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Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators

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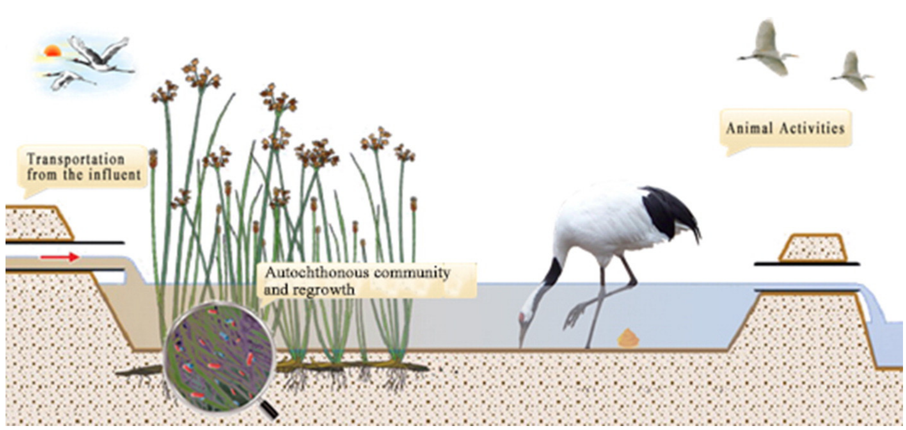
HIGHLIGHTS

- Knowledge on fate and removal of fecal indicator bacteria in CWs is not sufficient.
- Three sources of pathogens in CWs were summarized.
- Pathogens removal is influenced by hydraulic, vegetation, temperature and so on.
- Most frequent and well-validated removal mechanisms were discussed.
- Removal of pathogen was found to be exponentially related to the loading rate.

GRAPHICAL ABSTRACT



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ABSTRACT

Removal of human pathogens from wastewater is a critical factor with linkage to human health. Constructed Wetlands (CWs) are environmental friendly ecosystems that are applicable not only for chemical pollution control, but also for the reduction of pathogens from wastewater. Yet the knowledge on the fate and removal of such indicator bacteria in CWs is still not sufficient due to the complexity of removal mechanisms and influencing factors. This review serves to provide a better understanding of this state-of-the-art technology, which is necessary for further investigations and design development. The fecal indicator bacteria in CWs mainly come from three sources, namely, influent wastewaters, regrowth within the CWs, and animal activities. The properties of microbial contamination vary depending on the different sources. The removal of pathogens is a complex process that is influenced by operational parameters such as hydraulic regime and retention time, vegetation, seasonal fluctuation, and water composition. The most frequent and well-validated removal mechanisms include natural die-off due to starvation or predation, sedimentation and filtration, and adsorption. The concentration of the

Abbreviations: CWs, constructed wetlands; VF, vertical flow; HF, horizontal flow; HRT, hydraulic retention time; TC, total coliforms; FC, fecal coliforms; FS, fecal streptococci; CLP, *Clostridium perfringens*; ST, staphylococci; TSS, total suspended solids; UV, ultra violet.

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Mechanisms removal of bacteria
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main fecal indicator bacteria in the effluent was found to be exponentially related to the loading rate. Generally, horizontal subsurface flow CWs have better reduction capacity than free water surface flow CWs, and hybrid wetland systems were found to be the most efficient due to a longer retention time. Further improvement of fecal indicator bacteria removal in CWs is needed, however, levels in CW effluents are still higher than most of the regulation standards for reuse.

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1. Introduction

Water overexploitation and pollution as consequences of human population growth and economic development have caused a marked decrease of per capita water availability (WHO, 2006). Concomitantly with the rising demand for clean water, large amounts of wastewater are being generated. Even though various wastewater treatment technologies including centralized and decentralized systems have been developed, the overall treatment capacity is still relatively low in developing countries due to the economic concerns. Moreover, the standard limits for effluent quality control is mainly replying on organic compounds (COD, BOD), nitrogen and phosphorus. The sanitation control of pathogens in the effluent has not gain much attention so far. However, human health should not be jeopardized by residual pathogens remaining in the water after treatment (Winward et al., 2008a).

Most effluent wastewater in advanced treatment systems is disinfected by using chemicals such as chlorine. However, this practice can create further health related and ecological concerns due to the formation of disinfection by-products such as trihalomethanes, which have led to restrictions of chlorination for disinfecting wastewater (Toscano et al., 2013). Moreover, alternative forms of wastewater treatment are often needed, as centralized treatment is not always an economical option. This is especially the case in rural and remote regions in developing countries. Therefore, attention has been shifted to testing the capacity for human pathogen removal in eco-sustainable systems such as constructed wetlands (CWs), which are designed to reduce pollutants without or with less addition of disinfection chemicals (Decamp and Warren, 2000).

Research on CWs started essentially in the 1950s with the work of Dr. Käthe Seidel in Germany (Vymazal, 2010). Since then most studies on CWs have focused on the removal of organic and inorganic pollutants, but an increasing number of investigations has focused on the capacity of CWs to eliminate fecal indicator bacteria, i.e. surrogates for human pathogens (e.g. Gersberg et al., 1989; Green et al., 1997; García et al., 2008; Headley et al., 2013). Results from these studies suggest physico-chemical and biological mechanisms and factors that may contribute to fecal indicator bacteria removal in CWs such as adsorption, sedimentation, reactive oxygen species, starvation, and predation by other microbial entities (García and Bécares, 1997; Ottová et al., 1997; Boutilier et al., 2009). However, the complexity of abiotic and biotic relations in CWs has hampered a conceptual understanding of indicator bacteria removal processes in these treatment systems. In addition, the inherent variability between CW units even of the same type, e.g. difference in root density, hydraulics, and water characteristics, has impeded the systematic description and prediction of the removal processes that occur within these environments (Werker et al., 2002; Vymazal, 2005).

For reasons of analytical feasibility, wastewater quality is typically assessed based on enumerations of fecal indicators such as generic *Escherichia coli* rather than of specific human pathogens (Dufour et al., 2003). In line with that approach, this review addresses the potential pathogens and indicators in the various influents and within the wetlands but focuses almost exclusively on fecal indicator bacteria for the discussion of removal mechanisms such as natural die-off, sedimentation & filtration, adsorption and predation, and parameters influencing removal including hydraulic regime and retention time, vegetation, seasonal fluctuation (variability), water compositions, media and pH. The performance of various types of CWs and systems integrated with other advanced technologies are evaluated also based on the removal of fecal indicators. Finally, perspectives and implications for future work are provided.

2. Sources of pathogens and fecal indicators in CWs

There are about 60 known general types of waterborne human pathogens. These include viruses such as rotavirus, bacterial pathogens such