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An Investigation of the Sorptive Capacity of *Salviniamolesta, Pistiastratiotes, Lemna minor, Typhalatifolia* and *Azollafiliculoides* to Absorb Crude Oil

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Abstract: Oil has become one of the most important sources of energy in the world, due to the transporting and extraction of oil, spills may occur. Oil spills are catastrophic events that have great impact on marine and terrestrial ecosystem. This experimental study was conducted to evaluate the effectiveness of five (5) aquatic plants ability to remove oil from brackish, salt and fresh water. Used in both their fresh and dried state are the plants *salviniaMolesta, Lemna Minor, AzollaFiliculoides, Pistiastratiotes*and *TyphaLatifolia*. Samples were collected from the plants in both their fresh and dried state and the rate of sorption was analyzed using anAnalysis of variance (ANOVA) test. The results showed that the five afro mention aquatic plants can be used as a reactive measure for oil spill problems, hence a solution for future oil spill problems.

Keywords: Adsorption, phytoremediation, oil, spills, hydrophobicity, Sorption capacity.

INTRODUCTION

Situated on the North-eastern coast of South America, bounded by the Atlantic Ocean on the North, and neighbouring countries, Suriname on the East, Brazil on the South West and Venezuela on the North West side, stands Guyana. The country has an area of 214,970 square kilometres (km) (83,000 square miles), and population of approximately 746,955people (Bureau of Statistics, 2018) (Worldatlas, 2018).Guyana has four main geographical areas, the Coastal plain, the hilly sandy region, the Rupununi Savannah, the tropical rain forest and interior highlands (Reece, 2012).

Traces of petroleum have been recorded in Guyana since the 1750s, back when Dutch explorers were mapping the country (Kanason, 2018). Oil exploration in Guyana has been going on since in the year 1916 to the current date, it has been documented that Guyana has divided into two (2) petroleum basin, named the Guyana and the Takutu Basin.

The Takutu Basin is a Mesozoic, intracratonic Sedimentary basin bordered by the Kanuku Mountains in the south, the Pakaraima Mountains to the north, the Takutu River to the west and the Essequibo River to the east; it is situated in South Central Guyana and is shared with neighbouring country Brazil. The size of the Takutu basin is, 280 km long, 40 km wide and 6 km deep (Crawford *et al.*, 1983).

In 1982 a well was drilled by Home Oil Company which is known as Karanambo-1, a test was conducted on samples of the oil found in Karanambo-1, which showed the oil, contains less than 0.5% hydrogen sulphide, which means the oil was of good quality and sweet variety. The other wells drilled in the Takutu are Lethem-1 (1980), Turantsink-1 (1992) and Apoteri-K2 well (2011) (GGMC, 2018).

The Guyana basin is also divided into two other basins, which is, the Offshore and Onshore basin. The Onshore basin is the deepest part of the southern boundary, which is 150 miles from the Guyanese coastline, they are approximately thirteen (13) wells drilled in this basin dating back from 1916 to present date, some of the oil companies operating in this basin are NABI Oil and Gas Inc. and ON ENERGY Inc (GGMC, 2018).

NABI Oil and Gas Inc (OIL NOW, 2018) "Is a Guyanese-owned company that started in 2010 as a project management, logistical support, drilling and energy, construction company. In June 2012, the company was approved a lease for 2,300 square kilometres onshore in the Mahaica-Mahaicony area."

ON ENERGY Inc. is a subsidiary company of CGX Energy Inc. which is a Canadian owned oil and gas exploration company that holds three licenses in the

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Guyana-Suriname Basin, which was obtained in 2012 and 2013 by the government of Guyana ,the licenses held are “New Demerara Petroleum Agreement”, “New Berbice Petroleum Agreement” and “Corentyne Petroleum Agreement”. (OIL NOW, 2017)

Guyana gained the world’s attention in 2015, when an American Multinational oil and gas company, formed in 1999 by the union of Exxon and Mobil, currently known as ExxonMobil, announced major offshore findings of high quality hydrocarbon reservoirs, including crude oil, in an offshore concession which is 190Km from the country’s coastline (PRESSTV, 2015) (Corporate Watch, 2005).

According to Guyana Geology and Mines Commission (2018), a number of oil and gas companies are negotiating for concessions in the Offshore Guyana Area, some of the companies that have concession in the Offshore area are REPSOL, ANADARKO, ESSO/HESS/NEXEN, Mid-Atlantic Oil and Gas, Inc., RATIO Energy/Guyana Ltd and CGX Resources Inc.

An oil spill can be defined as “any accidental spill or release of crude oil or oil distilled products into a body of water ” (ENVIRONMENTAL POLLUTION CENTERS, 2017).These spills occur from tankers, offshore drilling rig or underwater pipeline (Dictionary, 2019) .

Crude oil is known to be an extremely toxic substance, containing approximately 100 and 200 known carcinogens in every 5 tonnes that are released into the oceans (Norsk Regnesentral , n.d.).

According to Nelson & Grubesic, (2017) “oil spills have a profound impact on ecosystems, the environment, public health, the economy, and communities”. An oil spill can occur through anthropogenic activities or naturally.

Oil spills are often caused by accidents involving tankers, barges, pipelines, refineries, drilling rigs, and storage facilities (Office Of Response and Restoration , 2018).

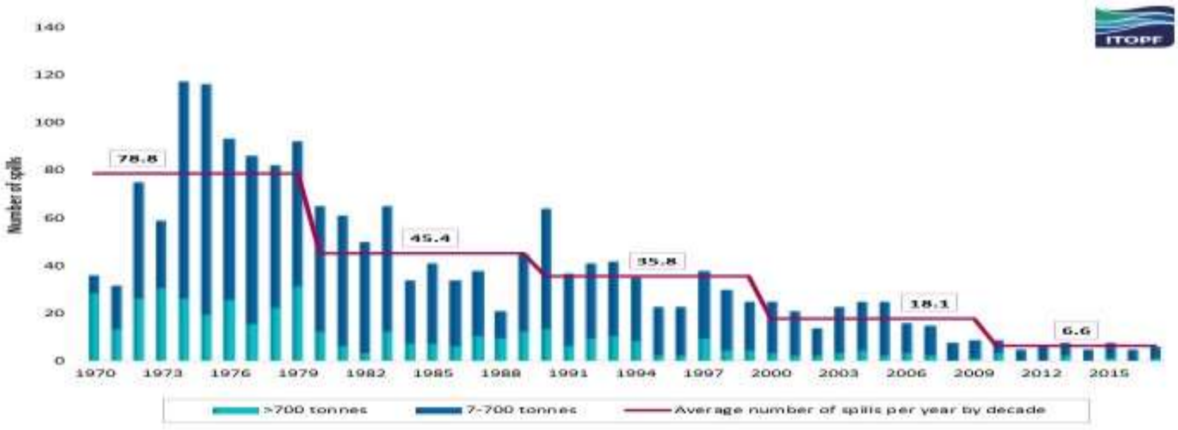

Figure 1. Graph Above Shows Statistics for Oil Spills, Occurring From Tankers, From The Year 1970-2017 (ITOPF, 2018)

Oil has become one of the most important sources of energy in the world for many decades, we depend on it every day, it has become a necessity for us. According to the World Energy Council (2016),oil remained the world’s leading fuel, accounting for 32.9% of global energy consumption (UKOG, 2018).

Offshore drilling for oil can be a bit unsafe, for human life and the environment. Marine oil spills are caused by accidents or by chronic and careless habits; which means that they are unpredictable. It is however estimated that approximately 706 million gallons of waste oil enter the ocean every year, with over half of the oil coming from land drainage and waste disposal. It is noted that marine Oil Spill pose great danger to, humans and the ecosystem; it affects fisheries, wildlife, and recreation (Water Encyclopedia, 2018).

Guyana is in the making of developing it oil and gas sector due to the discovery of oil in May 2015, offshore drilling known as Liza phase one is still in developing stage and is projected to start by 2020 (Invest Guyana, 2017).

With recent oil discoveries in Guyana, and the country as a signatory to the United Nations International Maritime Organization (IMO), Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC), there is an even greater need for Guyana to protect its waterways and sustain coastal livelihoods.

More so, since the plants *S. Molesta, P. Stratiotes, L. Minor, T. Latifolia and A. Filiculoides*consist of complex characteristics which allows them to absorb oil (bio-sorbents) while repelling water; this process can occur either by using the fresh and dry leaves of S.*Molesta, P. Stratiotes, L. Minor, A. Filiculoides*and the fibre of the *Typha* plant. These

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plants can be the future solution, to use as a reactive measure for potential oil spill problems.

According to International Energy Agency (2018), the global demand for oil is at 99.61 millions barrels of oil per day(BPD), and it is projected to rise to 100 million BDP (INDEPENDENT, 2018).

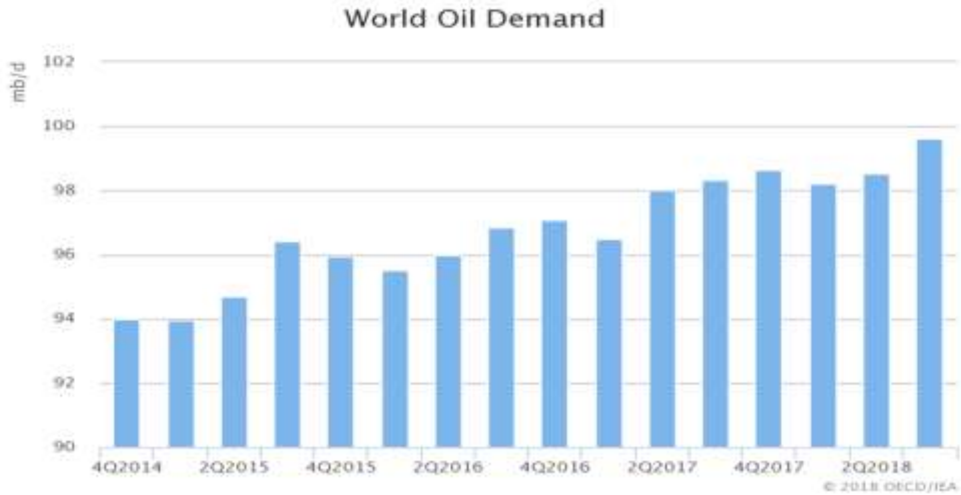

Figure 2. The graph above shows statistics for the global demand for oil (International Energy Agency, 2018)

Oil spills are catastrophic events that have a great impact on the environment and ecosystem, they are either caused intentionally or accidentally; and due to the great demand for oil, spills are more likely to occur.

The Marine ecosystem is a complex one, comprising of various organisms, such as, Micro-organisms, Vertebrates, and invertebrates, during an oil spill these organisms are exposed to high levels of toxins, (Hydrocarbons) which often cause severe health problems, that eventually leads to death ,this in turn, poses problems for commercial fisheries since plants, algae and some plankton serve as the primary producers for major food webs; and also serve as food to other higher trophic level organisms (Yuewen & Adzigbli, 2018).

Guyana is in the process of establishing its oil and gas sector, and according to Stabroek News (2018), Currently, there is only one piece of legislation that caters for oil spills, which is the Environmental Protection Act of 1996,there is no Marine Pollution act, only a draft ,it is noted that Guyana has international Commitments owed to various conventions such as the the United Nations Convention on the Law of the Sea, the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), and the International Convention for the Prevention of Pollution from Ships (MARPOL), which decrees the country to have a plans in place in response to an oil spills.

According to McCutcheon & Jorgensen (2008), Phytoremediation can be defined as the direct use of living green plants to treat and control waste in water soil and air; it is also a form of bioremediation ,that uses plants for immobilizing contaminants in soil and groundwater, moreso,there are six (6) known types of phytoremediation which are, Phytosequestration, Rhizodegradation, Phytohydraulics, Phytoextraction, Phytovolatilization and Phytodegradation (Phillips, 2019).

Phytosequestration-also known as phytostabilization and as phytoimmobilization, includes the prevention of mobility of organic pollutants into the soil thus reducing its bioavailability and stops them from entering into the food chain, more so, in this technique, the contaminants are immobilized in the soil by using different plants having the ability to stabilize the pollutants(Razzaq, 2017).

Rhizodegradation- also branded as phyto-stimulation, is the degradation of contaminants in the rhizosphere (soil surrounding the roots of the plants) by way of microbial activity which is enhanced by the presence of plant roots (Environmental Biotechnology, 2011).

Phytohydraulics- during this process plants act as biological pumps pulling in large volumes of contaminated water, this mechanism aids in controlling and minimizing the movements of contaminants in groundwater, more so, Plants are used to increase evapotranspiration, thereby controlling soil water and contaminant movement. This method contains the contaminant by modifying the hydrology to reduce the horizontal or vertical movement of water in the soil (Phytoremediation Protecting the Environment with Plants, n.d.).

Phytoextraction-also known as phytoaccumulation is the use of plants to remove

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contaminants from the environment and concentrate them in above-ground plant tissue so that they can be harvested (Bioremediation Technologies, n.d.).

Phytovolatilization-is a process that occurs as developing plants absorb water along with organic contaminants from the soil, transforming the contaminants into volatile compounds, and then releasing the volatile into the atmosphere through transpiration (European Regional Development Fund).

Phytodegradation- also referred to as Phyto transformation is a mechanism where the breakdown organic contaminants occur through a metabolic process within plants or the breakdown of contaminants surrounding the plant through the effect of enzymes produced by the plants (Environmental Biotechnology, 2011).

Phytoremediation works in numerous ways to remove pollutants from the environment, it has proven to be, an environmentally safe, cost-effective,ecologically friendly and culturally accepted technology. Phytoremediation can clean up contaminants from the soil while improving soil quality and fertility; moreover, plants that are used as phytoremediators are easily monitored by examining their growth potential in contaminated sites; furthermore, some crops products after harvesting, can be converted to biofuel, as a substitute for fossil fuel or for agricultural and domestic purposes (Ashraf *et al.*, 2010).

Phytoremediation like any other technology, has its advantages and disadvantages, which includes; advantages, it's easy to implement, does not require expensive equipment or highly-specialized personnel, it's an Environmentally friendly approach, cost-effective, socially accepted, easy to maintain, Long-term applicability, most promising approach to degrade contaminants; Disadvantages includes, The toxicity and bioavailability of biodegradation products are not permanently known, the success of phytoremediation depends on the location because other climatic factors can impact its effectiveness, Too high concentration of contaminants can result in plants death, Not as efficient in the absorption of contaminants such as polychlorinated biphenyls (PCBs),Entails a large surface area of land for remediation (Enivromental biotechnology).

According to Sara, Amirhossein & Nasiman (2015), Phytoremediation is considered a less expensive remediation system compared to other alternatives,for instance, soil excavation, pump and treat, soil washing, or incineration, however, they are many factors that influence the final cost of setting up any type of phytoremediation system ,these factors are type, size, and depth of contaminated site, contaminated media, site climate, vegetation type, and agronomic practices,moreover the total the cost of any type of phytoremediation system consist of its design, installation, annual operations, maintenance, and monitoring, likewise phytoremediation technology can lower remediation costs up to 50% to 80% .

Also ,mentioned by Sara, Amirhossein & Nasiman (2015), was the " Phytoremediation of Crude Oil Spills in Aquatic Ecosystem" using aquatic macrophytes ,these plants can either be used as phytoremediators for petroleum hydrocarbons or as bioaccumulators (sorbents) for crude oil ,it was noted that some of the valuable characteristics that make aquatic macrophytes applicable for phytoremediation are their ability to grow fast and, its ability to thrive in eutrophic waters, more so, due to hypoxic and anoxic conditions of sediments in aquatic ecosystem anaerobic degradation of crude oil happens which is a very sluggish and incomplete process. Some macrophytes transfer atmospheric oxygen from the shoots to the roots and increase the aerobic respiration of rhizosphere microbes.

Additionally, it was noted that they are limitations to phytoremediation, since the technology is new there is still a lot more that needs to be understood, moreover, phytoremediation has shown great promise when it comes to the cleaning up of polluted areas, whether it is the removal of heavy metals from soil and water or the removal of hydrocarbons from water and soil (Ndimele, 2010).

Oil spill pollution whether it may be on Land or in sea, has initiated an interest in creating eco-friendly and inexpensive ways in cleaning up spillage, *SalviniaMolesta, PistiaStratiotes, Lemna Minor, AzollaFiliculoides and the TyphaLatifolia* fibre have shown great promise when it comes to removal of crude oil from water; they are Eco-friendly, low-cost and easily degradable compared to other sorbents, the mention plants selectively removes the oil while repelling water, due to their superhydrophobic trichrome covered surface.

General objective

To evaluate the effectiveness of *SalviniaMolesta, PistiaStratiotes,Lemna minor, TyphaLatifolia* and *AzollaFiliculoides* in absorbing oil

Specific Objectives

To evaluate the water sorptivity of dried and fresh leaves of *SalviniaMolesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fiber*TyphaLatifolia*plant in brackish salt and fresh water.

To evaluate the oil sorptivity of dried and fresh leaves of *SalviniaMolesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fiber*TyphaLatifolia*plant.

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To determine if there is a relationship between water quality and water sorptivity; and between oil sorptivity and water sorptivity.

RESEARCH HYPOTHESES

Hypothesis 1

H_o- the water sorptivity of the dried and fresh biomass are the same for the plants *SalviniaMolesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fiber*TyphaLatifolia*plant in brackish salt and fresh water .

H_1- the water sorptivity of the dried and fresh biomass are not the same for the plants *SalviniaMolesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fiber*TyphaLatifolia*plant in brackish salt and fresh water.

Hypothesis 2

H_o- the oil sorptivity for the dried and fresh biomass of Salvinia*Molesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fiber*TyphaLatifolia*are the same.

H_1- the oil sorptivity for the dried and fresh biomass of Salvinia*Molesta, PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fibre*TyphaLatifolia*are not the same.

Hypothesis 3

H_o- there is a relationship between water quality and water sorptivity; and between oil sorptivity and water sorptivity.

H_1 - there is not a relationship between water quality and water sorptivity; and between oil sorptivity and water sorptivity.

Hypothesis 4

H_0- there is a relationship between water quality and water sorptivity

H_1 – there is not a relationship between water quality and water sorptivity

MATERIALS AND METHODS

Research design

The research design selected was "true experimental research design",with the dependent variables being oil and water, and the independent variables being, the dry/fresh plant biomass and time.

The purpose of this study was done to evaulate the effectiveness of five (5) types of aquatic plants abilty to remove oil from brackish,Salt and fresh water.

In order to determine the water quality paramters a Bench top mutimeter meter was used to test the following , for potential hydrogen (pH), total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO),and total suspended solids (TSS).

Five types of aquatic plants were used in this study ,*Pistia stratioes,Salvina Molesta,Typha latifolia,AzollaFiliculoides*and *Lemna minor* ; the aquatic plants were used in both their fresh and dried state.For *Typha Latfolia* ,only the fibers from the fruit of was used from this plant for the conducted expirement.

Crude oil are classfied from Light to heavy based on A specific gravity scale developed by the American Petroleum Institute (API) for measuring the relative density of various petroleum liquids, which is expressed in degrees (Schlumberger, 2019). According to the API gravity scale, crude oil wither an API gravity greater than ten (>10) are lighter than water and will float ,while those with an API gravity of less than ten (<)10 are heavier than water and will sink ;Guyana's crude oil is known to have an API gravity greater than thirty (>30) (Oil Now, 2018).

The oil used in this expirement was "Castor Diesel oil SAE40", the SAE40 stands for Society Of Automotive Engineers(SAE) and the number 40 indicates the grade of oil ,the higher the arithmetic value, higher is the viscosity.

Experimental method

The Method used in this expirement is one similar to that of Claudia *et al.* (2016); & (Ciesielczuk *et al.*, 2018).A Multifactor ANOVA test was used to perform a multifactor analysis of different the dependent variable and was also used to determine the significant differences among the means of the variables.

Independent variables

Time

Water quality

Dependent variables

Amount of water absorbed (cc)

Amount of oil absorbed (cc)

EXPERIMENTAL PROCEDURE

Collection of water

Brackish,salt and fresh water was collected and tested to meet the reqirement of various water quality parameter .The Fresh water was obtained from the University of Guyana compoud,the salt water from the Kitty Sea wall Area and the Brackish water from the Demerara river.

A Bench top mutimeter was used to determine Water quality parameters which includes pH, total dissolved solids , Electrical conductivity , Dissolved Oxygen, and total suspended solids.In order to determine the water quality paramaters the results retrived for the Bentop multimeter will be compared to Kubota & Tsuchiya (2010) water quality and standards .

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Collection of plants

The Plants(Salvinia *Molesta,Pistia Stratioes* and *Lemna Minor*) were retrived form the University of Guyana campus compound,*AzollaFiliculoides* was retrieved from a drainage area on the Mandela Avenue, and*Thypha Latifolia* was retrived from the,Le Repentir Cemtery, the plants were washed thoroughly using tap water .

Preparation of plants

Leaves of *Pistia Stratioes,AzollaFiliculoides*, Lemna *Minor* were air dried for a period of seven (7) days along with the fruit of the *Thypa Latifolia plant* ;the leaves of *the Salvina molesta* was dried in a an oven for 24 hours at 45 degrees celcius in brown paper bags ,the intial weights of the plants were ,35.26g and 63.26g and final weight ,6.13g and 11.58g .

Due to the lightness and size of the *thypa* fibers ,both the fresh and dried fibers were wrapped in gauze.

Carrying out the experiment

Three (3)Medium size plastics container were filled each with brackish,salt and fresh water.

The fresh and dry leaves of *salvina molesta,Pistia Stratiotes,AzollaFiliculoides*, and *Lemna minor* along with the fiber from the fruit of the typha plant were weighed before being submerged into ,Brackish,Salt and Fresh water,there was no specific weight that was used for the plant biomasses the plants were randomly selected and weighed. The plants were submerged for time intervals of 10,seconds,20seconds and 30 seconds, and was then weighed again ,this was repeated three (3) times for the most accurated reading.

The step above was repeated again for the submersion of the fresh and dry plant biomass in oil.

Data collection

The data was collected on spot during the time of the conducted expirement using precise calculations and visual observations.

Data Analysis

The data collected during this experiment was analyzed using a Multifactor analysis of variance (ANOVA) test to determine if there were differences among the sorption cpacity of the fresh and dry biomass of each plant compared with the time intervals,along with significant differences among the means.All data are presented using descriptive statistics such as means, range, standard deviation, percentages and all measurements were carried out in triplicates.

Limitations

The drying of the salvinia leaves ;the concave shape of the salvina caused an uneven drying which inturn caused the leaves to curl inwards concealing the Trichome

RESULTS AND DISCUSSION

Research Objective 1

To evaluate the water sorptivity of dried and fresh leaves of *SalviniaMolesta*, *PistiaStratiotes,Lemna minor,AzollaFiliculoides and* the fibre *TyphaLatifolia*plant in brackish salt and fresh water .

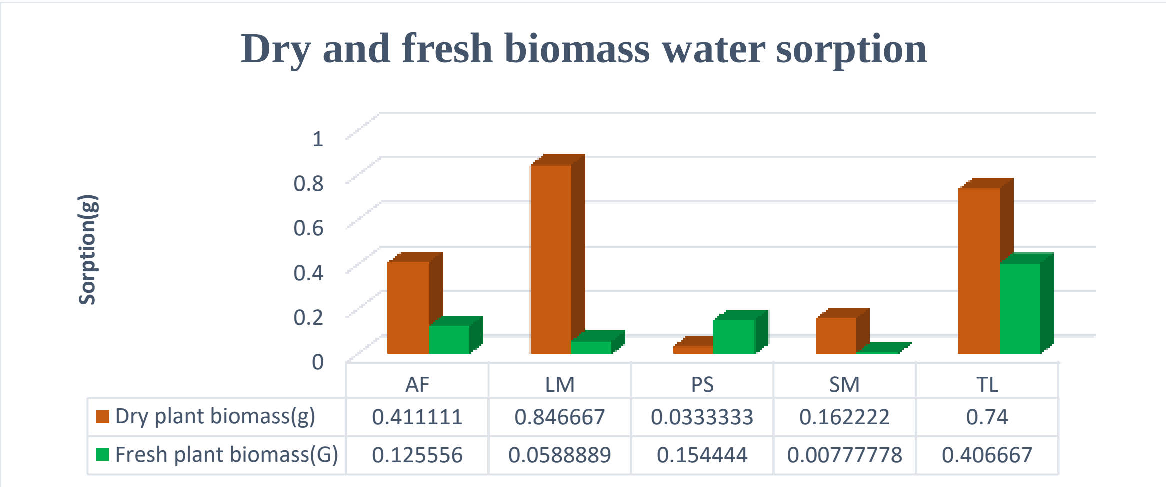

Figure 3. Shows the sorption of water by the fresh and dried biomass of SalviniaMolesta, PistiaStratiotes, Lemna minor, AzollaFiliculoides and the fibre TyphaLatifolia

The figure above depicts the sorption capacity for the fresh and dry biomass of the*Azolla* fern, it can be seen from the results that the fresh biomass remains somewhat hydrophobic absorbing (0.125556g) of water. The dry biomass absorbed (0.411111g) of water. The dry biomass absorbed (0.285556g) more water than the fresh biomass. From the result it can be see that there was a significant difference between the sorption capacity of the different biomasses (P-value: 0.0041).

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AzollaFiliculoides is an aquatic fern known for its hydrophobic properties, the fresh biomass due to its intact surface structure and plant organs remained hydrophobic. During the drying process of the Azolla leaves, much of the hairs on the plant became deformed and surface organs destroyed, allowing water to penetrate deep within the inner tissue of the plant, causing the dry biomass to absorb more water.

The graph above represents the overall sorptivity of water for the fresh and dry biomass of *Lemna Minor*. The dry biomass showed a higher sorptivity of water (0.846667g) and the fresh biomass showed the least amount of sorptivity (0.0588889g). The dry biomass absorbed (0.787778g) of water more than the fresh. From the results there was a significant difference between the sorptivity of the different type of biomass. (P-value:0.0000).

The fresh biomass of *L. Minor* seems to remain hydrophobic, due to the intact plant organs which makes the plant water repellant, the Dry biomass seems to have loss it hydrophobicity due to the cutin and wax, that are found on the leaflet surface being disintegrated due to the heat and the loss of moisture, this causes the water to penetrate into the plant tissue, causing the dry biomass to absorb to water (Borisjuk *et al.,* 2018).

The results above depict the sorptivity of the fresh and dry biomass of *P. Stratiotes* in water. The fresh biomass absorbed (0.154444g) of water and the dry biomass absorbed (0.0333333g), the fresh biomass absorbed (0.1211107g) more than the fresh biomass. From the results there was no significant difference between the type of biomass and the sorptivity (P-value: 0.3585).

Fresh leaves of *P. Stratiotes* are known for its water repellency on both side of the leaves, however the dry leaves of *P. Stratiotes* remain hydrophobic on both sides, since the leaves are covered in superhydrophobic trichome (Claudia, Isabelle, Matthias, Maryna,Kavalenka,N, Wilhelm, & Hendrik, 2016).During the drying process of *P.Stratiotes* leaves, the trichome became deformed and wrinkled, the researcher believes that due the deformity of the trichome no water droplet was able to be capture by the leaf. The fresh leaves exhibits hydrophobicity, the intact trichome on the fresh leaves caused water droplets to capture by the leaf, the researcher believes that the reason the fresh leaves was capable of absorbing more water is due to the perfectly intact trichome.

The graph above illustrates the sorptive capacity of the fresh and dry biomass of *SalviniaMolesta*, it can be seen that the dry biomass has a higher sorption for water (0.162222g) when compare to the fresh biomass (0.00777778g). The dry biomass absorbed (0.154444g) of water more that the fresh biomass. From the results there was a significant difference between the sorption capacity of the different type of biomass (P-value:0.0010).

The hairs or trichome of the *Salvinia* plant can only be found on the adaxial side of the leaf (Silvestre, Zambrano, Linis, & Janairo, 2019).The trichome of the salvinia plant is covered in a waxy crystal that gives the plant the water repellant properties. During the drying process much of the trichome became deformed and wrinkled, which would cause the plant to lose its hydrophobicity, also the dry leaves of *S. Molesta* has sorption taking place within the inner tissue of the plant (Claudia *et al.*, 2016).It was noted that only one side of the salvinia leaves has the water repellency properties, therefore when the leave become dried the and the hairs deformed the plant loses most of its water repellency.

The graph above shows the sorptivity of water using the fresh and dry biomass of *T. Latifolia*, it can be seen that the least amount of water absorbed was by the fresh biomass (0.406667g) and the most amount of water absorbed was by the dry biomass (0.74g). The dry biomass absorbed (0.333333g) more than the fresh biomass. From the results there was no significant difference between the sorption of water and the type of biomass (P-value:0.1218).

T. Latifolia fibers are bamboo-shaped structure exhibiting 4-dimensional open spaces, the Skelton of the fibers consists of lignocellulose coated by a hydrophobic wax coating with some amount of crystallinity (shengbin *et al.*, 2016). The unique chemical, physical and microstructural properties enable the cattail fiber to be highly hydrophobic and oleophilic. During the drying process of the fibers, most of the waxy coating was disintegrated, destroying the hydrophobic properties of the fibers, increasing the sorptive capacity, this caused water molecules to enter within the tissues of the fibers, enabling the dry biomass to absorb more water.

Research objective 2

To evaluate the oil sorptivity of dried and fresh leaves of *SalviniaMolesta*, *PistiaStratiotes*,*Lemna minor*,*AzollaFiliculoides and* the fibre *TyphaLatifolia*plant.

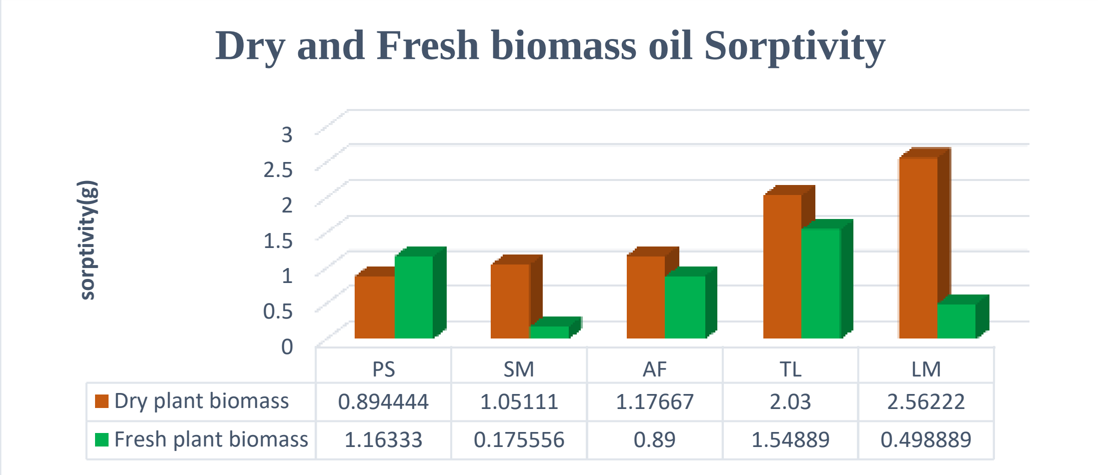

Figure 4. Shows the sorption of oil by the fresh and dried biomass of SalviniaMolesta, PistiaStratiotes, Lemna minor, AzollaFiliculoides and the fibre TyphaLatifolia

It can be seen from the results recorded that the fresh biomass has a greater sorption capacity when compared to the dry biomass.

The mean sorption of the dry biomass of *Pistia stratiotses* is (0.894444g) and the mean sorption for the fresh biomass is (1.16333). The results showed that the fresh biomass absorbed (0.268886g) more that the dry biomass. Although the fresh biomass absorbed more oil than the dry biomass there was no significant difference (P-value:0.0612).

The fresh biomass of *Pistiastratiotes* was capable of absorbing more oil than the dry biomass, due the trichome(hair) covered surface being intact and the increased surface wetting with low surface tension liquids (oils), and capillary action in the interstices between trichome (Claudia *et al.,* 2016). Air-dried leaves have comparable properties as vacuum-dried samples; During the drying process of the leaves of *P. Stratiotes*, the trichome(hair) becomes to some degree deformed and wrinkled, however due the deformations of the trichome, the oil absorption capacity becomes reduced. The hairs on the leaves influences the absorption capacity for high oil intake.

The graph above depicts the overall sorption capacity of the plant biomass in their fresh and dried state, it can be seen that dry plant biomass of *S. Molesta*has a greater sorption capacity for oil when compared to the fresh biomass. The mean amount of oil recorded for the dry biomass was (1.05111g) and for the fresh biomass (0.175556g), more so, the dry biomass absorbed (0.875556g) more than the fresh biomass. There was a significant difference between the sorptivity of the different plant biomass (P-value: 0.0000).

The hairs on the *Salvina*Leaves play a key role in the sorption of oil. *Salvinamolesta* is known for its superhydrophobic properties and for the shape of its wax covered trichome on the leave surface, the hair like structure is said to resemble that of an egg whisk, trapping oil and repelling water, however, the hairs can only be found on the upright side on the leaves, influencing low sorptivity (The Biomimicry Institute, 2018). For Dry *Salvinia* leaves has absorption within the inner tissue of the plant, in addition to absorption by surface structure(Claudia *et al.,* 2016).

The graph above depicts the overall sorptivity for the plant biomass of *A. Filiculoides*in itsfresh and dried state, it can be seen that dry plant biomass of *A. Filiculoides has* a greater sorption capacity for oil when compared to the fresh biomass. The mean amount of oil recorded for the dry biomass was (1.17667g) and for the fresh biomass (0.89g), more so, the dry biomass absorbed (0.286667) more than the fresh biomass. There was no significant difference between the sorptivity of the different plant biomass (P-value: 0.1354).

AzollaFiliculoides belonging to the family of Salviniaceae, is known for its small floating water repelling leaves, the *Azolla* fern is covered in tiny hairy that gives it a velvet like texture (Revolvy) The sorptivity of the dry leaves is not only influenced by the hairs of the plant but also by absorption within the inner tissue of the plant (Claudia, Isabelle, Matthias, Maryna,Kavalenka,N, Wilhelm, & Hendrik, 2016).The fresh leaves of the *Azolla*fern only absorbs oil on the surface on the leaves ,this limits the amount of oil being absorb.

The graph above depicts the overall sorption capacity of the plant biomass in their fresh and dried state, it can be seen that dry plant biomass of *L. Minor has* a greater sorption capacity for oil when compared to the fresh biomass. The mean amount of oil recorded for the dry biomass was (2.56222g) and for the fresh biomass (0.498889g), more so, the dry biomass absorbed (2.06333g) more than the fresh biomass. The results showed that there was a significant difference

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between the sorptivity of dry and fresh biomass (P-value: 0.0000).

Lemna minor is an aquatic plant known for its hydrophobic properties, the plant cuticle, which consist of cutin and waxesforms a hydrophobic coating covering the aerial surfaces of the plant (Borisjuk *et al.*, 2018). During the drying period for*Lemna* leaves most of the moisture along cutin and waxes are stripped away, this caused any liquid to be absorbed within the inner tissue of the plant and the plant surface the waxes and cutin prevent the plant from absorbing water but enable it to absorb oil on the leave surface.

The graph above depicts the sorption capacity of the fresh and dried biomass of *TyphaLatifolia*, it can be seen from the results recorded that the dry biomass has a greater sorption capacity when compared to the fresh biomass. The mean sorption of the dry biomass is (2.03g) and the mean sorption for the fresh biomass is (1.54889g). The results showed that the dry biomass absorbed (0.481111g) more that the fresh biomass. The results showed that there was no significant difference between the sorptivity of dry and fresh biomass(P-value: 0.1294).

Typha fibres are known for its hydrophobic and lipophilic properties. The morphological structure for *T. Latifolia fibres* showed promise for oil retention within the pores of the fibres, Cattail fibres are known to have a distinctive high wax coating and low surface energy ,the fibres of the plants also exhibited distinctive bamboo-shaped structure which was sunken in the middle part and protruded on both sides (Chelst *et al.*, 2017). The Dry biomass of the *Typha* plant retained more oil due to the increase sorptive capacity; during the drying process, much of the waxy coating on the fibres became disintegrated due to the heat and reduce moisture content, this caused the fibres sorptive capacity to increased and also the surface energy of the fibres to increase.

Research Objective 3

To determine if there is a relationship between water quality and water sorptivity; and between oil sorptivity and water sorptivity.

The correlation analysis revealed that there is a very weak positive between the pH and water sorptivity value for any of the species (P-value: 0.0000; Correlation value: 0.0637).

The correlation analysis revealed that there is a weak positive linear relationship between TDS and water sorptivity for any of the species (P-value: 0.6776; Correlation value :0.1398).

The correlation analysis revealed that there is a weak negative relationship between conductivity and water sorptivity for any of the species (P-value: 0.3597; Correlation value: -0.0577).

The correlation analysis revealed that there is a weak moderate downhill linear relationship between conductivity and water sorptivity for any of the species (P-value: 0.4044; Correlation value: 0.1274).

The correlation analysis revealed that there is a weak downhill linear relation between salinity and water sorptivity (P-value:0.8877; Correlation value: -0.0217).

With regards to the oil sorptivity and water sorptivity the correlation analysis showed that there was a moderate positive relationship (P-value:0.0000; Correlation value:0.6957).

CONCLUSION

For hypothesis 1 the null hypothesis is rejected. The drying process of *L. Minor* leaves led to the disintegration of cutin and the waxy coating on the adaxial size of the leaf, destroying the hydrophobic properties of the leaflet, this caused the water to be absorbed within the plant tissue, an intact cutin and waxy surface coating is what caused the plant to exhibit low sorption of water. *T. Latifolia* also has a waxy coating found on the fibers, this waxy coating is what make the fibers hydrophobic, However, the fibers became hydrophilic once dried due to the waxy coating being destroyed, the sorption of waster is also owed to characteristics and the concavity of the fibers. The dried and fresh biomass of *A. Filiculoides* and *S. Molesta* share similar chemical and morphological characteristic, since they both belong to the family of Salviniaceae, the hairs found on the plant surface of the leaves is what makes both plant hydrophobic, the dried biomass became hydrophilic due to the hairs being destroyed and the absorption of water within the plant tissue. *P. Stratiotes* remained hydrophobic even in its dried state, this is due to the trichome being found on the adaxial and abaxial sides of the leaves, the distortion of the hairs caused by drying, is what cause the plant to display low capillary movement of water between the gaps of the hairs.

For hypothesis 2, The null hypothesis is rejected. The deformed and winkled trichome, is likely to be the cause for the low sorptivity of oil, exhibited by *Pistiastratiotes*; the hairs became wrinkled due to the drying process with led to a reduction in the moisture content of the leaves. The fresh biomass however showed a higher sorption for oil due to the intact hairs and surface organs.The dried *biomass SalviniaMolesta* performed somewhat better when compared to the water lettuce, the trichome of *S. Molesta* has an egg whisk shaped tip that when submerged in oil, captures the oil within the hair due high capillary movement between the interstices. The poor performance of the biomass of S. *Molesta* was due to the hairs being located on the

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adaxial side of the leave. From the family of*Salviniaceae*, the aquatic fern *Azolla*share similar, chemical and biological composition to *S. Molesta*, that when dried, there is sorption within the inner tissues of the plant along with surface sorption, however. The cattail fibers are known for its ability to absorb oil, the density, structure, chemical composition and minuscule size of the fibers are what makes them the *T. Latifolia*fibers good sorbents, the drying process caused the waxy coating on the fiber of to disintegrate increasing sorptive capacity, absorbing more oil. The dry biomass of *Lemna Minor* exhibited good sorptivity owed to the fineness of the biomass and the capillary movement of the oil within the plant tissue, due to the disintegration of the waxy coat caused by the drying process.

For hypothesis 3 the null hypothesis is accepted (Correlation value:0.6957; P-value:0.0000).

For hypothesis 4 the null hypothesis is rejected. The reason for this, is that there weren't any strong relationships found between the water quality parameters and water sorptivity. this concludes that the fresh and dry biomasses of the aquatic plants *Pistoia Stratiotes, Lemna Minor, SalviniaMolesta, AzollaFilicudioes* and the fibre of the *TyphaLatifolia* can be used in brackish ,salt and freshwater and have the same effectiveness .

Recommendations

The following is recommended Studies should be done using other species of aquatic plants with similar morphological characteristic in both their dried and fresh state to see if they can also be used as natural sorbents for oil.

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