Science of the Total Environment 559 (2016) 268–281

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impact of treated wastewater reuse and floods on water quality and fish health within a water reservoir in an arid climate

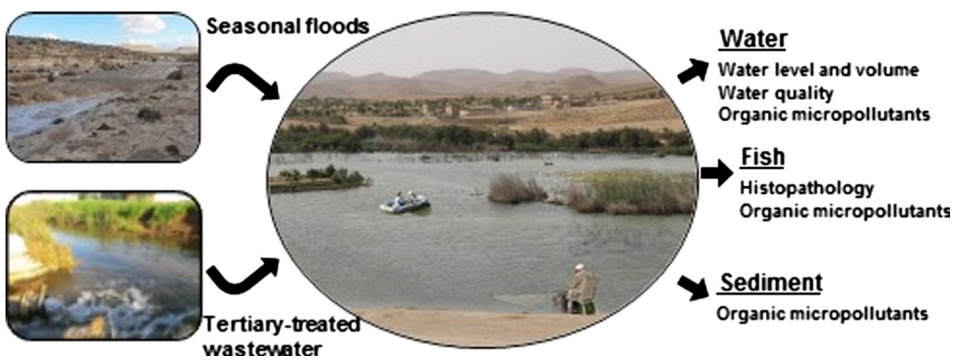
Inbal Zaibel [a,b], Dina Zilberg [b], Ludmila Groisman [c], Shai Arnon [a,*]

[a] Zuckerberg Institute for Water Research, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel
[b] French Associates Institute for Agriculture and Biotechnology of Drylands, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel
[c] National Public Health Laboratory, Ministry of Health, Israel

HIGHLIGHTS

- Treated wastewater (TWW) and floods are used to feed water bodies in arid regions.
- Water quality in Yeruham Reservoir (southern Israel) was mainly affected by floods.
- Organic micropollutant levels in water and sediments were low.
- Fish from the Yeruham Reservoir were healthy.
- Water reservoirs in rural arid regions may provide new economic benefits.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 14 March 2016
Accepted 14 March 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Treated wastewater reuse
Arid environments
Organic micropollutants
Fish health
Fish histopathology

ABSTRACT

Treated wastewater (TWW) reuse for agricultural irrigation is a well-established approach to coping with water shortages in semi-arid and arid environments. Recently, additional uses of TWW have emerged, including streamflow augmentation and aquatic ecosystem restoration. The purpose of the current study was to evaluate the water quality and fish health, in an artificial reservoir located in an arid climate (the Yeruham Reservoir, Israel), which regularly receives TWW and sporadic winter floods. The temporal distribution of water levels, nutrients and organic micropollutants (OMPs) were measured during the years 2013–2014. OMPs were also measured in sediment and fish tissues. Finally, the status of fish health was evaluated by histopathology. Water levels and quality were mainly influenced by seasonal processes such as floods and evaporation, and not by the discharge of TWW. Out of 16 tested OMPs, estrone, carbamazepine, diclofenac and bezafibrate were found in the reservoir water, but mostly at concentrations below the predicted no-effect concentration (PNEC) for fish. Concentrations of PCBs and dioxins in fish muscle and liver were much lower than the EU maximal permitted concentrations, and similar to concentrations that were found in food fish in Israel and Europe. In the histopathological analysis, there were no evident tissue abnormalities, and low to moderate infection levels of fish parasites were recorded. The results from the Yeruham Reservoir demonstrated a unique model for the mixture effect between TWW reuse and natural floods to support a unique stable and thriving ecosystem in a water reservoir located in an arid region. This type of reservoir can be widely used for recreation, education, and the social and economic development of a rural environment, such as has occurred in the Yeruham region.

* Corresponding author at: Zuckerberg Institute for Water Research, The Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, 84990, Israel.

http://dx.doi.org/10.1016/j.scitotenv.2016.03.099
0048-9697/

1. Introduction

Water quantity and quality are major factors controlling ecosystem functions and ecosystem services, which are defined as the benefits that humans can obtain from ecosystems (Boyd and Banzhaf, 2007). In water-stressed environments, supplying water for drinking and food production has always been a high priority. However, water resource management policies to control floods and to supply cultural services have also been widely applied. Many of the abovementioned uses of water require water ponding for storage. The increasing trends of water reuse and human impact on aquatic ecosystems challenge the multiple uses of water, requiring new approaches to efficiently utilize water resources (Vörösmarty et al., 2010).

One of the major approaches to efficiently utilizing water resources is through the reuse of treated wastewater (TWW), which is becoming a major strategy in coping with increasing water demand due to population growth (Levine and Asano, 2004; Tal, 2006). Accordingly, in arid and semi-arid regions, TWW reuse is rapidly expanding (Friedler, 2001; López-Serna et al., 2012). In Israel, for example, approximately 85% of TWW is reused, mostly for agricultural irrigation. Treated wastewater is also utilized for a variety of additional applications, such as irrigation of public gardens (Levine and Asano, 2004) and streamflow augmentation (Halaburka et al., 2013; Arnon et al., 2015). Regulation of TWW quality is, therefore, typically aimed at addressing the different reuse purposes and includes standards for water quality parameters, nutrients, heavy metals and other toxic elements (WHO, 2006; Israeli Ministry of Environmental Protection, 2010; USEPA, 2012).

Alongside the increasing use of TWW, there is recognition that TWW contains low concentrations (microgram-nanogram per liter) of various organic substances, which are commonly termed organic micropollutants (OMPs, Schwarzenbach et al., 2006). Organic micropollutants include, for example, pharmaceuticals and personal care products (PPCPs), polychlorinated biphenyls (PCBs), dioxins and pesticides, among others. Although wastewater treatment plants (WWTPs) reduce the levels of OMPs, their complete elimination is not achieved because these plants were not designed to deal with these types of compounds. Thus OMPs are continuously introduced into aquatic environments (Silva et al., 2012), and consequently, concerns have been raised regarding the reuse of TWW for agricultural activity (Kinney et al., 2006) and streamflow augmentation (Plumlee et al., 2012).

The development of new and sensitive analytical methods over the last several years has increased the number of chemicals that can be detected or quantified in surface waters, thus attracting the attention of researchers (Sedlak et al., 2000; Richardson, 2003; Schäfer et al., 2011; Brack et al., 2015). Consequently, every year, additional compounds are added to the list of OMPs that are of concern to aquatic biota (Luo et al., 2014; Snyder, 2014). Since TWW consists of a mixture of OMPs, rather than a single compound, the health effects that are caused by OMP exposure are related not only to the detected concentration of each chemical, but also to their integration (Gibson et al., 2005; Ankley et al., 2007; Hotchkiss et al., 2008). Additional natural stressors (e.g., reservoir water quantity and temperature) and biotic interactions (e.g., agonistic interactions and parasite burden) can influence the health-related effects. Ecotoxicological effects would, therefore, be best addressed using a multibiomarker analysis (Colin et al., 2015).

Considering the aforementioned challenges, bioindicators are becoming an attractive approach for evaluating the impact of OMPs on the aquatic ecosystem. This is particularly relevant to the subgroup of micropollutants that specifically interfere with the endocrine system, and is commonly termed endocrine disrupting chemicals (EDCs). Since the aquatic environment directly affects fish physiology (e.g., a reproductive system that is characterized as being very labile), exposure to contaminants may have profound effects on the fish (Adams et al., 1989; Scholz and Mayer, 2008).

Histopathological analysis is suitable for identifying localized changes in fish tissues following exposure to toxicants (McCarthy and Shugart, 1990; Huggett et al., 1992) the occurrence of which differed between different studies examining exposure to wastewater. Some reported no (Lozano et al., 2012) or mild and limited histopathological alterations (Escher et al., 1999), while others reported severe alterations. For example, Schmidt-Posthaus et al. (2001) reported on severe pathological alterations in internal organs and an increase in the occurrence of infectious diseases in trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) exposed to polluted river water. Bernet et al. (2004) reported on the occurrence of histopathological changes, primarily in the liver and gills of brown trout (*Salmo trutta*), following exposure to wastewater. Galus et al. (2013) reported on histopathological alterations in the kidneys and developing oocytes in zebrafish (*Danio rerio*) exposed to a pharmaceutical mixture of municipal wastewater. A comprehensive histopathological analysis was, therefore, incorporated into the present study.

Most of the studies examining the impact of OMPs on aquatic ecosystems were carried out in rivers and streams. Commonly, water samples were collected upstream and downstream from a WWTP discharge site, and then analyzed for the occurrence of OMPs (Ashton et al., 2004; Kolpin et al., 2004; Vieno et al., 2005). In several studies, fish were also collected in order to investigate the effects of TWW on fish health (Jobling et al., 2002; Schultz et al., 2010). Significantly fewer studies have inspected OMPs in water and sediments in lakes/ponds/wetlands that receive TWW (Metcalfe et al., 2003; Hoerger et al., 2014), and their effect on fish (Kavanagh et al., 2004; Kidd et al., 2007), while even fewer studies have performed multi-medium analyses of OMPs, considering together wastewater, surface water, sediment and biota, with an emphasis on estrogen bioaccumulation (Huang et al., 2013).

The recent trends and projection of increasing the reuse of TWW require the development of more efficient strategies to minimize the negative effects on the environment. It was hypothesized that under water scarcity conditions, TWW can be a reliable and sustainable water source for supporting a water reservoir for recreational activities. In order to test this hypothesis, this study evaluated the water quality and fish health in an artificial reservoir located in an arid climate, which regularly receives TWW and sporadic winter floods. The specific objectives of this study were to characterize the water quality in the Yeruham Reservoir by measuring the temporal distribution of nutrients; by measuring the occurrence of selected OMPs in water, sediment and fish tissues; and by evaluating fish health using histopathology.

2. Materials and methods

2.1. Study site description

The Yeruham Reservoir is an artificial water body located near the city of Yeruham in the Negev Desert, Israel (Fig. 1). The Negev Desert is an arid region with mean annual rainfall of <200 mm/year, mean annual temperatures of 18 °C, and an evaporation potential of over 2000 mm/year. Rainfall, temperature and evaporation data for this study were taken from the Israel Meteorological Service's website (http://www.ims.gov.il/), as recorded at the HaNegev Junction and Sede Boqer stations. Both stations are located <10 km from the Yeruham Reservoir. The reservoir was established in 1953, for the purpose of storing water from winter floods for irrigation. In order to create the reservoir, a dam of 80-m length and 15-m height was built at the intersection of the Yeruham and Revivim seasonal streams (Fig. 1). The reservoir receives flood water from the surrounding seasonal streams from sporadic rain events, which occur during the winter (November–April). When the reservoir is full, its area is 0.18 km^2, its volume is approximately 400,000 m^3, and the water level is 448.47 m above sea level.

Before the Yeruham WWTP was built in 2008, the reservoir received wastewater at different quality levels, including raw wastewater and wastewater after some stabilization in aeration ponds. Today, wastewater is treated by using conventional extended activated sludge technology and tertiary treatment by sand filtration and chlorination. Currently,