRT). The HRT is the time it takes for a drop of water to travel from inlet to outlet.

$$HRT = \frac{V}{\theta}$$

With

- HRT : Hydraulic retention time (day)
- V : volume of the system (m^3)
- θ : Quantity of greywater entering the system per day (m^3)

HRT = (1 x 0.25 x 0.15) x3 / 0.03 = 1.25 day = 30 h

3.2.6.4. Greywater saving quantities

The purpose of this study is to treat and reuse greywater for irrigation or toilet flushing or any other use needed. Consequently, it is important to know how much volume of reusable greywater this pilot can give.

To know the amount of water regenerated we should take into consideration the soil retention capacity of each chamber and the dimensions of the pilot. Therefore this value could change if soil retention and system dimensions change.

When we fed the system with 30L, we recovered 11.4L. Thus, our system can save 38% of the total water fed.

3.2.7. System requirements

For the system requirements we should pay attention to different aspects: required user participation, social acceptance, cost estimation, energy requirements for construction and maintenance.

3.2.7.1. Required user participation

Maintaining efficiency and lifespan of a system becomes the user's responsibility, therefore they need all the information and guidance. Basic maintenance and monitoring knowledge at least should be known. Because our pilot is a simple system it does not require enormous skills or certain level of education. First mission, is to minimize the use of greywater in general and educate users on chemical and detergents use, although our pilot is a small step in reducing water crisis, user's must learn how to control their water consumption. The second mission, is to ensure the right transport of water either manually or by pipes linked to a storage tank. The use of storage tank is not desirable because if the water is stored before treatment this could cause the breakdown of organic matter by microorganism and can lead to an anaerobic environment that can generates unpleasant odors. If enlarging the system can not be done for financial causes, stored tank must be ventilated as this can minimize odor problems. Users must check for any undesirable circumstances in the storage tank if the water wasn't directly or in 48 hours transferred to the system. Jumping to the system maintenance of course because we are using a sand adsorbent users should first keep an eye on the clogging problems in each chamber. Clogging is generally caused by high concentration of organic matter or microorganisms. This problem is the most affecting to the lifespan and efficiency of our system. Overloading of the system can cause an accumulation of organic matter and therefore affect the system. This problem can be minimized by proper dimensioning, plus we can eliminate any garbage present in greywater before entering the system. If clogging problem occurred, system should rest for several days or change the adsorbent or just clean and break the clogged soil. Resting time depend on grain size (finer materials recover slower). Then, plants health should be checked once in a while, if there is any changes in the color of leafs, if the plants becomes intoxicated, any signs of weakness in the steam and if there is any new buds. Users must pay attention to any leakage because this may indicate a problem with the system or with soil health. Soil in the first chambers must be checked once in a while in an agriculture lab to check salinity, pH and all other factors cited in the beginning of this chapter.

3.2.7.2. Estimated cost

Although the first goal of any treatment system is to ensure its performance, but we should always think about accurate capital and maintenance cost estimated. Because our pilot was created from a new idea therefore, we can't have a reliable previous sources to estimate the cost. When choosing the material of our pilot we though first of wood. but we took into consideration then that wood will cause problem with long term, in that purpose we shifted to aluminum for its light weight, rigidity, long term life, easy modification and water resistance. As we mentioned in the dimension paragraph, the pilot had 1m length, 0.25m depth, 0.15m height and a gradient of 1/20. But to be able to manipulate in each chamber the frame of the pilot was 1.2 m and we had a large space between each chamber. Plus to recover water from the last chamber we had 0.15 m space between the pilot and the floor. This dimension was chosen because more space will cause the pilot to swing and cause maybe leakage problems.

The cost of this pilot was 120$ and although we fed this system with 30L total, it could endure more volumes but we preferred sticking to 30L to prevent clogging problems and to be able to run tests for as much time as possible. Thirty litters were targeted for 1 person, but as we said earlier this dimension can bear the consumption of 2 persons. For hotels and resorts we prefer building as many treatment systems as possible to cover maybe each floor, rather than building 1 or 2 big systems for the whole building. The equipment chosen response to the potential expenses of most of the hotels in the region, therefore the feasibility of our treatment system is high. In addition, maintenance is mostly not costly and sand used can be recovered. Without forgetting the amount of water they will be preserving from flushing toilets or irrigation. Maybe the only problem that we faced in our situation is that till now, government are not forcing the separation of greywater and blackwater which can elevate the cost on hotels and resorts if they are willing to take actions. But we should always keep in mind that the cost of potable water will decrease after using this kind of system. For that, even with modifying the infrastructure of the building our pilot will still be economically viable. Replacement material of our pilot are easy to get, and is affordable to our users. Because our system does not require energy to work this also minimize the cost.

To ensure that our pilot pays off during its lifespan a cost-benefit analysis was taken into consideration.

3.2.7.2.1. Cost benefit analysis

Any system must assure that it pays off during its lifespan, in that purpose we could use the cost benefit analysis tool. The cost benefit analysis, is one of the tools that business decisions makers use to avoid making bad decisions. First of all, we should calculate all-inclusive costs (direct and indirect). For direct costs of our pilot we only have the pilot construction costs about 120$ for 1 unit and the annual maintenance cost (changing one of the chamber in case of any leakage: 20$, changing soil: 15$, unclogging the soil: 20$, changing plants: 10$) with 65$ total. As for indirect costs we have: initial training for users (20$), transportation cost (5$) and other cross-unit costs (30$). Therefore direct costs will be equal to 185$ and indirect costs 55$ and the total of costs will be equal to 240$.

Now we jump to benefit analysis. As we said earlier our system can recover 38% water fed to the system. In Lebanon, each resort or hotel has to pay a yearly fees that is tightly related to the amount of water they are consuming. Generally it is related to the number of persons in this hotel or resort and estimation water consumption, but with our system they can benefit from 38% off the water consumption of greywater that is significantly high in these kind of facilities. If we take for example a hotel with 20 rooms (10 single room and 10 double room) therefore we found 30 people in this hotel. In Lebanon, they calculate 1 m^3 for 4 persons per day. By dividing 30 to 4, the hotel needs 7.5 m^3 of water per day; that means 2700 m^3 per year. Each 360 m^3 cost 212.000 L.L per year then the hotel with 20 rooms only will pay a total of 1.590.000 L.L. In hotels greywater percentage of the total wastewater stream can reach up to 80%. If we consider that 80% of the total water consumption is greywater then this hotel will be paying 1.272.000 L.L for greywater imagine that this bill can become 483.360 L.L if our system recovered only 38% of the total water used. This user will be saving 788.640 L.L which is equal to 525.760 $. With a quick comparison the cost this 240 $ and the benefit is 525 $ and if we took into consideration that this hotel will be putting 2 systems that means that the cost will double (480 $) still he will benefit from the system.

3.2.7.3. Social acceptance

The level of engagement that the costumer is willing to give is the most important step to ensure before starting any treatment system. Too much maintenance, cultural factors, high cost and many other reasons force users to take a steps back toward reusing greywater or engage in any treatment system. Thus we should be sure of the willingness of user's to step into the greywater reuse process. Our primary target were hotels and resorts because of the high water demand found in these places. Although we should also take into consideration the high amount of water used in washing machines and in kitchen. To know more the willingness of resorts and hotels to accept the greywater treatment system idea, we brought together a small questionnaire that we can find in the Appendix 12. We wanted first to know if our target audience had any idea if we are suffering from water shortage problem or no. Fifty percent knew that we were in a water crisis and the other denied any water problem. We noticed then that most of hotels and resorts does not know the definition of greywater but, when we explained the concept and what we are working on and our vision, their interest in saving water grown. But this can illustrates how much our nation has a lack of awareness concerning the method of water reuse. The attitude of users and general public is a major factor that affect the success of water reuse.

As for the reuse option, we suggested irrigation or toilet flushing; only 2 of the 8 hotels and resorts were with using it for irrigation the rest chose toilet flushing. When asked why they chose toilet flushing over irrigation, they all replied the same response, that irrigation can be controlled but toilet flushing can't. Any treatment system needs maintenance therefore we asked how much hours they were willing to put in, 2 preferred putting only 1 hour, 2 preferred putting 2 hours and 4 chose more than 2 hours.

In our interview we asked our customers how much they are willing to pay over one unit. Three range were suggested 200$, 300$ or more than 300$. Even though our unit costs even less then 200$, 2 were willing to pay 200$, 4 were willing to pay 300$ and 2 were willing to pay more than 300$. But we noticed that their willingness was tightly related to the size of their resort or hotel and the 2 resorts that chose the least money are those who chose the least maintenance hours.

Even if our pilot showed its ability to treat greywater with a minimal cost, education is the vital component in the implementation of this reuse option and influencing public options to minimize the use and understand the crisis we are headed to.
Many factors influence people attitudes toward greywater reuse, for example, the availability of potable water, the low cost of potable water, education and traditions of the society.

3.2.8. Reuse options

According to our results the COD reached at the output a maximum of 100 mg/L, and for turbidity the value was at 3.67 NTU. Thus, this water can be used in all aerosols activities without having any risk of contamination and for irrigation. Washing of windows, toilet flushing, car washing, irrigation and other.

3.3. Conclusion

Relying on our previous analysis and previous studies, we were able to combine the concept of slanted soil and the concept of phytoremediation into one system. Our system is still in its first phase, implementation and a case study must be done in order to ensure the stability of its efficiency and to test the real lifespan of this system. The COD and turbidity parameters of treated greywater were very pleasant and comparing to other studies our pilot really brought a benefit. Choosing Lavender to be placed in the first chamber was a challenge because although it proved its ability to eliminate heavy metals but there was a lack of information regarding greywater. Reusing greywater is a must and every country should understand the importance of this source and the actions that can be taken toward minimizing the problem of water scarcity.

	1		2		3		4		5	
	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)
SGW	313.69		302.87		369.58		355.76		356.57	
Chamber 1	119.20	62	115.09	62	147.83	60	142.31	60	139.06	61
Chamber 2	101.32	15	97.83	15	125.66	15	120.96	15	118.20	15
Chamber 3	81.06	20	78.26	20	100.53	20	96.77	20	94.56	20

	6		7		8		9		10	
	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)	COD (mg/L)	Elimination (%)
SGW	360.63		347.76		347.76		281.24		339.82	
Chamber 1	147.86	59	139.10	60	132.15	62	106.87	62	129.13	62
Chamber 2	125.68	15	118.24	15	112.32	15	90.84	15	109.76	15
Chamber 3	100.54	20	94.59	20	89.86	20	72.67	20	87.81	20

Table 3. 2 . Elimination percentage of COD in each chamber in our pilot

	1		2		3		4		5	
	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)
SGW	10.20		9.80		13.6		11.95		10.5	
Chamber 1	9.89	3	9.31	5	13.19	3	11.59	3	10.08	4
Chamber 2	5.64	43	5.40	42	7.65	42	6.72	42	5.75	43
Chamber 3	2.82	50	2.70	50	3.67	52	3.23	52	2.87	50

	6		7		8		9		10	
	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)	Turbidity (NTU)	Elimination (%)
SGW	9.56		9.66		10.46		10.46		9.49	
Chamber 1	9.08	5	9.18	5	10.15	3	10.15	3	9.02	5
Chamber 2	5.36	41	5.32	42	6.09	40	6.09	40	5.41	40
Chamber 3	2.63	51	2.66	50	2.80	54	2.80	54	2.60	52

Table 3. 3. Elimination percentage of turbidity in each chamber in our pilot

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Conclusion

The present thesis has extended understanding of greywater, including its composition, characteristics, reuse options, guidelines and types. A greater understanding of the treatment technics that can improve grey water quality, specially slanted soil and phytoremediation, has also been established.

The following conclusions can be drawn from this work:

1- A review of the literature and experimental analysis revealed that greywater can be treated with multiple types of systems. To choose what suits you, you should have a knowledge of the type of your greywater (either low load greywater or high load greywater), and the capital that you are willing to pay for this system. For low load greywater slanted soil can be chosen or constructed wetlands and for high load greywater activated carbon can be used and of course biochar.
2- Adsorption is tightly related to adsorbent and can be affected by many factors like pH, temperature and pores.
3- Natural bricks residus originated from Central African Republic were tested along with activated bricks with HCl and bricks activated with HCl and FeOOH to see their ability to treat greywater. Natural bricks and bricks activated with HCl without FeOOH showed the highest results in eliminating pollutants comparing to those activated with both HCl and FeOOH. This can be clarified that FeOOH have the ability to substitute the sodium with another metallic cations that why they should great result in eliminating endocrine disrupting compounds and some heavy metals but couldn’t treat greywater.
4- Activated carbon was the best adsorbent in eliminating all kind of pollution. And in this thesis it also proved its ability to eliminate pollutants from greywater. Whereas activated carbon a Norit ROW 0.8 supra with a cylindrical shape or Norit ROX 0.8 with a pellets shape or Norit C Gran with granular shape they all showed great results. The elimination of chemical oxygen demand and turbidity reached a maximum of 98% for Norit ROW 0.8 supra.
5- Sand will always be the easiest most accessible adsorbent that anybody can find and run tests with. That’s why we chose 5 types of sand to test in columns to know which one can deliver great results. Fine sand, medium sand, coarse sand, microsand and gravel were

tested. Fine sand proved its elimination ability as well as microsand that faced a problem with clogging.

6- From the second chapter we knew that our pilot will be based on the concept of stacking different chambers vertically and using phytoremediation in one of these chambers. And after choosing which adsorbent we will be using in the second and third chamber we wanted to search for a plant to use. After testing different type of plants we chose the Lavender because of its ability to grow when irrigated with greywater, its repellent advantage and its removal capacity of heavy metals.

7- After putting all the pilot together we tested its efficiency and results showed a maximum of 100 mg/L chemical oxygen demand and a value of 3.67 NTU for turbidity in the output. Plus our pilot could recover 38% of the total water fed into the system with a cost of 120$ per unit. Water recovered can be then used in flushing or any other aerosol activity without any human or environmental risk or can be used in irrigation.

After the tests we have done to ensure the efficiency of the pilot we built, this product can be wildly spread and used in campuses, universities, hotels, resorts and residential buildings. This project is bigger than just this thesis; governments must see that we reach a point where we should start taking actions to prevent a major disaster. Therefore they should inforce new laws that oblige municipalities to change infrastructure and divide between greywater and wastewater. Local environmental communities must also realize the importance of this source and start enforcing people to make a difference. Our pilot tackles the real environmental problem of water scarcity, and response to water needs.

When we were working on this thesis there was some limitations that got in our way like the lack of guidelines concerning greywater in numerous countries and especially Arab countries except for Jordan. In addition, because the quality of greywater varies according to different factors thus, the quantification of risks is difficult especially in irrigation purposes.

As a perspective of our studies, we would like to take this pilot into action and make a case study in the Taynal Mosque in Tripoli- Lebanon because of the large space in the garden of the mosque and the easy accessibility of ablution water. Then we would like to make an experimental method and try to modify the dimensions of the pilot and test its efficiency in function of the dimension.

Also it would be good to try to test different types of plants (they could be also from the repellent group like menthe plant). A social and cultural study would be necessary to achieve if this kind of treatment system will be implemented. A bacterial analysis were done but should be studied deeper.

Appendix

Appendix 1: Greywater systems for single family dwellings taken from California greywater standards

APPENDIX J

Graywater Systems for Single-family Dwellings

J 1 Graywater Systems (General)

(a) The provisions of this Appendix shall apply to the construction, alteration and repair of graywater systems for subsurface landscape irrigation. Installations shall be allowed only in single-family dwellings. The system shall have no connection to any potable water system and shall not result in any surfacing of the graywater. Except as otherwise provided for in this Appendix, the provisions of the Uniform Plumbing Code *(U.P.C.) shall be applicable to graywater installations.*

(b) The type of system shall be determined on the basis of location, soil type and ground water level and shall be designed to accept all graywater connected to the system from the residential building. The system shall discharge into subsurface irrigation fields and may include surge tank(s) and appurtenances, as required by the Administrative Authority.

(c) No graywater system, or part thereof, shall be located on any lot other than the lot which is the site of the building or structure which discharges the graywater; nor shall any graywater system or part thereof be located at any point having less than the minimum distances indicated in Table J-1.

(d) No permit for any graywater system shall be issued until a plot plan with appropriate data satisfactory to the Administrative Authority has been submitted and approved. When there is insufficient lot area or inappropriate soil conditions for adequate absorption of the graywater, as determined by the Administrative Authority, no graywater system shall be permitted. The Administrative Authority is a city or county.

(e) No permit shall be issued for a graywater system which would adversely impact a geologically sensitive area, as determined by the Administrative Authority.

(f) Private sewage disposal systems existing or to be constructed on the premises shall comply with Appendix I of this Code or applicable local ordinance. When abandoning underground tanks, Section 1119 of the U.P.C. shall apply. Also, appropriate clearances from graywater systems shall be maintained as provided in Table J-1. The capacity of the private sewage disposal system, including required future areas, shall not be decreased by the existence or proposed installation of a graywater system servicing the premises.

(g) Installers of graywater systems shall provide an operation and maintenance manual, acceptable to the Administrative Authority, to the owner of each system. Graywater systems require regular or periodic maintenance.

(h) The Administrative Authority shall provide the applicant a copy of this Appendix.

J 2 Definitions

Graywater is untreated household waste water which has not come into contact with toilet waste. Graywater includes used water from bathtubs, showers, bathroom wash basins, and water from clothes washing machines and laundry tubs. It shall not include waste water from kitchen sinks, dishwashers or laundry water from soiled diapers.

Surfacing of graywater means the ponding, running off or other release of graywater from the land surface.

J 3 Permit

It shall be unlawful for any person to construct, install or alter, or cause to be constructed, installed or altered, any graywater system in a building or on a premises without first obtaining a permit to do such work from the Administrative Authority.

J 4 Drawings and Specifications

The Administrative Authority may require any or all of the following information to be included with or in the plot plan before a permit is issued for a graywater system:

(a) Plot plan drawn to scale completely dimensioned, showing lot lines and structures, direction and approximate slope of surface, location of all present or proposed retaining walls, drainage channels, water supply lines, wells, paved areas and structures on the plot, number of bedrooms and plumbing fixtures in each structure, location of private sewage disposal system and 100 percent expansion area or building sewer connecting to public sewer, and location of the proposed graywater system.

(b) Details of construction necessary to ensure compliance with the requirements of this Appendix together with a full description of the complete installation, including installation methods, construction and materials as required by the Administrative Authority.

(c) A log of soil formations and ground water level as determined by test holes dug in close proximity to any proposed irrigation area, together with a statement of water absorption characteristics of the soil at the proposed site as determined by approved percolation tests. In lieu of

percolation tests, the Administrative Authority may allow the use of Table J-2, an infiltration rate designated by the Administrative Authority, or an infiltration rate determined by a test approved by the Administrative Authority.

J 5 Inspection and Testing

(a) Inspection

(1) All applicable provisions of this Appendix and of Section 318 of the U.P.C. shall be complied with.

(2) System components shall be properly identified as to manufacturer.

(3) Surge tanks shall be installed on dry, level, well-compacted soil if in a drywell, or on a level, 3-inch concrete slab or equivalent, if above ground.

(4) Surge tanks shall be anchored against overturning.

(5) If the irrigation design is predicated on soil tests, the irrigation field shall be installed at the same location and depth as the tested area.

(6) Installation shall conform with the equipment and installation methods identified in the approved plans.

(7) Graywater stub-out plumbing may be allowed for future connection prior to the installation of irrigation lines and landscaping. Stub-out shall be permanently marked GRAYWATER STUB-OUT, DANGER—UNSAFE WATER.

(b) Testing

(1) Surge tanks shall be filled with water to the overflow line prior to and during inspection. All seams and joints shall be left exposed and the tank shall remain watertight.

(2) A flow test shall be performed through the system to the point of graywater irrigation. All lines and components shall be watertight.

J 6 Procedure for Estimating Graywater Discharge

The Administrative Authority may utilize the graywater discharge procedure listed below, water use records, or calculations of local daily per person interior water use:

(a) The number of occupants of each dwelling unit shall be calculated as follows:

First bedroom	2 occupants
Each additional bedroom	1 occupant

(b) The estimated graywater flows for each occupant shall be calculated as follows:

Showers, bathtubs and wash basins	25 GPD/occupant
Laundry	15 GPD/occupant

(c) The total number of occupants shall be multiplied by the applicable estimated graywater discharge as provided above and the type of fixtures connected to the graywater system.

J 7 Required Area of Subsurface Irrigation

Each irrigation zone shall have a minimum effective irrigation area for the type of soil and infiltration rate to distribute all graywater produced daily, pursuant to Section J-6, without surfacing. The required irrigation area shall be based on the estimated graywater discharge, pursuant to Section J-6 of this Appendix, size of surge tank, or a method determined by the Administrative Authority. Each proposed graywater system shall include at least two irrigation zones and each irrigation zone shall be in compliance with the provisions of this Section.

If the mini-leachfield irrigation system is used, the required square footage shall be determined from Table J-2, or equivalent, for the type of soil found in the excavation. The area of the irrigation field shall be equal to the aggregate length of the perforated pipe sections within the irrigation zone times the width of the proposed mini-leachfield trench.

No irrigation point shall be within 5 vertical feet of highest known seasonal groundwater nor where graywater may contaminate the ground water or ocean water. The applicant shall supply evidence of ground water depth to the satisfaction of the Administrative Authority.

J 8 Determination of Irrigation Capacity

(a) In order to determine the absorption quantities of questionable soils other than those listed in Table J-2, the proposed site may be subjected to percolation tests acceptable to the Administrative Authority or determined by the Administrative Authority.

(b) When a percolation test is required, no mini-leachfield system or subsurface drip irrigation system shall be permitted if the test shows the absorption capacity of the soil is less than 60 minutes/inch or more rapid than five minutes/inch, unless otherwise permitted by the Administrative Authority.

(c) The irrigation field size may be computed from Table J-2, or determined by the Administrative Authority or a designee of the Administrative Authority.

J 9 Surge Tank Construction (Figures 1, 2, 3 and 4)

(a) Plans for surge tanks shall be submitted to the Administrative Authority for approval. The plans shall show the data required by the Administrative Authority and may include dimensions, structural calculations, and bracing details.

(b) Surge tanks shall be constructed of solid, durable materials, not subject to excessive corrosion or decay, and shall be watertight.

(c) Surge tanks shall be vented as required by Chapter 5 of this Code and shall have a locking, gasketed access opening, or approved equivalent, to allow for inspection and cleaning.

(d) Surge tanks shall have the rated capacity permanently marked on the unit. In addition, GRAYWATER IRRIGATION SYSTEM, DANGER—UNSAFE WATER shall be permanently marked on the surge tank.

(e) Surge tanks installed above ground shall have a drain and overflow, separate from the line connecting the tank with the irrigation fields. The drain and overflow shall have a permanent connection to a sewer or to a septic tank, and shall be protected against sewer line backflow by a backwater valve. The overflow shall not be equipped with a shut-off valve.

(f) The overflow and drain pipes shall not be less in diameter than the inlet pipe. The vent size shall be based on the total graywater fixture units, as outlined in U.P.C. Table 4-3 or local equivalent. Unions or equally effective fittings shall be provided for all piping connected to the surge tank.

(g) Surge tanks shall be structurally designed to withstand anticipated loads. Surge tank covers shall be capable of supporting an earth load of not less than 300 pounds per square foot when the tank is designed for underground installation.

(h) Surge tanks may be installed below ground in a dry well on compacted soil, or buried if the tank design is approved by the Administrative Authority. The system shall be designed so that the tank overflow will gravity drain to a sanitary sewer line or septic tank. The tank must be protected against sewer line backflow by a backwater valve.

(i) Materials

(1) Surge tanks shall meet nationally recognized standards for nonpotable water and shall be approved by the Administrative Authority.

(2) Steel surge tanks shall be protected from corrosion, both externally and internally, by an approved coating or by other acceptable means.

J 10 Valves and Piping (Figures 1, 2, 3 and 4)

Graywater piping discharging into a surge tank or having a direct connection to a sanitary drain or sewer piping shall be downstream of an approved waterseal-type trap(s). If no such trap(s) exists, an approved vented running trap shall be installed upstream of the connection to protect the building from any possible waste or sewer gases. All graywater piping shall be marked or shall have a continuous tape marked with the words DANGER—UNSAFE WATER. All valves, including the three-way valve, shall be readily accessible and shall be approved by the Administrative Authority. A backwater valve, installed pursuant to this Code, shall be provided on all surge tank drain connections to the sanitary drain or sewer piping.

J 11 Irrigation Field Construction

The Administrative Authority may permit subsurface drip irrigation, mini-leachfield or other equivalent irrigation methods which discharge graywater in a manner which ensures that the graywater does not surface. Design standards for subsurface drip irrigation systems and mini-leachfield irrigation systems follow:

(a) Standards for a subsurface drip irrigation system are:

(1) Minimum 140 mesh (115 micron) 1-inch filter with a capacity of 25 gallons per minute, or equivalent, filtration shall be used. The filter backwash and flush discharge shall be caught, contained and disposed of to the sewer system, septic tank or, with approval of the Administrative Authority, a separate mini-leachfield sized to accept all the backwash and flush discharge water. Filter backwash water and flush water shall not be used for any purpose. Sanitary procedures shall be followed when handling filter backwash and flush discharge or graywater.

(2) Emitters shall have a minimum flow path of 1,200 microns and shall have a coefficient of manufacturing variation (Cv) of no more than 7 percent. Irrigation system design shall be such that emitter flow variation shall not exceed ± 10 percent. Emitters shall be recommended by the manufacturer for subsurface use and graywater use, and shall have demonstrated resistance to root intrusion. For emitter ratings, refer to Irrigation Equipment Performance Report, Drip Emitters and Micro-Sprinklers, Center for Irrigation Technolo-

gy, California State University, 5730 N. Chestnut Avenue, Fresno, California 93740-0018.

(3) Each irrigation zone shall be designed to include no less than the number of emitters specified in Table J-3, or through a procedure designated by the Administrative Authority. Minimum spacing between emitters is 14 inches in any direction.

(4) The system design shall provide user controls, such as valves, switches, timers and other controllers, as appropriate, to rotate the distribution of graywater between irrigation zones.

(5) All drip irrigation supply lines shall be PVC Class 200 pipe or better and Schedule 40 fittings. All joints shall be properly glued, inspected and pressure tested at 40 psi, and shown to be drip tight for five minutes, before burial. All supply lines will be buried at least 8 inches deep. Drip feeder lines can be poly or flexible PVC tubing and shall be covered to a minimum depth of 9 inches.

(6) Where pressure at the discharge side of the pump exceeds 20 psi, a pressure-reducing valve able to maintain downstream pressure no greater than 20 psi shall be installed downstream from the pump and before any emission device.

(7) Each irrigation zone shall include an automatic flush valve/vacuum breaker to prevent back siphonage of water and soil.

(b) Standards for the mini-leachfield system are (Figure 5):

(1) Perforated sections shall be a minimum 3-inch diameter and shall be constructed of perforated high-density polyethylene pipe, perforated ABS pipe, perforated PVC pipe, or other approved materials, provided that sufficient openings are available for distribution of the graywater into the trench area. Material, construction and perforation of the piping shall be in compliance with the appropriate absorption field drainage piping standards and shall be approved by the Administrative Authority.

(2) Clean stone, gravel or similar filter material acceptable to the Administrative Authority, and varying in size between 3/4 inch to 2 1/2 inches shall be placed in the trench to the depth and grade required by this Section. Perforated sections shall be laid on the filter material in an approved manner. The perforated sections shall then be covered with filter material to the minimum depth required by this Section. The filter material shall then be covered with landscape filter fabric or similar porous material to prevent closure of voids with earth backfill. No earth backfill shall be placed over the filter material cover until after inspections and acceptance.

(3) Irrigation fields shall be constructed as follows:

	Minimum	***Maximum***
Number of drain lines per irrigation zone	*1*	—
Length of each perforated line	—	*100 feet*
Bottom width of trench	*6 inches*	*18 inches*
Total depth of trench	*17 inches*	*18 inches*
Spacing of lines, center to center	*4 feet*	—
Depth of earth cover of lines	*9 inches*	—
Depth of filter material cover of lines	*2 inches*	—
Depth of filter material beneath lines	*3 inches*	—
Grade of perforated lines	*level*	*3 inches/100 feet*

J 12 Special Provisions

(a) Other collection and distribution systems may be approved by the Administrative Authority as allowed by Section 201 of the U.P.C.

(b) Nothing contained in this Appendix shall be construed to prevent the Administrative Authority from requiring compliance with stricter requirements than those contained herein, where such stricter requirements are essential in maintaining safe and sanitary conditions or from prohibiting graywater systems.

J 13 Health and Safety

(a) Graywater may contain fecal matter as a result of bathing and/or washing of diapers and undergarments. Water containing fecal matter, if swallowed, can cause illness in a susceptible person.

(b) Graywater shall not include laundry water from soiled diapers.

(c) Graywater shall not be applied above the land surface or allowed to surface and shall not be discharged directly into or reach any storm sewer system or any water of the United States.

(d) Graywater shall be not be contacted by humans, except as required to maintain the graywater treatment and distribution system.

(e) Graywater shall not be used for vegetable gardens.

Table J-1 Location of Graywater System

Minimum Horizontal Distance From	Surge Tank (feet)	Irrigation Field (feet)
Buildings or structures[1]	5[2]	8[3]
Property line adjoining private property	5	5
Water supply wells[4]	50	100
Streams and lakes[4]	50	50
Seepage pits or cesspools	5	5
Disposal field and 100 percent expansion area	5	4[5]
Septic tank	0	5[6]
On-site domestic water service line	5	5[7]
Pressure public water main	10	10[8]
Water ditches	50	50

NOTES: When mini-leach fields are installed in sloping ground, the minimum horizontal distance between any part of the distribution system and ground surface shall be 15 feet.

[1]Including porches and steps, whether covered or uncovered, but does not include car-ports, covered walks, driveways and similar structures.

[2]The distance may be reduced to 0 feet for aboveground tanks if approved by the Administrative Authority.

[3]The distance may be reduced to 2 feet, with a water barrier, by the Administrative Authority, upon consideration of the soil expansion index.

[4]Where special hazards are involved, the distance may be increased by the Administrative Authority.

[5]Applies to the mini-leachfield type system only. Plus 2 feet for each additional foot of depth in excess of 1 foot below the bottom of the drain line.

[6]Applies to mini-leachfield-type system only.

[7]A 2-foot separation is required for subsurface drip systems.

[8]For parallel construction or for crossings, approval by the Administrative Authority shall be required.

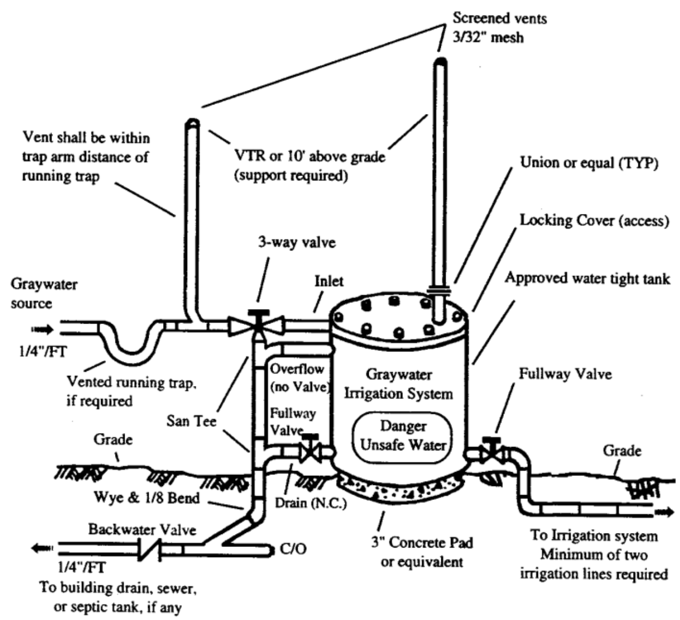
Table J-2 Mini-Leachfield Design Criteria of Six Typical Soils

Type of Soil	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	Maximum absorption capacity, minutes per inch, of irrigation area for a 24-hour period
1. Coarse sand or gravel	20	5
2. Fine sand	25	12
3. Sandy loam	40	18
4. Sandy clay	60	24
5. Clay with considerable sand or gravel	90	48
6. Clay with small amount of sand or gravel	120	60

Table J-3 Subsurface Drip Design Criteria of Six Typical Soils

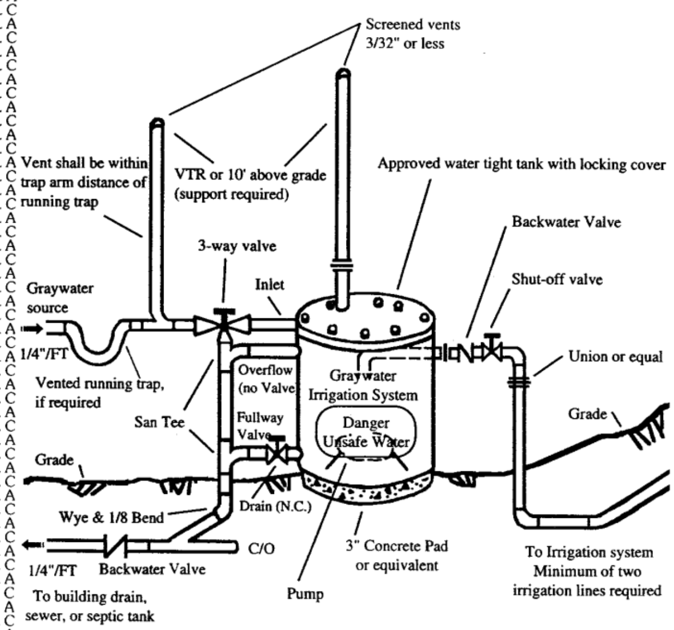
Type of Soil	Maximum emitter discharge (gal/day)	Minimum number of emitters per gpd of graywater production
1. Sand	1.8	0.6
2. Sandy loam	1.4	0.7
3. Loam	1.2	0.9
4. Clay loam	0.9	1.1
5. Silty clay	0.6	1.6
6. Clay	0.5	2.0

Use the daily graywater flow calculated in Section J-6 to determine the number of emitters per line.



Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 1—Graywater System Single Tank—Gravity (conceptual)



Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 2—Graywater System Single Tank—Pumped (conceptual)

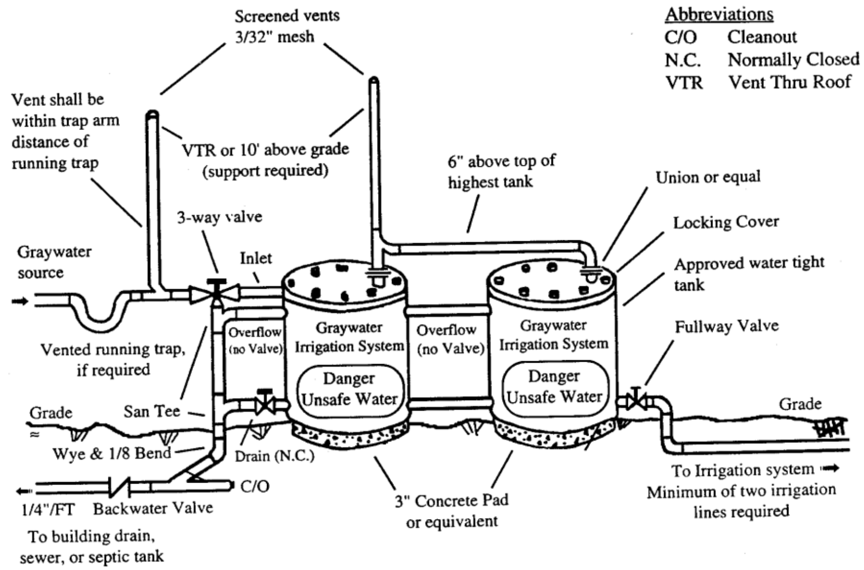


Figure 3—Graywater System Multiple Tank (conceptual)

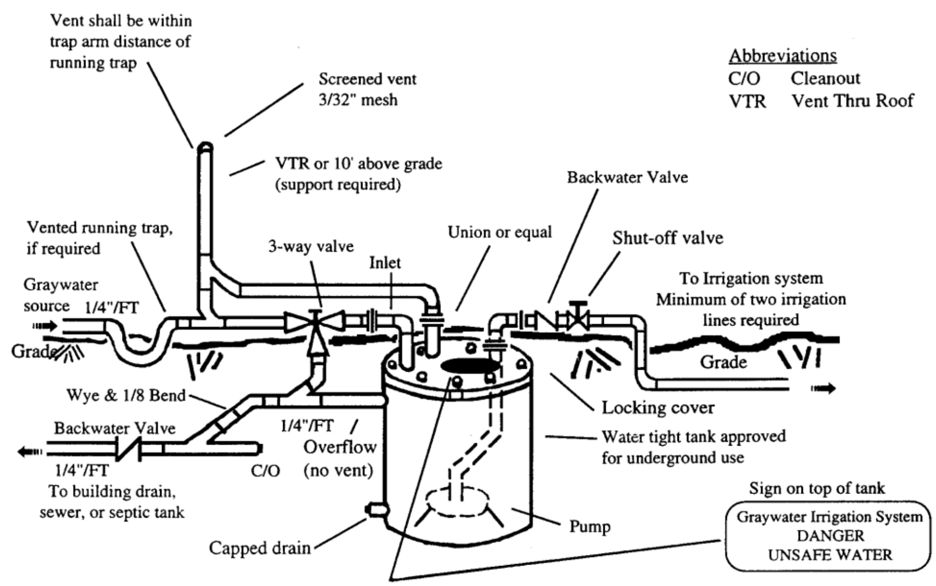


Figure 4—Graywater System Underground Tank (conceptual)

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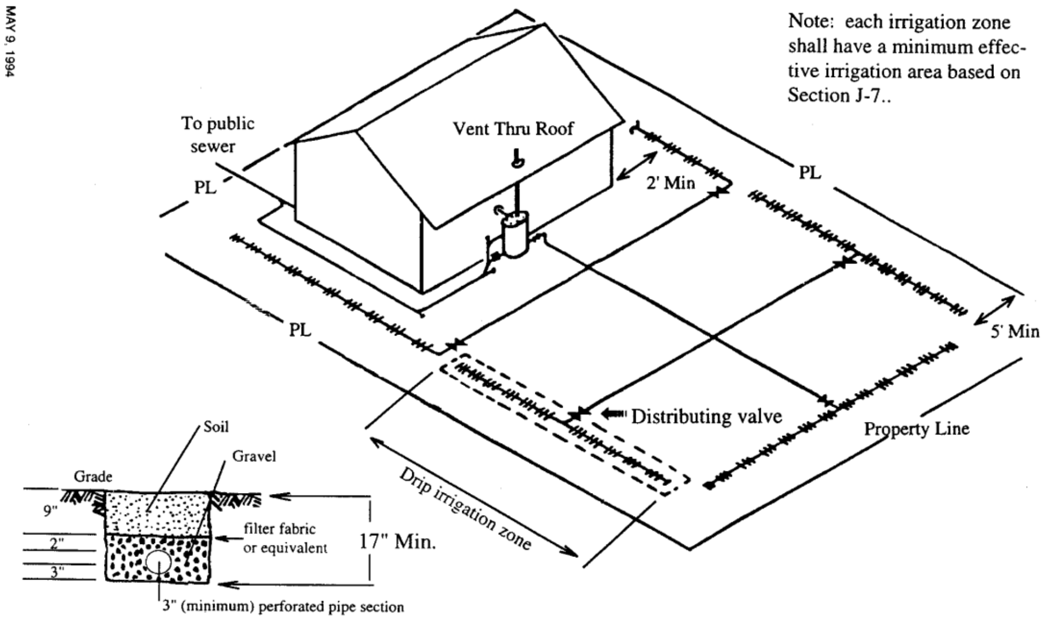
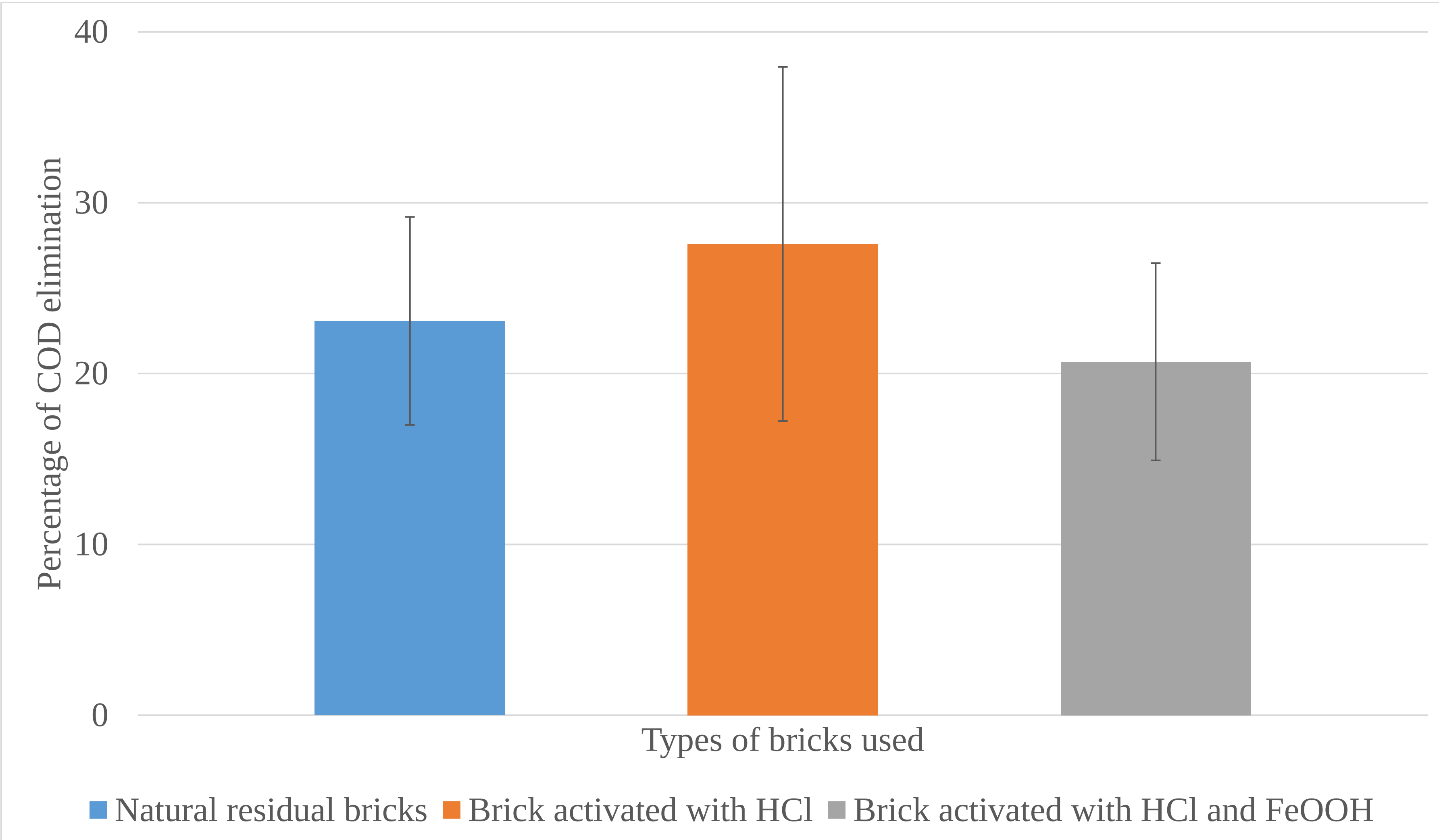


Figure 5—Graywater System Irrigation Layout (conceptual)

Appendix 2 –. The maximum elimination percentage of COD with the standard deviation of 3 residual types of bricks



Appendix 3 – The maximum elimination percentage of turbidity with the standard deviation of 3 residual types of bricks

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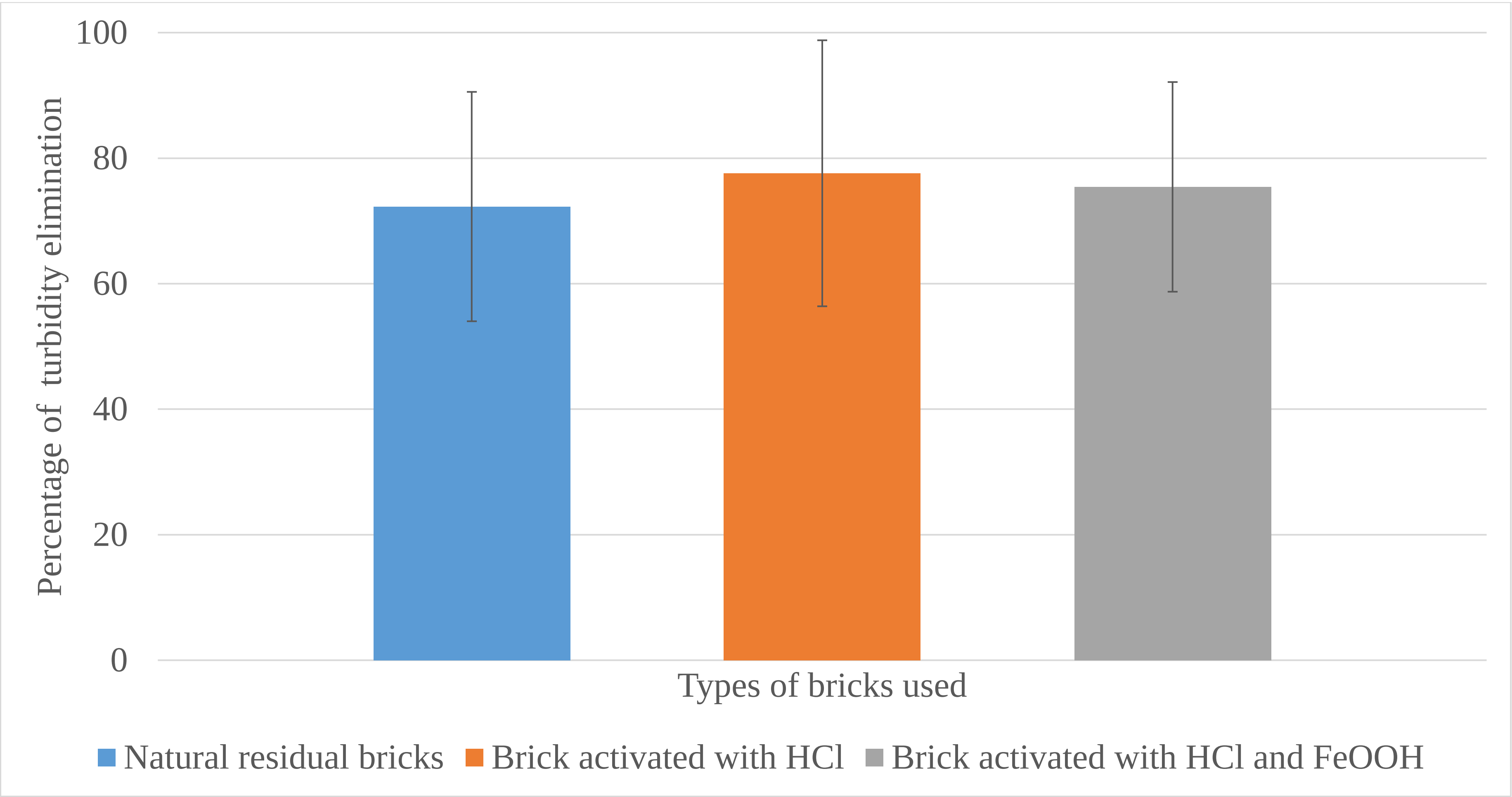
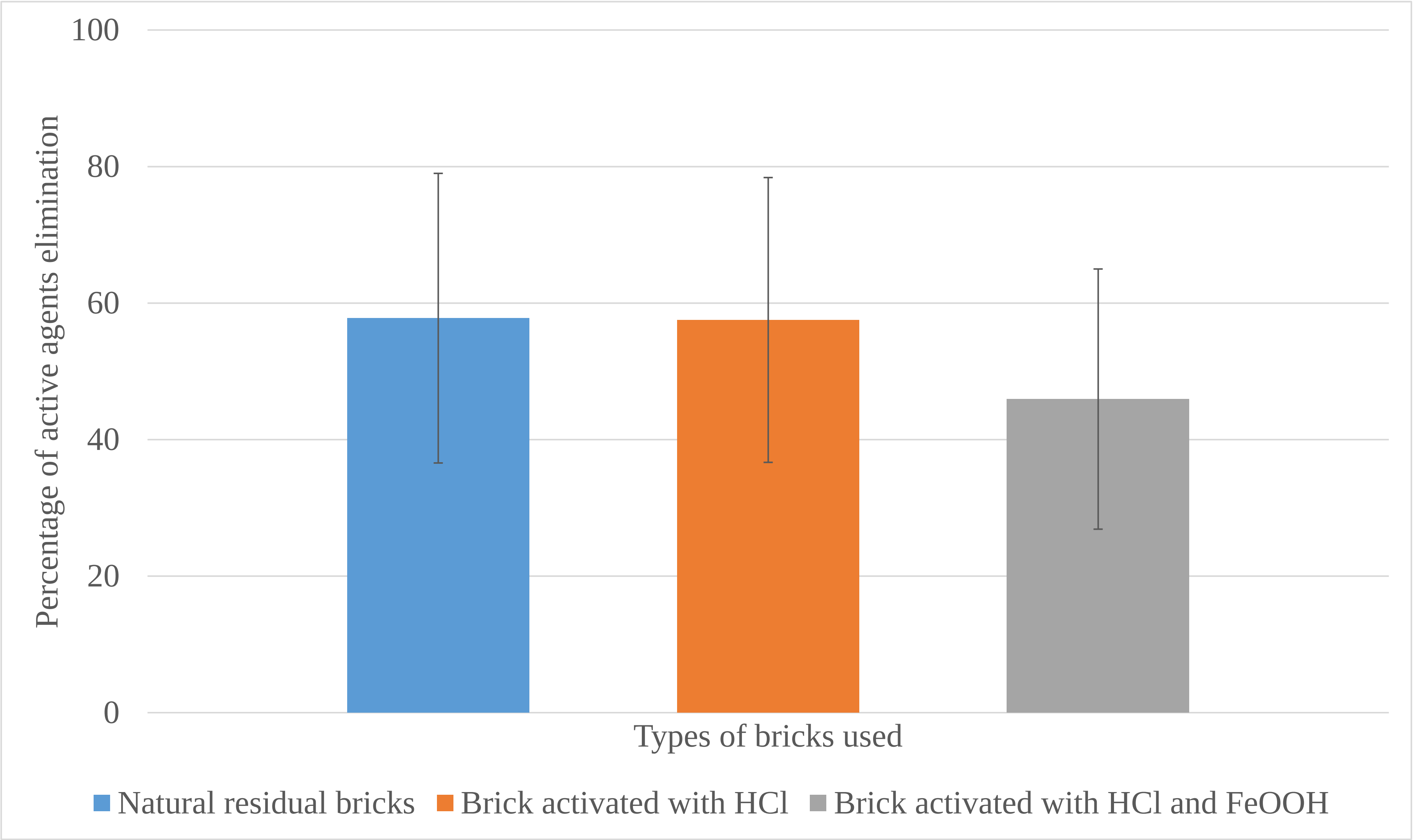
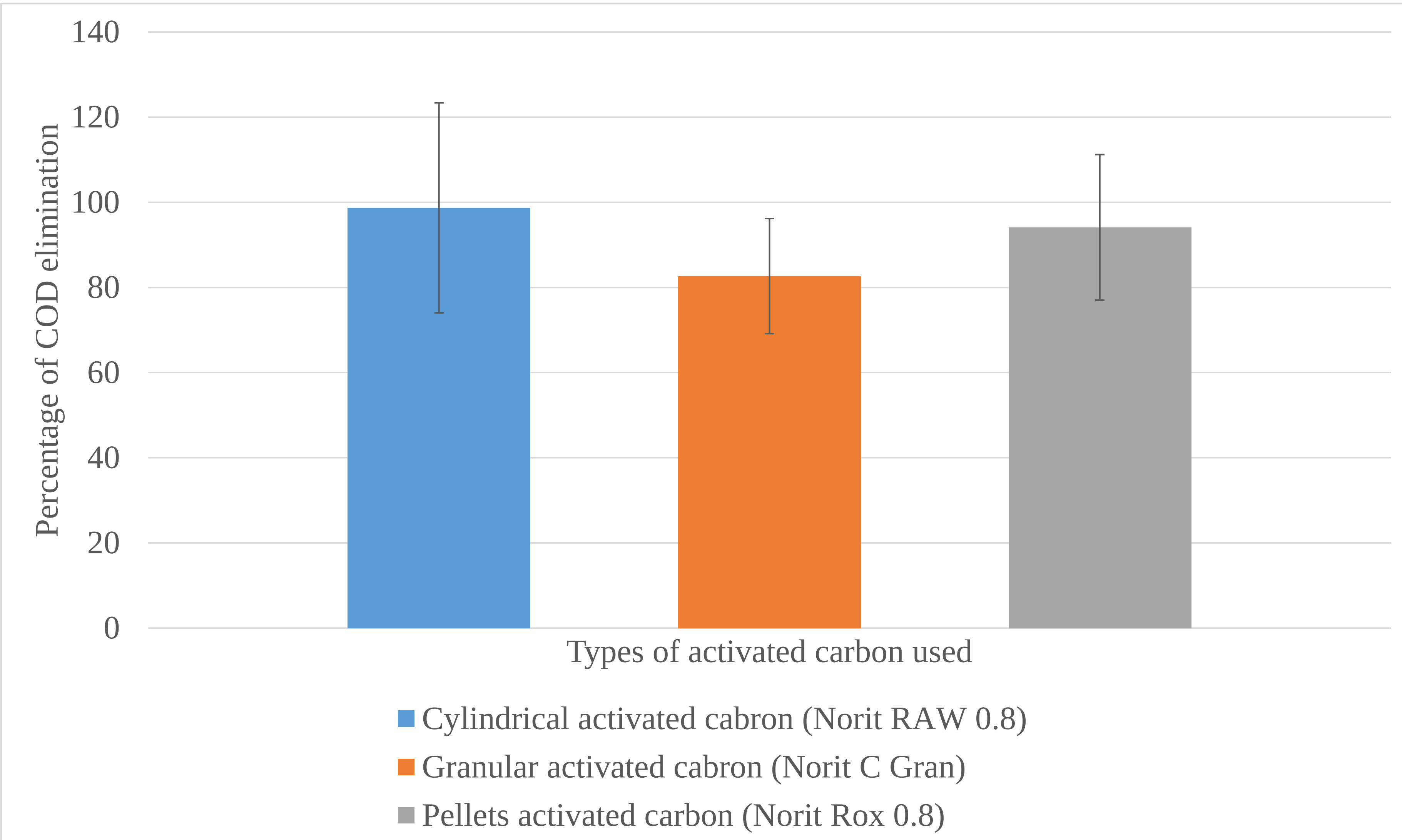


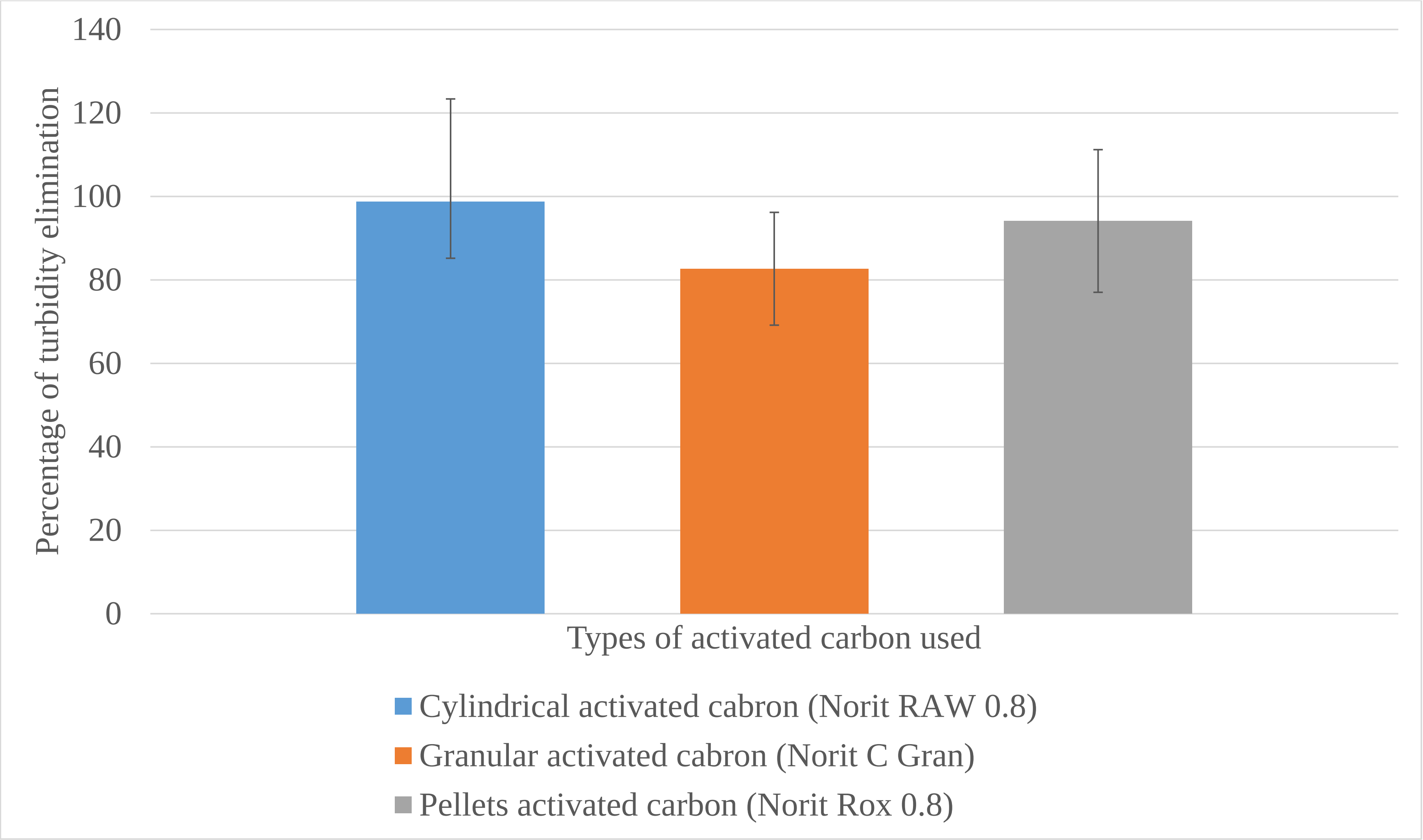
Appendix 4 – The maximum elimination percentage of active agents with the standard deviation of 3 residual types of bricks



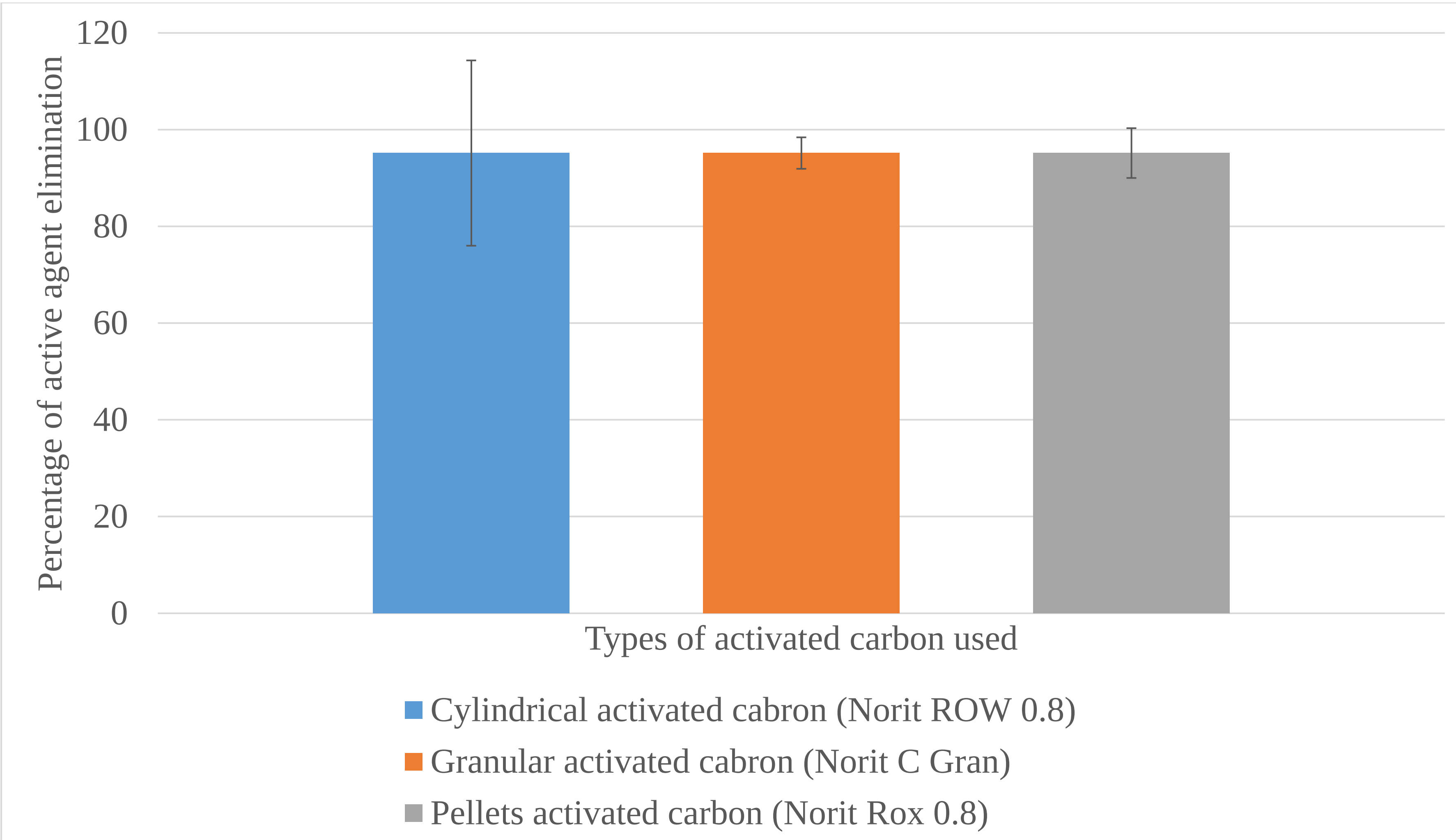
Appendix 5 – The percentage of elimination of COD for the 3 types of activated carbon



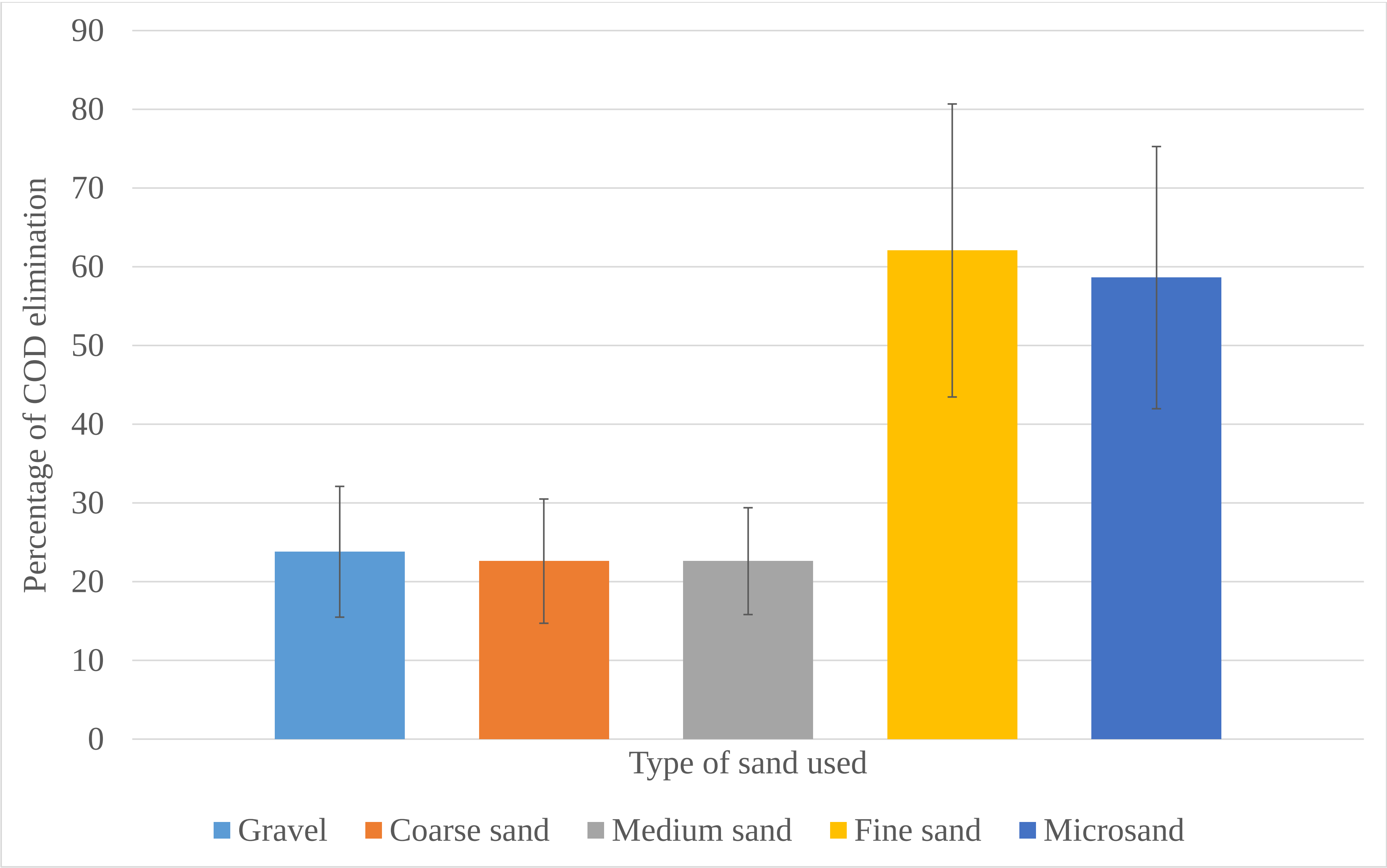
Appendix 6 – The percentage of elimination of turbidity for the 3 types of activated carbon



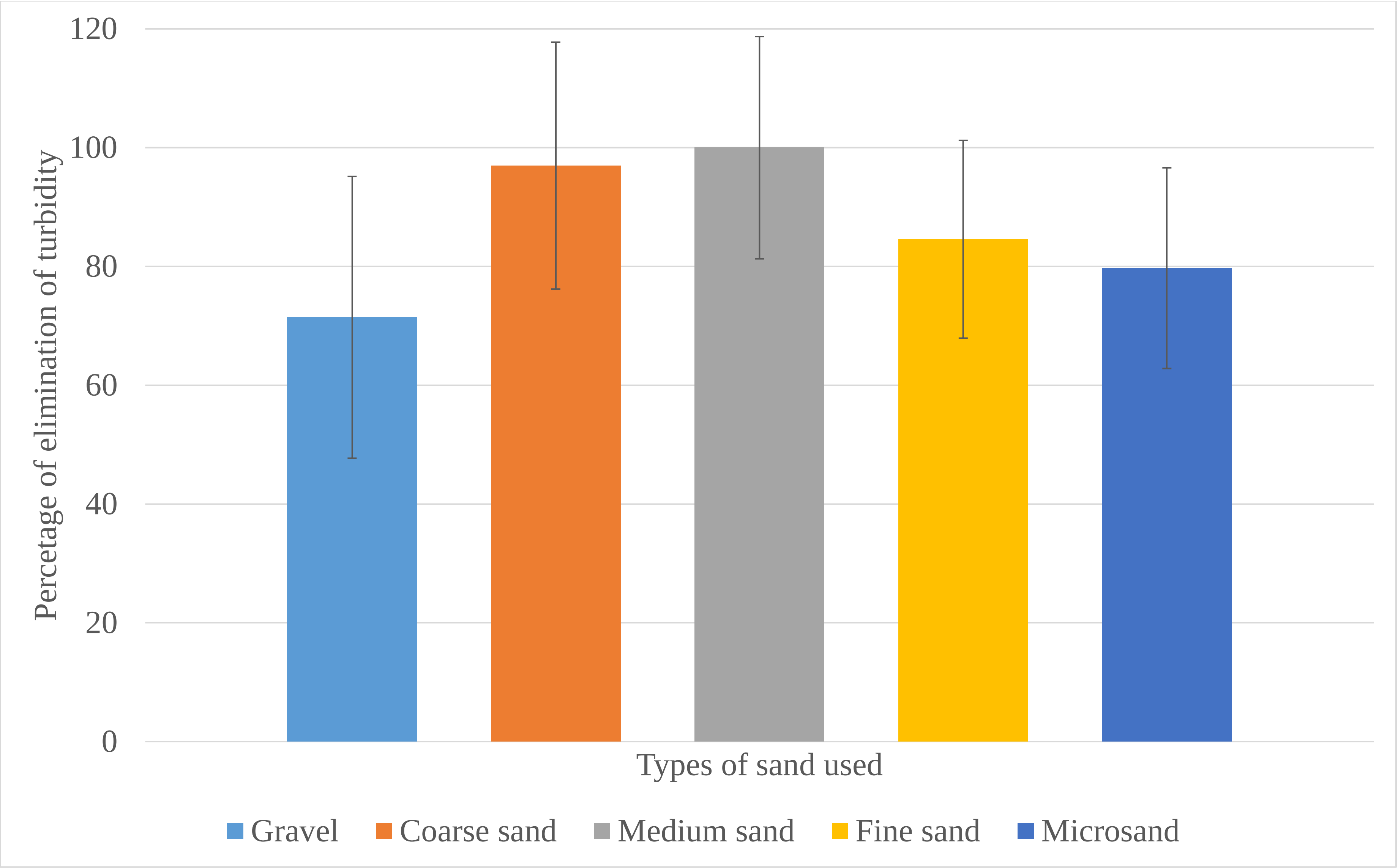
Appendix 7 – The percentage of elimination of COD for the 3 types of activated carbon



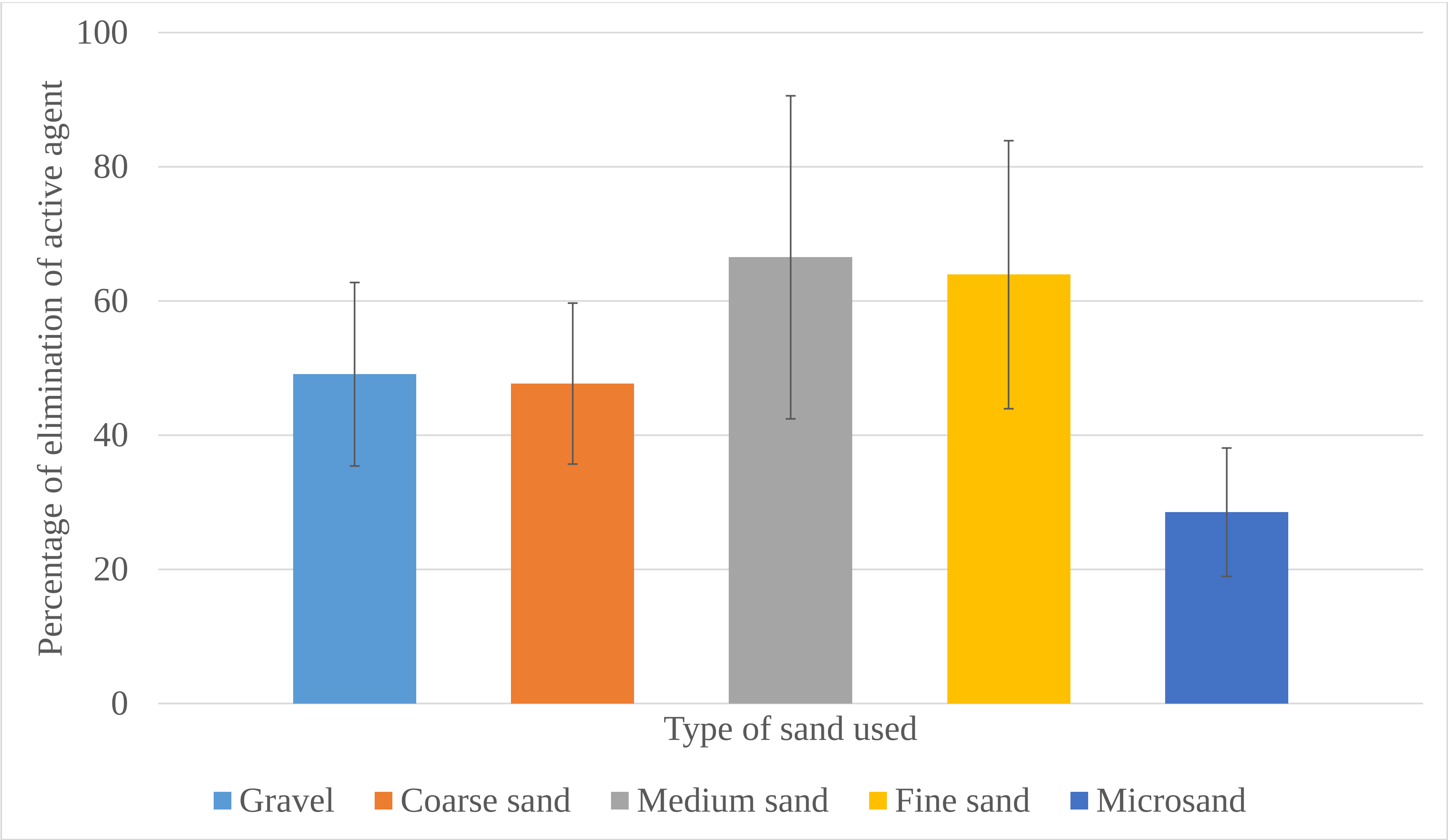
Appendix 8 – The percentage of elimination of COD for the different types of sand



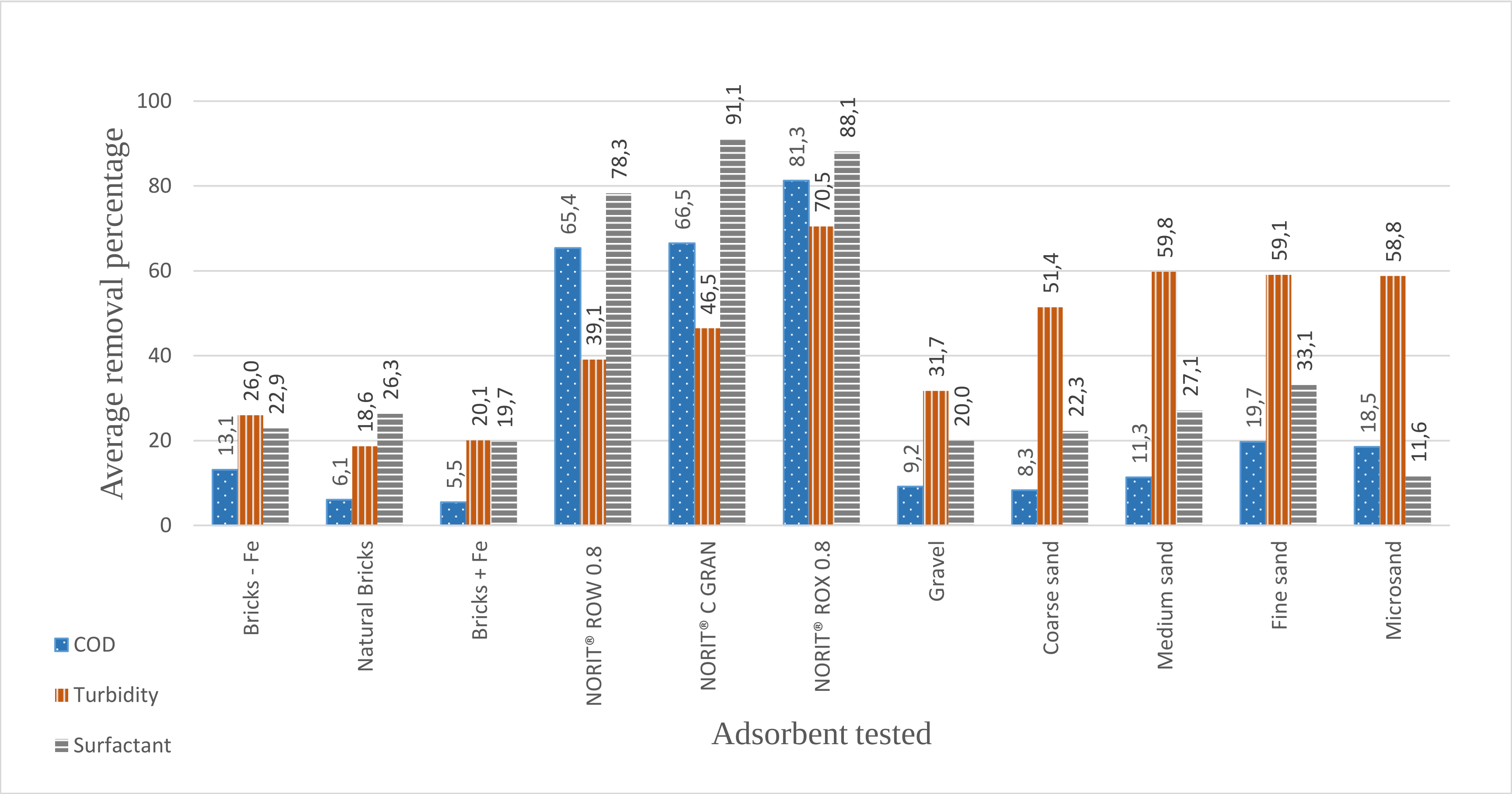
Appendix 9 – The percentage of elimination of turbidity for the different types of sand



Appendix 10 – The percentage of elimination of active agent for the different types of sand



Appendix 11 - Summary of the average removal percentages for all adsorbents tested



Appendix 12 - Questionnaire

A- Information :
   1- Name of the resort
   2- Numbers of chambers
   3- Estimated water consumption
   4- When is the pic of the water consummation
B- Knowledge of greywater importance:
   5- Do you think that Lebanon suffers from a water problem??
   6- Do you know the meaning of greywater: yes / no
   7- Do you think that greywater and wastewater are separated? Yes/no
   8- After knowing the definition are you with or against reusing this water after treatment: with/without
   9- Can you accept using greywater for toilet flushing or irrigation: yes/no
   10- In what field would you prefer reusing treated greywater? Irrigation/toilet flushing
   11- How much time are you willing to give for regular maintenance required for the treatment system?? None/ 1hour/ 2hour/ more than 2 hours.
   12- How much are you willing to pay for one greywater treatment system unit? 200$/ 300$/ more than 300$

A- Information	1	2	3	4	5	6	7	8
Name of the resort/ hotel	Via mina	Quality inn	Lamunia	Miramar	Las salinas	Sawary	Florida	San stephano
Numbers of chambers	22	112	24	347	912	252	288	350
Estimated water consumption (L/day)	5280	20160	4320	62400	215640	46560	51840	63000
Estimated water consumption (m^3/day)	5.28	20.16	4.32	62.4	215.64	46.56	51.84	63
When is the pic of the water consummation	Evening	Evening	Evening	Afternoon	Evening	Evening	Afternoon	Evening
B- Knowledge of greywater importance								
Do you think we have water problem	No	Yes	No	Yes	Yes	No	No	Yes
Do you know the meaning of greywater	No	No	No	Yes	Yes	No	No	No
Do you think that greywater and wastewater are separated	No	No	No	No	No	No	No	No
with or against reusing this water after treatment	With	With	With	With	With	With	With	With
Can you accept using greywater for toilet flushing or irrigation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
In what field would you prefer reusing treated greywater	toilet flushing	Irrigation	toilet flushing	toilet flushing	toilet flushing	toilet flushing	toilet flushing	Irrigation
How much time are you willing to give for maintenance (hour)	1	2	1	>2	>2	>2	2	>2
How much are you willing to pay ($)	200	300	200	>300	>300	300	300	300