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Yard phytoarchitecture for onsite sanitation of household wastewater containing copper

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ABSTRACT

Copper can be found in various equipment, building materials, and consumer products. When buildings are used, copper can enter wastewater in different ways. It is challenging for occupants to remove copper physically or chemically since they can potentially reduce copper levels through yard phytoarchitecture. This study aims to formulate houseplants' suitability to become decorative plants for the yard phytoarchitecture, simultaneously as onsite sanitation. This study identified the copper deconcentration pathway in wastewater by studying published works-based research. Literature was collected and selected based on recency, accessibility, and the relationship among copper, wastewater, and plants. The study findings show that processing copper by plant has the greatest opportunity to be implemented on a building scale. The yard phytoarchitecture system involves arranging plants in the yard, which serves both as a decorative feature and a way to treat the building's wastewater. It can be used on dry yards or ponds and only requires a small amount of land. The plants used should have low leaf density and high root density. It plays a dual role consisting of onsite sanitation infrastructure and yard aesthetics, which mutually strengthen the environmental health locally and positively effect on a larger scale.

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1. INTRODUCTION

Copper is one of the metals widely used for consumer and building infrastructure products. Indoor sources of copper are found in foodstuffs for a balanced diet without negative health effects [1]. Personal care products such as hair dye or shampoo can contain copper compounds [2] in everyday life. When washed down the drain, those personal care products contribute to copper content in wastewater over time. The activities exist in daily life, which create un-friendly environmental conditions. Therefore, processing copper initially helps over-accumulate copper concentration in a natural environment.

Meanwhile, copper materials are used for electrical and drinking water piping systems for building infrastructure. Physically, copper has a reddish-brown color and an attractive appearance. The color is a popular choice for the architectural decoration of buildings and household items, such as kitchenware and cookware. Copper alloys combine with zinc to create brass and tin to form bronze chemically [3], all of which result in valuable products, including championship trophy materials. Microbiologically, copper is toxic to microbes, which makes it a natural disinfectant. This antimicrobial property has made copper used in buildings for protection against microbial infections [4]. Buildings and equipment that use copper materials can experience deterioration in the long run. Copper particles can be released as these products age, degrade, and wash into the wastewater during cleaning activities. In addition, corrosion, or small leaks in copper piping systems, can release copper particles into the wastewater.

Copper is one of heavy metals' most common environmental pollutants [5]. The average concentration of copper in domestic wastewater is around 2.0 mg/L [6] and can be more or less depending on the socio-cultural aspects of the population of an area. The presence of copper in domestic wastewater is of concern because of its potential environmental impact. In high concentrations, copper can be toxic to aquatic organisms [7], especially fish and other sensitive species. As a result, copper can interfere with wastewater treatment processes, affecting the performance of microbial treatment systems.

Communities may have limitations in the chemical processing of copper, while microbial processing is unsuitable because copper is a disinfectant. Plants are a promising possibility in copper removal because copper is a micronutrient that plants need [8]. Likewise, it is easier for many people to prepare plants and maintain their lives than to provide chemical processing. Thus, attention to the copper content in the domestic wastewater of a building directs the need for a phytotreatment that is easy to operate and affordable by the community. Since plants need sufficient space for their lives and consider wastewater disposal, it is considered feasible for the application of yard phytoarchitecture.

Yard phytoarchitecture is an extension of the indoor phytoarchitecture of a building [9]. The two phytoarchitectures have the same function but differ in the placement of decorative plants. The similarity of functions is for the comfort, health of the occupants through the provision and arrangement of decorative plants [10]. The yard phytoarchitecture can also be developed for wastewater treatment of a building as an onsite sanitation system. Furthermore, the simultaneous mechanisms, which serve both as decorative plants and for domestic wastewater treatment, also contribute to the functioning of the yard phytoarchitecture, making it the ideal choice for developing high-rise and domestic buildings.

Therefore, this paper aims to configure a yard phytoarchitecture removing copper in domestic wastewater employing aquatic and terrestrial plants. The physical attributes of leaves and roots show the unique traits of different types of plants. Determining where to plant them in a yard is important for practical purposes. Additionally, the organic matter quality is functioning as a limiting factor of application. The suitability of plants is based on the leaf and root morphology, placement in the yard, and the quality of organic matter in domestic wastewater.

2. RESEARCH METHOD

The source, generation, and processing of copper in wastewater are identified based on copper's physical and chemical properties, as depicted in Figure 1. Those describe the steps to handle copper in wastewater properly. As a result, a pathway for reducing copper levels is created to meet landscaping needs.

Literature research used Harzing's Publish or Perish 8 software. The PubMed and Crossref platforms were used to collect topics related to copper and plants and used the title words and keywords "copper" and "plants" for the last ten years of publication. Additional literature beyond these sources is needed for issues that are relevant and important in confirming the clarity of a problem. In addition, journal articles are the majority of articles taken as priority studies. Selection screening includes ease of access and publications that are twenty years old. This additional literature comes from reputable journals that can be accessed through the Google search engine. All types of literature are in English and openly accessible.

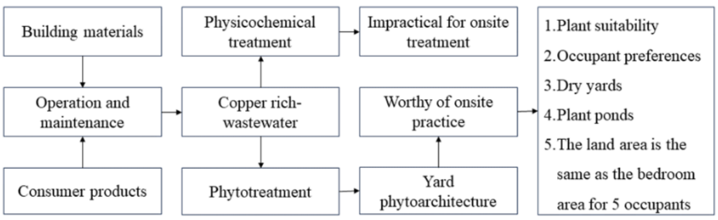

Figure 1. Copper deconcentration pathway in household wastewater

3. RESULTS AND DISCUSSION

Copper is a chemical element that is generally insoluble in water. Pure copper (Cu), copper oxide (CuO), or copper sulfide (CuS) tend to be difficult to dissolve in water [11]. Several technical methods can be used for copper removal [12] depending on the initial concentration of copper and the quantity of wastewater. Proper wastewater characterization and an understanding of local environmental regulations are essential for selecting the most suitable copper removal treatment method [13]. In practice, several methods are carried out, considering the presence of other pollutants that influence copper concentrations.

3.1. Removal potential

Physical methods using membrane filtration [14], such as reverse osmosis [15] and nanofiltration [16], [17], can effectively remove copper ions from water the method is by passing water through a semipermeable membrane that retains copper ions while allowing clean water to pass through. Another method is electrowinning [18], an electrolytic process in which copper ions are reduced and deposited onto the cathode. This method often recovers copper from highly concentrated copper solutions, such as in mining operations.

The chemical method involves adding chemicals to wastewater to form copper compounds, which are insoluble and precipitate as solids. Chemicals commonly used for precipitation include lime [19], [20] as calcium hydroxide, sodium hydroxide, and sodium carbonate. Ion exchange is a process in which copper ions are exchanged with other ions on the surface of a solid resin material [21]. In comparison, adsorption attaches copper ions to the surface of adsorbent materials, such as activated carbon or zeolite [22]. Both methods are effective for processing low to medium concentrations of copper.

Biological treatments can also be carried out using the ability of microorganisms to accumulate or absorb copper ions from water [23]. Biological treatment can be used to exploit the properties of certain microbes to remove copper from wastewater. Microbial treatments can extract or recover copper from ores, waste materials, or industrial processes. This method, known as bioleaching [24] or biomining, is an environmentally friendly alternative to traditional copper extraction techniques such as smelting or roasting. The selection of microorganisms generally uses certain types of bacteria, archaea, or fungi because of their ability to interact with copper ore. Microorganisms acidithiobacillus ferrooxidans (23) are the most commonly used microorganisms, which oxidize metal sulfides to soluble metal sulfates.

Copper is an essential plant micronutrient, meaning copper is needed in small amounts for proper growth and development [25]. Copper is important in various physiological processes [26], such as photosynthesis, respiration, and enzyme activation. However, like many other essential elements, copper can be toxic to plants [27] in excessive amounts in the growing medium. The need for copper and its limitations for living plants opens up opportunities for copper removal using phytotreatment as the development of biological treatment.

3.2. Onsite phytodetoxification

Wastewater treatment can incorporate several processes to remove copper from wastewater before it is released into the environment. Individuals and communities need to be aware of potential sources of copper in domestic wastewater and take appropriate actions to reduce their impact on the environment. An effective copper removal can be initiated at the source of its generation in each building [28], known as an onsite treatment [29].

When conditions permit, the onsite copper removal approach allows wastewater effluent to be channeled into local soil recharge [30]. In addition, the effluent can be channeled into the wastewater sewerage system for further centralized treatment. If effluent meets water quality standards, it can be discharged into receiving water bodies [31]. Wherever the effluent is disposed of, the quality of the effluent is not toxic to the biota. Thus, the purpose of onsite treatment is none other than to detoxify copper-containing wastewater.

Several plant species can accumulate copper without being significantly affected by its toxicity, known as hyperaccumulators. Examples of copper-processing aquatic plants in constructed wetlands for a maximum processing contact time of three days include eichhornia crassipes, commonly known as water hyacinth. For an initial Cu concentration of 4 mg/L, a significant reduction in Cu concentration was achieved after the 24 h period [32]. The aquatic plant *Desmostachya bipinnata*, commonly known as big cordgrass, reduced the concentration of Cu from 14.1 mg/L to 1.3 mg/L in 24 h of contact [33]. The aquatic *Pistia stratiotes*, commonly called water lettuce, reduced about 1 mg/L Cu over a 24 h holding time [34]. Meanwhile, examples of terrestrial plants capable of processing copper include Indian mustard *(brassica juncea)* [35], amaranth *(amaranthus paniculatus)*, and sunflower *(helianthus annuus)* [36].

The success of copper removal for reduction in a short time can be applied to onsite phytodetoxification. The short processing time is a limit to the implementation of the onsite system by considering the limited area of a house's yard. Regarding wastewater quantity, in typical tropical conditions, each person produces a maximum of 0.2 m3/d [37]. A well-known aquatic plant capable of treating wastewater, *Salvinia molesta* can respond to pollutants within 24 hours of contact time [38], and the pond depth is 0.5 m. The land area needed for processing is around 0.4 m2/person. With the additional space for operation and maintenance and the possibility of using a combination of terrestrial plants around the ponds, the total land area required to place the plants is approximately 1.0 m2/person. For five people per household, the copper processing area is roughly the size of a bedroom. Thus, onsite copper phytodetoxification is considered feasible and promising for its application.

Plant removal of copper is a natural and environmentally friendly method of reducing copper levels in wastewater [39]. Socially, houseplants have become a habit of being in yards and fences for various purposes such as aesthetics, thermal comfort, and land boundaries [40]. Regarding procuring new plants, they are generally affordable for the community and have regenerative capabilities to minimize operating and maintenance costs. Thus, using houseplants for copper phytodetoxification fulfills the three pillars of the sustainable development goals (SDGs) 2030.

3.3. Suitable plant selection

Due to its antimicrobial properties, copper is sometimes used in disinfectant aerosols and other disinfection products. When applied to surfaces, it can help kill or inhibit the growth of microorganisms, including bacteria and viruses. However, copper is not typically used in its elemental form in these products [41]; instead, copper compounds or ions may be used. Accordingly, copper is not easy to transport in the air, which cannot be appeared in ambient air [42]. Therefore, the mechanism of copper removal through aerial plant parts, the so-called phylloremediation, is conditional.

The unsuitability of copper phylloremediation directs the selection of plants with low leaf density. Houseplants with low leaf density have relatively sparse foliage or fewer leaves per unit of space [43]. These plants can be an interesting addition to a garden, creating a more open and airy feel. Some houseplants with low leaf density are as follows.

Snake plant *(sansevieria)* is known for their upright, sword-like leaves spaced apart [44]. The plant is excellent for low-light conditions. Ponytail palm *(beaucarnea recurvata)* has a unique, bulbous trunk and long, slender leaves that grow from the top, giving it a low leaf density. Succulents have many varieties, like *echeveria* and *haworthia*, and have compact rosettes of leaves with space in between [45]. Plant *dracaena marginata* has long, thin leaves that are sparsely arranged along the stem, creating an elegant look [46]. Air plants *(tillandsia)* are known for their minimal root system and the fact that they do not need soil [47]. They have slender, often curly leaves and can be displayed creatively. Madagascar dragon tree *(dracaena marginata)* has thin, arching leaves that give it a low-density appearance [48]. Aloe plants have thick, fleshy leaves with some spacing between them [49]. They are also easy to care for. Cacti have sparse, prickly foliage, allowing them to thrive in arid conditions [50]. Burro's tail *(sedum morganianum)* has trailing stems adorned with small, fleshy leaves, giving it a unique look [51]. When choosing houseplants [52] with low leaf density, consider the light conditions in a building environment. Some plants are great for low-light areas, while others require more sunlight. In addition, plants with sparse foliage may need less frequent watering than those with dense leaves.

Certain copper compounds, such as copper sulfate (CuSO4) and copper chloride (CuCl2), can still interact with water and dissolve under acidic conditions [53]. These copper compounds can be removed through the absorption process through plant roots [54]. Therefore, the removal of copper by plants depends on the rhizosphere processing capabilities of aquatic or terrestrial plants or a combination of both.

The suitability of copper removal through rhizosphere processing directs the selection of plants that can immobilize copper in the root zone. Therefore, high root-density plants should be selected to capture as much copper as possible. Plants with high root density typically have an extensive and densely packed root system in the soil [55]. This characteristic can provide several advantages for the plant, such as improved nutrient and water uptake, better stability, and competition with neighboring plants. Some examples of plants with high root density are as follows.

Grasses, including turf and prairie grasses, often have high root density [56]. Their dense root systems help them capture nutrients and water efficiently, making them resilient in various ecosystems. Many fibrous root plants have fibrous root systems, such as most herbaceous annuals and perennials, with high root density [57]. These roots are fine and branching, allowing effective nutrient and water absorption. Sedges are a type of grass-like plant with high root density [58]. They are commonly found in wetland environments and suitable for wastewater treatment. Clover plants are known for fixing nitrogen in the soil, have a dense root system, and can stabilize cadmium [59]. Bamboo is a fast-growing plant with a high root density [60]. Its dense root network helps it grow rapidly and makes it an excellent choice for soil stability. Vetiver grass is often used for soil stability, land remediation, and wastewater treatment because of its dense and deeply penetrating root system [61]. Some coniferous trees, like pines and spruces, have relatively high root density [62]. Their extensive root systems can help them access water and chemicals from a wide area.

Copper removal's specific mechanisms and effectiveness may vary among plant species, and some plants are more tolerant to copper than others [63]. Soil conditions, copper concentrations [64], and the plant's overall health also affect how plants cope with copper toxicity [65]. In yard settings, it is often more practical to manage copper toxicity through soil amendments using compost, crop rotation, or copper-tolerant plant varieties [66] rather than relying solely on a plant's natural mechanisms for copper detoxification [67]. Also, maintaining proper soil pH and avoiding excessive copper applications can help prevent plant toxicity.

4. CONCLUSION

In operations, household equipment and materials can enrich wastewater pollutants. An approach to reducing environmental pollution, which occupants can carry out, is onsite sanitation using a yard phytoarchitecture system. Yard phytoarchitecture can take the form of planting plants in a dry yard or a plant pond, whatever allows its application on site. Plants that are suitable for this purpose are those that have the characteristics of low leaf density and high root density. Wastewater that has undergone plant processing can be infiltrated into local soil safely. While the local soil can absorb wastewater effluent less, the effluent can be channeled safely to existing wastewater drainage facilities. Various houseplants are recommended to beautify the yard environment according to the occupants' preferences. This yard phytoarchitecture adds value to environmental security protection and positively impacting a wider scale. In addition, the yard phytoarchitecture opens an opportunity to be developed technically, sociologically, and regulatory to elevate its value in a community.

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