Chapter

TRUMPED BY TRADITIONAL HAZARDS: EDC EXPOSURE FROM RECYCLED WASTEWATER COMPARED TO OTHER WATER RELATED RISKS IN DEVELOPED AND DEVELOPING NATIONS

Vivian Futran Fuhrman[1,*], Alon Tal[1], Alfred Abed-Rabbo[2], Nader el-Khateeb[2], Nina Gordon-Kirsch[1], Tal Godinger[3], Wa`d Odeh[3] and Shai Arnon[3]

[1]Institute for Dryland, Environmental and Desert Research,
The Jacob Blaustein Institutes for Desert Research,
Ben-Gurion University of the Negev, Sede Boqer, Israel
[2]Water and Environmental Development Organization (WEDO),
Bethlehem University, Bethlehem, Israel
[3]Zuckerberg Institute for Water Research,
The Jacob Blaustein Institutes for Desert Research,
Ben-Gurion University of the Negev, Sede Boqer, Israel

ABSTRACT

Israel is the global leader in wastewater reuse making it the ideal test case to investigate human exposure to contaminants via recycled wastewater pathways. Studies around the world have revealed that wastewater frequently contains endocrine disrupting compounds (EDCs) that are not completely removed by traditional treatment. As these compounds can harm ecological and human health, it was initially hypothesized that residual EDCs were contributing to reproductive problems in Israel's population. The fate of EDCs from wastewater effluent in Israel and the Palestinian West Bank's shared water basins was assessed over a two year period, and the associated health risks and economic costs of competing wastewater treatment options evaluated. Results from this analysis can inform both developed and developing nations since Israel highly treats and reuses most of its

* Corresponding Author: Vivian.futran@gmail.com.

wastewater while only a small percent of sewage undergoes any treatment in the Palestinian territories. EDCs in the region's aquatic environment were measured at concentrations consistent with global averages. According to modeling results, human exposure to bisphenol A via recycled wastewater is likely small compared to ingestion through food. While a potential health risk was identified from bisphenol A in recycled wastewater, it was most pronounced in extreme exposure situations and when reproductive capacity was already compromised. In the West Bank, a cost-effectiveness analysis determined that the marginal improvement in removal rates of estrogens from building tertiary versus secondary level wastewater treatment facilities would not justify the added cost to the Palestinian Authority. Secondary treatment of sewage removed EDCs sufficiently, and the money saved by not investing in tertiary treatment could be better used to provide more essential sanitation services. Tertiary treatment produces other important environmental benefits in which countries like Israel may wish to invest, but it yields only marginally better EDC removal, so developed countries aiming to reduce overall EDC exposure should target sources other than treated wastewater. These findings suggest that EDCs from treated wastewater merit continued research, and demonstrate the importance of environmental cooperation in regions with bifurcated development. However, as EDCs are not the biggest risk to human health in developed or developing nations at this time, they should not be the primary driver for policy governing wastewater management.

INTRODUCTION

As water scarcity threatens a growing number of regions worldwide, more countries are turning to reuse of treated wastewater effluent to balance their water budget even while the environmental and health consequences of unregulated organic contaminants in this source of water are still under investigation. For example, in Israel ambitious government goals have driven innovation in water management and treatment technology [1] helping position it as a leader in the field [2]. Israel recycles its municipal wastewater at a globally unprecedented rate, recapturing 96% for treatment to at least secondary levels and reusing 86% [1]. This is more than 80 times the rate of <1% wastewater recycled by the US [1, 3, 4], and over four times the second highest rate of about 20% in Spain [1]. While an "integrated water management" system has helped Israel overcome an arid climate and a limited supply of fresh water, pioneering technologies like wastewater reuse have raised concerns regarding unknown health implications.

At the same time, neighboring communities in the Palestinian territories face exposure to contaminants in untreated and poorly treated wastewater. The Palestinian Authority (PA) still faces chronic shortages in water availability and acute water quality risks including exposure to microbial pathogens and other traditional contaminants [5, 6], even as emerging contaminants such as endocrine disrupting chemicals (EDCs) gain increasing attention on the international stage.

EDCs are a heterogeneous category of "chemicals of emerging concern" commonly found in wastewater systems [7, 8]. While hormones are endogenously produced and emitted by plants, animals, and humans, natural concentrations in the environment are augmented by anthropogenic sources of synthetic EDCs found in pharmaceuticals, personal care products, foods, plasticizers, pesticides, and other household, industrial, and agricultural products [9–12]. These can leak directly into the aquatic environment or be discharged into the sewage system by humans where their fate depends on the type of treatment the wastewater receives [13]. Today EDCs are ubiquitous in aquatic environments [10, 14].

EDCs mimic or disrupt hormone function regulated by the endocrine system [15]. Exposure to EDCs can impair normal endocrine system functioning via estrogen, androgen, or thyroid pathways, disrupting various related networks and processes in the body [15]. This can damage wildlife [16–19] and has the potential to damage human health [20–24]. EDCs have been linked to a range of problems including adverse reproductive and developmental health effects in males and females, congenital malformations, hormone mediated cancers, and metabolic processes among others [25]. Concentrations of EDCs as low as parts-per-trillion can disturb endocrine processes [26–28], especially for vulnerable subpopulations in hormone-driven developmental stages such as pregnancy, adolescence, and menopause [29–32].

Health risks associated with EDCs will become easier to assess as the vast number of chemicals with endocrine potential are evaluated and better characterized. In the meantime, scientists and risk assessors can still advise the policy community regarding best practices for avoiding dangerous exposure to EDCs. The goal of this analysis is to investigate the transport and fate of EDCs from wastewater effluent in Israel and the West Bank to determine whether they pose a risk to human health. It is especially germane in this region as Israel's effluent reuse rate is unparalleled while Palestinians still discharge copious amounts of sewage, often untreated, into the ambient environment. In evaluating the resulting hydrological, economic, and health consequences, this study seeks to provide a clearer picture regarding whether EDCs should be a driver for public policy in both developed and developing nations. It also highlights important management strategies to protect environments shared by countries in close proximity with extremely different economic realities.

The chapter presented here was completed as part of a PhD dissertation under a larger joint research initiative between Ben-Gurion University of the Negev and The Water and Environmental Development Organization (WEDO), and supported by the USAID Middle East Regional Cooperation (MERC) Program (grant TA-MOU-11-M31-015). The primary objective of this MERC project was the collaboration of a joint Israeli-Palestinian research team in identifying and measuring endocrine disrupting compounds (EDCs) in the aquatic environment of Israel and the Palestinian West Bank at different stages in the wastewater treatment process, as well as in different environments that have a long history of receiving wastewater discharges in the region (e.g., streams and irrigation). The goal of the project was to take the field (water sampling) and laboratory (chemical analysis) results, and translate these raw data into actionable recommendations for the region. This called for a combination of methodologies from various disciplines: public health/risk assessment, economics, and policy assessment.

BACKGROUND

Wastewater Management in Israel and the West Bank

In Israel, almost all municipal wastewater is recaptured, directed to wastewater treatment facilities, and treated to a minimum of secondary (biological) treatment levels, or even to tertiary (chemical and advanced) treatment levels. Israel currently reuses most of the 500 million cubic meters per year of municipal wastewater it produces [33]. Effluents are then allocated for industrial uses, stream rehabilitation, landscaping, and above all agricultural irrigation. Already 50% of Israeli agricultural irrigation water came from recycled sewage in 2014, and Israel plans to increase its rate of municipal wastewater reuse from 86% to 90% over the next 5-7 years [1]. To keep up with increasing consumption and met these goals, Israel plans to augment artificial water sources (desalination, seawater and imports), doubling net allocations to agricultural irrigation by 2050 [34] without "risk to soil and water sources" [35].

Although they share a border as well as most of their surface catchments and major groundwater aquifers, Israel and the Palestinian territories face extremely different realities with regards to water resources. While Israel is a developed country with highly advanced national water management and governance systems [54], the PA—in charge of most of the populated areas in the West Bank—is considered an economically developing country. Palestinians face very limited water resources and physical infrastructure, weak institutions and operators, political hurdles, stressed finances, and demographic growth [55, 56]. The only wastewater reuse that occurs is local, small scale, and considered a negligible amount [56]. Consequently, there is a deficit of water and sanitation infrastructure, services, and operations in the PA [57]. Israel captures and treats approximately 15-17 million cubic meters of the PA's sewage water every year at the expense of the PA [6, 58]. This water is then sold and reused inside of Israel without payment to the PA for the value of the natural resource [6].

As of 2012, only 31% of the Palestinian population was connected to a wastewater collection network [56]. The water infrastructure suffered an average of 30% loss from leakage [56] and included only two fully functioning municipal wastewater treatment plants (WWTPs) in 2014 [59]. Subsequently, 65% of Palestinian sewage is collected in cesspools that leach into the ground while 33% is dumped directly into dry river beds that flow freely throughout the year [56]. This untreated wastewater can percolate into the ground, contaminating aquifers [5, 56, 60]. At present, there are streams in the West Bank comprised solely of wastewater [61] which release foul smelling odors [62] and can expose locals to pathogens from human and industrial waste [5]. Many of these streams flow into Israel as the West Bank is topographically located at the head of the catchment, which contributes to the long lists of grievances the Palestinian and Israeli governments have against each other with regards to shared water resources.

Reproductive Health and Evidence of Emerging Contaminants

Studies around the world have demonstrated that EDCs are commonly found in wastewater [36–39]. Many of these compounds are not completely removed by primary, secondary, or sometimes even tertiary wastewater treatment [40–43] and can only be eliminated through advanced treatment techniques [30, 44]. It was therefore hypothesized that wastewater treated to conventional levels in Israel might be contributing to the release of trace amounts of EDCs in effluent [10, 45–47]. Once in the environment, these compounds can make their way into fresh water where they are increasingly ubiquitous [10, 48–50], or if used for irrigation, can be taken up by crop plants [51–53]. This recognition elicited alarm as to whether the concentration of EDCs in Israel's aquatic environment might be increasing with every new cycle of use, increasing human exposure and threatening health.

Growing reproductive health problems in Israel suggested there may be meaningful environmental exposures to EDCs in the region. Evidence includes a decreased age of menarche in female army recruits [63], a steady decline in the age of puberty among the general population of Israeli girls [64], an increase in the prevalence of male factor infertility [65–67], an increase in testicular cancer rates [68], a reduction in male sperm count and motility [69], a decrease in normal sperm morphology among sperm donors [70], and a decrease in sperm motility and concentration among sperm donors [71]. If these trends continue, the average Israeli male could be characterized as "reproductively impaired" by 2020 according to World Health Organization (WHO) criteria [72]. Despite possible confounders and other limitations associated with this data, it was initially suspected that emerging contaminants in treated wastewater effluent such as EDCs could be partially responsible for deleterious health trends [72, 73].

Previous studies in Israel have detected contaminants of emerging concern across various environmental media. In the 1980's and 1990's, high concentrations of industrial solvents were detected from wells beneath a field that had been irrigated with recycled wastewater [74–76]. In 2008, Chefetz et al. reported pharmaceutical compounds in secondary treated wastewater at concentrations similar to those described in wastewater effluents, and described their movement through irrigated soil. Avisar et al. studied the long term impact of wastewater irrigation and found that high concentrations of antibiotics had moved through soil and into the water table below [77], which added to a list of environmental antibiotics and metabolites identified locally [78]. Using carbamazepine as tracer, Gasser et al. [79] demonstrated percolation into a section of the Israeli Coastal Aquifer from a wastewater effluent recharge system nearby. In 2011, Shenker et al. found that pharmaceuticals could be taken up by crops irrigated with reclaimed wastewater at realistic levels. Finally, in 2014 Malchi et al. discovered measurable levels of pharmaceutical compounds in root vegetables including varieties eaten raw. For example, there were 5-10 nanograms per grams of carbamazepine found in carrots (with the precise amount depending on the soil treatment). Although these studies did not focus on EDCs, they demonstrated the leaching potential and subsequent risk of organic compounds originating in wastewater.

Previous Regional Investigation of EDCs

Despite the steady stream of research evaluating the environmental effects of wastewater reuse in Israel, no similar studies of wastewater's effect on Palestinians had been undertaken heretofore. This study was undertaken to fill that gap, as well as to provide regional information on EDCs in the aquatic environment. Preceding this study, there had been minimal data collected on EDCs in this region [80–82] even though these compounds are of growing global concern. A comprehensive survey of EDC concentrations in the region's water resources had yet to be conducted, and there had not been an assessment undertaken of these chemicals' presence following different treatment technologies. In addition, there had not been a transboundary project systematically assessing the fate and implications of EDCs from wastewater throughout the Palestinian/Israeli shared aquatic environment.

The physical proximity of Israel and the PA makes it possible to study whether EDCs should be a water policy priority in developed nations, developing nations, and areas straddling both conditions. Such an asymmetrical geographic juxtaposition is common throughout the world, with extreme economic and environmental disparities found between contiguous countries such as the US and Mexico, the Dominican Republic and Haiti, North and South Korea, etc., as well as areas like Eastern and Western Europe. As such, this study has far-reaching relevance.

ANALYSES

Hydrological Sampling and Chemical Analysis

In 2012, the study presented here was launched to investigate the fate and transport of EDCs from recycled wastewater in the aquatic environment of Israel and the West Bank. The project was a collaborative effort between Israeli and Palestinian researchers utilizing a range of expertise, and the first such project focusing on EDCs. The study was designed to be the most comprehensive investigation of EDCs in the region to date, and the first in the context of recycled wastewater. Four water sampling campaigns were conducted in 2013 and 2014 (two summer and two winter) covering 60 locations across Israel and the West Bank. The samples reflected various treatment processes from raw sewage to primary, secondary, and tertiary treatments, all the way through discharge into the irrigation water system or into local streams and groundwater. All water samples underwent chemical analysis at the laboratories of Israel's Ministry of Health using U.S. Environmental Protection Agency (EPA) standard methods [83].

As no significant seasonal differences were detected in between measurements, the concentration values were averaged across the three campaigns included in analysis (summer 2013, winter 2014, and summer 2014). In total, five EDCs were detected in Israel including endogenous estrogenic hormones (estriol, estrone), xenoestrogens (bisphenol A and 4-tert-octylphenol), and one estrogenic compound used in personal care products (triclosan) (See Table 1 below). One additional estrogenic hormone was detected, 17-beta estradiol, but only below the limit of detection and was thus not included in analysis.

The same estrogenic EDCs were identified in the West Bank. Figure 1 below shows the EDCs detected in influent (raw/untreated) and effluent (treated and released) wastewater at the only two major WWTPs functioning in the West Bank at the time of analysis [59]. Levels of estrone and estriol in raw and treated wastewater were similar across both Palestinian WWTPs, while triclosan was only detected in Al Bireh WWTP, bisphenol A (BPA) was only found in Al Bireh's influent, and 4-tert-octylphenol was not detected in the influent or effluent of either WWTP. Comparing these two WWTPs to the averages across Israeli WWTPs, estrone and estriol in influent were higher in the West Bank—close to or over 100 nanograms per liter (ng/L)— than in Israel where they were under 100 ng/L. Nonetheless, the concentrations in the West Bank were very close to those measured in Israel's effluent (all under 5 ng/L). BPA in the influent of Al Bireh was higher than in Israel by about 500 ng/L, but was reduced to zero in both the West Bank and Israel after treatment. Triclosan levels in the influent and effluent in Al Bireh were comparable to Israeli levels.

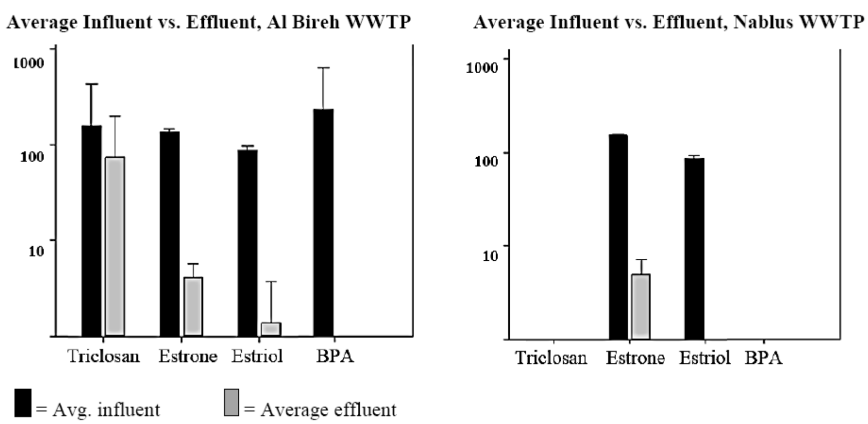
Table 1. Range, average, and median concentrations of EDCs measured in raw and treated wastewater in Israeli WWTPs (ng/L)
(Adapted from Godinger [83])

	Raw WW			**Treated WW**			**Limits of Detection**
Compound	**Range**	**Average**	**Median**	**Range**	**Average**	**Median**	**Summer ’13 / Winter ’14 / Summer ’14**
Estriol	0-124	51	46	0-9.4	1.7	0	.03/.05/.05
Estrone	0-181	65	72	0-13	2.1	0.3	.01/.05/.05
BPA*	0-6793	801	238	0	0	0	5/1/1
OP**	0-4960	691	0	0-50	3.3	0	5/1/1
TCS***	162-6800	1272	981	0-400	80	0	5/5/5

*BPA= Bisphenol A
**OP= 4-tert-octylphenol
***TCS= Triclosan

Both Al Bireh and Nablus treat wastewater to secondary levels, whereas five out of the six Israeli WWTPs included in this study treat wastewater to tertiary levels (and the sixth to secondary levels). Nonetheless the secondary technology utilized in the PA appears to be removing EDCs adequately, at rates comparable to those in Israel, despite the significantly higher Israeli investment and capacity.

Of the 60 locations sampled across Israel and the PA, 19 in the PA contained raw wastewater lacking any treatment. The remaining 41 locations consisted of fresh water or wastewater that received some treatment—even if only at a basic level—and were then released. These samples, representing “treated” wastewater effluent as it moved through the environment, were the subject of further examination. (See Appendix A for average concentration of the EDC in these samples). Estradiol equivalencies (EEQ) were calculated for the five EDCs detected in both Israel and the West Bank. EEQs express estrogenic potency relative to estradiol [85–87] which effectively normalized units so that concentrations can be directly compared.



Adapted from Odeh [84].

Figure 1. EDC Concentrations in raw and treated wastewater in PA WWTPs (ng/L).

Estradiol equivalencies (EEQs) are calculated by multiplying each compound concentration by its estradiol equivalency factor (EEF) and is set to one for estradiol [86, 88]. An EEF is defined as half the maximal effective concentration of estradiol divided by half the maximal effective concentration (EC) of another EDC ($EC50_{Estradiol}/EC50_{EDC}$). An EEF is multiplied by a compound's concentration to calculate the compounds estradiol equivalent (EEQ). In this analysis, the EEFs for estrone, estriol, and BPA were borrowed from a paper by Vega-Morales et al. [86] which averaged values from a mix of *in vitro* bioassays to find average EEFs. Triclosan and 4-tert-octylphenol were not included in this paper so the EEF for triclosan was taken from Blavier [89], and for 4-tert-octylphenol an average of EEFs from across the literature [41, 90, 91] was used to approximate the scope of the EEFs used for the other compounds. The EEFs used for each EDC in this analysis are as follows: .11 for estrone and estriol, 5E-08 for triclosan, .00021 for 4-tert-octylphenol, and .00039 for BPA.

It is important to note that EEQs are a toxicological as opposed to a biological concept. The value in finding total EEQ and percent contribution to total EEQ is based on the assumption that the estrogenic potency of these EDCs is always additive which may not be the case. For now, estrogenic bioassays converted into EEQs provide a way to calculate the influence of these compounds, however the data on potency and endpoints of various EDCs is still growing which affects our understanding of EDCs individually and in mixtures [92]. While estrogenic compounds are relatively well studied compared to other EDC groups [93], the assumptions underlying their assessment may change with the advancement of our knowledge in the future.

EEQs were calculated for each compound concentration at the different locations across Israel and the West Bank where treated wastewater effluent was sampled (see Appendix B for average concentration of the EDC expressed as EEQs). The EEQs were averaged across all locations to yield one average EEQ for each compound, and the contribution that each compound made to estrogenicity was expressed as percent of total EEQ. This was done for all treated wastewater samples in the region (Table 2), for the samples from Israel only (Table 3), and for the samples from the West Bank only (Table 4).

Table 2. Estrogenic Equivalencies and Contribution to Total Estrogenicity for Treated Wastewater Samples from Israeli and the West Bank Combined

	Estrone	Estriol	Triclosan	4-tert-Octylphenol	BPA	Total
Average (ng/L)	3.00	2.45	93	3	11	
Standard Deviations	3.90	4.99	149	2	47	
N (number of samples)	41	41	41	27	41	
EEQ (average)	0.3	0.3	4.65E-06	1.28E-03	4.47E-03	0.605
Contribution to Total EEQ	54.56%	44.49%	<.01%	0.21%	0.74%	

The EEQ data facilitate a comparison between the estrogenic contributions of each EDC to help understand their relative impact on health. It is clear from this analysis that estrone and estriol make the largest contribution to estrogenicity across the board. Estrone makes the largest contribution when all locations are considered together (approximately 55%) as well as when

Israeli locations are considered in isolation (approximately 61%), and estriol makes the largest contribution in West Bank locations (approximately 69%). This is consistent with findings that endogenous hormones tend to be the main contributors to the estrogenicity of sewage [94–96] as they are much more potent than synthetic EDCs [97]. Estrone and estriol are equally estrogenic relative to estradiol (i.e., both have EFFs of .11), however results here show that treated wastewater in the West Bank contains about twice the concentration of estriol compared to estrone whereas estrone predominates in Israel.

Table 3. Estrogenic Equivalencies and Contribution to Total Estrogenicity for Treated Wastewater Samples from Israel

	Estrone	Estriol	Triclosan	4-tert-Octylphenol	BPA	Total
Average (ng/L)	3.41	2.15	110	3	14	
Standard Deviations	4.21	2.76	162	2	54	
N (number of samples)	32	32	32	18	32	
EEQ (average)	0.4	0.2	5.51E-06	5.33E-04	5.28E-03	0.617
Contribution to Total EEQ	60.76%	38.30%	<.01%	0.09%	0.86%	

Table 4. Estrogenic Equivalencies and Contribution to Total Estrogenicity for Treated Wastewater Samples from the West Bank

	Estrone	Estriol	Triclosan	4-tert-Octylphenol	BPA	Total
Average (ng/L)	1.55	3.50	32	4	4	
Standard Deviations	2.12	9.66	58	1	1	
N (number of samples)	9	9	9	9	9	
EEQ (average)	0.2	0.4	1.59E-06	8.63E-04	1.60E-03	0.558
Contribution to Total EEQ	30.48%	69.08%	<.01%	0.15%	0.29%	

The EEQ data also provide a way to assess the additive estrogenic potency of all five EDCs cumulatively. According to this analysis, after averaging across locations and campaigns and then summing across compounds, the total EEQ was similar for Israel (approximately .62 ng/L EEQs) as for the West Bank (approximately .56 ng/L EEQs). It should be noted that this data may be skewed as there were nearly 4 times more data points for Israel (32 sampling locations) than for the West Bank (9 sampling locations). This may have rendered a more representative picture of Israel than of the West Bank. Future research can improve the resolution of such an evaluation.

Based on the chemical results described above, two additional types of analyses were performed: human health risk and cost-effectiveness.

Exposure Assessment and Relative Risk

For this study on Israel and the West Bank, an assessment of exposure and subsequent health effects was conducted using the chemical analysis results and a specially designed model. EDCs present many challenges to conventional risk assessment methods rendering it imprudent or impossible to calculate *absolute* risk from EDCs. This is in part due to gaps in knowledge regarding EDC functioning, and in part because EDCs often function differently than traditional contaminants [98]. However, risk assessment tools can still be used with caution to evaluate EDCs [99] alongside appropriate risk communication and full transparency regarding steps taken and uncertainty involved. Risk can be estimated relative to other sources or over time, different exposure scenarios weighed, or health outcomes approximated where dose-response curves are available.

The model in this study was designed to calculate exposure to EDCs for a hypothetical scenario, and to predict a potential health impact associated with the given exposure. The exposure and risk associated with BPA— a widely manufactured industrial EDC— were calculated as a "proof of concept" to demonstrate that such a model is effective methodology for calculating exposure, and connecting information to determine a health outcome. The model was designed to be very conservative in order to capture a "worst-case" exposure scenario. It was presumed that if exposure is relatively safe in this scenario, then the general public in a real life scenarios is all the more likely to be safe. As oral ingestion is humans' primary route of exposure to BPA, intake of BPA from recycled wastewater was estimated from a combination of two exposure pathways: drinking groundwater infiltrated by treated wastewater, and eating crops irrigated with treated wastewater. This exposure scenario is hypothetical as none of the well water tested thus far was contaminated. However, the scenario is plausible, especially as water scarcity in the region increases and water demand is not met [58], driving the need to dig water wells even where it is illegal and unregulated. This makes the Palestinian population particularly vulnerable to EDC exposure through this source.

The model demonstrated that, even in a conservative scenario, the exposure to BPA from recycled wastewater through these two sources combined was still slightly less than that calculated by the European Food Safety Authority to come from food in a typical Western diet [100]. This implies that the exposure of the general public to BPA through recycled wastewater is most likely lower than that through diet. To provide context for the calculations of BPA exposure from recycled wastewater, Israeli biomonitoring data of measured concentrations of BPA in the population's urine was used to back-calculate aggregate BPA exposure (from all sources combined). The total BPA exposure was found to be beneath the threshold set forth in the safety standards of the United States and European Union of 4 micrograms per kilogram of body weight per day [100].

Finally, the model was able to connect the exposure estimate with a human health outcome. Using a concentration-response curve established for human males [101], the model calculated the impact had by BPA exposure through treated wastewater on four key semen parameters: concentration, volume, progressive motility, and normal morphology. The apical effect on male fertility was predicted by the model using a modified version of the van der Steeg equation [102] to translate the impact on sperm parameters into effect on chances of fertility within one year. It was found that the health impact on sperm would be appreciable most of all for 1) the most extreme intake situations (i.e., the highest percentiles of exposure), and 2) individuals already demonstrating compromised sperm health (i.e., those individuals in the lowest percentiles of sperm function). (Publication of full model design and findings is forthcoming. Contact authors for more details).

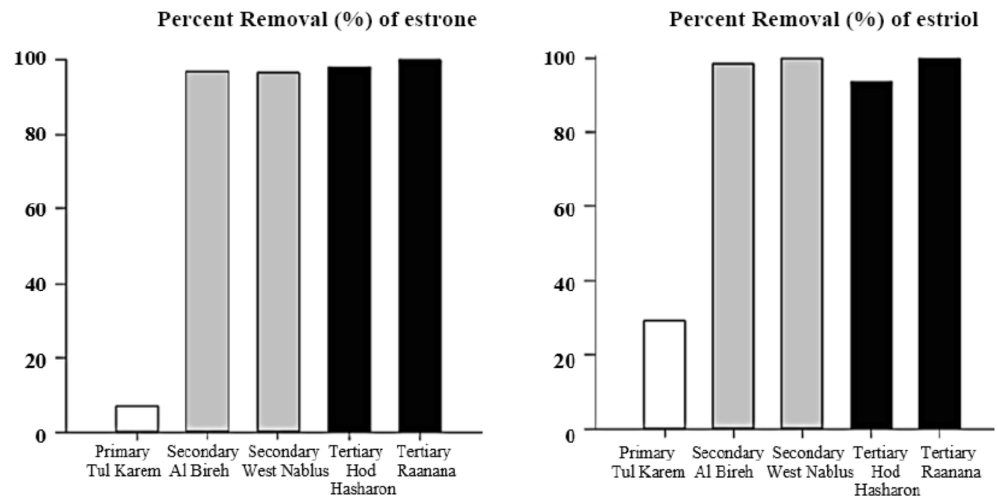
There are limitations inherent in this modeling and assessment, and a case study on BPA cannot guarantee that findings apply to other EDCs. Future epidemiological and biomonitoring studies in the region are necessary to confirm this, and will need to be complimented by improvements in our understanding of EDC characteristics including mechanisms of action, mixture effects, low dose effects, and other basic elements of function and process. Moreover, additional case studies are needed to determine whether the same is true for compounds including potent endogenous hormones. However, available data on BPA indicate that complete removal from wastewater effluent constitutes an inefficient method of exposure prevention when compared to reducing other sources of exposure.

This is especially true in light of the high expense required to treat wastewater to advanced levels. Israel is already investing in treating its wastewater to high levels, but the PA has limited resources that must allocated to high priority needs at the expense of lower priorities. Thus, it is particularly important for the PA to understand the cost of tertiary wastewater treatment relative to the gains, and in consideration of other alternative uses for these funds. This is discussed in the next section below.

Cost-Effectiveness Analysis

The second analysis conducted based the chemical results was a cost-effectiveness analysis (CEA) for the West Bank. This CEA was intended to determine whether it would be better to maintain primary and secondary wastewater treatment facilities in the West Bank which remove most of the EDCs from wastewater, or to pay for tertiary treatment levels which remove slightly more EDCs from wastewater. A CEA compares mutually exclusive scenarios to assess their effectiveness per dollar spent. The ratio of a scenario's total cost to its quantified effectiveness is compared; the cost is divided by effectiveness to procure a cost-per-unit effectiveness measure for each option. The smallest ratio indicates the greatest effectiveness at the lowest cost [103]. A CEA cannot dictate if an investment is or is not worthwhile because it does not consider any non-market or environmental variables. However a CEA can compare between the effectiveness of investment choices based on a comparison of cost and incremental gain [104].

For this West Bank CEA, one primary municipal WWTP (Tul Karem) and two secondary (Al Bireh and West Nablus) were used as a case study. As no tertiary level WWTPs exist in the West Bank, two from Israel (Hod Hasharon and Raanana) were used as a surrogate since most of the relevant characteristics (local materials, electricity and wages) are comparable across the border [103]. For the CEA effectiveness measure, estrone and estriol removal rates were calculated by comparing concentrations in samples of wastewater influent and effluent at the WWTPs of different treatment levels (see Figure 2 below). These two compounds were chosen for the case study as they contribute the most to the water's estrogenicity, and because there was adequate data available for both. Approximately a ten-fold increase in removal rates was observed between primary and secondary treatment levels, but only a slight increase of 2% between secondary and tertiary treatment levels. Yet attaining such a modest incremental improvement between secondary and tertiary treatment doubled the total cost of WWTP building and operations.



Adapted from Gordon-Kirsch [103].

Figure 2. Removal Rates at Each WWTP.

To calculate the cost values used in this CEA, the start-up costs of building and of operating a plant over time were used (See Table 5 below). When a large secondary WWTP in the West Bank (West Nablus) is compared to a somewhat smaller tertiary WWTP in Israel (Hod-Hasharon), associated costs for the secondary WWTP is lower across the board: 25% less for building costs, 26% less for yearly operations, and 30% less for the combined total (See Table 6 below).

It is important to consider size and capacity of WWTPs prior to drawing conclusions from cost comparisons of wastewater treatment levels. When cost was calculated per cubic meter of treated water and amortized (where initial costs are spread out over the life of the WWTP), secondary WWTPs are still less expensive at 2.3 NIS per cubic meter of wastewater (amortized) than tertiary WWTPs at 2.43 NIS per cubic meter of wastewater (amortized) when they are performing at full capacity, albeit by a smaller margin of 5% [103]. Using these effectiveness and cost measures, the Cost-Effectiveness (CE) ratio was calculated for secondary and tertiary WWTPs with costs including start-up and operation. Secondary treatment had a significantly lower CE ratio (See Table 7 below) confirming that this constitutes the optimal wastewater management strategy in the West Bank with regards to estriol and estrone removal [103].

Table 5. CEA Case Study WWTP Inflows, Startup Costs, and Operational Costs
(Adapted from Gordon-Kirsch [103])

WWTP	Treatment	Daily average inflow (m^3/d)	Building Costs (NIS)	Yearly Operations + Maintenance (NIS/yr)
Tul Karem	Primary	~5,000 (cap 13,000)	2.302 million	120,000
Al Bireh	Secondary	~6,000 (cap 5,000)	34.72 million	1.88 million
West Nablus	Secondary	~9,000 (cap 15,000)	104.64 million	2.424 million (below inflow cap)
Hod Hasharon-Kfar Saba	Tertiary	25,895	138 million	14 million
Raanana	Tertiary	12,301	ND*	ND*

* ND = no data. Raanana WWTP provided no operational costs, so the individual cost of treatment per unit was used.

Table 6. Comparing Building, Operating, and Total Costs of CEA Secondary and Tertiary WWTPs in New Israeli Shekels (NIS) and US dollars (USD)

	Unit	Building Cost	Yearly Operational Cost	Total Cost
Secondary WWTP	Million NIS	104.64	2.42	107.06
	Million USD	27.35	.63	27.98
Tertiary WWTP	Million NIS	138.00	14.00	152.00
	Million USD	36.09	3.66	39.75
Savings of Secondary vs. Tertiary WWTP		25%	26%	30%

Table 7. Cost Effectiveness Ratio Values for Estrone and Estriol
(Adapted from Gordon-Kirsch [103])

	Estrone	Estriol
Al Bireh Secondary Treatment	1.93	1.90
West Nablus Secondary Treatment	2.03	1.96
Hod Hasharon Tertiary Treatment	2.46	2.58
Raanana Tertiary Treatment	ND*	ND*

*ND= No data

The CEA presented here indicates that investing in upgrading WWTPs to tertiary levels in the West Bank would not be an optimal strategy in terms of cost per unit removal of estriol and estrone. The vast majority of chemicals and any associated human health risks that they might pose by disrupting the endocrine system are eliminated when secondary level WWTPs are running smoothly, producing water safe enough to reuse for producing many agricultural products that are not eaten raw (e.g., cotton and fodder) [105,106]. In fact, some farmers in Israel argue that wastewater treated to secondary levels is better than water treated to tertiary levels as it contains more nutrients and saves money on fertilizer [107,108]. In light of the Palestinian government's limited resources in the face of many competing priorities, money saved by building WWTPs to secondary instead of more expensive tertiary levels could be utilized to expand water and sanitation services and sewage infrastructure in general producing far greater benefits to human and environmental well-being.

In cases where international donors are willing to fund the building costs of water infrastructure projects in the PA [109], there are several reasons why it would be wise for the Palestinian government to advocate for secondary WWTPs in lieu of tertiary level technologies at this time. First, the former cost less to build which will allow donors to stretch their budget to additional sanitation initiatives. For instance, surplus funding could go towards reducing the vast number of Palestinians who do not receive basic sewage collection and treatment services at all. Supplemental irrigation projects could also be funded with this money to help make use of treated wastewater (which is currently an under-tapped resource in the Palestinian territories), or to increasing local human capacity through training of engineers and other water management professionals.

Second, if outside funding covered the up-front capital costs of building WWTPs, the Palestinian government would be able to operate double the number of secondary WWTPs for the same money as they would spend to operate one tertiary WWTP, or it could operate one secondary WWTP for twice as long. This could double the number of people that would receive treatment of their sewage for the same cost. Building a secondary WWTP would help the PA make the most use of potential water resources in the face of growing scarcity due to climate change and a growing population [57]. Such a strategy would help decrease present Palestinian dependence on purchases from external sources such as *Mekorot*, the National Israeli water utility, or from private delivery trucks [57].

There is a real life example underway as plans to build a secondary WWTP in the Hebron Governance of the West Bank move forward. This WWTP will serve an estimated 104,000 people [103], and will treat sewage coming from 80% of the municipality. The plan involves four phases:

1) Building the WWTP to serve the immediate needs of treating 80% of the existing sewage;
2) constructing an agricultural irrigation system for reuse of the treated effluent;
3) building a network of sewers to capture the remaining 20% of the municipality which is unsewered;, and
4) capacity building among communities in the area [57].

Financing the first phase of building the WWTP with a capacity to treat 15,000 CM/day of wastewater would cost an estimated 61.65 million USD, and phases two through four will cost a total of approximately 40 million USD. If the finding of the CEA is correct—building a tertiary WWTP can cost double the price of building a secondary WWTP— the anticipated savings from building a secondary treatment level WWTP in Hebron could be used to implement phases two through four. Alternatively, the extra money could be used to build another secondary WWTP that treats an additional 15,000 CM/day, easily covering the wastewater treatment needs of a medium sized city, or five smaller towns [110].

Operating twice the number of secondary WWTPs could also double the environmental gains by reducing the untreated wastewater that is presently released into the environment carrying pathogens and contaminants including EDCs. After treatment, this water could instead be used to grow crops and ameliorate the pervasive water scarcity in the West Bank. Already, a lack of wastewater treatment has contributed to extensive contamination of aquifers shared by Israel and the PA [111–114]. Studies have demonstrated that continuous contamination of the Eastern Mountain aquifer providing water to the West Bank would seriously undermine its future ability to provide any safe water [57].

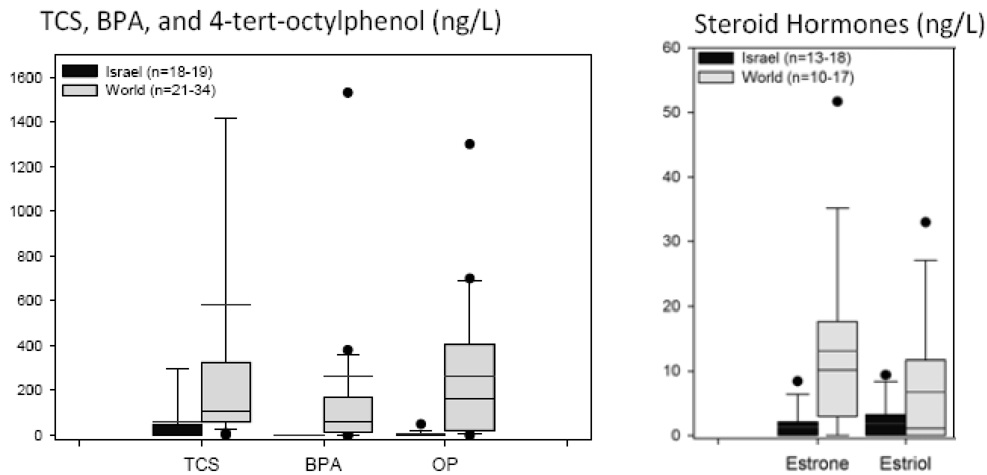
In Israel, the considerations driving wastewater treatment decision were fundamentally different from this CEA conducted for the West Bank for two reasons. First, Israel has already overcome most of the basic water quality and water access challenge that are still the top problems in the PA. Second, even though irrigation with recycled water has contributed emerging contaminants in Israeli soil and groundwater, other well-known contaminants were the main concern. While secondary level WWTPs remove organic load as well as pathogens, they do not address boron, brines, or heavy metals which can contaminate soil [108]. These are released in effluent used for irrigation and can quickly build up to levels that threaten groundwater, soil, and crops. Consequently, the upgrade to tertiary treatment was first pursued in Israel to reduce levels of nutrients (nitrogen and phosphorous) in wastewater effluent; EDC removal was an unintended benefit. Wastewater treated to this level can expand the safe uses available for treated wastewater while avoiding nutrient buildup.

To finance such an investment in Israel, local authorities are usually responsible for operations and maintenance costs of WWTPs, while the initial costs of building or upgrading a WWTP are generally paid for by the Israeli national government. Israel's Water Authority has a "Master Plan" in place that estimates a cost of 150 million USD for building and upgrading WWTPs in Israel between 2015 and 2019 to meet national goals, and a cost of 673 million USD for treatment of wastewater [34]. Since then, an independent analysis estimated that the cost of upgrading Israeli treatment facilities to meet new standards would actually be 228 million USD with an annual cost of 33.23 million USD for operations and maintenance (132.92 million USD over 4 years) [115], which totals 360.92 million USD.

RESULTS

Israel: Advanced Wastewater Treatment for EDC Removal vs. Other Water Recycling Risks

In Israel, the combined estrogenicity of the five EDCs measured in treated wastewater was found to be approximately .617 ng/L EEQs, but it is important to put this number into context. Comparing daily EEQ doses from recycled wastewater calculated in this study to oral exposure from other sources, two orders of magnitude more estrogen was consumed via food and pharmaceuticals than through recycled wastewater [116], and four orders of magnitude more is consumed taking oral contraceptives [117]. EDC levels in the region's treated wastewater as a whole were found to be within global averages, and concentrations in Israel's treated wastewater were found to be below global averages [83]. See Figure 3 which compares concentrations in Israel to those from a combination of global studies [90, 97, 118–144].



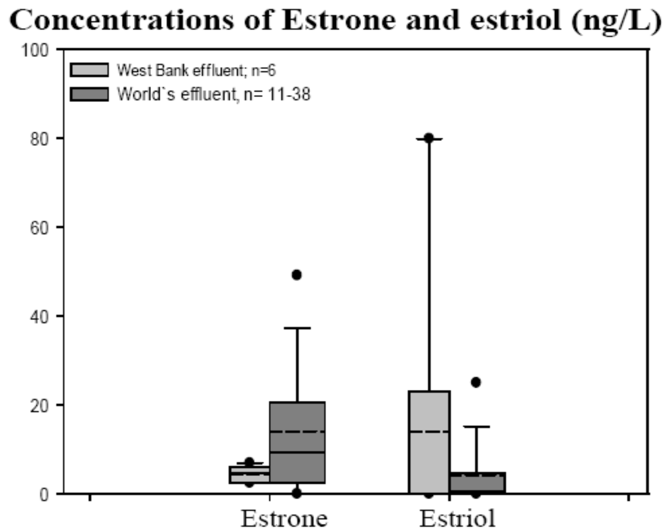
Box edges at 25th and 75th percentiles, error bars at 10th and 90th percentiles, red lines at averages, black lines at medians, and (●) at extreme values.
Adapted from Godinger [83].

Figure 3. EDCs Concentrations in Israel and Globally.

Until recently, only concentrations greater than 1 ng/L EEQ from in vitro assays were thought to be associated with adverse effects on individuals in vivo. Today, safe EEQs are believed to be lower: between 0.1 to 0.4 ng/L for wildlife [145], suggesting that levels of estrogenicity in Israel's treated wastewater effluent may threaten ecological health. Health effects of BPA exposure via recycled wastewater were only noteworthy where there was usually extreme exposure and/or preexisting semen conditions. This merits further study, both to confirm these findings and expand them through case studies on other EDC's and other health endpoints. However, the case study of human health risk from EDCs based on a BPA and fertility data indicates that risk to the general population from EDC exposure via recycled wastewater is relatively minimal.

PA: Benefits of Tertiary WWTP vs. Alternate Spending Plans

In treated Palestinian wastewater, the total estrogenicity based on the average concentrations of five EDCs was found to be 0.558 ng/L EEQs which is below levels in Israel, and very close to meeting the most stringent safety threshold estimates. Endogenous hormone levels in the West Bank's treated effluent are within the of distribution of global averages (see Figure 4 below) [84]. This should be confirmed by continued sampling in the PA locations included in this study to determine whether this situation is changing, and to reflect changes in water resource management and reuse. For now, this serves as the best data-driven indicator available that secondary treatment is sufficient to protect human health, even assuming expanded recycling of effluents there in the future.



Box edges at 25th and 75th percentiles, error bars at 5th and 95th percentiles, dashed lines at averages, black lines at medians, and (●) at outliers.
Adapted from Odeh [84].

Figure 4. Concentrations of Estrone and Estriol in West Bank's Treated Wastewaters vs. World's.

DISCUSSION

Recommendations for Israel

The chemical, exposure risk, and cost analyses have helped clarify the best direction for a wastewater treatment strategy in Israel and similar developed nations. None of the challenges associated with treated wastewater necessitate abandoning the practice of sewage recycling in Israel. In fact, the country should complete the upgrading of its existing network of WWTPs to tertiary wastewater treatment in order to protect the soil and water from non-EDC threats (e.g., salinization, excess nutrients and other organic micro-pollutants). Tertiary and advanced treatment should continue to be an important priority and critical part of a strategy to open up the possibility of unlimited agricultural uses or even direct ingestion of treated wastewater without increasing risk to human health, but is not essential in Israel from the perspective of addressing human health risks from EDC exposure at this time. Advancing beyond tertiary levels to additional expensive advanced treatments to address EDC exposure at this stage would be premature, however EDC exposure can be addressed through other more targeted and comprehensive mitigation options.

Management of EDC exposure goes well beyond wastewater treatment to sources such as food, personal care products, and pharmaceuticals that should be addressed as a package. The Israeli government should begin to confront overall EDC exposure, but wastewater reuse should not be the central focus of new regulation. Advanced nations like Israel that have already met citizens' basic needs and wish to pursue EDC exposure reduction are advised to focus on other more significant and straightforward exposure sources such as foods containing soy, food containers such as cans and plastic packages, and polycarbonate cooking tools. Source reduction efforts can include take-back programs for unused pharmaceuticals, fines for manufacturing domestic personal care products and foods containing prominent estrogenic EDCs, and/or subsidies for development of safer replacement compounds and products [146–148].

To ensure that EDC concentrations in recycled wastewater do not contribute more to human exposure in the future, water should be checked for concentration levels of common EDCs, and for estrogenicity overall Water for drinking and bathing should be monitored for EDCs, as well as applications such as effluent irrigation for water-fed produce, and groundwater which may be vulnerable [149]. The Israeli government would do well to ensure its EDC screening and testing procedures remain in line with global best practices over time. To reach its maximum potential, Israel's should establish a comprehensive basin-wide EDC monitoring policy with Palestinian input [150,151]. The importance of such cooperation will be discussed further in the Conclusions section below.

Recommendations for PA

The analyses conducted in this study also clarify several realities that should help inform the PA operational decisions regarding the importance of EDCs as a water policy driver in developing countries. When the marginal improvement from tertiary wastewater treatment is considered in light of the relatively modest budgets available for infrastructure, upgrading to tertiary levels would not return an improvement in EDC reduction proportionate to the expense. The cost savings from foregoing tertiary treatment when building new WWTPs across Palestine could be utilized for other basic infrastructure and sanitation service needs that are still lacking including pipes for wastewater removal and fresh water distribution, schemes for irrigation with treated wastewater that adhere to international standards [152], and capacity building projects that teach locals to operate wastewater systems and utilize the products efficiently and sustainably.

This money could also be put towards addressing myriad non-EDC insults associated with wastewater reuse that pose the highest risk to human and environmental health: release of pathogens, and soil or plant accumulation of nutrients and metals. Today 20-25% of Palestinian households still lack reasonable wastewater collection and sewage treatment [6, 56]. The result of such low wastewater treatment capacity results in the situation currently found in the Palestinian territories; for lack of a better option, large portions of the sewage produced by the population is released untreated into the environment. Historically, the Palestinian people have borne the burden of this deficiency in their shared region, including periodic outbreaks of hepatitis, typhoid, and dysentery [153]. Even in recent decades, infants still die arguably preventative deaths from infectious disease associated with water and hygiene. Hospitalizations and unreported illnesses are also very common although less difficult to document [107]. Treating all sewage to secondary levels would provide treated water of reasonable quality to more people, and would benefit the natural environment on which they rely.

If the public policy objective were purely based on maximal reduction of all risks of endocrine disruption, then contaminant removal via tertiary treatment may make the most sense [103]. However considering Palestinian economic challenges, the limited wastewater management capacity and infrastructure of the PA at present, and the health risks posed by conventional contaminants, resources spent on this incremental improvement in the quality of treated water would be better utilized by the PA to address more pressing needs. Secondary treatment is thus a preferable choice, especially if accompanied by guidelines on safe use of such effluent for reuse. Over time secondary plants can easily be upgraded to tertiary levels once investments in water infrastructure and capacity have met basic needs. However, until the vast majority of sewage is collected and treated, Palestinian decision makers would be wise to invest in secondary WWTPs and other basic infrastructure and capacity building projects to protect public health and best serve the wellbeing of their citizens.

To this end, future Palestinian policy should proceed according to two iterative stages: expeditiously building WWTPs that contain primary and secondary treatment facilities to address the most urgent environmental and human health threats from traditional contaminants in untreated sewage; and eventually upgrading to tertiary treatment levels, but only after these basic needs are addressed. At the same time, policy and guidance encouraging safe and efficient effluent use must be provided to allow Palestinians to make the best use of the water they already have. As of 2011, more than 40% of the water supply was allocated for agricultural use (as opposed to domestic use) in the Palestinian territories [58]. Water managers should seek to lower current Palestinian limits on concentrations of contaminants to allow reuse of effluent in agriculture or aquifers [154]. Such effluent used safely would free up fresh water for drinking and other forms of direct consumption. Effluents must play a key role in sustainable water management and development if the Gaza Strip and West Bank are to provide citizens with enough clean water [155–157].

A timeline should be laid out for this development. Inter-Palestinian cooperation between its Ministry of Health, Ministry of Planning and International Cooperation, Environmental Quality Authority, and Legislative Council will be indispensable in coordinating enforcement of the laws and regulations relevant to water. These efforts should be supported by Israel through knowledge sharing and financial support as the benefits of this investment will be shared across the border.

Regional Cooperation

Israeli cooperation with the PA will be necessary to ensure that EDC environmental and health protection measures are effective. Under a "temporary" agreement that is almost two decades old, Israel and Palestine have had only modest success at joint management of their water, but surely not enough and not always in official state capacities [158]. In the past, animosities between the two governments have prevented the establishment and cooperative enforcement of basin-wide standards [150,151]. Palestinians have been hesitant to sign a request for assistance for fear of weakening their negotiation position, and joint projects were blocked by similar fears regarding power positions on both sides [159]. In general, Israel has chosen to make unilateral water management decisions as the benefits have been high, including water independence and decreased vulnerability [160].

For a sustainable regional water policy to emerge, Israel and the PA should negotiate a way to "share the costs of transboundary wastewater treatment," and avoid unfair distribution of negative transboundary externalities with regards to water use [160,161]. Positive steps in this direction could include Palestinians receiving the benefits of information sharing, capacity building, new wastewater treatment plants in Palestinian territories [162], and transfers of desalinated water as an emergency measure in the meantime [149,163]. This cooperation could lead to the necessary basin-wide initiatives [162] and basin-wide approach to management [164]. Future initiatives must include curbing the amount of untreated sewage released into the environment. This will enable the region to both eliminate contamination from wastewater discharges, and expand its freshwater supply to achieve water security.

Conclusion

While Israel has largely overcome traditional hygiene and sanitation obstacles and can focus on emerging water quality challenges, the West Bank potentially faces both. The question answered by this study is whether EDCs should drive water policy in Israel and in the PA—specifically regarding the decision of whether to further upgrade wastewater treatment levels—based on the current state of knowledge. At this point in time, the answer is that upgrading wastewater treatment is *not* the best way to address the most urgent human health risks from raw wastewater in the Palestinian territories, nor from EDCs in Israel. Findings indicate that risk from traditional contaminants, not EDCs, should still be the driver for water policy and wastewater management in both countries, albeit for different reasons.

This study on EDCs in the region was intended not only to inform the water policies of developed and developing nations in general, and provides essential lessons regarding the fate of environments shared by groups with different economic capacities. Neighboring countries are likely to feel the effects of the water management strategies being implemented by their neighbors, regardless of their own infrastructure and services. They will share the consequences of damage to the region's natural environment, regardless of a political and socio-economic separation. Thus, when an area of economic disparity faces environmental contamination, the lesson learned from this case study is to strive for cooperation.

Such cross border environmental and public health agreements have been successful in other areas of economic disparity including the US and Mexico [165], between eastern and western Europe [166], in a few cases in Haiti and the Dominican Republic [167], and elsewhere [168]. In Israel and the West Bank, the ideal solution would be a unified basin-wide policy with agreements to jointly managing wastewater so that populations on both sides are protected. Considering the vastly different political and economic reality faced by Israel and the West Bank, such an initiative would be greatly facilitated by knowledge transfers and training from Israel to the PA. It would also help collaboration if join projects were funded proportionately by each government based on financial capacity. This will be especially challenging to achieve at a national level with governments in political conflict zones, but in cases where government are unwilling to negotiate, non-governmental organizations and academic institutions can step in. Research projects such as this are a foundational first step.

Improving wastewater treatment should be a shared Israeli and Palestinian goal in order reduce all types of contamination in their shared water basin, and to protect their common environment. It is clear from the case study in Israel and the PA that EDCs can be found in the aquatic environment of the entire region, so monitoring EDC levels should become part of both governments' regular water management protocol in case the situation should change in the future. Without significant efforts on both sides of the border, Israelis and Palestinians will all continue to face both traditional and emerging contaminants in wastewater released to the environment. The land and water resources of the region until now have provided food and water to sustain both peoples, but may be unable to do so in the future without interventions. Developing and developed nations can both benefit from this lesson, especially in areas where both economic realities inhabit a shared environment.

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APPENDIX A. EDC CONCENTRATIONS ACCORDING TO LOCATION IN NG/L (NANOGRAMS/LITER)

Location	Estrone	Estriol	Triclosan	4-tert- Octylphenol	BPA
Israel	0.3	0.03	5		5
Israel	0.5646	7.802	5		5
Israel	4.1	0.03	60.33333333		5
Israel	1.2168	2.56	28.66666667		2.333333333
Israel	1.426366667	3.326666667	74		5.3
Israel	0.8845	0.03	101		5
Israel	1.336733333	2.16	27.66666667		4.133333333
Israel	0.8026	0.03	5		5
Israel	1.85525	3.325	5		3.8
Israel	0.65	0.043333333	179.6666667	2.333333333	2.333333333
Israel	0.036666667	0.043333333	103.3333333	2.333333333	2.333333333
Israel	5.5192	10.4086	99.56666667		1
Israel	11.8901	4.0587	70.16666667		17.33333333
Israel	5.816666667	0.525	5		17.33333333
Israel	3.366666667	0.293333333	397	2.333333333	8.666666667
Israel	0.036666667	0.043333333	150.3333333	2.333333333	2.333333333
Israel	3.65	0.043333333	170	2.333333333	307.3333333
Israel	2.32	0.043333333	136.6666667	2.333333333	2.333333333
Israel	4.2	5.843333333	103.3333333	2.333333333	2.333333333
Israel	4.233333333	0.043333333	5	2.333333333	2.333333333
Israel	21.3	7.733333333	784	2.333333333	2.333333333
Israel	0.05	0.05	5	1	1
Israel	8.3	4.993333333	368	2.333333333	2.333333333
Israel	4.903333333	1.393333333	276.3333333	2.333333333	2.333333333
Israel	1.6	4.6	5	8.666666667	2.333333333
Israel	4.866666667	2.293333333	201.6666667	2.333333333	2.333333333
Israel	1.6	3.26	136.6666667	2.333333333	5.333333333
Israel	0.556533333	0.043333333	5		2.333333333
Israel	1.931333333	0.043333333	5		2.333333333

Appendix A. (Continued)

Location	Estrone	Estriol	Triclosan	4-tert- Octylphenol	BPA
Israel	2.253333333	1.76	2.543	2.333333333	2.333333333
Israel	5.803333333	1.86	2.55	2.333333333	1
Israel	1.725	0.05	5	1	1
PA West Bank	4.948443953	2.10463817	77.33333333	3	3
PA West Bank	4.754094374	0.04	5	3	3
PA West Bank	3.04013461	0.03	174	5	5
PA West Bank	1.116441284	29.2	5	1	1
PA West Bank	0.01	0.03	5	5	5
PA West Bank	0.01	0.03	5	5	5
PA West Bank	0.01	0.03	5	5	5
PA West Bank	0.01	0.03	5	5	5
PA West Bank	0.01	0.03	5	5	5
Average	2.986275	2.429407938	93.04454472	3.061728395	11.46910569

Appendix B. EDC Concentrations According to Location Expressed as EEQs (ng/L EEQ)

Location	Estrone	Estriol	Triclosan	4-tert- Octylphenol	BPA	EEQ Total per location
Israel	0.033	0.0033	0.00000025		0.00195	0.03825025
Israel	0.062106	0.85822	0.00000025		0.00195	0.92227625
Israel	0.451	0.0033	3.01667E-06		0.00195	0.456253017
Israel	0.133848	0.2816	1.43333E-06		0.00091	0.416359433
Israel	0.156900333	0.365933333	0.0000037		0.002067	0.524904367
Israel	0.097295	0.0033	0.00000505		0.00195	0.10255005
Israel	0.147040667	0.2376	1.38333E-06		0.001612	0.38625405
Israel	0.088286	0.0033	0.00000025		0.00195	0.09353625
Israel	0.2040775	0.36575	0.00000025		0.001482	0.57130975
Israel	0.0715	0.004766667	8.98333E-06	0.000979133	0.00091	0.078164783
Israel	0.004033333	0.004766667	5.16667E-06	0.000979133	0.00091	0.0106943

Location	Estrone	Estriol	Triclosan	4-tert- Octylphenol	BPA	EEQ Total per location
Israel	0.607112	1.144946	4.97833E-06		0.00039	1.752452978
Israel	1.307911	0.446457	3.50833E-06		0.00676	1.761131508
Israel	0.639833333	0.05775	0.00000025		0.00676	0.704343583
Israel	0.370333333	0.032266667	0.00001985	0.000979133	0.00338	0.406978983
Israel	0.004033333	0.004766667	7.51667E-06	0.000979133	0.00091	0.01069665
Israel	0.4015	0.004766667	0.0000085	0.000979133	0.11986	0.5271143
Israel	0.2552	0.004766667	6.83333E-06	0.000979133	0.00091	0.261862633
Israel	0.462	0.642766667	5.16667E-06	0.000979133	0.00091	1.106660967
Israel	0.465666667	0.004766667	0.00000025	0.000979133	0.00091	0.472322717
Israel	2.343	0.850666667	0.0000392	0.000979133	0.00091	3.195595
Israel	0.0055	0.0055	0.00000025	0.000419629	0.00039	0.011809879
Israel	0.913	0.549266667	0.0000184	0.000979133	0.00091	1.4641742
Israel	0.539366667	0.153266667	1.38167E-05	0.000979133	0.00091	0.694536283
Israel	0.176	0.506	0.00000025	0.003636781	0.00091	0.686547031
Israel	0.535333333	0.252266667	1.00833E-05	0.000979133	0.00091	0.789499217
Israel	0.176	0.3586	6.83333E-06	0.000979133	0.00208	0.537665967
Israel	0.061218667	0.004766667	0.00000025		0.00091	0.066895583
Israel	0.212446667	0.004766667	0.00000025		0.00091	0.218123583
Israel	0.247866667	0.1936	1.2715E-07	0.000979133	0.00091	0.443355927
Israel	0.638366667	0.2046	1.275E-07	0.000979133	0.00039	0.844335928
Israel	0.18975	0.0055	0.00000025	0.000419629	0.00039	0.196059879
PA West Bank	0.544328835	0.231510199	3.86667E-06	0.001258886	0.00117	0.778271786
PA West Bank	0.522950381	0.0044	0.00000025	0.001258886	0.00117	0.529779517
PA West Bank	0.334414807	0.0033	0.0000087	0.002098143	0.00195	0.34177165
PA West Bank	0.122808541	3.212	0.00000025	0.000419629	0.00039	3.33561842
PA West Bank	0.0011	0.0033	0.00000025	0.002098143	0.00195	0.008448393
PA West Bank	0.0011	0.0033	0.00000025	0.002098143	0.00195	0.008448393
PA West Bank	0.0011	0.0033	0.00000025	0.002098143	0.00195	0.008448393
PA West Bank	0.0011	0.0033	0.00000025	0.002098143	0.00195	0.008448393
PA West Bank	0.0011	0.0033	0.00000025	0.002098143	0.00195	0.008448393
Average	0.330012871	0.269063411	4.65223E-06	0.001284789	0.004472951	0.604838675

BIOGRAPHICAL SKETCH

Name: Vivian Futran Fuhrman
Affiliation: PhD Candidate, Ben Gurion University

SUMMARY: Diverse experience driving environmental projects, research, and events at the intersection of science and policy. Expertise in human health risk assessment and exposure to endocrine disrupting chemicals. Familiarity with academic, private and government perspectives on water scarcity, public health and energy efficiency in buildings.

Education:

Ben-Gurion University, Beersheva, Israel 2011-2016 (expected)
PhD, Environmental Risk and Policy

University of Pennsylvania, Philadelphia, PA 2010-2011
MES (Master of Environmental Studies), GPA 3.9/4.0

Arava Institute for Environmental Studies,
Kibbutz Ketura, Israel 2009
Certificate in Environmental Studies

Duke University, Durham, NC 2003-2007

BA, Political Science/International Relations

Address: 205 Walden Street, Apt. 4k, Cambridge,
Massachusetts, 02140, USA

Research Experience:

Ben-Gurion University, Israel 2011-2015
PhD Candidate

- Dissertation topics: How endocrine disrupting chemicals (EDCs) challenge traditional risk assessment; Modeling relative exposure to estrogenic EDCs from recycled wastewater for human health risk assessment; Regional and global policy implications of EDC exposure from wastewater recycling and cost efficiency analysis of treatment options
- Drylands, Deserts & Desertification Conference: Co-convened session on Zero Net Land Degradation for UN Convention to Combat Desertification, co-authored conference session outcome (see Publications)
- Green Building Project: Year-long government funded research on global green building initiatives and incentive

Book Project, Arlington, VA 2008-2009

Author's Assistant

- Worked with Dr. Jordan D. Lewis, global alliance expert, on multidisciplinary book addressing human group relations

Duke University Psychology Laboratories, Durham, NC 2006
Lab Assistant

- Infant language acquisition project

Eagleton Institute of Political Science at Rutgers University
New Brunswick, NJ 2005

Research Intern

- Coordinated primary research and data collection on Young Elected Leaders Project

Professional Experience:

Product Stewardship Institute, Boston, MA
2015-present
Associate for Policy and Programs

Global Water Alliance, Philadelphia, PA 2010-2011
Program Manager

EPA Region 3 Office of Water, Philadelphia, PA 2010-2011
Student Intern

ManageEnergy, Arglington, VA 2008- 2009
Special Projects Manager

ICF International (Environmental Consulting firm),
Fairfax, VA 2007-2008
Research Assistant

Professional Appointments: (NA)

Honors:

- Ben Gurion University Negev Scholarship, Faran Fellow
- University of Pennsylvania, Masters of Environmental Studies Program, Award: Outstanding Graduate in Master of Environmental Studies Program

Publications Last Three Years:

Futran Fuhrman, V., "Endocrine Disrupting Chemicals in Treated Wastewater: Risk Assessment and Management Implications in Israel and the West Bank," Ben Gurion University, PhD Dissertation (2015).

Futran Fuhrman, V., A. Tal, S. Arnon, "Why Endocrine Disrupting Chemicals (EDCs) Challenge Traditional Risk Assessment and How to Respond," Journal of Hazardous Materials 286 (2015): 589-611

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Futran, V., "Tackling Water Scarcity: Israel's Wastewater Recycling as a Model for the World's Arid Lands?" Australia Water Engineers magazine June/July (2013)

Futran, V., "Tackling Water Scarcity: Israel's Wastewater Recycling as a Model for the World's Arid Lands?" UNESCO's Global Water Forum (2013)

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