

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/379537888>

# Yard phytoarchitecture for onsite sanitation of household wastewater containing copper

Article in *International Journal of Advances in Applied Sciences* · June 2024

DOI: 10.11591/ijaas.v13.i2.pp291-297

---

CITATIONS

0

---

READS

44

3 authors:



**Ganjar Samudro**

Universitas Diponegoro

66 PUBLICATIONS 559 CITATIONS

SEE PROFILE



**Harida Samudro**

Universitas Islam Negeri Maulana Malik Ibrahim Malang

24 PUBLICATIONS 111 CITATIONS

SEE PROFILE



**Sarwoko Mangkoedihardjo**

Institut Teknologi Sepuluh Nopember

125 PUBLICATIONS 1,000 CITATIONS

SEE PROFILE

# Yard phytoarchitecture for onsite sanitation of household wastewater containing copper

Ganjar Samudro<sup>1</sup>, Harida Samudro<sup>2</sup>, Sarwoko Mangkoedihardjo<sup>3</sup>

<sup>1</sup>Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia

<sup>2</sup>Department of Architecture, Faculty of Science and Technology, State Islamic University of Malang, Malang, Indonesia

<sup>3</sup>Department of Environmental Engineering, Faculty of Civil, Planning, and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

## Article Info

### Article history:

Received Oct 14, 2023

Revised Dec 22, 2023

Accepted Feb 28, 2024

### Keywords:

Aesthetics

Construction materials

Copper

Plants

Ponds

Sanitation

Wastewater

## 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.

*This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.*



## Corresponding Author:

Ganjar Samudro

Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro

Prof. Sudarto, S.H. Street, Tembalang, Semarang 50275, Indonesia

Email: ganjarsamudro@live.undip.ac.id

## 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.

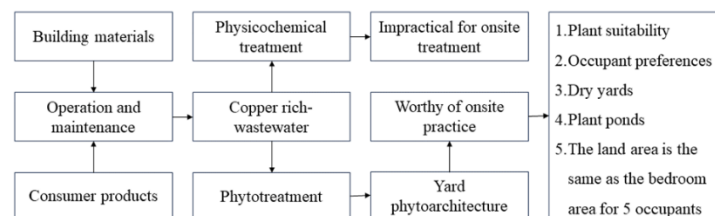


Figure 1. Copper deconcentration pathway in household wastewater

## 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 m<sup>3</sup>/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 m<sup>2</sup>/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 m<sup>2</sup>/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 (CuSO<sub>4</sub>) and copper chloride (CuCl<sub>2</sub>), 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.

#### ACKNOWLEDGEMENTS

The authors would like to thank Universitas Diponegoro, Semarang; Universitas Islam Negeri Maulana Malik Ibrahim, Malang; Institut Teknologi Sepuluh Nopember, Surabaya, for providing facilities to carry out this work.

#### REFERENCES




- [1] N. N. I. of Health, "Copper: fact sheet for health professionals," *Office of Dietary Supplements*, 2022, [Online]. Available: <https://ods.od.nih.gov/factsheets/Copper-HealthProfessional/>
- [2] N. Madnani and K. Khan, "Hair cosmetics," *Indian Journal of Dermatology, Venereology, and Leprology*, vol. 79, no. 5, p. 654, 2013, doi: 10.4103/0378-6323.116734.
- [3] A. G. Nord, I. Ullén, and K. Tronner, "Analysis of copper-alloy artefacts from the viking age," *Journal of Nordic Archaeological Science*, vol. 19, pp. 21–30, 2020.
- [4] J. Abraham, K. Dowling, and S. Florentine, "Can copper products and surfaces reduce the spread of infectious microorganisms and hospital-acquired infections?," *Materials*, vol. 14, no. 13, pp. 1–27, Jun. 2021, doi: 10.3390/ma14133444.
- [5] A. M. Elkhataf *et al.*, "Recent trends of copper detection in water samples," *Bulletin of the National Research Centre*, vol. 45, no. 218, pp. 1–18, Dec. 2021, doi: 10.1186/s42269-021-00677-w.
- [6] I. M. Hassana, B. A. Omotayo, I. M. Hassana, and B. A. Omotayo, "Heavy metals accumulation in edible part of vegetables irrigated with untreated municipal wastewater in tropical savannah zone, nigeria," *African Journal of Environmental Science and Technology*, vol. 8, no. 8, pp. 460–463, Aug. 2014, doi: 10.5897/AJEST2013.1531.
- [7] P. P. Leal *et al.*, "Copper pollution exacerbates the effects of ocean acidification and warming on kelp microscopic early life stages," *Scientific Reports*, vol. 8, no. 14763, pp. 1–13, Oct. 2018, doi: 10.1038/s41598-018-32899-w.
- [8] R. A. Wuana and F. E. Okieimen, "Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation," *ISRN Ecology*, vol. 2011, pp. 1–20, Oct. 2011, doi: 10.5402/2011/402647.
- [9] H. Samudro, S. Ganjar, and S. Mangkoedihardjo, "Overview of indoor plants: phytoarchitecture as a building health platform," *Journal of Design and Built Environment*, vol. 22, no. 3, pp. 69–87, Dec. 2022, doi: 10.22452/jdbe.vol22no3.5.
- [10] H. Samudro, G. Samudro, and S. Mangkoedihardjo, "Retrospective study on indoor bioaerosol - prospective improvements to architectural criteria in building design," *Israa University Journal for Applied Science*, vol. 6, no. 1, pp. 23–41, Oct. 2022, doi: 10.52865/LSBY9811.
- [11] R. Sekine *et al.*, "Aging of dissolved copper and copper-based nanoparticles in five different soils: short-term kinetics vs. long-term fate," *Journal of Environmental Quality*, vol. 46, no. 6, pp. 1198–1205, Nov. 2017, doi: 10.2134/jeq2016.12.0485.
- [12] S. Maiti, B. Prasad, and A. K. Minocha, "Optimization of copper removal from wastewater by fly ash using central composite design of response surface methodology," *SN Applied Sciences*, vol. 2, no. 12, p. 2151, Dec. 2020, doi: 10.1007/s42452-020-03892-8.
- [13] N. A. A. Qasem, R. H. Mohammed, and D. U. Lawal, "Removal of heavy metal ions from wastewater: a comprehensive and critical review," *npj Clean Water*, vol. 4, no. 36, pp. 1–13, Jul. 2021, doi: 10.1038/s41545-021-00127-0.
- [14] Y. Liu, H. Wang, Y. Cui, and N. Chen, "Removal of copper ions from wastewater: a review," *International Journal of Environmental Research and Public Health*, vol. 20, no. 5, p. 3885, Feb. 2023, doi: 10.3390/ijerph20053885.
- [15] R. H. Harharah, G. M. T. Abdalla, A. Elkhaleefa, I. Shigidi, and H. N. Harharah, "A study of copper (ii) ions removal by reverse osmosis under various operating conditions," *Separations*, vol. 9, no. 6, p. 155, Jun. 2022, doi: 10.3390/separations9060155.
- [16] J. Zheng *et al.*, "Selective removal of heavy metals from saline water by nanofiltration," *Desalination*, vol. 525, p. 115380, Mar. 2022, doi: 10.1016/j.desal.2021.115380.
- [17] I. Trus, M. Gomelya, V. Vorobyova, and M. Skiba, "Effectiveness of complexation-nanofiltration during water purification from copper ions," *Journal of Chemical Technology and Metallurgy*, vol. 56, no. 5, pp. 1008–1015, 2021.
- [18] S. H. Sadrabadi, H. Naderi, H. R. Zare, and S. M. Moshtaghion, "Removal of copper ions from dilute sulfuric acid solutions: effect of solution composition and applied potential," *International Journal of Mining and Geo-Engineering*, vol. 56, no. 3, pp. 239–247, 2022, doi: 10.22059/IJMG.2022.329665.594927.
- [19] X. Zhang *et al.*, "A study on the removal of copper (ii) from aqueous solution using lime sand bricks," *Applied Sciences*

- (Switzerland), vol. 9, no. 4, 2019, doi: 10.3390/app9040670.
- [20] E. Balladares *et al.*, "Neutralization and co-precipitation of heavy metals by lime addition to effluent from acid plant in a copper smelter," *Minerals Engineering*, vol. 122, pp. 122–129, 2018, doi: 10.1016/j.mineng.2018.03.028.
- [21] F. L. Aranda, A. Gayoso, V. Palma-Onetto, and B. L. Rivas, "Removal of copper ions from aqueous solutions by using resins from pinus radiata bark resins," *Journal of the Chilean Chemical Society*, vol. 67, no. 1, pp. 5403–5407, 2022, doi: 10.4067/S0717-97072022000105403.
- [22] G. Buema, L. M. Trifas, and M. Harja, "Removal of toxic copper ion from aqueous media by adsorption on fly ash-derived zeolites: kinetic and equilibrium studies," *Polymers*, vol. 13, no. 20, 2021, doi: 10.3390/polym13203468.
- [23] L. Dusengemungu, G. Kasali, C. Gwanama, and K. O. Ouma, "Recent advances in biosorption of copper and cobalt by filamentous fungi," *Frontiers in Microbiology*, vol. 11, Dec. 2020, doi: 10.3389/fmicb.2020.582016.
- [24] Y. Jia, H. Sun, Q. Tan, J. Xu, X. Feng, and R. Ruan, "Industrial heap bioleaching of copper sulfide ore started with only water irrigation," *Minerals*, vol. 11, no. 11, 2021, doi: 10.3390/min11111299.
- [25] M. T. Lafuente, R. Sampedro, D. Vélez, and P. Romero, "Deficient copper availability on organoleptic and nutritional quality of tomato fruit," *Plant Science*, vol. 326, 2023, doi: 10.1016/j.plantsci.2022.111537.
- [26] G. Chen, J. Li, H. Han, R. Du, and X. Wang, "Physiological and molecular mechanisms of plant responses to copper stress," *International Journal of Molecular Sciences*, vol. 23, no. 21, 2022, doi: 10.3390/ijms232112950.
- [27] A. R. Mir, J. Pichtel, and S. Hayat, "Copper: uptake, toxicity and tolerance in plants and management of cu-contaminated soil," *BioMetals*, vol. 34, no. 4, pp. 737–759, 2021, doi: 10.1007/s10534-021-00306-z.
- [28] A. Sedayu and S. Mangkoedihardjo, "Performance evaluation of housing contractor by applying the principles of environmentally friendly infrastructure," *International Journal of Civil Engineering and Technology*, vol. 9, no. 4, pp. 1014–1022, 2018.
- [29] H. Samudro, G. Samudro, and S. Mangkoedihardjo, "Phytoarchitecture integrates hybrid onsite phytosanitation to suppress building environmental pollution," *Pollution*, vol. 9, no. 3, pp. 1174–1189, 2023, doi: 10.22059/POLL.2023.353062.1735.
- [30] M. Shawaqfah, F. Almomani, and T. Al-Rousan, "Potential use of treated wastewater as groundwater recharge using gis techniques and modeling tools in dhuleil-halabat well-field/jordan," *Water (Switzerland)*, vol. 13, no. 11, 2021, doi: 10.3390/w13111581.
- [31] L. Yang, J. Wei, J. Qi, and M. Zhang, "Effect of sewage treatment plant effluent on water quality of zhangze reservoir based on edfc model," *Frontiers in Environmental Science*, vol. 10, 2022, doi: 10.3389/fenvs.2022.874502.
- [32] C. R. Palihakkara, S. Dassanayake, C. Jayawardena, and I. P. Senanayake, "Floating wetland treatment of acid mine drainage using eichhornia crassipes (water hyacinth)," *Journal of Health and Pollution*, vol. 8, no. 17, pp. 14–19, 2018, doi: 10.5696/2156-9614-8.17.14.
- [33] A. S. Sheoran, "Management of acidic mine waste water by constructed wetland treatment systems: a bench scale study," *European Journal of Sustainable Development*, vol. 6, no. 2, 2017, doi: 10.14207/ejsd.2017.v6n2p245.
- [34] V. Z. Novita, S. S. Moersidik, and C. R. Priadi, "Phytoremediation potential of pistia stratiotes to reduce high concentration of copper (cu) in acid mine drainage," *IOP Conference Series: Earth and Environmental Science*, vol. 355, no. 1, 2019, doi: 10.1088/1755-1315/355/1/012063.
- [35] M. Narasimha and H. Oliveira, "Metal hyperaccumulation in plants - biodiversity prospecting for phytoremediation technology," *Electronic Journal of Biotechnology*, vol. 6, no. 3, pp. 285–321, 2003.
- [36] M. M. Rahman, S. M. Azirun, and A. N. Boyce, "Enhanced accumulation of copper and lead in amaranth (*amaranthus paniculatus*), indian mustard (*brassica juncea*) and sunflower (*helianthus annuus*)," *PLoS ONE*, vol. 8, no. 5, 2013, doi: 10.1371/journal.pone.0062941.
- [37] S. Datta, I. H. Mafat, and R. Saxena, "Sensitivity analysis of water wastage in indian households," *Materials Today: Proceedings*, vol. 77, pp. 111–116, 2023, doi: 10.1016/j.matpr.2022.10.144.
- [38] H. M. Mustafa and G. Hayder, "Cultivation of s. molesta plants for phytoremediation of secondary treated domestic wastewater," *Ain Shams Engineering Journal*, vol. 12, no. 3, pp. 2585–2592, 2021, doi: 10.1016/j.asej.2020.11.028.
- [39] N. Politaeva and V. Badenko, "Magnetic and electric field accelerate phytoextraction of copper lemma minor duckweed," *PLoS ONE*, vol. 16, no. 8 August, 2021, doi: 10.1371/journal.pone.0255512.
- [40] H. Kotta, S. Mangkoedihardjo, Y. Ludang, and S. Trisutomo, "The design of riparian zone in waterfront area of tanjung bunga, makassar," *International Journal of Civil Engineering and Technology*, vol. 9, no. 8, pp. 580–584, 2018.
- [41] A. Fateh, M. Aliokhazraei, and A. R. Rezvanian, "Review of corrosive environments for copper and its corrosion inhibitors," *Arabian Journal of Chemistry*, vol. 13, no. 1, pp. 481–544, 2020, doi: 10.1016/j.arabjc.2017.05.021.
- [42] I. B. Santoso and S. Mangkoedihardjo, "Mapping cumulative carbon dioxide concentrations at two meters above the ground for greenspace assessment in surabaya," *Middle East Journal of Scientific Research*, vol. 18, no. 3, pp. 288–292, 2013, doi: 10.5829/idosi.mejsr.2013.18.3.12472.
- [43] J. A. Postma, V. L. Hecht, K. Hikosaka, E. A. Nord, T. L. Pons, and H. Poorter, "Dividing the pie: a quantitative review on plant density responses," *Plant Cell and Environment*, vol. 44, no. 4, pp. 1072–1094, 2021, doi: 10.1111/pce.13968.
- [44] M. Willburn, *Tropical plants and how to love them: building a relationship with heat-loving plants when you don't live in the tropics - angel's trumpets - ... - gingers - hibiscus - canna lilies and more!* Cool Springs Press, 2021.
- [45] R. A. M. Cabahug, S. Y. Nam, K.-B. Lim, J. K. Jeon, and Y.-J. Hwang, "Propagation techniques for ornamental succulents," *Flower Research Journal*, vol. 26, no. 3, pp. 90–101, 2018, doi: 10.11623/frj.2018.26.3.02.
- [46] P. Maurya *et al.*, "Influence of season, indole 3-butyric acid and media on rooting and success of single leaf- bud cutting of lemon (*citrus limon burm.*) in bihar," *Scientist (Philadelphia, Pa.)*, vol. 1, no. 3, pp. 459–469, 2022.
- [47] A. K. Eskov, V. A. Viktorova, E. Abakumov, and G. Zotz, "Cellular growth in aerial roots differs from that in typical substrate roots," *Frontiers in Plant Science*, vol. 13, 2022, doi: 10.3389/fpls.2022.894647.
- [48] CABI, "Dracaena marginata (madagascar dragon tree)," *CABI Compendium*, 2019, doi: 10.1079/cabicompendium.19902.
- [49] E. V. Christaki and P. C. Florou-Paneri, "Aloe vera: a plant for many uses," *Journal of Food, Agriculture and Environment*, vol. 8, no. 2, pp. 245–249, 2010.
- [50] A. A. Isaac, "Overview of cactus (*opuntia ficus-indica* (l)): a myriad of alternatives," *Studies on Ethno-Medicine*, vol. 10, no. 2, pp. 195–205, 2016, doi: 10.1080/09735070.2016.11905488.
- [51] M. Cristini, "Sedum morganianum," *The Cactus Explorer*, vol. 15, pp. 48–60, 2016.
- [52] H. Samudro, G. Samudro, and S. Mangkoedihardjo, "Prevention of indoor air pollution through design and construction certification: a review of the sick building syndrome conditions," *Journal of Air Pollution and Health*, vol. 7, no. 1, pp. 81–94, 2022, doi: 10.18502/japh.v7i1.8922.
- [53] J. M. Casas, F. Alvarez, and L. Cifuentes, "Aqueous speciation of sulfuric acid-cupric sulfate solutions," *Chemical Engineering Science*, vol. 55, no. 24, pp. 6223–6234, 2000, doi: 10.1016/S0009-2509(00)00421-8.




- [54] V. Kumar *et al.*, “Copper bioavailability, uptake, toxicity and tolerance in plants: a comprehensive review,” *Chemosphere*, vol. 262, 2021, doi: 10.1016/j.chemosphere.2020.127810.
- [55] J. Correa, J. A. Postma, M. Watt, and T. Wojciechowski, “Soil compaction and the architectural plasticity of root systems,” *Journal of Experimental Botany*, vol. 70, no. 21, pp. 6019–6034, 2019, doi: 10.1093/jxb/erz383.
- [56] Roger C. Anderson, “Evolution and origin of the central grassland of north america: climate, fire, and mammalian grazers,” *Journal of the Torrey Botanical Society*, vol. 133, no. 4, pp. 626–647, 2006.
- [57] W. Vannoppen, S. D. Baets, J. Keeble, Y. Dong, and J. Poesen, “How do root and soil characteristics affect the erosion-reducing potential of plant species?,” *Ecological Engineering*, vol. 109, pp. 186–195, 2017, doi: 10.1016/j.ecoleng.2017.08.001.
- [58] R. L. Barrett, “Ecological importance of sedges: a survey of the australasian cyperaceae genus lepidosperma,” *Annals of Botany*, vol. 111, no. 4, pp. 499–529, 2013, doi: 10.1093/aob/mct008.
- [59] E. Benyas, J. Owens, S. Seyedalikhani, and B. Robinson, “Cadmium uptake by ryegrass and ryegrass–clover mixtures under different liming rates,” *Journal of Environmental Quality*, vol. 47, no. 5, pp. 1249–1257, 2018, doi: 10.2134/jeq2018.01.0015.
- [60] A. Emamverdian, Y. Ding, F. Ranaei, and Z. Ahmad, “Application of bamboo plants in nine aspects,” *Scientific World Journal*, vol. 2020, 2020, doi: 10.1155/2020/7284203.
- [61] U. Leknoi and S. Likitlersuang, “Good practice and lesson learned in promoting vetiver as solution for slope stabilisation and erosion control in thailand,” *Land Use Policy*, vol. 99, 2020, doi: 10.1016/j.landusepol.2020.105008.
- [62] V. Gryc, H. Vavrčik, and K. Horn, “Density of juvenile and mature wood of selected coniferous species,” *Journal of Forest Science*, vol. 57, no. 3, pp. 123–130, 2011, doi: 10.17221/18/2010-jfs.
- [63] N. Novello *et al.*, “Independent variation in copper tolerance and copper accumulation among crop species and varieties,” *Plant Physiology and Biochemistry*, vol. 156, pp. 538–551, 2020, doi: 10.1016/j.plaphy.2020.09.039.
- [64] F. Pietrini, M. Carnevale, C. Beni, M. Zacchini, F. Gallucci, and E. Santangelo, “Effect of different copper levels on growth and morpho-physiological parameters in giant reed (*arundo donax* L.) in semi-hydroponic mesocosm experiment,” *Water (Switzerland)*, vol. 11, no. 9, 2019, doi: 10.3390/w11091837.
- [65] A. Wairich *et al.*, “Throwing copper around: how plants control uptake, distribution, and accumulation of copper,” *Agronomy*, vol. 12, no. 5, 2022, doi: 10.3390/agronomy12050994.
- [66] H. Amin *et al.*, “Copper (cu) tolerance and accumulation potential in four native plant species: a comparative study for effective phytoextraction technique,” *Geology, Ecology, and Landscapes*, vol. 5, no. 1, pp. 53–64, 2021, doi: 10.1080/24749508.2019.1700671.
- [67] G. Zhang *et al.*, “Copper uptake, essentiality, toxicity, detoxification and risk assessment in soil-plant environment,” *Chemosphere*, vol. 1, no. 2, pp. 1–8, 2020.

## BIOGRAPHIES OF AUTHORS






**Ganjar Samudro**    is a lecturer and an assistant Professor in the Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia. He got his bachelor's and master's degrees in environmental engineering from Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia; doctor of philosophy, Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Japan. Currently, his research focuses on bioenergy and environmental sanitation ecotoxicology pertaining to his doctoral research in waste to energy. He can be contacted at email: ganjarsamudro@live.undip.ac.id.



**Harida Samudro**    is an architect and a lecturer at the Architecture Department Universitas Islam Negeri (UIN) Maulana Malik Ibrahim Malang, Indonesia. He got his bachelor's and master's degrees in Architecture from Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. Recently he focuses his research on architecture design and education. He can be contacted at email: haridasamudro@arch.uin-malang.ac.id.



**Sarwoko Mangkoedihardjo**    is a bachelor of sanitation engineering at the Institut Teknologi Bandung, Bandung, Indonesia; master of science with a specialization in environmental sanitation from State University of Ghent, Belgium; doctor of agricultural sciences, Universitas Brawijaya, Malang, Indonesia. During his career, he has deepened his expertise in environmental sanitation and phytotechnology, which includes: drinking water; sanitation for wastewater, solid waste and all related wastes; ecosystem management; biodiversity; waste energy; public health; and support for agricultural productivity. He can be contacted at email: prosarwoko@gmail.com.

*Yard phytoarchitecture for onsite sanitation of household wastewater containing copper (Ganjar Samudro)*