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Insight into the risk of replenishing urban landscape ponds with reclaimed wastewater

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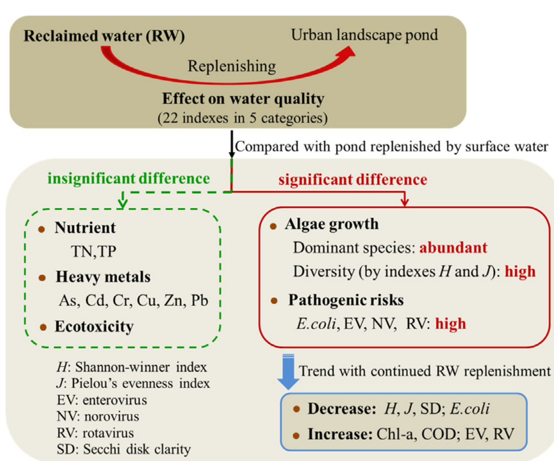
HIGHLIGHTS

- Significant risk of replenishing landscape ponds by reclaimed water were identified.
- Great differences were observed in algae and pathogens between RW- and SW-ponds.
- RW-ponds showed Cyanophyta-Chlorophyta-Bacillariophyta type with high algal diversity.
- Health risk is relatively higher in RW-ponds and viral pathogens are the main driver.
- Duration of RW replenishment remarkably affects algal growth and pathogen risk.

GRAPHICAL ABSTRACT



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ABSTRACT

Increasing use of reclaimed wastewater (RW) for replenishing urban landscape ponds has aroused public concern about the water quality. Three ponds replenished with RW in three cities in China were chosen to investigate 22 indexes of water quality in five categories. This was achieved by comparing three pairs of ponds in the three different cities, where one pond in each pair was replenished with RW and the other with surface water (SW). The nutrients condition, heavy metal concentration and ecotoxicity did not differ significantly between RW- and SW-replenished ponds. By contrast, significant differences were observed in algal growth and pathogen risk. RW ponds presented a Cyanophyta-Chlorophyta-Bacillariophyta type with high algal diversity while SW ponds presented a Cyanophyta type with low diversity. Regrowth of bacterial pathogens and especially survival of viral pathogens in RW, was the main driver behind the higher risk for RW ponds compared with SW ones. The duration of RW replenishment was proved to

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have a marked impact on the algal growth and pathogen risk. With continued RW replenishment, non-dominant algal species subjected to decrease while dominant species were enhanced resulting in the biomass increasing but diversity declining, and the risk posed by viral pathogens might become greater.

1. Introduction

Water shortages are a dire concern in many countries and regions of the world because of population growth and accelerated industrialization and urbanization. In this context of scarcity, alternative water resources (AWRs) are becoming increasingly prominent as a way to meet different water needs. Such AWRs mainly include rainwater, industrial recycled water and reclaimed wastewater (RW). Due to its stable quality and continuity of supply, RW has been widely used [1,2].

Although RW can ease the problem of water shortages, the safety of wastewater reuse is occasionally questioned, as some compounds commonly found in RW, such as nutrients and micropollutants, have negative consequences for reuse. For agricultural use, salts and heavy metals can accumulate in soils following extended RW irrigation and can have consequent deleterious effects on yield [3–5]. For municipal use, health risks can be generated by pathogens from the spray irrigation of a green area with RW [6,7]. For industrial use, pipes can become corroded through microbial action [8]. Finally, for environmental use, the high concentration of nutrients in RW may have negative impacts on ecosystems in the receiving water bodies in the environment [2,9].

With increasing water shortages comes the need in the urban waterscape for new water resources, and RW is gradually being used more often for replenishing urban landscape ponds. In California, USA, about 25% of the effluent from wastewater treatment plants (WWTPs) is used for lake replenishment [10]. About 50% of the effluent from WWTPs is used to improve water features in nearby recreational leisure venues in Osaka, Japan [10]. In recent years, China has experienced rapid development and there is an increased demand in urban life for attractive water scenes [11]. China has taken great effort to conserve and augment the limited water resources available to meet the growing water demands. Also, water reclamation, has been established as a key components of the national water strategy [12]. In most cities, RW has become the first option of water resource management for replenishing landscape ponds, such as at Olympic Park in Beijing [13], Eco-wetland Park in Tianjin (the first theme park focused on environmental protection in China [14]) and Kunming Pool in Xi'an (the largest artificial lake in northwestern China [15]).

Although RW can satisfy the Chinese water quality standards for environmental reuse [16], use of RW instead of the traditional surface water (SW) for landscape needs will certainly affect the water quality of the receiving ponds. In urban landscape scenes, the primary objective of RW use is to help create an aesthetically pleasing water landscape, and until now, most studies on RW use in this context focused on aesthetic aspects, such as controlling algal growth and eutrophication [13,14,17]. Few studies have measured non-sensory indexes of water quality for RW-replenished water features, and research attention has mainly focused on the concentration of heavy metals in the water column and sediment, as well as their accumulation characteristics and corresponding technologies for controlling them [18,19]. Furthermore, there are even fewer studies on the impact of toxic organic micro-pollutants and pathogens from RW replenishment. Toxic organic chemicals are one of the dominant hazardous components of wastewater, and conventional treatment processes cannot remove them thoroughly [1]. Of the various pollutants, persistent organic pollutants, disinfection by-products and microbial metabolic products have received much attention because they are slow to degrade, can bio-accumulate and can be ecologically toxic and carcinogenic [20,21]. In addition, although most pathogens are killed during wastewater treatment processes by disinfection, the bacterial pathogens can regrow because of the availability of nutrients in the water bodies replenished with RW, and the viral pathogens may survive and remain infective in the water environment due to their high resistance to the inactivation of disinfection of wastewater treatment, especially for chlorination [22]. In recent years, health problems caused by pathogens following wastewater reuse are being reported more and more frequently. This includes acute gastroenteritis caused by rotavirus, vomiting and abdominal pain caused by norovirus, and enteric fever caused by *Salmonella* [6,23,24]. In short, it is necessary to analyse the impact of replenishing urban landscape waters with RW in a more comprehensive manner. This should mainly focus on the impacts on the trophic condition, algal growth, accumulation of heavy metals, toxicity of organic micro-pollutants and health risks posed by pathogens.

The water quality in such replenished water bodies will also be influenced by external environmental factors such as the local climate and atmospheric deposition, and intrinsic factors such as depth, coverage and hydraulic retention time. Özkan et al. [25] assessed the relative roles of different environmental factors in phytoplankton growth by investigating 195 Danish lakes and ponds in a spatially explicit framework, and found that the main influencing factors were lake chemistry (especially total nitrogen [TN] and total phosphorus [TP]) and lake morphology (especially lake depth), but that climate conditions (including air temperature and solar radiation) had little effect. Phillips et al. [26], through analysing a large dataset of 1138 European lakes and ponds, also concluded that the water quality was affected by lake morphology and local climate. Wang et al. [27] concluded that the water cycle plays an even more important role in stabilizing water quality than does the control of nutrient levels. Therefore, the present approach to studying the effect of replenishing urban ponds with RW was to compare these RW ponds with ponds replenished by SW located in the same region and with similar characteristics, including hydraulic retention time, coverage and depth.

The objective of this research was to gain insight into the effect of RW replenishment on urban landscape ponds by comparing such RW ponds with counterparts replenished by SW, and to reveal the differences related to visual effects, ecology and health risk. In total, three RW-replenished landscape ponds in three different cities were chosen to investigate 22 indexes of water quality in five categories: trophic condition, algal growth, heavy metals, ecotoxicity and pathogenic risk. This was done by comparing the RW ponds with nearby ponds replenished by SW in each of the three cities. The paper identified the key effects on the water quality from RW replenishment, which will be useful for landscape planners and managers to determine what should be monitored and what proactive steps should be taken to minimize any negative effects of RW use. Such insights will also help to promote further use of RW as a water source for replenishing urban landscape ponds and to relieve the urban water shortage problem.