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Research article

The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm

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ABSTRACT

Wastewater management is included in one of the 17 Sustainable Development Goals (SDGs): SDG 6 is dedicated to water and sanitation and sets out to “ensure availability and sustainable management of water and sanitation for all”. SDG 6 expands the Millennium Development Goals (MDGs) focus on drinking water and basic sanitation to now cover the entire water cycle, including the management of water, wastewater and ecosystem resources. A UN report in 2017 states that likely over 80% of the wastewater worldwide is still discharged without adequate treatment. In several countries the wastewater management is nowadays a norm, but still there are open discussions about the kind of approach to be adopted, i.e. centralisation vs. decentralisation. The choice of the adopted technologies is strictly linked to environmental performances and economical aspects; one of the possible causes for the still enormous amount of untreated wastewater discharged into the environment can be the low “willingness to pay” for this kind of service and therefore a great focus should be given to all the technologies that are able to lower the treatment costs still maintaining reliable and robust performances in the long term. When considering wastewater as a carrier of valuable primary chemicals that can be easily converted to marketable products (fertilisers, bio-plastics, soil conditioners, biofuels, etc.), and as well as a relevant source of “new water” to be used for specific purposes, wastewater and runoff management can be highlighted as one of the most exciting challenges and occasions for a sustainable development in the near future.

The paper aims to clarify the future role of CWs in circular economy, resource-oriented, and ecosystem services approaches, which want to respond to sanitation worldwide and the future research needs. We give an overview on how the conventional wastewater treatment scheme (what we call “waste paradigm”) should move towards more sustainable water and biogeochemical cycles following the new resource-oriented, circular economy and ecosystem service views. On this basis, we review the potential application of CWs within this new, and needed, paradigm. Finally, a meta-analysis shows that the scientific community involved in CWs should put more effort in making CWs more suitable for these new tasks.

1. Introduction

Constructed wetlands (CWs – also known as treatment wetlands) are used for many different applications. They can be applied to diffuse as well as point-source pollution. They treat water towards particular reuse purposes, sludge from wastewater treatment for agricultural application (Vymazal and Březinová, 2015), stormwater runoff (Adyel et al., 2016), combined sewer overflows (Masi et al., 2017), industrial effluents (Vymazal, 2014). To cover the wide range of possible applications very different types of CWs have been designed and are still further developed. In general CWs emulate natural wetlands in both form and function. This is part of their beauty. As with natural wetlands, which can be large or small, have free water or mainly underground flow, have a stable or varying water table, be saturated or not, have a continuous, an interval or an intermittent feeding, and many more variations, all these possibilities are tapped into to create the best treatment environment according to the task at stake. Additionally some

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features have been taken from technical developments, e.g. forced aeration (Wu et al., 2014) or active filling media (Bruch et al., 2011). CWs can be something of a riparian zone, along of rivers or lake shores; they can restore former, drained, wetlands or create new wetland zones. It is possible to design them as integrated part of a park or garden, to put them up on walls (Masi et al., 2016) or even inside of buildings or on their roofs (Masi et al., 2015). They have even been built on boats (Van Oirschot et al., 2015). Beside the particular treatment aimed at, wetlands can provide a variety of other typical ecosystem functions, some of which are wildlife habitat, evapotranspiration and thus cooling, water storage and management, recreation, landscaping, green in the built environment.

All available evidence points towards the need for a major decoupling of our well-being from resource demand very soon. A wide vision of the current and future environmental issues at planetary level is leading to the identification of the following general challenges:

- cut greenhouse gas emissions to 4% of present levels globally;
- consume all but no fossil fuel (Gruber and Galloway, 2008);
- eliminate mined phosphorus demand within the next 80 years (Cordell et al., 2011);
- drastically reduce reactive nitrogen production and release into the biosphere (Galloway et al., 2008);
- massively cut biodiversity loss;
- deal locally with lack of available fresh water in several regions of the world.

These are quite respectable challenges and there are a range of others to mention (Meadows et al., 2007). Rockström et al. (2009) suggests that where we tackle the challenge, e.g. ozone layer depletion, we have a chance to succeed. This, however, is not possible without a major revision of the way we do things.

The anthropogenic inputs have drastically influenced both the C and N cycles, as well demonstrated by the analysis of the gas composition in perennial ice cores and the measured increase in the atmospheric levels of CO_2 and N_2O throughout the last thousands of years (Galloway et al., 2008).

The interaction between water usage and the Carbon cycle is nowadays very far from being sustainable; all efforts are made to reach by any means a complete oxidation of the organic compounds, obtaining CO_2 as final product, and thus contributing to its global emission in a considerable way. This process is taking place in all the biological treatment systems, wetlands included. Reduced carbon is instead a precious electron-source in soils that have been leached by intensive agricultural practices and are accumulating nitrates, which are subject to a denitrification process limited by the lack of carbon (Kindler et al., 2011). The decoupling of the carbon and nitrogen cycles, induced by changes in fixation, mobility and speciation of both elements by anthropic activities, can lead to complex results, like ocean acidification and increase of the net primary productivity both in water bodies and inland; in this last case the C uptake is limited by N and P availability (Gruber and Galloway, 2008; Huang et al., 2016; Vitousek et al., 1997).

Talking specifically about sanitation, or management of human excreta, where especially urine is a valuable source of reactive N and P and faeces an efficient sink and ultimately source of reduced C, it is quite evident that sanitation can play a relevant role in reconnecting C and N cycles. Soil and water quality restoration need the development of strategies for an integrated management of these resources because of the soil-water-waste nexus (Lal, 2015). These strategies should mainly focus on keeping C in its reduced forms, enhancing as much as possible the soil organic C sequestration and related simultaneous positive effects, i.e. restoration of degraded soils, enhancement in biomass production, purification of surface and ground waters, and reduction of atmospheric CO_2 emissions from fossil fuel (Lal, 2014). By the Haber-Bosch reaction we are currently synthetizing about 150 million tons of reduced nitrogen per year that is then used as fertiliser. About 70% of this amount is lost to watercourses through erosion, leaching and by the practices of industrial agriculture. The about 7 billion humans living on the planet are generating almost 32 million tons of organic Nitrogen, mainly contained in urine. This simple calculation is showing the completely uneconomic approach adopted by several high-income countries in mixing urine with the domestic wastewater, generating in this way the most difficult step in the further treatment. Urine segregation at the source could be easily implemented, providing a decentralised availability of macronutrients and drastically simplifying the remaining wastewater treatment targets to the removal of organic compounds and suspended solids. Finally in the next decades the world population will have to deal with local availability of water with proper quality for human usage. There is an increasing awareness that for several reasons our freshwater resources are quite limited and need to be protected both in terms of quality and quantity. This water challenge affects not only the water community, but also decision-makers and every human being. Considering water scarcity, which includes water shortage, water stress and water crisis, in the current state of management of this primary resource worldwide, correcting measures still can be taken to avoid the local lacks to be worsening. Wastewater management also found recognition in one of the 17 Sustainable Development Goals: SDG 6 is dedicated to water and sanitation and sets out to “ensure availability and sustainable management of water and sanitation for all”. SDG 6 expands the MDG focus on drinking water and basic sanitation to now cover the entire water cycle, including the management of water, wastewater and ecosystem resources, recognising that these issues are inseparable. The wastewater issue is urgent, especially if we think that about 80% worldwide wastewater is currently discharged without adequate treatment, as reported in a recent UN report (Koncagül et al., 2017).

This paper examines the future role of CWs in a sanitation aiming at reducing, if not eliminating, the decoupling of the biogeochemical cycles, and producing new resources from what is currently considered just waste by adopting circular economy, resource-oriented, and ecosystem services approaches. We firstly highlight how the conventional wastewater treatment scheme (what we call “waste paradigm”) should move towards more sustainable water and biogeochemical cycles. Secondly, we review the potential application of CWs within this new, and needed, paradigm. Finally, we investigate with a meta-analysis where the scientific community involved in CWs is looking for, and if the majority of the research is in agreement with the new paradigm.

2. From waste paradigm to resource oriented, circular economy and ecosystem service science

Using resources, water and substances contained, in cycles will impact urban water management, including sanitation. “Treatment” of water called waste by “eliminating” as much of the substances contained as possible, in order to release the water safely into the aquatic environment (Fig. 1), will be substituted with smart collection and processing of all resources, i.e. water, other substances contained and energy, from households and factories for their further use and marketability (Fig. 2). For the expected changes of water systems see also Table 1.

A major task of sanitation will be to separate between useable and harmful substances, including pathogens or waters particularly loaded with pathogens, for specific applications, or to avoid some