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The Potential of Talisay-Dagat (*Terminalia catappa* L.) for Phytoremediation in Langihan Lagoon, Butuan City, Agusan del Norte, Philippines

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ABSTRACT

The study aims to determine the potential of Talisay-dagat (*Terminalia catappa* L.) for phytoremediation and to examine its influence on reducing concentrations of heavy metals in the soil of Langihan Lagoon, Butuan City. Soil, roots, and leaves were collected and brought to the Regional Soils Laboratory using microwave-assisted aqua-regia digestion and determination through Inductively Coupled Plasma Optical Emission Spectrometer. The study made use of mathematical computations such as translocation factor (TF), bioconcentration factor (BCF), and enrichment factor (EF) to determine whether the tree is a hyperaccumulator, excluder, or indicator. In the TF results, *T. catappa* was a hyperaccumulator for Ni and Cu, considering that the concentration exceeds one (1) while demonstrating as a possible excluder for Cr. There was also an emphasis on limited absorption of heavy metals, as evidenced by the BCF and EF value of less than 1. The results show that based on TF, BCF, and EF values, only TF shows the effectivity of restricting the root-shoot ratio translocation of Ni and Cu (TF > 1). Regression analysis found that the absorption of *T. catappa* was not influenced by the amount of heavy metal in the soil within the studied condition. This insight was crucial in understanding the plant's absorption and could guide further research or practical applications in environmental management and phytoremediation.

1. Introduction

Heavy metal pollution has become a global problem (Mahar et al. 2016) that has attracted considerable public attention (Li et al. 2019) and is increasing due to industrialization and the disturbance of the natural nutrient cycles (Ali et al. 2013; Sumiahadi and Acar 2018) and stored in soils from human activities and natural activities (Elnazer et al. 2015). The current state of environmental contamination is extremely dangerous, endangering the fundamental foundation of human existence (Motuzova et al. 2014). This is true when enterprises utilize the soil for the discharge of treated liquid effluents, deposition of exhaust gas, and solid waste disposal (Adnan et al. 2022; Gabarrón et al. 2017). The term "heavy metal" encompasses toxic elements like lead, cadmium, chromium, nickel, copper, zinc, and mercury, posing biological risks to ecosystems. The heavy metals found near hazardous waste sites can cause toxicity at low exposure levels (Jacob et al. 2018). Although metals are necessary in small quantities, their presence in the ecosystem presents significant health and environmental hazards for all living things. Heavy metals accumulate in plants from the soil because living things are unable to break them down, and trees might experience long-term harm and effects from this (Nyangon et al. 2023).

In tropical countries like the Philippines, *Terminalia catappa* L., commonly known as Talisay-dagat, is a versatile tree often planted for shade, ornamental, and edible nuts, yet it remains underutilized for some purposes (Ladele et al. 2016). It is a fast-growing tree that naturally thrives in coastal areas and belongs to the Combretaceae family. Although *T. catappa* has been extensively studied, the majority of research has focused on its medicinal properties, including antitumor and antioxidant properties (Pandya et al. 2013), including its wound healing applications (Chanda et al. 2013), other research is about its potential as a biofuel (Khan et al. 2013), and as an indicator for acid-based reactions (Iha et al. 2014).

Phytoremediation is a financially practical way to remediate. Phytoremediation technique removes pollutants from the environment by utilizing plants and the microorganisms that live with them (Kong and Glick 2017). According to the findings of Ullah et al. (2015), phytoremediation is a financially viable way to remediate soil contaminated by metals by breaking down, stabilizing, and/or eliminating the toxins (Pinto et al. 2014). According to Chibuike and Obiora (2014), it works best when the contaminants are widespread and within the plant's root zone. Considering their extensive study history, using green plants to remediate contaminated soil appears to be a promising solution to heavy metal issues (Sarwar et al. 2017). Phytoremediation was generally acknowledged as an affordable method of restoring the environment supporting literature in the field indicates that this technology is thought to be more economical and environmentally beneficial than traditional methods for cleaning up contaminated places (Yadav et al. 2022). According to Mahar et al. (2016), hyperaccumulation of metals appears to be an evolutionary adaptation of plants to life.

In urban areas in Butuan City, particularly in Langihan Lagoon, Barangay Holy Redeemer, it was observed that the area is more likely contaminated due to its proximity to the public market, roadway, households of dwellers/communities, and the site was exposed to a variety of anthropogenic activities. Thus, the present study aimed to determine the potential of *T. catappa* as phytoremediation in mitigating soil contamination in Langihan Lagoon and to understand the influence of heavy metals presence and concentration in the soil on the total absorption of *T. catappa*.

2. Materials and Methods

2.1. Location of the Study

The study was done in a site that encompasses a Lagoon predominantly surrounded by *T. catappa,* namely the Langihan Lagoon, located at Barangay Holy Redeemer, Butuan City, Caraga Region, Philippines, with a population of 8,726 as determined by the 2020 census and this represents 2.34% of the total population of the said city. Remarkably, the lagoon identified as a known point source of contamination, receives pollutants from industrial run-off, wastewater disposal, and illegal dumping of solid wastes. These activities have notably influenced the soil matrix in the lagoon's vicinity, creating an intricate interplay between contaminated soil and *T. catappa* species (**Fig. 1**).

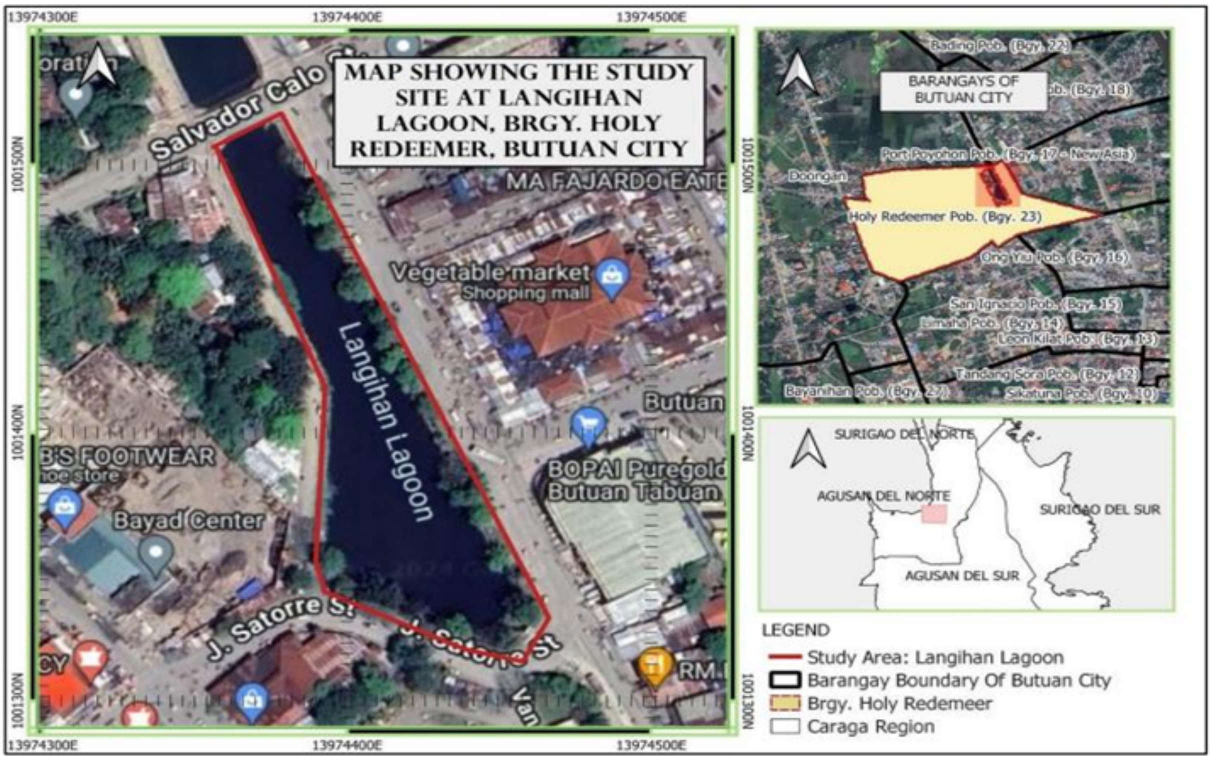

Fig. 1. The study site at Langihan Lagoon, Barangay Holy Redeemer, Butuan City, Caraga Region, Philippines.

2.2. Sampling Methods

The study employed simple random sampling to select eight mature *T.catappa* whose diameter at breast height ranges from 20–30 cm and already existed between the year 2015, which became the subject of sample collection, including the soil surrounding the tree and its roots and leaves.

2.2.1. Soil sampling

The soil was collected uniformly around the designated tree. The topsoil including dried leaves, twigs, manure, and other impurities was removed. The collection method followed the procedure prescribed by the Department of Agriculture, Caraga Region where a sample was excavated in a "v" shape reaching a depth of 15 cm below the surface. The collected soil was placed in a sack and then partitioned into quadrants. The initial elimination includes the first and fourth quadrants, while the soil from the second and third quadrants is combined. The process was iteratively repeated until a 1 kg sample was subjected to air drying. Before the soil was pulverized and sieved, residues, including tiny plant roots, were removed (Zhang et al. 2019). The soil was sieved using a 3 mm mesh sieve, packed, labeled and submitted for heavy metal analysis, particularly Ni, Cu, and Cr, at the Regional Soils Laboratory of the Department of Agriculture, using the Microwave-assisted aqua-regia digestion and determination through Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

2.2.2. Roots collection

Root samples were collected at 0.5 m depth from each *T.catappa* with a weight of 500 g, and selecting matured roots was observed following the procedure prescribed by the Department of Agriculture, Caraga Region. The roots were put in an oven set at 70°C for 12 hours, the sample was dried to a crisp and brittle texture where the analytical process took place at the Regional Soils Laboratory of the Department of Agriculture, Caraga Region, using the Microwave-assisted aqua-regia digestion and determination through ICP-OES. The aqua regia extraction was based on the procedure recommended by the International Organization for Standardisation (ISO 1995). In this process, 250 ml Pyrex digestion tubes were filled with a 3 g sample. The sample underwent an initial pre-digestion step at room temperature for 16 hours using a 28 ml mixture of 37% HCl and 70% HNO_3 in a 3:1 ratio. The suspension was then digested at 130°C for 2 hours using a reflux condenser. The resulting suspension was filtered through an ashless Whatman 41 filter, diluted to 100 ml with 0.5 mol l−1 HNO_3, and stored in polyethylene bottles at 4°C for analysis (Sastre et al. 2002).

2.2.3. Leaves collection

Leaves were systematically collected in an east-to-west direction, following the guidelines provided by the Department of Agriculture, Caraga Region. A set of five leaves was collected in every direction on the tree's first branch, totaling the sample with further precautions that will be used to prevent gathering leaf-like imperfections, pesticide treatment, bird droppings, and infectious insects. The collected leaves were then oven-dried at 70–80°C, and drying took 12–24 hours depending on the original condition of the sample, and was dried to a crisp until it reached its brittle state (Clemson University Regulatory Services 2024). These leaves were carefully placed in zip-lock bags after being powdered. They were submitted for analysis at the Regional Soils Laboratory of the Department of Agriculture in the Caraga Region, using microwave-assisted aqua-regia digestion and determination through ICP-OES. The aqua regia extraction was based on the procedure recommended by the International Organization for Standardisation (ISO 1995).

2.3. Data Analysis

The data were encoded and organized in the Microsoft Excel Office 365 Program. The analysis was conducted for heavy metal concentrations in plant tissues (leaves and roots) within the chosen *T. catappa* species. Another fundamental mathematical computation was used, this centered on the determination of translocation factor (TF) (Equation 1) (Santos et al. 2021; Yoon et al. 2006). Bioconcentration factor (BCF) (Equation 2) is the ratio of the plant roots to soil concentration, it was used to assess the movement of heavy metals from contaminated soils into the plant roots (Ndeda and Manohar 2014; Santos et al. 2021; Yoon et al. 2006). The determination of a hyperaccumulator, indicator and exluder (**Table 1**) followed the criteria of the previous studies (Baker et al. 2000; Ndeda and Manohar 2014; Santos et al. 2021; Yoon et al. 2006). Enrichment Factor (EF) (Equation 3) is the ratio of concentration of plant shoot to soil concentration (Santos et al. 2021). Regression analysis was also used to test the relationship between the concentration of soil heavy metals and the absorption of *T. catappa*.

$$TF = \frac{Metal\ concentration\ in\ shoots\ (ppm)}{Metal\ concentration\ in\ roots\ (ppm)} \quad (1)$$

$$BCF = \frac{Metal\ concentration\ in\ roots\ (ppm)}{Metal\ concentration\ in\ soil\ (ppm)} \quad (2)$$

$$EF = \frac{Metal\ concentration\ in\ shoots\ (ppm)}{Metal\ concentration\ in\ soil\ (ppm)} \quad (3)$$

Table 1. Criteria for hyperaccumulator, excluder and/or indicator type of plant (Adriano 2001; Baker et al. 2000; Ndeda and Manohar 2014; Santos et al. 2021; Yoon et al. 2006)

Hyperaccumulator	Excluder/Regulator	Indicator
- Ratio of heavy metal concentrations of TF > 1 - Ratio of heavy metal concentrations of EF > 1 - Pb, Cu, Co, Cr, and Ni have > 1000 µg/g or 10.000 µg/g of Fe, Mn, and Zn or Cd > 50 µg/g in any aboveground tissue in their natural habitat without suffering toxic effects	- High levels of heavy metals in the roots but with TF quotients < 1	- Metal levels in the tissues reflect the levels in the sediments - Indicators are plant species that correspondingly respond to metal concentrations in soils

3. Results and Discussion

3.1. Presence of Heavy Metals in Soil

Plant tissues can absorb heavy metals that remain in the soil; thus, the soil's absorption of heavy metals can significantly increase their presence beyond natural levels. From the results obtained, Ni has the highest content acquired from the soil having a mean value of 216.61 ppm out of the eight soil samples assisted with a standard deviation of 94.82 ppm and was followed by Cr and Cu (**Table 2**). This indicates that Ni has considerable toxicity procured in Langihan Lagoon, Butuan City. According to Bhalerao et al. (2015), Ni may be a serious issue on land adjacent to municipalities, industrial areas, or even agricultural land that receives waste products like sewage sludge.

Table 2. Mean amount of soil heavy metals

Heavy Metals	Concentration (ppm)
Nickel (Ni)	216.61 ± 94.82
Chromium (Cr)	160.61 ± 67.68
Copper (Cu)	65.27 ± 5.30

According to WHO (1996), the permissible limit of Ni in the soil is 35 ppm, 100 ppm for Cr and 36 ppm for Cu. Microorganisms, animals, and plants are all extremely hazardous to heavy metals such as N, Cr, and Cu. Due to increased anthropogenic and geological processes, heavy metal-polluted soils are becoming more commonplace worldwide (Chibuike and Obiora 2014). Furthermore, heavy metals Ni, Cr, and Cu are necessary for plants to complete their life cycle because they cannot obtain another nutrient that can substitute them (Harasim and Filipek 2015). Contaminated land must be cleaned up and made free of heavy metals to improve the ecosystem for all living organisms (Dixit et al. 2015).

Given the presence of heavy metals in nature, this topic has received a lot of attention. In a study conducted by Fazil et al. (2023) at Mardan Industrial Estate, their presented results point to the potential application of the identified twenty-one plant species for heavy metal remediation in contaminated areas, particularly for Ni present in soil. This is to offer a viable path for ensuring the development of environmentally safe, long-lasting, and inexpensive phytoremediation methods to address heavy metal contamination. Once Ni is available in the soil, it is an essential element for the growth of a tree and development through the roots as it occurs and travels naturally across the environment.

3.2. Heavy Metal Absorption of T. catappa

3.2.1. Presence of heavy metals in the root system

The analysis of the absorption of heavy metals in the roots of *T. catappa* in Langihan Lagoon, Butuan City, as shown in **Table 3**, reveals notable variations among heavy metals. Ni has the highest mean value of 9.19 ppm having a standard deviation of 3.87 ppm indicating a considerable uptake by roots and depicting the variability of Ni absorptions across the root samples, followed by Cu and Cr that exhibits 8.28 ppm and 6.20 ppm mean concentration, and the dispersion of the absorption among roots of 2.07 ppm for Cu and 3.09 ppm for Cr. Similar reports indicated that Ni and Cr were also found in the roots of *Terminalia macroptera* (Yakubu et al. 2015). As stated by Nazareno and Buot (2015), in their study of the naturally grown trees in the landfill of Cebu City, Cr in *T. catappa* was not detected in roots but is present in the stem and a candidate for remediating contaminated soils. The results by Cabugsa and Hermita (2014) show that Cu uptake in roots of *T. catappa* seedlings amended by ethylenediaminetetraacetic acid (EDTA) was relatively low. A similar idea is stated by Matakala et al. (2023), emphasizing that the total heavy metal content in the soil and the plant's ability to transport metals from the soil up to the roots are critical.

Table 3. Mean amount of heavy metals in the root system of *T. catappa*

Heavy Metals	Concentration (ppm)
Nickel (Ni)	9.19 ± 3.87
Copper (Cu)	8.28 ± 2.07
Chromium (Cr)	6.20 ± 3.09

Since phytoremediation is a complex process, it can be affected by several factors, such as biotic and abiotic factors, present in the soil. In this study, mature *T. catappa* trees having a well-developed root system were used, allowing them to access deeper soil layers and persistent contaminants in the Lagoon. De Bernardi et al. (2020) findings enhance the ability of some plant species such as Sorghum (*Sorghum bicolor* L.) to stabilize heavy metals in roots. This is attributed to their ability to accumulate Ni, especially at the root level, by increasing the bioavailability of Ni in the rhizosphere. These insights contribute to the understanding of heavy metals remediation strategies in terms of Ni, Cu, and Cr accumulation in plant roots. However, heavy metals' predetermined end is accumulation being absorbed by plants from the soil and surroundings through the root system where they might move up the food chain affecting not just the plant but also its end users (Ashar et al. 2022) and may diminish the nutritional value and slows down the growth of plants because of changes to their biochemical and physiological processes.

3.2.2. Presence of heavy metals in the leaves

In examining the absorption of heavy metals by *T. catappa* leaves, notable variations are observed among different samples. Cu now attained the highest mean concentration with 13.29 ppm and the standard deviation of 4.39 ppm respectively indicating the variability of heavy metal absorptions in leaf samples (**Table 4**). Ni follows with a mean concentration of 11.21 ppm and a standard deviation of 5.82 ppm, while Cr shows a mean concentration of 3.54 ppm, measuring a dispersion of 1.66 ppm. According to WHO (1996), the permissible limit of plants for Cu is 10 ppm, Ni is 10 ppm, and Cr is 1.30 ppm, Ni and Cr exceed the permissible value as also used by Iqbal et al. (2011).

Table 4. Mean amount of heavy metals in the leaves of *T. catappa*

Heavy Metals	Concentration (ppm)
Copper (Cu)	13.29 ± 4.39
Nickel (Ni)	11.21 ± 5.82
Chromium (Cr)	3.54 ± 1.66

Matakala et al. (2023) studied the *Combretum molle* (Combretaceae) and other native species found in tailing dams effectively restricting the root-to-shoot translocation of heavy metals. This indicates the potential suitability of some plants with the same family, such as *T. catappa* for Cu phytoremediation as these elements are essential to plants' growth and development. In addition, Cu was highest in leaves as observed in the results because it is essential to the growth of plants. Cu belongs to the eight micronutrients needed for the plant growth (Shabbir et al. 2020) in low concentrations (Hajar et al. 2014). However, Cu has been distinguished to move several toxic effects on various biophysiochemical processes (Ameh and Sayes 2019).

There are very few studies of hyperaccumulation of nickel particularly in tropical regions, and the Ni hyperaccumulation by plants is not well understood. Some data are concentrated on only a few species and metals (Pollard et al. 2014). In the presence of Ni, the contents of mineral nutrients in plant organs may increase, decrease, or stay even (Bhalerao et al. 2015). Safari et al. (2018) studied *Conocarpus erectus* (Combretaceae) and found that this species can capture Ni from the air and absorb it from contaminated soils. Cr is a non-essential heavy metal for living systems, considered one of the most toxic elements that has detrimental effects on plants and animals (Handa et al. 2018) and Cu is transported and absorbed in reduced form (Mir et al. 2021). Based on the study of Kapoor et al. (2022), Cr has two forms (mobile and immobile), and further studies are required to overcome Cr contamination and suitable remediation strategies.

3.2.3. Heavy metal uptake and translocation of T. catappa through TF, BCF, and EF calculations

The translocation factor (TF) explains the distribution of heavy metals, specifically Ni, Cu and Cr among the soil and the roots of *T. catappa*. The TF and BCF factors should be greater than one to be a hyperaccumulator (Baker et al. 2000; Ndeda and Manohar 2014; Santos et al. 2021; Yoon et al. 2006). Cu obtained the highest BCF value (0.13), followed by Ni with a BCF value (0.04), and Cr obtained the lowest BCF value (0.04) (**Table 5**). Ni having a BCF value of 0.04 explains that a limited portion of the heavy metals are present in the soil taken by the roots (**Table 5**). Meanwhile, the Cu of BCF value of (0.13) indicates a higher uptake of Cu by the roots of *T. catappa*. The BCF value of 0.04 indicates that Cr is taken up by roots although to a lesser extent than Cu and Ni. The study of Tauqeer et al. (2019) suggests that *Conocarpus erectus* (Combretaceae) can stabilize Ni and Cr with a BCF value of less than 1. Since there is limited data about the ability of the Combretaceae family particularly *T. catappa* to stabilize heavy metals in the soil a similar study could be one of the possible supports for this claim. Ni and Cu exhibit TF values greater than one. Ni has a TF value of 1.22, and Cu has a TF values of 1.60. The values explain the potential of *T. catappa* as a hyperaccumulator for Ni and Cu while a potential excluder for Cr with TF of 0.57. Hyperaccumulator (extreme accumulator) can thrive and tolerate heavily contaminated soils; in contrast, excluders can survive through a restriction mechanism as influenced by species and genotypes, even among crops sensitivity and tolerance vary (Adriano 2001). Furthermore, Cu obtained a high EF value (0.20) followed by Ni (0.05) and Cr (0.02), this indicates that these heavy metals were accumulated by the plant.

Table 5. Results of *T. catappa* which is probable as a hyperaccumulator, excluder or indicator for Ni, Cu, and Cr

Heavy Metals	Soil Concentration (ppm)	Roots concentration (ppm)	Leaves concentration (ppm)	BCF	TF	EF
Copper (Cu)	522.20	66.28	106.29	0.13	1.60**	0.20
Nickel (Ni)	1,732.90	73.53	89.67	0.04	1.22**	0.05
Chromium (Cr)	1,284.90	49.64	28.31	0.04	0.57*	0.02

Notes: ** = hyperaccumulator values > 1; * = excluder < 1.

According to Thakur et al. (2016), a hyperaccumulator can accumulate and absorb heavy metals in high concentrations in the aboveground tissues without affecting physiological processes. Matakala et al. (2023) studied the *Combretum molle* (Combretaceae) and other native species found in tailing dams, which have the potential for phytostabilization of Cu, Cr, and Ni. Nyenda et al. (2023) also supported this study, which recommended planting *C. molle*, *C. zeyheri*, and *C. apiculatum* (Combretaceae) for tailings with high Ni. Adriano (2001) explains bioavailabilty in the soil-plant system and explains that plant species and genotypes influence the sensitivity or tolerance of plants to excess metals. Rascio and Nava-Izzo (2011) discusses the phenomena of hyperaccumulation in plants, especially in response to heavy metal contamination, which further supports the observations of values BCF > 1. The EF analysis of Ni, Cu, and Cr revealed relatively low EF values with 0.05, 0.20, and 0.02, respectively, indicating a limited absorption of these heavy metals in the plant tissues compared to the soil. The study of Lorestani et al. (2011) showed that none of the collected plants were suitable for phytoextraction of Cu, these plants were found naturally in heavy metal-contaminated soil.

This suggests that the plant species are not significantly accumulating these metals with concentrations in the leaves being notably lower than in the soil samples. Printarakul and Meeinkuirt (2022) conducted a related study on heavy metal accumulation in bryophytes, where they found Cu exhibiting a low EF value of (0.9) in bryophyte tissues, suggesting minimal enrichment. The study highlights that the sources of heavy metals in the bryophyte community are primarily lithological rather than anthropogenic, providing valuable insights into the limited accumulation of Ni, Cu, and Cr in the studied plant species. The results show that based on TF, BCF, and EF equations, only TF shows the effectivity of restricting the root-shoot ratio translocation of Ni and Cu (TF > 1). Plants with more than one bioconcentration factor and translocation factor of greater than one can be used in phytoextraction (Santos et al. 2021). Furthermore, if the plant's bioconcentration factor is higher than one and its translocation factor is lower than one, the plant has the potential for phytostabilization (Yoon et al. 2006). The phytoextraction process involves the movement of heavy metals to the plant's harvestable parts, such as the shoots (Yoon et al. 2006). In contrast, phytostabilization relies on the plant's ability to limit the transfer of metals from the roots to the shoots (Yoon et al. 2006).

3.3. Regression Analysis for Cu Absorption

Fig. 2 provides the model result of determining the relationship of Cu absorption of *T. catappa* to the presence of heavy metals in the soil. The intercept had an estimate of 82.24 and r^2 of 0.48. However, the total plant Cu absorption had an estimate of -0.79 and the p-value of 0.057, slightly above the significance threshold. In conclusion, the total absorption of Cu by *T. catappa* may not have a statistically significant impact on the presence and concentration of Cu in the soil within Langihan Lagoon. According to Cabugsa and Hermita (2014), phytoextraction is a complex process and not affected by a single factor like the concentration of heavy metals in the soil, but also the presence of other biotic and abiotic factors in the soil. The study by Chiou and Hsu (2019) aimed to create regression models to predict plant Cu concentration based on different Cu extraction methods in soil. These models aim to explain a large part of the variation in Cu concentration in the plant using different factors. However, although moderate success was achieved in predicting Cu concentrations, the study recognizes the limitations of relying solely on soil Cu extraction methods to explain the complex relationship between soil Cu levels and plant uptake. Thus, although informative, the study demonstrates the need for further research that examines broader factors outside of Cu extraction methods in soil to better understand Cu accumulation in plant tissue.

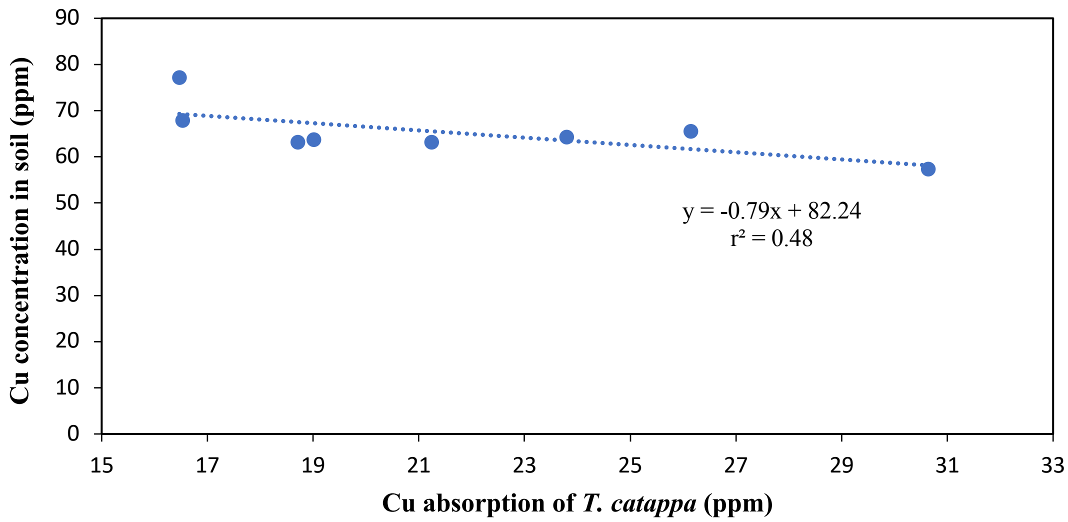

Fig. 2. Relationship between Cu absorption (root and shoot) of eight *T. catappa* and soil Cu concentration.

3.4. Regression Analysis for Ni Absorption

Fig. 3 summarizes the results of determining the influence of *T. catappa* on the presence of Ni in the soil of Langihan Lagoon. The results of the study show that there is no significant relationship between the Ni concentration in soil and absorption of *T. catappa* with a p-value of 0.79, intercept estimate of 242.41, r^2 of 0.012 and a predictor variable of -1.26. The result was supported by the study of Dube et al. (2019), who examined the difference of heavy metals, including Ni in a tropical reservoir by the species *Typha domingensis* and highlighted the influence of numerous factors on the uptake of heavy metals in plant tissues like metal availability, environmental conditions, and plant type. Furthermore, the study also emphasizes that the multiple factors should also be considered, suggesting the need for broader data to better understand the acquisition of Ni in the environment.

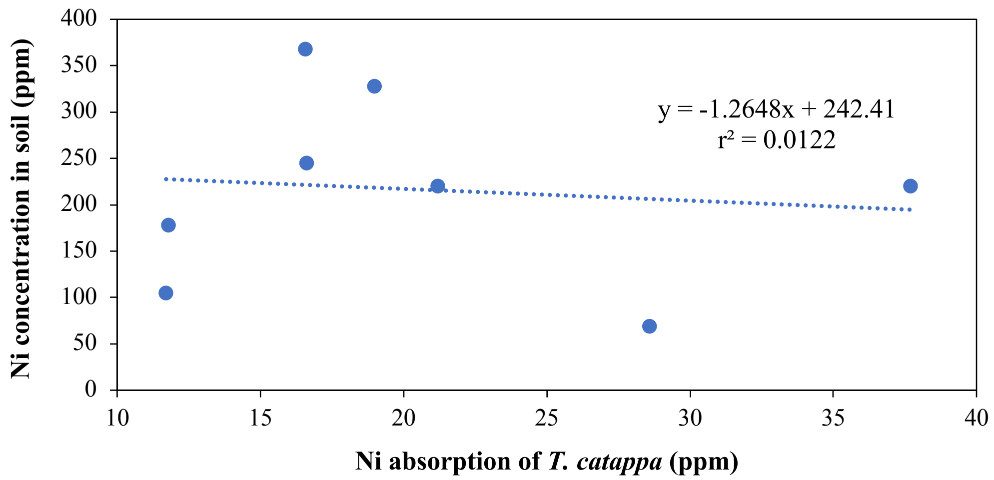

Fig. 3. Relationship between Ni absorption (root and shoot) of eight *T. catappa* and soil Ni concentration.

3.5. Regression Analysis for Cr Absorption

Fig. 4 provides the model for determining the relationship of Cr absorption of *T. catappa* to the presence of heavy metals in the soil. The results of the study also show that there is no significant relationship between Cr concentration in soil and absorption of *T. catappa* with a p-value of 0.83, intercept estimate of 144, r^2 of 0.0084 and a predictor variable of 1.71. Based on the p-value, the results also show that the absorption of Cr of *T. catappa* in the soil was not statistically significant. The significance of regression analysis has been brought to the attention of heavy metals regression researchers around the world. According to several studies (Kooh et al. 2018; Sarkar and Majumdar 2011), among the methods used in optimizing the phytoremediation process is regression modeling. The results could provide a framework for studying how *T. catappa* could affect the amount of Cr in the soil. Furthermore, this underlines the need to explore further the possible factors that affect heavy metal absorption by plants.

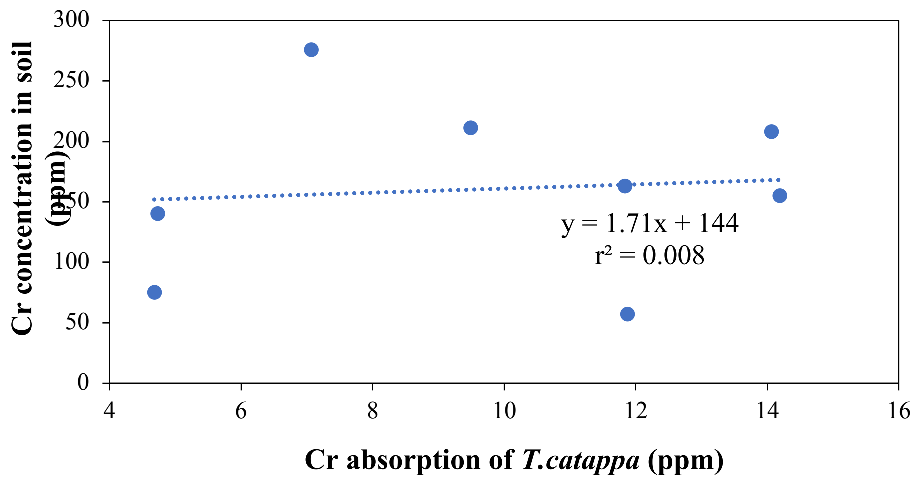

Fig. 4. Relationship between Cr absorption (root and shoot) of eight *T. catappa* and soil Cr concentration.

4. Conclusions

The study shows that *T. catappa* is a potential hyperaccumulator for Ni and Cu based on TF value > 1 and a potential excluder for Cr where TF value < 1. Based on regression analysis the total absorption of Ni, Cu, and Cr by *T. catappa* shows no correlation and no statistically significant impact on the presence and concentration of heavy metals in the soil ($r^2 < 0.5$). This may be because of the few tree samples in the study and the environmental factors. Also, these findings emphasize the complexity of heavy metal absorption, indicating that factors beyond *T. catappa* influence soil metal concentrations. *T. catappa* shows potential for hyperaccumulation based on its ability to translocate metals to its shoots, but it may not be effective in overall accumulation and soil uptake. Further research is needed to comprehensively understand the mechanisms involved, considering metal availability, as well as comparing with other known hyperaccumulators would be beneficial to fully understand and leverage the *T. catappa* phytoremediation capabilities. More information from this will help explore the potential of tree species for phytoremediation.

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