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Research article

Endocrine disrupting compounds in streams in Israel and the Palestinian West Bank: Implications for transboundary basin management

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ABSTRACT

Endocrine disrupting compounds (EDCs) frequently enter surface waters via discharges from wastewater treatment plants (WWTPs), as well as from industrial and agricultural activities, creating environmental and health concerns. In this study, selected EDCs were measured in water and sediments along two transboundary streams flowing from the Palestinian Authority (PA) into Israel (the Zomar-Alexander and Hebron-Beer Sheva Streams). We assessed how the complicated conflict situation between Israel and the PA and the absence of a coordinated strategy and joint stream management commission influence effective EDC control. Both streams receive raw Palestinian wastewater in their headwaters, which flows through rural areas and is treated via sediment settling facilities after crossing the 1949 Armistice Agreement Line. Four sampling campaigns were conducted over two years, with concentrations of selected EDCs measured in both the water and the sediments. Results show asymmetrical pollution profiles due to socio-economic differences and contrasting treatment capacities. No in-stream attenuation was observed along the stream and in the sediments within the Palestinian region. After sediment settling in treatment facilities at the Israeli border, however, significant reductions in the EDC concentrations were measured both in the sediments and in the water. Differences in sedimentation technologies had a substantial effect on EDC removal at the treatment location, positively affecting the streams' ability to further remove EDCs downstream. The prevailing approach to addressing the Israeli-Palestinian transboundary wastewater contamination reveals a narrow perspective among water managers who on occasion only take local interests into consideration, with interventions focused solely on improving stream water quality in isolated segments. Application of the "proximity principle" through the establishment of WWTPs at contamination sources constitutes a preferable strategy for reducing contamination by EDCs and other pollutants to ensure minimization of public health risks due to the pollution of streams and underlying potable groundwater.

1. Introduction

Contamination of streams with toxic substances and their rehabilitation have received considerable attention during the last few decades (Bernhardt et al., 2007, 2005; Plumlee et al., 2012). While rehabilitation relies mostly on scientific knowledge, successful rehabilitation of transboundary streams also requires agreements between countries; thus, on many occasions, non-scientific considerations are incorporated into rehabilitation designs (Kallioras et al., 2006). There are many cases where bi- and multi-lateral conventions regulate actions to ensure that good water quality in joint basins is maintained, and water quantity is

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shared based on the needs of the parties (Fischhendler, 2007; Shmueli, 1999). Management of transboundary streams becomes especially complicated, however, when an asymmetry exists between the riparian states. Asymmetry can be found in the stringency and scope of local regulations (e.g., water quality standards), the financial abilities of the parties, political power, existing economic interests, etc. (Brochmann and Gleditsch, 2012; Shmueli, 1999). Such underlying asymmetry characterizes many of the transboundary streams that flow from the Palestinian Authority (PA) into Israel (Tal and Katz, 2012).

Most of the coastal streams in the central region of Israel originate in the highlands within the PA (Fig. 1). While 96% of the wastewater in Israel is treated before reuse or release into the environment (Cohen et al., 2016; Tal and Katz, 2012), only about 20% of the raw sewage produced within the PA (including much of the sewage produced in Israeli settlements) is treated within the PA. Another 14% of the wastewater from the PA is captured and treated in Israel, while the rest of the raw wastewater (66%) is eventually released to the environment with approximately a quarter of it into transboundary streams (Cohen et al., 2016, 2011). As a result, many of these naturally ephemeral streams that receive wastewater have become perennial, flowing year-round. The rapid population growth in the region (Tal, 2016a), the increasing demand for water, and the lack of major WWTP construction due to lack of funding or political conflicts (Tal and Katz, 2012) are all expected to cause further stream deterioration.

The flow of untreated wastewater in the streams that meander through Palestinian and Israeli rural and urban environments raises various concerns. The immediate concern to public health and livestock is related to direct contact with the water that contains pathogens and contaminants. Another concern is the percolation of wastewater and contaminants into the groundwater since most of the upper segments of these streams flow over a karst bedrock overlying the Mountain Aquifer (Avisar et al., 2009). This aquifer is one of the major water reservoirs in the region, providing water to both the Palestinian and Israelis with 128 and 402 million m^3/year, respectively (Cohen, 2016). Several studies on the water quality in these transboundary streams were conducted during the last decade (Abramson et al., 2010; Angel et al., 2010; Asaf et al., 2007; Lipchin, 2014). These studies consistently confirmed that while pathogen and nutrient loads were significantly reduced during the flow of sewage in the streams, most of the contaminants (70–90%) were not reduced to non-toxic levels, thus posing significant health risks. In addition, Abramson et al. (2010) surprisingly found that both Israelis and Palestinians revealed common restoration preferences, including a similar willingness to pay for restoration. None of the abovementioned studies, however, looked at the occurrence and fate of micropollutants, a suite of chemical compounds that are found in wastewater at relatively low concentrations and are often found in aquatic environments (Peng et al., 2008; Schwarzenbach et al., 2010).

EDCs are one major subgroup of micropollutants (Luo et al., 2014). EDCs refer to a diverse range of chemicals; their sources range from industrial products (e.g., plasticizers, flame retardants), consumer products (e.g., synthetic hormones, detergents), biocides (e.g., pesticides), animal and human secretions (e.g., natural hormones) to various transformation products of contaminants (e.g., octylphenol) (Luo et al., 2014). Considerable research has been directed at environmental exposure to EDCs because of the adverse risks they pose to reproduction and other critical physiological functions in humans and wildlife species (Futran et al., 2015). Most of the studies about EDCs in streams focus on their toxic effects and their fate along the streams (Acuña et al., 2014; Backhaus and Karlsson, 2014; Schwientek et al., 2016).

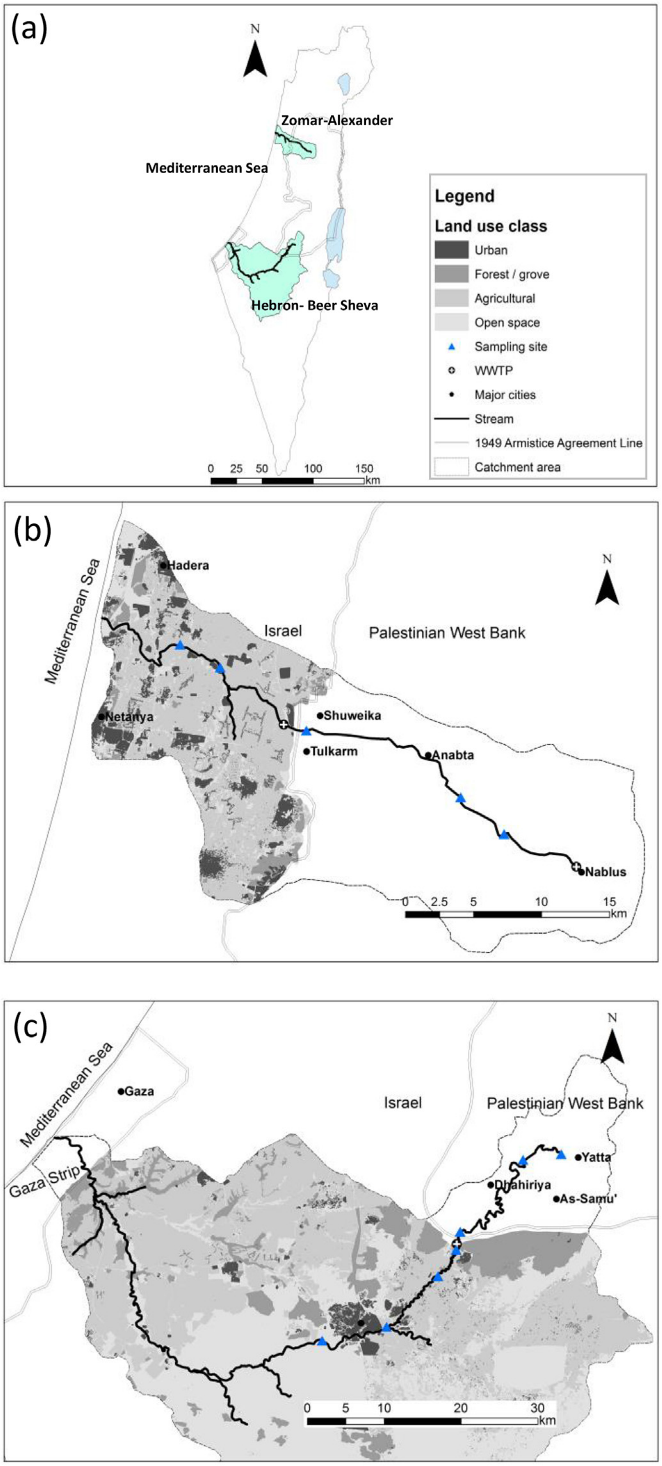

Fig. 1. Map of the study area showing borders and catchment boundaries (a), major cities, land use and sampling locations for the Zomar-Alexander (b) and the Hebron-Beer Sheva (c) catchments. Land use information in the PA was not available.

This study was designed in response to the severe gap in available information about the fate of EDCs in Mediterranean streams, especially on the sea's eastern side, and the implications for transboundary stream management in conflict regions. Local dynamics constitute an extreme case of how the release of EDCs upstream can affect communities downstream. Data are presented characterizing the EDC concentrations along two transboundary streams that originate in the Palestinian West Bank but soon cross into Israel, draining into the Mediterranean Sea (Fig. 1). The streams are located in a region that suffers from longstanding conflict with environmental management affected by the political and security instability, and decades of very modest cooperation in water management. We assessed how local geopolitical and socioeconomic dynamics influence the fate of EDCs along two typical transboundary streams. We also propose a viable management solution that will allow the two sides to launch interventions with mutual environmental and economic benefits.

2. Materials and methods

2.1. Study sites

The transboundary catchments of the Zomar-Alexander and the Hebron-Beer Sheva Streams were selected for this study (Fig. 1). Both streams originate in the Samarian and Judean Mountains within the Palestinian Authority and flow downhill to the west into the coastal region of Israel. The Hebron-Beer Sheva Stream reenters the Palestinian Gaza Strip before it empties into the Mediterranean Sea. The Mediterranean region's climate is characterized by a relatively short winter season with most of the rainfall occurring from November to March, and four hot dry summer months (Zimmo and Petta, 2005). The average winter and summer temperatures in Israel and the PA are 15 °C and 26 °C, respectively (Israel Meteorological Service, 2017). The average yearly precipitation varies greatly from north to south and is about 600 mm in the Zomar catchment and 200 mm in the Hebron catchment.

2.1.1. Zomar-Alexander Stream

The total length of the Zomar-Alexander Stream from its headwaters in the PA to the Mediterranean Sea is 50 km, and its catchment area contains some 600 square kilometers. The eastern edge of the Zomar-Alexander headwaters lies near the Palestinian city of Nablus, and the stream flows along 27 km in the Palestinian region (Fig. 1b). This stream was naturally ephemeral but became perennial in the 1950s, when raw domestic wastewater was discharged from the western neighborhoods of Nablus. A new WWTP was recently built in Nablus and has been operative since 2013. This WWTP utilizes an activated sludge technology and releases the effluents after secondary treatment into the Zomar Stream. Additional waste channels flow into the stream along its length from stone cutting factories, olive processing plants, and runoff from nearby agricultural areas (Shraideh et al., 2013; Tal et al., 2010). The stream crosses the 1949 Armistice Agreement Line into the Israeli side, where the flow is immediately diverted to the Yad Hana WWTP for treatment. This WWTP was built in 2003 as a temporary solution for capturing wastewater from the PA. Despite the increase in wastewater volume over the last decade, and the catastrophic incidents of akar release into the stream (the waste from olive oil production), no changes were made to the Yad Hana WWTP (The State Comptroller of Israel, 2017). The treatment is limited to primary processes including: solid separation by cone-shaped containers and oxidation in an aeration pond with an approximate residence time of two weeks. Then, the effluents are utilized for agriculture and, to a lesser extent, released back into the Alexander Stream (Fig. 1b and Appendix I).

2.1.2. Hebron-Beer Sheva Stream

The total length of the Hebron-Beer Sheva Stream from its headwaters to the Mediterranean Sea is 135 km, and its catchment area covers 3500 square kilometers. The stream's headwaters lie near the Palestinian city of Hebron, and the stream flows along 43 km in the PA before reaching the border with Israel (Fig. 1c). This stream was naturally ephemeral but has been perennial since the 1990s, when raw domestic wastewater was discharged from Hebron and the Israeli town of Qiryat Arbah. Additional waste streams flow into the stream along its length from stone cutting factories and runoff from nearby agricultural areas (Asaf et al., 2007; House of Water and Environment (HWE), 2012; Yaqob et al., 2015). Much like the Zomar-Alexander Stream, the Hebron Stream's water is immediately diverted to a primary treatment facility after crossing the 1949 Armistice Agreement Line into Israel. The treatment is primarily comprised of sediment settling ponds (House of Water and Environment (HWE), 2012; Tal et al., 2010). Then, the effluents are released back into the Beer Sheva Stream and flow toward the city of Beer Sheva and further west into Gaza until reaching the Mediterranean Sea (Fig. 1c and Appendix I).

2.2. Sample collection

Four sampling campaigns were conducted during the years 2013–2014 (two summer and two winter campaigns). Water samples were taken during each campaign, at five and seven locations along the Zomar-Alexander Stream and the Hebron-Beer Sheva Stream, respectively, using grab samples from the middle of the streams (Fig. 1). The two-liter samples were stored in precleaned amber glass containers, were acidified to pH 2 with HCl 6N to prevent microbial activity, and transported to the laboratory on the same day. The samples were kept at 4 °C until extraction (within 14 days). Sediment samples were taken at four and six locations along the Zomar-Alexander Stream and the Hebron-Beer Sheva Stream, respectively, only during the summer of 2013 and winter 2014. The samples were taken from the bottom of the stream, stored in pre-cleaned glass vials (40 ml) and transported to the laboratory on the same day of the sampling. The sediments were kept at −20 °C until the extraction and analysis (<1 year).

2.3. Sample preparation and chemical analysis

The same suite of EDCs was targeted in the water and sediment samples. Laboratory testing assessed the concentrations of: estrone, 17-β estradiol, estriol, testosterone, bisphenol A (BPA), octylphenol (OP), nonylphenol, Tert-nonylphenol, atrazine, and Dichlorodiphenyltrichloroethane (DDT). In addition, Carbamazepine (CBZ) was measured as a marker compound since it has been reported to behave conservatively in the environment (Buerge et al., 2009; Nakada et al., 2008).

EDC extraction from the water was done using solid phase extraction (SPE) with C18 Empore extraction disks following EPA protocol 539 (USEPA, 2010a, b). CBZ was extracted according to EPA method 525.2 (USEPA, 1998). The samples were extracted with methanol and were evaporated in a water bath (60 °C) under nitrogen to a final volume of 1 ml, which was kept in 20-ml glass vials at −20 °C until analysis.

Sediment sample preparation was done according to methods reported in the literature (e.g., Fernandez et al., 2009; Heidler and Halden, 2007; Pothitou and Voutsa, 2008). The samples were centrifuged under 4500 rpm for one hour and freeze-dried for three days. Phenanthrene D_{10} was used as the internal standard for CBZ. Extraction of the dry sediments was done according to EPA protocol 1694 for hormones and phenols (USEPA, 2007). Briefly, 10 gr of the dried sediments were extracted with Acetone: Hexane 60:40 using an accelerated solvent extraction (ASE) device (Dionex ASE 200, Dionex; Sunnyvale, CA). The extraction conditions were set at a temperature of 75 °C and a pressure of 1500 psi. A preheating period was set at one minute and a static extraction period of five minutes, which was followed by a solvent flush of 60% of the cell volume. This cycle was repeated three times.

Extracts were evaporated to a volume of 3 ml under nitrogen gas. Cleaning of the extracts was then done by Florisil cartridges. Samples were then evaporated again to a volume of 1 ml for CBZ. For EDCs, samples were completely dried and re-dissolved by adding 1 ml of methanol. The final extracts were kept in 20-ml glass vials at −20 °C until analysis.

The instrumental analysis was done according to EPA protocols 1694, for hormones and phenols (USEPA, 2010b), and 525.2, for CBZ (USEPA, 1995). CBZ was analyzed with GCMS (TRACE 2000 GC) equipped with an Rxi®-5Sil MS column (Restek, Bellefonte, PA), 30 m*0.25 mmID*0.25 μm and an ion trap mass spectrometer (FINNIGAN POLARIS/GCQ plus). EDC analysis was done by ES-LCMSMS (Waters Xevo TQS Instrument), and Acquity UPLC BEH C18 1.7 μm 2.1*50 mm column for separation. The minimum quantification limit (MQL) values of the EDCs, as well as the marker compound in the water and the sediments, are shown in Appendix II. The differences in MQL values are caused by sample volume differences and the matrix effect on each substance.

2.4. *Quality assurance/quality control (QA/QC)*

The sampling and analytical scheme was performed according to the aforementioned EPA analytical methods. With each batch of samples, the following controls were performed: laboratory and field blanks, laboratory fortification blank and matrix (spiked blank and samples). The accuracy of the measurements were ±30%. Target compounds were identified by comparison of retention times and full mass spectrum (EPA 525.2) or 2–3 multiple reaction monitoring (MRM) transitions (EPA 539/1698 (U.S. EPA, 2007) for EDCs in water and sediment, respectively) of the substance in the sample and its authentic standard, which were tested under the same conditions. Analyte concentrations were calculated using standard internal calibration procedures. Internal standards that were used included Phenanthrene D$_{10}$, -D$_{16}$, Estradiol $^{13}C_6$, Estriol $^{13}C_3$, Estron $^{13}C_6$, and Testosterone D$_5$. Analytical standards were purchased from Sigma-Aldrich, CIL. Reagents for extractions and instrumental analysis included methanol, ethyl acetate, methylene chloride, sodium sulfate, hydrochloric acid, and ammonium acetate. All analytical grade reagents were purchased from Sigma-Aldrich and J.B. Baker.

3. Results and discussion

3.1. *EDC distribution along the streams*

To illustrate the spatial patterns of EDCs and the role of treatment in their removal, CBZ and EDC concentrations were plotted against the distance from their sources (Figs. 2 and 3). Additional information on the concentrations in water appears in Appendix III, while the measurements of the concentrations in the sediments appear in Appendix IV. CBZ concentrations in the water were quite constant along the streams and revealed no sensitivity to the changing conditions or treatment at the border (Fig. 2). Moreover, no CBZ was adsorbed to sediments (Fig. 3). This pattern also suggests that the streams consisted mainly of raw wastewater, and dilution from interactions with other water sources (e.g., upwelling groundwater or other inputs to the streams such as seasonal rain and runoff) is not significant. It can be inferred that evaporation during flow does not cause any substantial decline in concentrations, analogous to a removal process. The CBZ patterns verified that it can also be efficiently used as a nonreactive tracer in polluted streams as was shown in other aquatic systems (Buerge et al., 2009; Clara et al., 2005; Nakada et al., 2008).

In most cases, the fate and transport of EDCs on the Palestinian side was similar to those of a nonreactive tracer (i.e., patterns were similar to those of CBZ). Some changes were observed in the estrone and estriol concentrations in the Zomar Stream, probably due to leakage from animal feedlots and grazing activities, since they were absent at the source due to removal at the Nablus WWTP. On the other hand, the data in Fig. 2a clearly show that the concentrations of most EDCs in the Zomar-Alexander Stream decreased at the border due to treatment at the Yad Hana WWTP. This, however, was not the case in the Hebron-Beer Sheva Stream where concentrations were similar on both sides of the border. Further downstream in the Beer Sheva Stream, the EDC concentrations started to decline, which suggests that the removal of sediments at the border had a positive effect on the ability of the stream to remove EDCs (Fig. 2b).

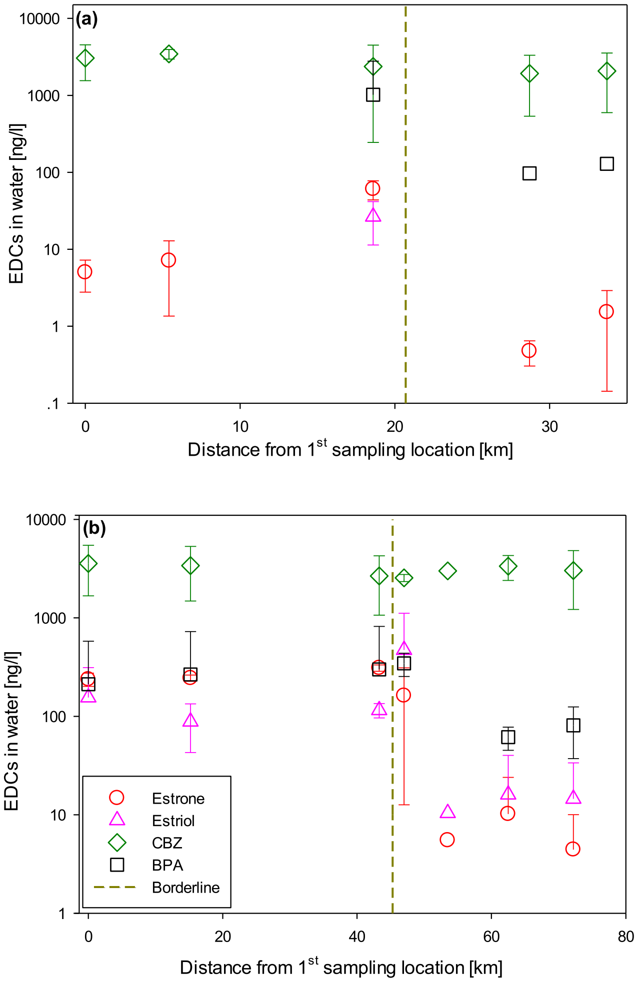

Fig. 2. Average concentrations of EDCs in the water along the Zomar- Alexander Stream (a) and the Hebron-Beer Sheva Stream (b). Standard deviations are based on three samples in Hebron and Zomar, and four samples in Beer Sheva and Alexander. The zero distance marks the entry location of the wastewater to the streams.

The ability of a stream to uptake nutrients or other contaminants along its flow path is commonly termed “in-stream attenuation” (or “self-purification”). In-stream attenuation often involves interactions between complex physical, chemical, and biological processes (Spellman and Drinan, 2001). Under various conditions, streams can remove nutrients relatively efficiently. At the same time, however, the removal of organic micropollutants (e.g., pharmaceuticals, industrial compounds, EDCs, etc.) usually require much greater distances than for nutrient removal (Barber et al., 2011). Thus, the assumption that in-stream attenuation can be

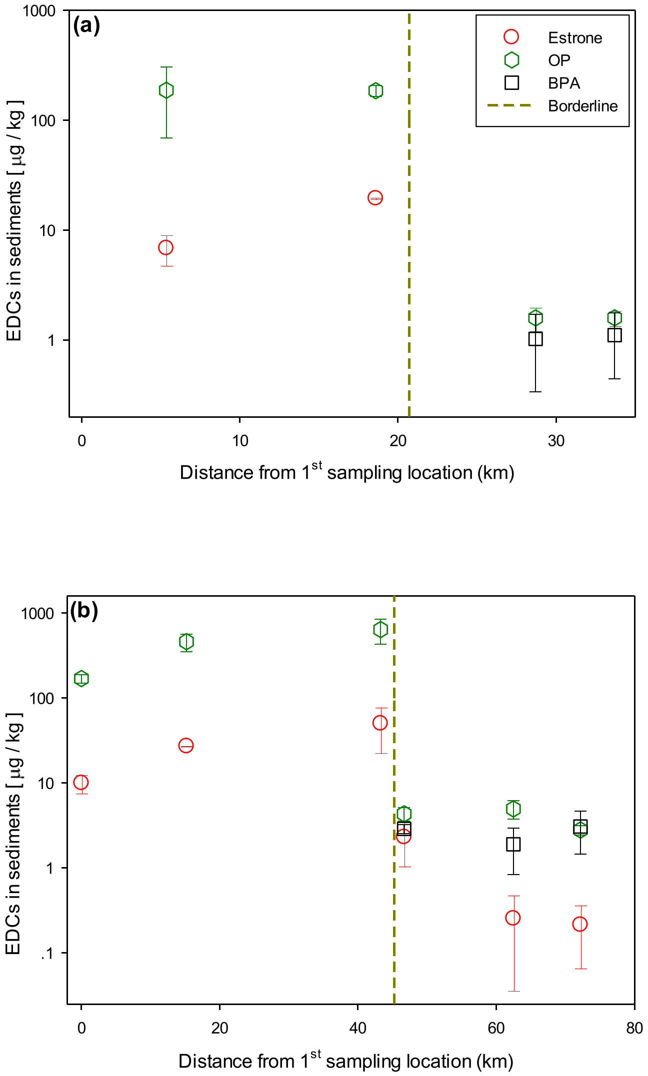

Fig. 3. Average concentrations of EDCs in sediments along the Zomar- Alexander (a) and the Hebron-Beer Sheva (b) Streams. Standard deviations are based on two samples. The zero distance marks the entry location of the wastewater to the streams.

used to mitigate the problem of EDC contamination in surface waters appears to have little empirical basis. It is certainly not relevant in relatively short water courses, especially in streams that receive raw wastewater. The decline of EDCs further downstream in the Beer Sheva Stream (Figs. 2 and 3) suggests that sediment removal in the WWTP enables the degradation of EDCs, which does not occur on the PA side of the border. It is postulated that the removal of particles from the water enabled sun penetration deeper into the water column supporting both and enhancing degradation due to photolysis and algae growth that promote oxygen production, which support aerobic biodegradation (Acuña et al., 2014; Muñoz and Guieysse, 2006). Despite the clear trend of decline due to treatment at the border, the current data set cannot be used to explicitly identify the degradation mechanisms or mass fluxes of EDCs in the different sections along the streams.

3.2. Mitigation of pollution in shared catchments

Despite innumerable indications during the last few decades of widespread contamination across Israeli-Palestinian catchments, the situation remains largely unchanged (Israel Water Authority, 2009; Lipchin, 2014; Tal and Katz, 2012). This is surprising because since 1994, policy discussions and government activities have focused on stream restoration (Asaf et al., 2007; Israel Ministry of Environmental Protection, 2015; The State Comptroller of Israel, 2017). It is even more surprising since Israeli and Palestinian communities share common perceptions about the severity of stream contamination and the availability of potential solutions, despite objective social and economic differences. In a transboundary contingent value study, Abramson et al. (2010) reported a high commitment to stream restoration and irrigation on both sides. Nevertheless, irrigation with treated wastewater is still not widely accepted in the PA, partly because of social and psychological barriers (Al-Sa`ed, 2010).

The contrast in water strategies is partly driven by the fundamentally disparate socioeconomic conditions: the average monthly salaries in the PA and Israel are $590 and $2880, respectively (PCBS, 2016; CBS, 2017). Yet, the fact that Palestinians are willing to pay more of their limited income for stream restoration than their Israeli neighbors may be linked to the severity of the environmental conditions they face as upstream riparian inhabitants of the most polluted segments (contiguous to sewage sources) of transboundary streams. Israelis on the other hand, are willing to pay relatively less because they have more options for recreation and their daily lives are less fragmented geographically, allowing them to travel greater distances for recreation (Abramson et al., 2010).

There are many definitions for "*stream rehabilitation*" but all involve ensuring reasonable water quality as a basic requirement for healthy ecosystems and habitatble environments. Wastewater capture and effective sewage treatment are essential to meet the water quality standards (e.g., nutrients, organic loads, pathogens, etc.) required for stream rehabilitation or for reuse via irrigation. Today, the treated wastewater standards differ between Israel and the PA (Al-Sa`ed, 2010; Inbar, 2007). The Palestinian standards are designed for regulating irrigation. However, the permissible concentrations of pathogens, nutrients and other pollutants are still higher than those required in Israel prior to stream discharge.

While wastewater treatment is a critical first step for stream rehabilitation, other restoration activities are needed to revive the region's transboundary streams. These include catchment scale land use management (Kandler et al., 2017), riparian buffer zone development (Kandler et al., 2017; Turnock, 2001), and in-stream clean-up of sediments (Shmueli, 1999), as well as a range of other recreational and environmental initiatives (Tal, 2017). The widespread occurrence of EDCs in the water and the sediments of the studied streams (Figs. 2 and 3) demands immediate attention. In recent papers, the relevant concentrations of key EDCs in wastewater were measured, and a cost-benefit analysis was conducted to determine the best approach to treating this problem (Dotan et al., 2016; Gordon-Kirsch et al., 2017). Nevertheless, to the extent they exist today, regulations of organic micropollutants (OMPs), in general, and EDCs, in particular, are promulgated primarily for drinking water (Israel Ministry of Health, 2013; USEPA, 2016; WHO, 2011). This is ironic, as EDCs only emerged as a salient issue on the environmental policy agenda as a result of their impacts on natural systems, primarily reproductive damage to organisms in surface water ecosystems (Arcand-Hoy and Benson, 1998; Colborn et al., 1993).

No formal EDC water quality standards exist for environmental systems, and thus, no routine monitoring of EDCs takes place in streams, rivers and lakes, in order to evaluate these water bodies' ecological status and potential damage to them. This is partly due to the analytical difficulties associated with reliable monitoring, the high analytical costs, and inadequate knowledge regarding the associated health risks. Israel and Palestine's situation is far from unique; regulation of EDCs in aquatic systems in the EU and the US is also extremely limited, primarily due to the lack of a clear framework that defines the risks from individual OMPs or mixtures of them (Backhaus and Karlsson, 2014). While characterizing the health risks associated with EDC exposure is difficult for many reasons, the ecological impacts have been widely documented for some time (Colborn et al., 1996). Morever, notwithstanding present gaps in scientific understanding, it is widely accepted that OMPs, and specifically EDCs, have negative impacts on the environment, which were confirmed by recent research about this largely unaddressed environmental challenge (e.g., Gavrilescu et al., 2014; Jiang et al., 2013; Luo et al., 2014).

The results presented in this study corroborate a multitude of other cases that have demonstrated the inability of streams to remove EDCs over considerable distances (Tamtam et al., 2008). As the human footprint across the globe expands, the problem of EDC contamination in streams is becoming ubiquitous and persistent. In general, present estimates reveal that 71% of transboundary streams are severely affected by humans, with many people also suffering significant health problems associated with degraded water quality (TWAP, 2017). The preferred approach for addressing this problem is to tackle stream contamination as close as possible to its source. This is often referred to as the “proximity principle,” a widely accepted axiom in environmental management (New South Wales, 2017; Okuda and Thomson, 2007).

Despite efforts to reduce point and non-point sources, the overall challenge of maintaining the quality and ecological integrity of local streams remains a vexing problem, especially when mitigation activities are not coordinated at the scale that includes an entire catchment area (Peña, 2002; Sadoff and Grey, 2002). When streams flow across international boundaries, solving environmental problems becomes an even greater challenge due to the differences in regulations, socioeconomic statuses, and preexisting conflicts (Toset et al., 2000; Wolf, 1998). The contrasting EDC concentrations and exposures identified in this study constitute a particularly conspicuous example of these challenges, manifesting the profound asymmetries between the Israeli and Palestinian realities.

In order to attain a viable solution for transboundary streams, in general, and those shared by Israel and the PA, in particular, we outline four major typologies of transboundary catchments that suffer from contamination (Fig. 4). For the cases shown in Fig. 4a and c, the upstream sections are located in developed countries. The socioeconomic status of developed countries usually creates sufficient capacity to maintain reasonable wastewater treatment and pollution control. In such cases around the world, cooperative frameworks, in the form of joint committees or international organizations, are frequently established to manage streams and rivers at a level that ensures acceptable water quality and ecological health. Through transboundary cooperative standards and coordinated interventions, such institutional configurations have also proven capable of initiating successful restoration efforts in contaminated streams. Europe has been particularly conscientious in this regard, within the EU's Water Framework Directive (WFD).

One success story for the typology shown in Fig. 4a is the Rhine River that flows through six countries, but receives wastewater from nine. In 1963, the states bordering the Rhine River ratified the Convention of the International Commission for the Protection of the Rhine (ICPR) in response to pervasive deterioration in water quality. The participating riparian states (Switzerland, France, the Netherlands, Germany, Luxembourg, and the European Union since 1976) agreed on discharge reductions to increase the oxygen concentrations and improve the ecological status of the river (Mostert, 2009; Shmueli, 1999). The exceptional progress attained in protecting the Rhine can be attributed to the wide engagement and compliance by all the parties, creating a rehabilitation model that has been adopted in other transboundary basins around the world.

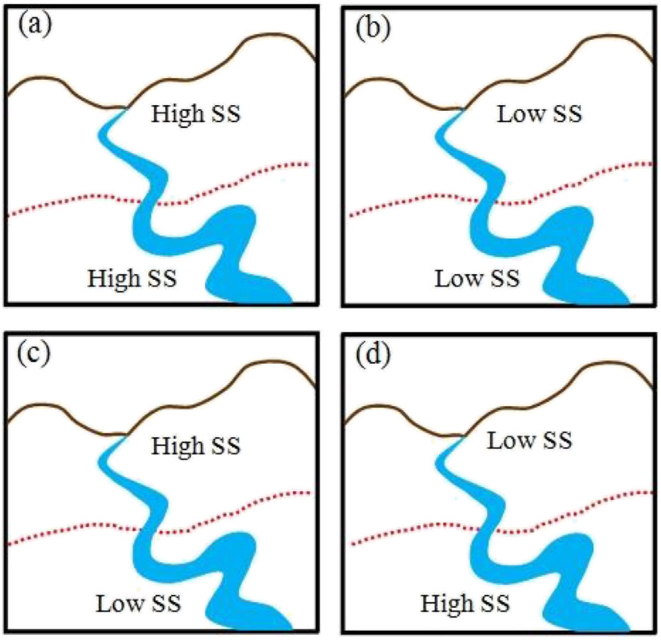

Fig. 4. Four major typologies of communities sharing the same catchment.“High SS” represents a developed economy with high socioeconomic status, while “Low SS” represents a developing economy with low socioeconomic status. Dashed red line indicates a border.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The Colorado River, flowing from the US to Mexico, is another case exemplifying the typology shown in Fig. 4c. The river is managed by the International Boundary & Water Commission (IBWC), an international body created by the US and Mexico in 1889. In 1944, a Water Treaty was established between these two countries to coordinate their water allocations in the basin (Carter et al., 2017). The treaty addresses the salinity problem that arises from the massive use of the Colorado River's water for agricultural production, as well as industrial and domestic demands on the US side of the border. The flow reduction caused by water diversions, along with evaporation losses from reservoirs in the upstream segments within the US, has led to concentration increases of solutes and caused deterioration in water quality further downstream within the Mexican segments (Carter et al., 2017; Kallioras et al., 2006). As part of the Colorado River treaty, the US agreed to improve the water quality on the Mexican side and to facilitate environmental solutions through binational efforts. For example, the US funded a clean-up program in the Mexicali Valley lands damaged by salty water and also constructed a desalination plant in Yuma, Arizona (IBWC, 2017; Peña, 2002; Carter et al., 2017). Despite the potential use of a desalination plant that was constructed to improve the river's water quality, the plant has rarely been used due to high operational costs and the unexpected excess flow in the Colorado River in the years following the plant's construction (Carter et al., 2017).

Another example of US efforts to undertake unilateral efforts with transboundary benefits involved diverting highly saline irrigation waters into the Cienega de Santa Clara wetlands, near the Gulf of California (Carter et al., 2017). In short, given the asymmetrical economic capacities within the river basin, progress in attaining mutual water quality goals was made possible by the willingness of the US to utilize its advantageous financial circumstances to support a range of environmental solutions.

Unfortunately, emulating such dynamics is not possible in situations in which a developing counry is situated in the upstream sections of a basin, such as the dynamics shown in Fig. 4b and d.

In cases in which inadequate financial resources or professional capacity (shortage of technical knowledge) preclude the establishment of advanced water treatment facilities, external funding has proven to be invaluable in making meaningful progress (Darakas, 2002; Hills et al., 1998; Kallioras et al., 2006). Such a case is illustrated in Fig. 4b. At the same time, when external involvement and support are unavailable, conflict or at least heightened tensions may arise. Such disputes emerged between Sudan and Egypt over the Nile River, as well as between Pakistan and India over the Indus Basin (Miner et al., 2009; Wolf, 1998).

In countries with low socioeconomic capabilities, such as those shown in Fig. 4b, the salient issue of concern is often water *quantity*. For example, the treaty on the Ganges-Brahmaputra only addresses water allocation and not its quality, despite the fact that water quality is actually poor (Shmueli, 1999). This is probably due to the immediacy of the benefits associated with a minimum guaranteed supply of water rather than the more amorphous gains from improving water quality. It is also often assumed that once sufficient water is secured, further efforts to improve quality can be made (El-Fadel et al., 2003; Yoffe et al., 2003). On the other hand, in more affluent regions, such as those shown in Fig. 4a, the incentive for cooperation more frequently involves water *quality* (Toset et al., 2000). In cases such as in Fig. 4b, identifying mechanisms to increase financial support has proved to be critical in generating peaceful solutions (Shmueli, 1999).

The last typology illustrates the complex case of an asymmetrical structure in which a developing country with low socioeconomic status is located upstream of a developed country (Fig. 4d). This case represents the situation in most of the streams traversing the PA into Israel, as well as various other cases around the world for example, the Tijuana River that flows from Mexico to the US (Frisvold and Caswell, 2000; Sánchez-Munguía, 2011), the Senqu River that flows from Lesotho to South Africa (Willemse, 2007) and, to a lesser extent, the Nisa River that flows from the Czech Republic to Germany (Kandler et al., 2017). The latter case illustrates how the transboundary water issue can be resolved by agreements and joint committees. Nonetheless, it involves countries (the Czech Republic and Germany) with much smaller discrepancies in socioeconomic status than those separating Israel and the PA.

The most simple and conventional concept for solving transboundary issues is the “polluter pays” principle. However, this paradigm is often irrelevant in river basins when one or more of the riparian entities face financial limitations, or when there is meaningful asymmetry in economic capabilities. In asymmetrical situations, other alternatives need to be developed as illustrated in the case of the Tijuana River, where the “polluter pays” principle failed (Fischhendler, 2007). When the “polluter pays” principle cannot be applied, alternative *cost-burden* principles that take into consideration political and economic asymmetries should be implemented in order to provide reasonable solutions (Fischhendler, 2007). The cost-burden principles can range from equal payment to a calculus where an ability to pay is figured in and the beneficiary pays the difference. Despite the existence of such creative models, finding the most appropriate approach requires considerable time for discussions and trust, comodities which currently remain scarce in the Israeli Palestinian context.

During the past several decades, the cooperative environmental dynamics between Israel and the PA have largely been characterized by stagnation. Recently, Israel's State Comptroller, typically restrained on such politically charged topics, issued a blistering report about Israel's lack of initiative in resolving transboundary water problems (The State Comptroller of Israel, 2017). This position is confirmed in the findings of this research and in a litany of previous studies (Abramson et al., 2010; Angel et al., 2010; Asaf et al., 2007; Tal et al., 2004).

One example of the present pathology involves the planned upgrade of Israel's Yad Hana WWTP, located in the center of the country, on the border with the PA. The upgrade is designed to cope with the increasing volumes of wastewater and the seasonal inflows of akar-residuals from olive oil production, characterized by high organic and chemical loadings. The anticipated estimated investment should reach the sum of about 80 million USD, which will probably be deducted from Palestinian tax revenues. But alternatively, a coordinated action, launched by the Israeli–Palestinian Joint Water Committee (JWC) might be able to offer a more promising cost-effective strategy (the JWC was founded in 1995, but essentially ceased to function in 2000).

A more plausible idea might be to use the same amount of money to invest in wastewater treatment and management within the PA contiguous to the olive oil production facilities, with the JWC providing technical support and monitoring performance levels. Such a strategy would yield similar results in the receiving waters of Israel's Alexander Stream, but would also serve to benefit the Palestinian and Israeli environment by preventing groundwater pollution caused by percolation of the contaminated stream water into the aquifer below. Palestinian farmers and municipalities could be provided treated wastewater for agriculture, and health hazards along the stream could be meaningfully reduced. It can be argued that at the moment, the greatest barrier to expediting such a logical solution is the fundamental lack of confidence prevailing between the parties. To be sure, the Israeli-Palestinian conflict dynamics do not originate in the contamination of shared streams. The unhealthy geopolitical situation and the fragmented control of the Palestinian West Bank surely contribute to the lack of progress in finding a way forward in joint rehabilitation efforts of contaminanted river basins. The fact that wastewater flows from the PA into Israel historically has been singled out by politicians, exacerbating existing suspicions and contributing to an atmosphere of enmity. Because such dynamics are not uncommon in most of the transboundary streams in the region, there is a pressing need to seek better environmental outcomes. Preventing the release of contaminants into upstream sections of transboundary streams through source reduction should, therefore, constitute a paramount policy priority.

At present, reduction of contamination loads at the source is difficult due to lack of funding for constructing new WWTPs or even operating existing WWTPs in the PA. In cases where some reduction can be achieved in the WWTPs, lack of control of non-point sources may lead to the re-appearance or increase in concentrations of various contaminants (e.g., estrone and estriol in the Zomar Stream, Fig. 2a).

The contrasting economic conditions between Israel and the PA, as manifested by the disparate technical capacities and wastewater infrastructure, make the search for a viable solution a daunting task. This asymmetry led Israeli water managers to adopt an in-stream intervention that captures wastewater as it enters Israel. While certain improvements in water quality can be achieved by the presence of WWTPs at the border for some parameters, our findings suggest that such a strategy ultimately produces dissatisfying results and leads to the release of numerous contaminants, including nutrients, metals, and organic compounds, into the ground and surface waters of both parties (Figs. 2 and 3, Angel et al., 2010; Cohen, 2016; Lipchin, 2014; Tal et al., 2010).

A more promising approach would be to provide economic incentives for wastewater treatment and industrial pretreatment at the pollution sources. Reuse of treated wastewater for irrigation and agricultural development in the PA would become possible, offering a significant economic opportunity (Levine and Asano, 2004; Tal, 2016b), even as it is still considered with caution by Palestinian society (Al-Saʽed, 2010). The combination of environmental restoration and economic development through agriculture offers a win-win environmental/economic dividend that is much more compelling and likely to receive international funding (Bennett and Ragland, 1998; Twite, 2010). Nonetheless, experience in Israel (which recycles over 86% of its sewage) suggests that such a policy commitment must be predicated on exceptionally high treatment levels. Otherwise, the long-term damage to the soil and its fertility may be prohibitive (Tal, 2016b). At the moment, tertiary treatment has not been adopted in the active WWTPs in the PA and should be considered in future plans.

To make meaningful progress, political and financial opportunities must converge (Shmueli, 1999). Both sides should understand that they have common interests and goals that are best achived through cooperative ventures. Such were the circumstances existing between Jordan and Israel during the peace negotiations when many of the water-related controversies between the two countries were resolved (Sosland, 2007). Moreover, a sustainable solution requires not only technological fixes but institutional arrangements that will allow the sides to jointly conduct an adaptive management strategy that responds to ever-changing conditions (Tal, 2016c). The existing Joint Water Committee needs to become active once again. It is critical that its members be granted the authority to improve ongoing communications and enjoy greater scientific independence, enabling the parties to work together to solve future pollution problems (Jayousi, 2010; Kallioras et al., 2006; Kerret, 2010) Working on a catchment scale, rather than in an area defined by an arbitrary geopolitical border, is the only way to make meaningful basin-wide progress in the long run (Page and Kaika, 2003).

4. Conclusion: a call for reform

In transboundary resources, asymmetry in economic and technical capacity can be reflected in contrasting situations when poorer countries are located upstream from wealthier ones. EDC exposure offers a good example of these dynamics. The change in the concentrations of selected EDCs in water and sediments along the two transboundary streams crossing from the PA into Israel reveals that no natural attenuation occurred on the Palestinian side. Concentrations of EDCs, and especially estrogenic compounds, decreased after the wastewater underwent treatment on the Israeli side of the 1949 Armistice Agreement Line. Present treatment focuses on sediment removal, which indeed results in reductions of up to three orders of magnitude in EDC concentrations in the sediment. This removal rate is far higher than that observed in the water. Solid separation by cone-shaped containers and oxidation in an aeration pond proved much more efficacious for removing EDCs than sediment removal through gravity settling.

Israel has come to address the asymmetry in sanitation infrastructure between it and its neighbor by treating sewage flowing in transboundary streams on its side of the border, so that the wastes enter Israel only as treated effluents. This strategy is unsatisfactory for removing EDCs and other wastewater-derived contaminants because it does not present a comprehensive solution to the parties' public health and water quality problems, which needs to address groundwater and sediment contamination. This applies to the streams of both riparian and transboundary groundwater aquifers. If Israeli water managers, cooperating with their Palestinian counterparts chose to follow the “proximity principle” and invest in WWTPs within the PA, it would surely yield greater benefits to both parties.

This strategy should be combined with a basin-scale approach to creating a master plan that encompasses the needs of all partners. Enlisting support through public opinion and professional assistance can also contribute to the integrity of the decision-making process. For example, such a bottom-up, professional approach has emerged in the design of a masterplan for the Yarkon-El Auja catchment (Yarqon River Authority, 2017) by the Yarkon River Authority and its Palestinian partners. For any solution to be devised, it is essential that the parties work together to identify the best cost-burden principle and the potential sources of international aid to expedite implementation of a common, basin-wide strategy.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2017.09.017.

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