Investigating the phytoremediation capacities of Corncob and Water Hyacinth to treat oil spills

Word count: 2233

Identification of Context:

Environmental Issue:

Oil is an important global energy source, accounting for just under 40% of global energy production in 2018 (Ritchie and Rosen). It is transported globally in large quantities, causing oil spills when it is accidentally released into aquatic/terrestrial environments. Crude oil can block sunlight from being absorbed by phytoplankton, which is harmful to marine food webs (Saadoun). It can blind aquatic life, hamper respiration, and dehydrate marine life (Saadoun). When spilled on land, crude oil can destroy soil microorganisms, contaminate freshwater sources for humans, and contaminate aquatic food production systems for many human communities (Nwadiogbu et al.).

Hence, there is a need to treat oil spills effectively. Usually, synthetic sorbents are used to both **absorb** and **adsorp** oil (See Fig. 1) to combat oil spills (Nwadiogbu et al). However, many are too expensive to be readily available for all socioeconomic classes, and some may have harmful byproducts that persist in the environment (Zamparas et al.)

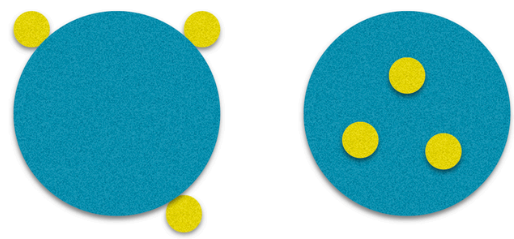


Fig. 1 - Adsorption (adhesion to outer surface) vs Absorption (permeating inside the sorbent) – (The Daily Garden)

Hence, a more cost-effective alternative avenue that is being explored is Phytoremediation, which involves using plants containing microorganisms to degrade oil (Atta et al.). Phytoremediants are compared using sorption capacities, which is defined as the mass intake of oil divided by the mass of phytoremediant used (Rani et al. 135). The mass intake is obtained by measuring the volume absorbed and adsorped and then multiplying it by the density.

This investigation focuses on comparing the effectiveness of two phytoremediants that can adsorb and absorb oil to act as low-cost, natural materials to treat oil spills.

Research Question:

Is there a significant difference between the volume of Rice Bran oil absorbed and adsorbed by different masses of Corncob (*Zea mays*) and Water Hyacinth (*Eichhornia crassipes*) stems to compare their potential to treat crude oil spills in aquatic ecosystems?

Planning:

Choice of Phytoremediants and Oil to test

Material	Significance
Corncob	TERI markets a bioremediant for oil spills known as "Oilzapper", but the IB Animal Experimentation Policy forbade me from using it due to its bacterial composition (TERI). However, it contains Corncob as a carrier material, so I decided to test the plant instead.
Water Hyacinth	The plant grows excessively in small water bodies - treating oil spills with it can solve issues related to its invasive overgrowth. Its stem was chosen to be tested out of all of the plant parts based on secondary data (Rani et al. 136).
Rice Bran Oil	As tests with crude oil would be infeasible due to its volatile nature, I chose to use Rice Bran oil instead. It has a density of 0.96 g/cm^3, similar to that of crude oil (Genesis Group).

Independent and Dependent Variables

	Variable	Significance
Independent Variable	**Mass of phytoremediants used** (1.00, 2.00, 3.00, 4.00, 5.00 ± 0.01 g)	**How was it measured:** electronic balance **Justification for range:** 1.00 gram was chosen as the starting mass for both materials based on a study from the University of Tamil Nadu (Rani et al. 135); thereafter masses differ by 1 gram to allow observation of a significant difference in oil intake between masses
Dependent Variable	**Volume of Rice Bran oil absorbed and adsorbed** (ml)	**How was it measured:** graduated cylinder Volume readings were converted to mass, which was used to calculate sorbtion capacities

Control Variables

Control Variables	Significance
Temperature	Trials performed at room temperature – approximately 25ºC If not controlled, a large temperature increase can increase rate of oil degradation (Zekri and Chaalal)
Time	Each mixture was left for 24 hours If not controlled, a sample left for a longer period would record a higher oil intake
Number of pieces suspended	Within each mass group, the same number of similarly sized pieces were placed in each beaker If not controlled, a beaker with more pieces will have a higher surface area for adsorption compared to one with less pieces, so the sorbtion capacity will be overestimated
Type of Oil	Rice Bran oil used for all trials If not controlled, using multiple varieties with different densities may cause random error since the masses of oils for a given volume in the beakers will vary
Ratio of water and oil	Mixture composed of 100 ml water and 10 ml oil If not controlled, mixtures of different proportions may lead to different volumes of oil being absorbed and adsorbed

Hypothesis:

There will be a significant difference between the volumes of oil absorbed and adsorbed by the two phytoremediants and Water Hyacinth will absorb and adsorb more due to its higher sorbtion capacity compared to Corncob.

Materials:

- Rice Bran oil (500 ml)
- Corncob pieces (75 g)
- Water Hyacinth stems (75 g)
- Multiple beakers (250 **±** 12.5 ml)
- Graduated cylinder (50 ± 0.1 ml)
- Electronic Balance (± 0.01 g)
- Separating funnel
- Iron stand and clamp
- Glass stirring rod
- Weigh boat
- Tap water
- Scissors

Procedure:

1. Beakers are filled with approximately 100 ml of tap water, to which 10.0 ml of measured Rice Bran oil is added using a graduated cylinder.
2. Corncob pieces are cut and placed on a pre-weighed weigh boat.
3. For Water Hyacinth, scissors are used to cut only the stem, and excess water is shaken off and the piece is weighed in the weigh boat.
4. The process of cutting and weighing repeats until a piece matches with one of the five predetermined mass groups.
5. The phytoremediants are placed in the beakers with oil.
6. After 24 hours, the phytoremediant pieces are taken out and the remaining mixture of oil and water is poured into the separating funnel.
7. With the lid closed, the funnel is shaken thrice to allow the mixture to settle. Two distinct levels of oil and water form over time.
8. The cap of the funnel is opened and the stopcock is used to let out the water. The remaining oil is poured back into the graduated cylinder to measure the final volume. Since the initial volume was constant, a difference between the final and initial volumes can be calculated.
9. Rinse the separating funnel and graduated cylinder between trials to improve accuracy.

Number of samples:

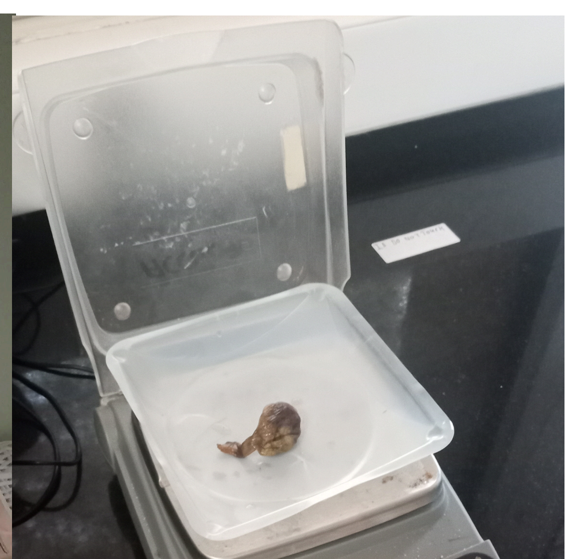
This process is repeated five times for each of five mass groups of Corncob and Water Hyacinth to get 25 total measurements for each material. This ensures a good sample size to calculate a T-Interval with.

Safety Considerations:

- Scissors were used carefully while cutting Corncobs.
- Due to lack of access to a ring clamp, the separating funnel was attached to a burette clamp which was slightly more unstable – the glassware was hence used with care.
- The separating funnel was vented by opening the cap before releasing the water since pressure builds up inside the funnel during the process.

Ethical and Environmental Considerations:

- Hands were washed after each set of trials to not cross-contaminate the materials.
- Rice Bran Oil was poured into the sink so as to not stain other areas.
- While cutting the Water Hyacinth stems, care was taken to not damage other parts of the plant.



Results, Analysis and Conclusion:

Qualitative Data:

Corncob	Water Hyacinth
Smaller pieces; pieces are slightly submerged in water	Larger pieces; pieces float on top of water
No significant change in size	Swells up as time progresses
Colour of the piece darkens over time	Colour remains approximately the same
For both phytoremediants, as the mass of the phytoremediant increased, the number of bubbles present in the leftover mixture increased (i.e. 5 gram beakers had more bubbles than 1 gram beakers)	

Table 1 Raw Data: Initial and final volumes of Rice Bran oil – Corncob

	Initial and Final Volumes of Rice Bran oil (± 0.1 ml)									
Mass of Corncob (± 0.01 g)	**Trial 1**		**Trial 2**		**Trial 3**		**Trial 4**		**Trial 5**	
1.00	10.0	9.5	10.0	9.7	10.0	9.8	10.0	8.8	10.0	9.9
2.00	10.0	9.2	10.0	9.2	10.0	8.9	10.0	8.8	10.0	9.7
3.00	10.0	8.9	10.0	8.2	10.0	5.3	10.0	7.8	10.0	7.9
4.00	10.0	8.1	10.0	7.6	10.0	6.9	10.0	8.3	10.0	7.9
5.00	10.0	7.5	10.0	8.2	10.0	7.9	10.0	8.2	10.0	8.5

Table 2 Raw Data: Initial and final volumes of Rice Bran oil – Water Hyacinth

	Initial and Final Volumes of Rice Bran oil (± 0.1 ml)									
Mass of Water Hyacinth (± 0.01 g)	**Trial 1**		**Trial 2**		**Trial 3**		**Trial 4**		**Trial 5**	
1.00	10.0	6.9	10.0	6.8	10.0	9.0	10.0	8.2	10.0	9.2
2.00	10.0	5.9	10.0	6.0	10.0	5.8	10.0	6.0	10.0	7.0
3.00	10.0	6.2	10.0	5.7	10.0	6.1	10.0	4.8	10.0	4.0
4.00	10.0	4.6	10.0	4.0	10.0	3.4	10.0	4.0	10.0	4.9
5.00	10.0	2.8	10.0	2.8	10.0	5.5	10.0	3.5	10.0	2.9

Sample Calculation of Volume absorbed and adsorbed:

Trial 1 – 1.00 grams of Corncob

$$Initial\,Volume: 10.0\,ml,\ Final\,Volume = 9.5\,ml$$

$$Difference\ in\ volume = 10.0 - 9.5 = 0.5\,ml$$

The volume intake equals the amount of oil absorbed and adsorbed.

Table 3 Processed Data: Volume of Rice Bran oil absorbed and adsorbed by Corncob

	Volume intake of Rice Bran oil (± 0.1 ml)				
Mass of Corncob (± 0.01 g)	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1.00	0.5	0.3	0.2	1.2	0.1
2.00	0.8	0.8	1.1	1.2	0.3
3.00	1.1	1.4	4.7	2.2	2.1
4.00	1.9	2.4	3.1	1.7	2.1
5.00	2.5	1.8	2.1	1.8	1.5

Table 4 Processed Data: Volume of Rice Bran Oil absorbed and adsorbed by Water Hyacinth

	Volume intake of Rice Bran oil (± 0.1 ml)				
Mass of Water Hyacinth (± 0.01 g)	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1.00	3.1	3.2	1.0	1.8	0.8
2.00	4.1	4.0	4.2	4.0	3.0
3.00	3.8	4.3	3.9	5.2	6.0
4.00	5.4	6.0	6.6	6.0	5.1
5.00	7.2	7.2	4.5	6.5	7.1

Calculation of Sorption Capacities (SCs):

A sorption capacity can be defined as:

$$\frac{Mass\ absorbed}{Mass\ of\ material} = \frac{Difference\ in\ mass}{Mass\ of\ material} = \frac{0.96\ x\ Difference\ in\ volume}{Mass\ of\ corncob\ or\ water\ hyacinth}$$

0.96 refers to the density of the oil. Here is a sample calculation for 2.00 grams of Water Hyacinth, Trial 3, from Table 4.

$$4.2\ ml = Difference\ in\ volume$$
$$Difference\ in\ mass = 0.96\ x\ 4.2 = 4.0\ grams$$

$$Sorbtion\ capacity = \frac{4.0\ grams\ absorbed\ and\ adsorbed}{2.00\ grams\ Water\ Hyacinth} = 2.0\ g/g$$

Table 5 Processed Data: Calculated SCs of Corncob

	Sorption Capacity (g/g)				
Mass of Corncob (± 0.01 g)	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1.00	0.5	0.3	0.2	1.2	0.1
2.00	0.4	0.4	0.5	0.6	0.1
3.00	0.4	0.6	1.5	0.7	0.7
4.00	0.5	0.6	0.7	0.4	0.5
5.00	0.5	0.3	0.4	0.3	0.3

Overall Mean SC of Corncob: 0.5 g/g

Table 6 Processed Data: Calculated SCs of Water Hyacinth

	Sorption Capacity (g/g)				
Mass of Water Hyacinth (± 0.01 g)	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
1.00	2.9	3.0	0.9	1.7	0.7
2.00	2.0	1.9	2.0	1.9	1.4
3.00	1.2	1.4	1.2	1.7	1.9
4.00	1.3	1.4	1.6	1.4	1.2
5.00	1.4	1.4	0.9	1.2	1.4

Overall Mean SC of Corncob: 1.6 g/g

Sample Calculations for Mean Volume intake and Mean Sorbtion Capacity:

- All five measurements of volume intake (Row 6 Table 3) and Sorbtion Capacity 5.00 grams of Corncob (Row 6 Table 5)

Mean volume intake: $\frac{2.5+1.8+2.1+1.8+1.5}{5} = 1.9\ ml$

Mean sorbtion capacity: $\frac{0.5+0.3+0.4+0.3+0.3}{5} = 0.4\ g/g$

Table 7 Processed Data: Mean volume intake of Rice Bran oil and associated standard deviations for Corncob and Water Hyacinth

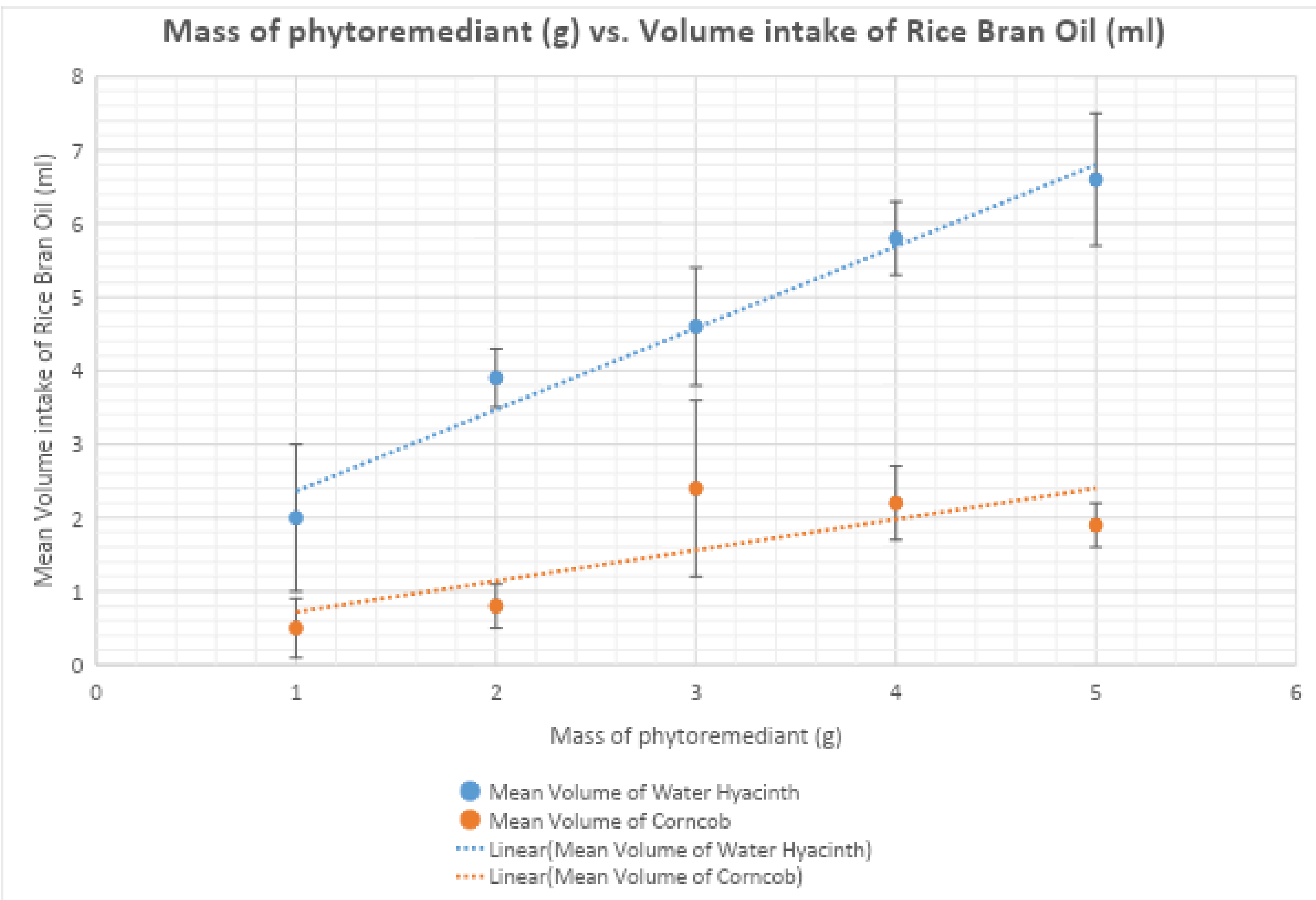
Mass of piece (± 0.01 g)	Mean Volume intake for Corncob pieces (ml)	Standard Deviation of Volumes (ml)	Mean Volume intake for Water Hyacinth pieces (ml)	Standard Deviation of Volumes (ml)
1.00	0.5	0.4	2.0	1.0
2.00	0.8	0.3	3.9	0.4
3.00	2.4	1.2	4.6	0.8
4.00	2.2	0.5	5.8	0.5
5.00	1.9	0.3	6.6	0.9

Mass of piece (± 0.01 g)	Mean Sorption Capacity of Corncob (g/g)	Standard Deviation of SCs (g/g)	Mean Sorption Capacity of Water Hyacinth (g/g)	Standard Deviation of SCs (g/g)
1.00	0.4	0.4	1.8	1.0
2.00	0.4	0.2	1.9	0.2
3.00	0.8	0.4	1.5	0.3
4.00	0.5	0.1	1.4	0.1
5.00	0.4	0.1	1.3	0.2

Table 8 Processed Data: Mean sorbtion capacity and associated standard deviations for Corncob and Water Hyacinth

Note: Standard Deviations have been calculated to be plotted as uncertainties since they represent the variation in the calculated datasets of Tables 7 and 8

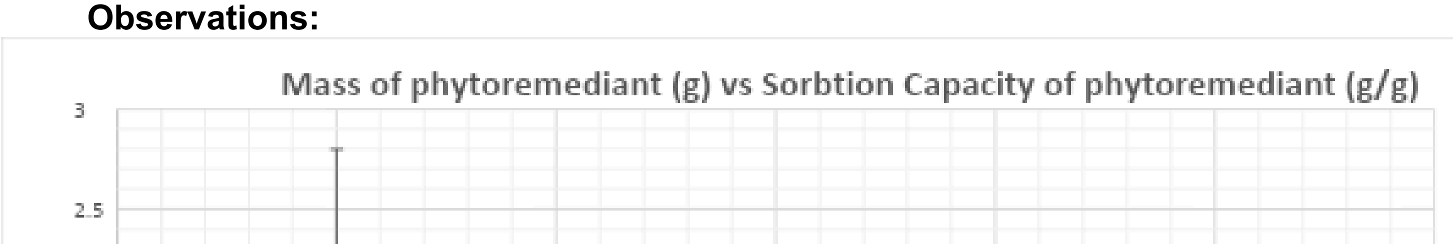
Graph 1 – Based on Table 7



Note: Horizontal error bars in the mass are too small to be seen for this graph and the following one

Graph 2 – Based on Table 8

Observations:



Graph 1 shows that the slope for Water Hyacinth is 0.69 ml higher than that of Corncob, so as mass increases, Water Hyacinth reports larger volume intakes compared to Corncob. Water Hyacinth also has a larger y-intercept and R^2 values. Larger vertical error bars show that Water Hyacinth has higher variability in its volume intake.

Graph 2 reports a consistently higher sorbtion capacity for Water Hyacinth, which also decreases slightly as mass increases, whereas Corncob's capacity stays almost constant at around 0.47 g/g.

Use of the 2-Sample T-Interval:

A T-Interval for the difference in the materials' mean sorption capacities was used to determine whether the differences in their efficacy occurred by chance or not. The randomness condition and 10% rule are satisfied since this is an experiment. Both datasets' boxplots were made and checked for skewness. Each of the two datasets for the T-interval contained all 25 sorption capacity values for the respective material. The 95% Confidence Interval is:

Output of the T-Interval - (0.80026, 1.3037)

Conclusion:

There is a significant difference between the efficacies of Corncob and Water Hyacinth to mop up Rice Bran oil. The T-interval supports this since Water Hyacinth has a higher sorbtion capacity than Corncob by a value between 0.80026 and 1.3037 g/g. Since 0 is not in the interval, the difference is statistically significant.

Tables 5 and 6 support the hypothesis that Water Hyacinth is the more effective phytoremediant, since the mean sorbtion capacity of Water Hyacinth is 1.1 grams higher than Corncob. Graph 2 visually shows this difference in their sorbtion capacities. Graph 1 shows how the slope and y-intercept of Water Hyacinth is higher than those of Corncob, so for equal masses of both phytoremediants, Water Hyacinth will treat more oil. A possible explanation is that as Water Hyacinth's mass increases, the space in the air sac of the stem increases, which allows for more absorption compared to Corncob's densely packed center.

The R^2 values from Graphs 1 and 2 are higher for Water Hyacinth than Corncob. Hence, Water Hyacinth follows a stronger linear relationship than Corncob, so its data can be extrapolated more reliably. However, Graph 1's vertical uncertainties show how Water Hyacinth has higher variability, so it sometimes may not remove a predicted volume of oil.

Finally, Graph 2 shows how the sorbtion capacity of Water Hyacinth decreases as mass increases when theoretically it should stay constant. Qualitative data explains this since Water Hyacinth floats on oil whereas Corncob is submerged – as mass increases, the increase in the Surface Area of Water exposed to the oil is relatively small, so the amount of oil mopped up through adsorption alone does not increase significantly. Hence, the overall sorbtion capacity drops slightly.

Discussion and Evaluation:

A limitation of the experiment was the high uncertainty from the graduated cylinder, which limited the accuracy of the calculated sorbtion capacities. Additionally, Surface Area could not be accurately controlled during the experiment, which slightly affected the contributions of adsorption to the volumes of oil measured.
However, the conclusions obtained from this investigation are very valid. The parameters in the T-Interval, tables, and graphs all support the conclusion that Water Hyacinth was significantly more effective than Corncob. Many control variables ensured that conclusions without confounding variables could be made, and a large number of trials accounted for chance variation in the dependent variable. The methodology used whole pieces of both materials to model how lower socioeconomic classes would likely use the phytoremediants in reality. Hence, this investigation has immense ramifications for the emerging field of phytoremediation, as societies look for cost-effective, clean materials to remediate oil spills.

Error Analysis and Modifications:

Error	Significance	Improvements
Large standard deviations for 1.00 g Water Hyacinth (Graph 2) and 3.00 g Corncob (Graph 1)	Random error - More variability means less reliability when used industrially	Use a more accurate graduated cylinder to increase precision and decrease variability
Small quantities of oil left on the mouth of the separating funnel between trials	Systematic error - Oil left on the sides of glassware are not measured, so differences in volume are underestimated	After separating the mixture once, refill the funnel with water to remove oil from the sides and separate again
Higher amounts of emulsification for higher masses	Systematic error - emulsified oil cannot be accurately separated	Swirl the contents of the funnel for some time until the emulsion is lost

Extension:

The same materials can be tested in powdered form to determine whether the increase in Surface Area to Volume Ratio increases their sorbtion capacities.

Application:

Water Hyacinth can be used to remediate oil spills in aquatic environments. The investigation showed that it had a higher sorbtion capacity than Corncob (which is already used as a carrier material in bioremediants), so the use of Water Hyacinth is realistic.

Water Hyacinth has limitations - it has a lower sorbtion capacity compared to synthetic sorbents and is also hydrophilic in nature, which means that interactions with water are more favorable than interactions with oil, affecting adsorption (Nwadiogbu et al.). Limitations also include transportation costs and the cost of grinding them into powders or other forms for use.

However, communities in lower socioeconomic classes cannot readily afford or procure synthetic sorbents, but may have large amounts of Water Hyacinth due to their excessive growth in water bodies. Hence, Water Hyacinth can act as a cost-effective, natural form of remediation without any harmful byproducts for such communities around the world.

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