



Clogging of Substrate in Constructed Wetlands: Causes, Effects and Control Measures

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Abstract

The purpose of this review article is to present the primary factors that cause clogging of substrate in Constructed wetlands (CWs), as well as the consequences and possible solutions. A wide range of sources, including books, scholarly and internet articles, were used in the literature study. Substrate clogging is a major problem in CWs, which results in slowing down the flow of water and, finally, a significant reduction in the system's treating wastewater effectiveness. The deposition of suspended matter, the development of sludge, precipitation of chemicals and deposition inside the pore spaces, the growth of plant root systems, the production of gas, and the compaction of the clogging layer all contribute to this technical and operational challenge. Evaluating the extent of substrate clogging in CWs is a difficult task because this phenomenon is influenced by several factors. Clogging impact can be assessed using a variety of methods, including tracer testing, hydraulic conductivity measurements, and clogging matter characterization. A preventive or restorative strategy can be used to address this issue. Pre-treatment of wastewater, proper substrate and aquatic plant selection, earlier removal of leaves and dead roots, and backwashing are some of these strategies.

Keywords: Hydraulic efficiency pretreatment, influent, wastewater, constructed wetland,

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1. Introduction

The amount of waste generated keeps growing in lockstep with the world's population growth. One of the major concerns of governments is the

management of waste generated (Nayan et al., 2021). Roughly, 80 percent of wastewaters is directly discharged in to the waterbodies without even being treated or recycled. This is really a serious health risk as well as a threat to the ecosystem (Torrens et al., 2020). Pollutants removal from wastewaters has been accomplished using a number of strategies that can be classified as conventional or non-conventional. Mechanization is higher in conventional wastewater treatment methods than in non-conventional wastewater treatment methods. Pumping and power are usually required, as well as competent people for preservation and system processing (Fahad & Saphira Mohamed, 2019). Ion exchange, evaporation, chemical precipitation, membrane methods and carbon adsorption have all been reported to significantly work towards treatment of wastewater. These methods are either no longer capable of meeting today's stringent effluent regulations or are becoming increasingly expensive (Rajasulochana & Preethy, 2016). In light of the global water scarcity crises, non-traditional water resources must be considered in order to meet the growing demand for clean freshwater. Poor sanitation and hygiene conditions, as well as waste management and disposal techniques, can harm the public health and the environment (Almuktar et al., 2018). Constructed wetlands (CWs) are man-made features designed to treat wastewater using natural processes such as bacteria species, substrates and aquatic species. These are designed to mimic the same processes occurring in natural wetlands, but in a slightly more controlled context (Vymazal, 2010). CWs (Figure 1) are growingly being used to treat many different types of wastewaters, including domestic wastewater, industrial heavy oil-produced water and municipal in a sustainable, energy-efficient and cost-effective manner (Shui et al., 2013)(Varnell et al., 2009).



Figure 1: A constructed wetland in Dodoma, Tanzania

Many CWs have been reported as having serious clogging and flooding issues (El et al., 2021)(Pucher & Langergraber, 2019)(Phillips, 1997). Chemical, physical, or biological factors can cause CW clogging (shown in **Figure 2**). The physical process of introducing suspended particles into the CW system always results in a decrease in substrate porosity. A chemical process that produces insoluble salt precipitates contributes to CW blockage. Bacterial extracellular polymers accumulate in the CW, causing biological functions to be blocked (Wang et al., 2021). According to some research, the amount of wastewater solids that can accumulate on the CW substrate is determined by influent parameters and flow rate (De la Varga et al., 2013). As a result, the efficacy of CW's wastewater treatment decreases (Cao et al., 2021)(Ying et al., 2011). As a result, this review has covered the causes, effects, and control strategies for preventing substrate clogging. This review will be particularly valuable to the effective development of CW technologies.



Figure 2: Wastewater on top of substrate as a result of clogging

2. Factors Influencing Clogging of CW

A literature survey on the factors that contribute to CW clogging reveals a diversified set of variables along with complex interrelationships among these variables. This complication makes it complicated to articulate the clogging problem efficiently when just few factors are taken into account (Tatoulis et al., 2017). Several nations and institutions, for example, have provided design criteria for constructed wetlands. The basic idea is that adhering to these standards will reduce the likelihood of clogging. According to research, even in well-designed systems, clogging can occur due to improper wastewater pre-treatment, as well as suspended particles (SS) and organic matter (OM) overloading (Pucher & Langergraber, 2019). As a result, these factors are dispersed across the CW's design, processes, and influent qualities. Table 1 lists some studies on various factors that influence CW clogging.

Table 1: Factors influencing clogging of CW

Factor	Effect	Reference
Sizing	Clogging occurred, ➤ After 2 months with Hydraulic loading rates (HLR) of 150 mm/d and 0.06/4 mm substrate	(Langergraber et al., 2003)

	➤ After 1 month with HLR of 250 mm/d and 1/4 mm substrate.	
	Clogging is also accelerated by restricting the depth of the wetland without having taken the rooting depth of the Vetiver grass into consideration.	(Austine, 2017)
Distribution System	Because the vegetation was planted in rows, wastewater flowed between the rows of Vetiver grass in the horizontal subsurface flow wetland when it clogged.	(Austine, 2017)
Pipes	The position of the outlet pipe affects hydraulic behavior and, as a result, water flow routes.	(A. Pedescoll et al., 2013)
	The clog is particularly severe in the vicinity of the inlet.	(F. Licciardello et al., 2019)
Bed media	Drainable porosity and accumulated solids are correlated by 89.2%,	(A. Pedescoll et al., 2013)
	The grain size distribution of the substrate influences the pore size distribution and hydraulically active pore volume.	(Langergraber et al., 2003)
	The hydraulic behavior is influenced by the gravel matrix. The substrate in planted CW will experience approximately 20% loss in hydraulic conductivity compared to unplanted ones.	(A. Pedescoll et al., 2013)
	Sand clogging is shallow compared to gravel which clog deeper into the bed.	(Blazejewski & Murat-Blazejewska, 1997)
Macrophytes	Different plant species have different influence to clogging of CW. The underground biomass weight of <i>T. angustifolia</i> is twice that of <i>P. australis</i> . This increases its like hood to cause clogging	(A. Pedescoll et al., 2013)

	After three years of operation, the CW accumulated solids in the substrate, with the root system of common reed accounting for 35-70 percent of the total accumulated solids.	(Anna Pedescoll et al., 2011)
	It is still unclear how plant roots affect hydraulic conductivity, and further research about how to assess their impacts is necessary.	(G. F. Hua et al., 2014)
Pretreatment	Pretreatment procedures have the potential to drastically minimize the amount of TSS and BOD entering the CW.	(Ying et al., 2011)
	The concentration of SS after primary treatment process should not exceed 100 mg L^{-1} to enter the CW	(Pucher & Langergraber, 2019)
TSS concentration	TSS concentrations in the influent should not exceed 100 mgL^{-1} ($5 \text{ gm}^{-2}\text{d}^{-1}$) (under Central European climate conditions)	(Kimwaga et al., 2004)(Winter & Goetz, 2003)
Flow	Hydraulic loading rates (HLR) $< 100 \text{ mm/d}$ could be operated without clogging.	(Langergraber et al., 2003)
	When a CW is operated in a batch mode, it accumulates somewhat more sludge than when it is operated in a continuous hydraulic mode.	(Anna Pedescoll et al., 2011)
	Hydraulic conductivity and accumulated solids are correlated by 74.5%	(Anna Pedescoll et al., 2011)
Chemical processes	Chemical precipitates of phosphates, carbonates, aluminum and iron hydroxides, and magnesium and calcium oxides have a potential of causing clogging of CW.	(de Matos et al., 2018)(Miranda et al., 2017)(Aiello et al., 2016)

Biofilm	The substrate porosity can be affected by different communities of microorganisms growing and adhering to the substrate as support material	(de Matos et al., 2018)(Aiello et al., 2016)(Langergraber et al., 2003)
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Table 1 illustrates a generalized concept: CW clogging is caused by a variety of factors and cannot be explained solely by looking at design, bed procedures, or influent characteristics. Because clogging is still a problem in CWs, more research involving a variety of factors is needed to find a solution.

3. Effects of CW Clogging

Clogging has an impact on the design and operation of CWs, which should be taken into account to avoid a significant decrease in their lifetime (De la Varga et al., 2013)(Feliciano Licciardello et al., 2020)(Morris et al., 2011). Different effects are expected due to the differences in how different factors contribute to CW clogging (Aiello et al., 2016). The emergence of preferential flow paths and the exclusion of large sections of the filter due to minor changes in local flow velocities are the first effects (de Matos et al., 2018). The forming of a clogging mat on the surface of CW creates an unequal distribution of wastewater, resulting in filter component exclusion, surface standing water, as well as overflow (F. Licciardello et al., 2019). Low hydraulic efficiency results in poor pollutant removal efficiency due to the obvious short contact period, lowered oxygen delivery renewal, and decreased activity in the dead zone (Miranda et al., 2017)(Feliciano Licciardello et al., 2020). It also affects the structure, evenness, diversity and richness of microbial communities (Zhu et al., 2020). Much of this contributes to a decrease in the pore size distribution of the substrate media, which affects CW efficiencies (Tatoulis et al., 2017). It increases the likelihood of human contact with wastewater, and also the generation of foul odors (Pucher & Langergraber, 2019)(F. Licciardello et al., 2019).

4. Control of CW Clogging

Controlling clogging in CWs can indeed be achieved either through preventative measures or restoration. Chemical, physical, and biological pretreatment are used to reduce clogging by reducing suspended solids and organic loads. Prevention alone will not keep CWs from clogging, and it will

increase capital and operational expenditures, as well as the amount of land required for waste-water treatment. Traditional methods for unclogging clogged CWs include resting and restoring, in which the substrates are replaced and the system is backwashed (Cao et al., 2021). The following sections provide descriptions of various pre-treatment processes.

4.1. Prevention Methods

Despite the fact that clogging is a complicated and poorly understood process, influent suspended solids play an important role in clogging. Two methods for preventing clogging in CWs are wastewater pre-treatment, which reduces the amount of suspended solids and organic matter load, and the use of gravel, which has a higher hydraulic conductivity than soils (Tatoulis et al., 2017). As just a consequence, it is generally accepted that effective wastewater pre-treatment is critical for the long-term operation of CW (De la Varga et al., 2013)(Hdidou et al., 2022).

4.1.1. Wastewater Pre-processing

In several regions of the world, septic tanks are used to collect and dispose of household wastewater on-site. This system is most commonly used in rural areas where sewage systems are not linked to the public sewer system (Richards et al., 2016). This system's main processes are decomposition of organic matter and solids settling from domestic wastewater (Nguyen et al., 2007). A septic tank can eliminate up to 30 percent of nitrogen load and 50 percent of organic matter on average (Adegoke & Stenstrom, 2019). A number of studies have found that combining septic tanks with CW improves wastewater treatment performance (Saeed et al., 2021). A report from an investigation on treating septic tank effluents with three baffle flow CWs shows a removal of nitrogen (58.50 %) and phosphorus (95.97 %) (Cui et al., 2015). When a septic tank was integrated with CW, the effluent COD and BOD were reduced by 87 percent and 89 percent, respectively. In the same study the system managed to reduce the fecal coliform count by around 5 log units (Abdel-Shafy & El-Khateeb, 2013). In a different research hybrid tidal flow CW was used to treat septic tank effluent. The results show the removal of $\text{NH}_3\text{-N}$ (33.30% - 72.71 %), TP (35.55% - 77.68 %), and TN (16.25% - 53.17 %). This study concluded that treatment efficiency would be increased by increasing recirculation frequency (Cui et al., 2012). Even at a pilot scale, the integration of solar septic tank and CW demonstrated efficiency in the

removal of sediments, pathogens, organic matter and nutrients (Koottatep et al., 2021). All of these studies show that integrating septic tanks and CW can produce effectively treated wastewater.

Coagulation/flocculation is the oldest method of treatment for both stable and intermediate leachates. In this procedure, chemicals are used to create an insoluble final product. This method uses ionic mechanisms to remove organic compounds that are not easily biodegradable (Rahmadyanti et al., 2021). All of these processes increase the sedimentation rate in wastewater (Ying et al., 2011). Small particles and colloids are agglomerated in the coagulation-flocculation technique to form larger particles. Organic matter, turbidity, and other soluble contaminants are reduced as a result of this process (Teh et al., 2016). The quality of wastewater is determined by COD and turbidity during this process, with high COD indicating the presence of organic matter, and turbidity indicating the presence of suspended solids (El et al., 2021). According to the findings of various researchers, CW can effectively treat wastewater with less organic matter and TSS (Thivyatharsan & Rajendran, 2017). When a coagulation (moringa oleifera seeds powder) and CW integrated system were used to treat batik wastewater, the system removed 89.33 percent, 98.11 percent, and 92.05 percent of COD, TSS, and fat, oil, and grease, respectively (Erina Rahmadyanti & Febriyanti, 2020). Nonetheless, there are a number of drawbacks in this process, including the formation of iron and aluminum, as well as significant maintenance and operational costs, an excess of sludge generation, and the health risk of causing diseases such as Alzheimer's and neurological ailments. These concerns necessitate the conduct of studies to investigate various coagulant alternatives that are inexpensive, effective, and producing less sludge (Erina Rahmadyanti & Febriyanti, 2020).

Waste or Wastewater Stabilization Ponds (WSPs) are sanitation systems made up of large open basins that treat greywater, blackwater, or fecal sludge using natural processes (Verbyla & Sperling, 2017; Abdullahi et al., 2014). When wastewater moves slowly through wide, shallow basins, it is aided in photosynthesis by wind and sun energy. Despite the fact that a large amount of space is required, the chemical and energy requirements are minimal (Yildiz, 2012). There are three types of WSP systems: anaerobic, facultative, and maturation. Depending on the desired effluent quality, these multiple ponds are organized in series. Besides, at any given location, there is often

more than one series, with each series consisting of an anaerobic pond, a facultative pond, and one or more maturation ponds (Mara, 2008). Various studies on incorporating WSPs and CW demonstrate the system's effectiveness in wastewater treatment and a great option with simple and low energy requirements (De la Varga et al., 2013). When compared to traditional methods, the combination of CWs and WSPs is capable of eliminating microbes to the required standards (Kayombo & Ladegaard, 2004). In a study done in Tanzania, the use of CW after the stabilizing pond was able to completely eliminate helminths from wastewater (Outwater et al., 2020). In studies where CW was paired with WSP the results show efficiency in the reduction of TSS, BOD₅ (Tsalkatidou et al., 2009) and nitrogen contents (Mayo, 2020). This method has a number of disadvantages, including a large land requirement, the risk of leakage contaminating groundwater, the impact of weather conditions on treatments, and the possibility of suspended particle issues (algae) (Spellman & Drinan, 2014).

Filtration is among the most significant procedures in the wastewater treatment process (Erina Rahmadyanti et al., 2020). This is an important treatment method for removing a range of contaminants from surface water and wastewater for a variety of applications (Chaudhary et al., 2003). A biofilter is a filter that contains microorganisms and is used for capturing and degrading pollutants through various mechanisms such as adsorption, biological oxidation, and filtration (Permatasari et al., 2018). They have been used for treating wastewater, water, and air with great success (Chaudhary et al., 2003). The need for backwashing, complex air and water distribution systems, high nitrite residue in the effluent, and biofilm sloughing on occasion are all major drawbacks of this system (Yildiz, 2012). The filter's efficiency is determined by several factors, including the preservation and growth of microorganisms and the type of substrate used, which can be dirt, activated carbon, sand, charcoal, or bark (Singh et al., 2018). A combination of biofilter and CW system was studied for treatment of wastewater, the final effluent had 30 mg/L, 15 mg/L, 5 mg/L and 0.5 mg/L for COD, TN, NH₄⁺-N and TP respectively (Jing et al., 2015). A study of this system at the pilot scale removed BOD and COD at the rate of 99 percent and 95 percent respectively (Ling et al., 2009). This system is capable of removing BOD by more than 70 percent and eliminate indicator bacteria by up to 5 logs (Jenssen P & Vrale L, 2003).

4.1.2. Substrate Selection

The materials to be used as a substrate in CW are very important for the performance and life of the CW (Hassan et al., 2021; Lei et al., 2021). The substrate is essential for pollutant sorption, system hydraulic conductivity for sufficient flow of water in CWs, plant rooting support, microorganism adhesion, and suspended solids retention (Li et al., 2014). Several aspects need to be considered when selecting substrate materials for CWs, the most important of which are cost and availability. Physical properties that define hydraulic feasibility and clogging probability are also considered, as are chemical compositions that control the safety of the substrates and their ability to eliminate pollutants, and biochemical characteristics (Hdidou et al., 2022)(Wu et al., 2015) which can be summarized in Figure 3.

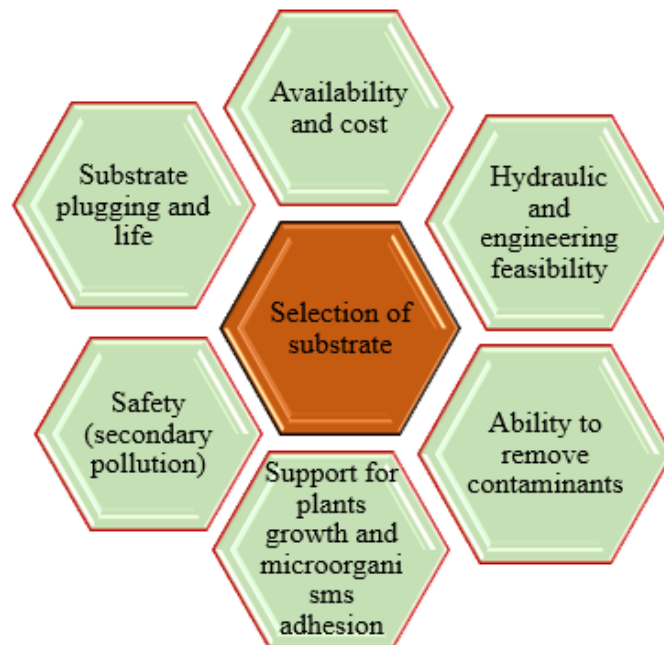


Figure 3: Factors for the selection of substrates for constructed wetlands

The substrates used in CWs can be divided into two types: traditional and emerging materials. The traditional materials primarily consist of soil, sand, gravel, zeolite, granite, manganese sand, anthracite, volcanic rocks, forsterite, and quartz, among others (Yang et al., 2018; H. Wang et al., 2018). Nevertheless, using gravel and/or sand in CW systems can trigger serious

issues, such as plant settlement issues, low adsorption performance, and clogging (Wu et al., 2015). Hollow bricks, steel slag, ceramic, activated carbon, artificial ecological substrates, and sponge iron are some of the recently developed materials that are gaining increasing attention in order to improve CW performance (Wang et al., 2018) and reduce the rate of clogging (Saraiva et al., 2019). However, the potential application of these materials is unclear due to the desired properties such as a high pollutants removal capacity and a suitable particle size that is large enough to prevent clogging but small enough to have a water holding capacity to sustain microbial activities (Lei et al., 2021). To avoid clogging, a balance is required between the substrate purification performance and hydraulic conductivity (Hdidou et al., 2022). Gravel is the most commonly used substrate in constructed wetlands due to its ease of availability, low cost, and excellent operating performance (Stefanakis, 2020) while the mixture of gravels and sand offers better hydraulic conditions and pollutants removal (Stottmeister et al., 2003). The data collected from full scale operating CWs in Brazil on operational parameters plants and construction aspect shows that most of CWs (67 %) were filled with gravel or with some other material (Fadanelli et al., 2019). The results from this study are summarized in Figures 4 and 5.

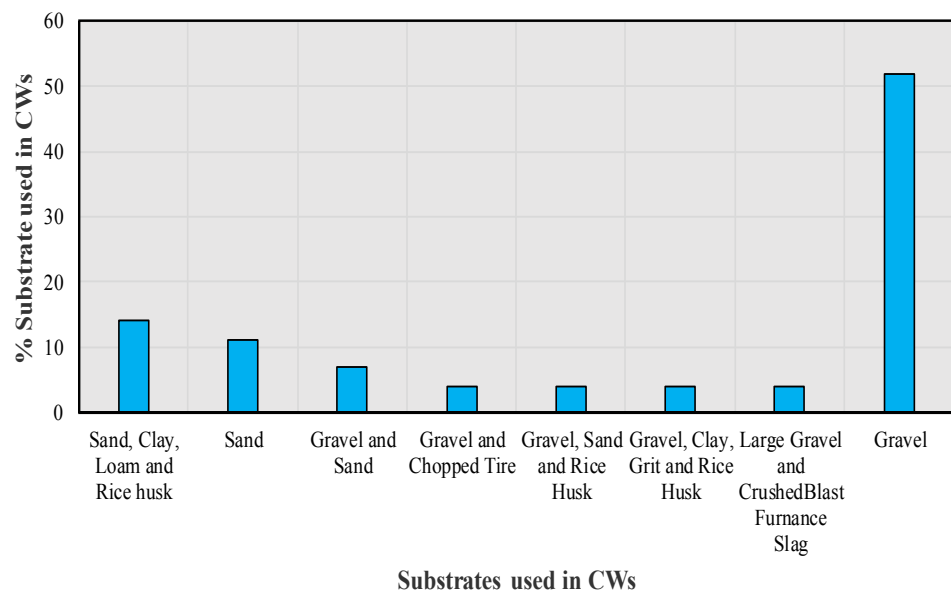


Figure 4: Substrates used in horizontal flow CWs (Fadanelli et al., 2019)

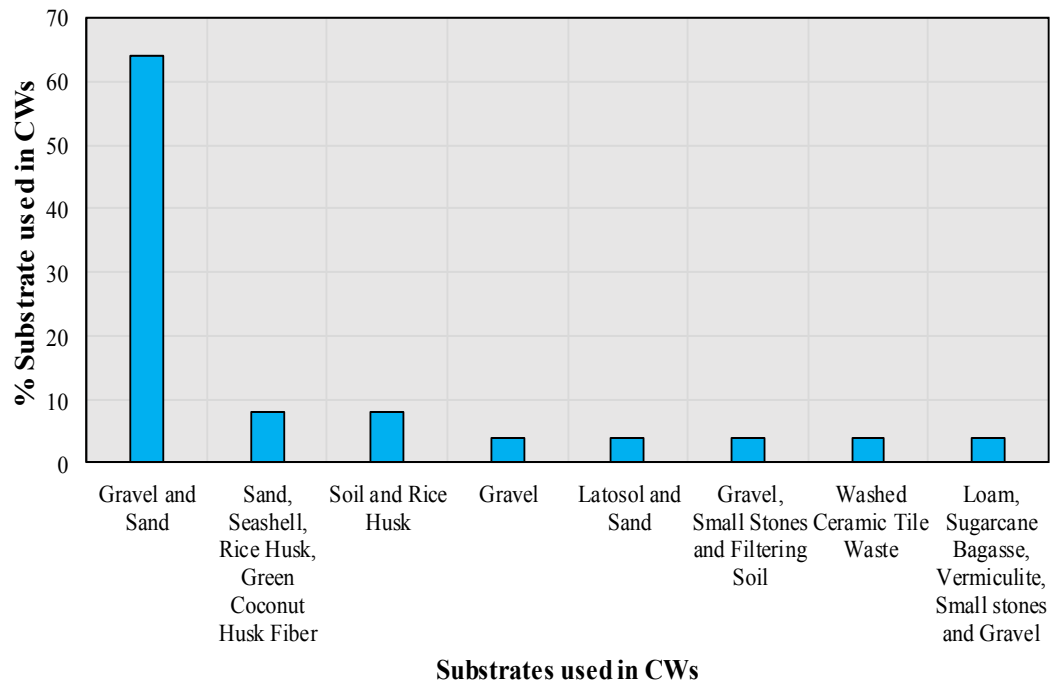


Figure 5: Substrates used in vertical flow CWs (Fadanelli et al., 2019)

4.2. Restoration Methods

The restoration of the clogged CW can be done by either washing the clogged substrate materials and return them to the CW, replacing completely or partially the clogged substrate with a new one (Stanković, 2017; Tran et al., 2019; Vymazal, 2005) or exposing the clogged substrate to oxidising agent such as H_2O_2 (Tatoulis et al., 2017; H. Z. Li et al., 2011; Lohith Reddy D, 2014). The traditional restoration method is to replace the clogged substrate with clean ones. While this method is relatively effective, it is costly for wastewater facility owners, and may necessitate the closure of sections of the facility for extended periods of time (Nivala & Rousseau, 2009; Li et al., 2011). Another expense is the disposal of excavated materials, which can be avoided by washing the material and reintroducing it into the CW. Furthermore, these processes destroy the plants in CW, necessitating

replanting and additional time before reusing the CW (Hua et al., 2010). As a result, these techniques are unworkable in third-world countries.

5. Conclusions and Future studies

From the literatures reviewed (findings of this study's, the following conclusion can be drawn in this study, some points can be highlighted:

- i) Clogging of CW substrate is a result of complex interaction of various variables such as hydraulic load, organic loading, substrate porosity, water depth, oxygen supply conditions, and plants. As a result, it is difficult to explain the phenomenon using only a few factors. This requires investigations, which involves various factors in full-scale CW.
- ii) More research is needed to learn more about the interdependence of these components. Plants' impact on clogs in CW is unclear, and it differs greatly from species of plants, maturity level, substrate, and CW design. As a result, more research into the role of plants in CW clogging and how to measure the effects is extremely important.
- iii) Only a few pretreatment procedures have been tested in CW as clogging prevention methods. By reducing the amount of suspended matter entering the CW, reducing organic loading, and efficiently restoring the substrate's permeability, wastewater pre-treatment can effectively prevent or delay clogging. In order to improve wastewater treatment, future research should look into the compatibility of CWs with pretreatment procedures.

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