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CASE STUDY

A case study of urban water balancing in the partly sewered city of Nablus-East (Palestine) to study wastewater pollution loads and groundwater pollution

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Untreated sewage can contribute a significant proportion of urban groundwater recharge, via on-site sanitation facilities and sewer exfiltration. In the West Bank of the Palestinian Territories 94% of sewage is discharged untreated to the ground or surface waters. This has contributed to increasing nitrate concentrations in groundwater, which is the critical water source. In this case study of a drainage catchment from the city of Nablus, a water balance indicates that sewage as a source of groundwater recharge is as much as 50% of total recharge from precipitation, and nitrogen pollutant loads by area are up to 60% as much as those from agriculture. Results suggest that 22% of total wastewater flow directly infiltrates the ground via cesspits and sewer exfiltration.

Keywords: wastewater; on-site sanitation; groundwater; nitrate; recharge; Palestine

Introduction

Nearly half the population of the developing world lacks access to improved sanitation, and even where basic sanitation infrastructure exists, wastewater treatment often does not (Scott *et al.* 2004). Cities in the developing world are often unsewered, partially sewered, or have sewage networks unable to cope with growing volumes of wastewater (Foster and Chilton 2004). An estimated 90% of sewage worldwide is disposed of into the environment without any treatment (Corcoran *et al.* 2010), and recent studies have demonstrated that raw sewage can contribute a significant proportion to urban groundwater recharge (Ellis *et al.* 2004, Wakida and Lerner 2005). In a case study of urban areas in Sub-Saharan Africa, for example, it was estimated that raw wastewater as recharge may be as high as 10–50% of total precipitation and that only 30% of sewage is treated (Nyenje *et al.* 2010).

Unsewered areas that rely on on-site sanitation systems, such as cesspits and septic tanks, are particularly problematic and can contribute significantly to groundwater pollution (Foppen 2002, Pujari *et al.* 2007, Lu *et al.* 2008). A growing number of case studies have documented a trend of nitrate contamination in urban groundwater across the world, many of which have identified residential sewage from on-site sanitation facilities as the pollution source. Jin *et al.* (2004) used chemical and isotopic techniques to demonstrate that the major source of elevated nitrate concentrations in groundwater under Hangzhou City (China) was domestic sewage, and furthermore identified the point source as residential septic tanks. Foppen (2002) reported elevated and increasing nitrate levels in the groundwater of Sana'a (Yemen) over a 5 year period, ranging from 1–3 mmol/l NO_3^-, which was attributed to high strength wastewater seepage from cesspits in the partially sewered city. Zingoni *et al.* (2005) used groundwater sampling to describe a correlation between areas with higher densities of pit latrines to high nitrate levels (20–30 mg/l) in the city of Harare (Zimbabwe).

Sewered areas can also contribute to groundwater pollution, via sewer exfiltration and untreated end-of-pipe dumping. Sewer exfiltration remains poorly understood and characterized (Rutsch *et al.* 2006, Rueedi *et al.* 2009), however it is gaining recognition as a source of pollution to groundwater (Wakida and Lerner 2005). A number of different case studies have estimated that up to 10% of the wastewater flow leaks to groundwater via exfiltration, potentially contributing 30–40% of total annual groundwater recharge or more in arid areas where natural recharge is low (Lerner 2002, Ellis *et al.* 2004, Rueedi *et al.* 2009). Lerner *et al.* (1999) found nitrate concentrations in urban groundwater to be just as high as those in rural groundwater in the sewered city of Nottingham (UK) and concluded that sewers contributed 13% of urban nitrogen loading in the city. Furthermore, Umezawa *et al.* (2008) described severe sewer leakage as the major source of nutrient contamination in metropolitan Jakarta and Manila (Phillipines).

Thus, while many studies see nutrient enrichment as an agricultural problem, residential sewage can also contribute

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significantly to chemical pollution of groundwater. Nitrate in groundwater poses a serious health risk, because it can lead to methaemoglobinaemia (blue-baby syndrome) in infants when concentrations in drinking water reach levels above 10 mg/l nitrate-nitrogen (World Health Organization 2003). There are relatively few removal pathways for N from sewage-contaminated soils. Ammonium (NH_4^+-N) from sewage is readily oxidized to highly mobile nitrate (NO_3^--N) under aerobic soil conditions, with gaseous losses via denitrification and ammonia volatilization considered relatively insignificant in most studies where an aerobic unsaturated zone is present (Fourie and van Ryneveld 1995, Foppen 2002). Walker (1973) concluded that the only significant active mechanism for reducing NO_3^--N concentrations resulting from septic tanks was via dilution with uncontaminated groundwater.

In the West Bank of the Palestinian Territories, wastewater poses a particularly critical threat to groundwater. The Mountain Aquifer underlying the West Bank is a crucial freshwater supply for both Palestinians and Israelis; however it is also used as a repository for wastewater. Unlined cesspits are the dominant form of sanitation in the West Bank, serving the nearly 60% of the households that lack connection to public sewage networks (PCBS 2011), and even in sewered areas, most sewage is discharged into wadis without treatment (UNEP 2003). Although four treatment facilities were built in the West Bank in the 1970s, none are still functioning. Currently, there is only one active treatment plant in the West Bank, located in Al Bireh. In operation since 2000, it serves less than 6% of the West Bank population (UNEP 2003, Hareuven 2009).

Groundwater nitrate levels in the West Bank frequently exceed safe concentrations and have had an increasing trend over time (Anayah and Almasri 2009). Studies have suggested human sewage to be a significant source of nitrate in groundwater (Khayat *et al.* 2006, Anayah and Almasri 2009), however few if any studies have attempted to quantify contaminant loads from wastewaters in the region. Here, we analysed the impact of sewage as recharge in a major urban catchment in the West Bank of the occupied Palestinian Territories (oPT) using a water balance. The purpose of this study was to offer a primary estimate of the quantity of wastewater as recharge and the extent of nutrient loading from wastewater in the eastern catchment of the city of Nablus, which lies above the Mountain Aquifer and is the primary urban centre in the Wadi Fara'a catchment, a drainage that serves as the recharge area for critical springs and wells. While the city of Nablus is mostly sewered, currently 100% of the city's sewage is disposed of without any treatment.

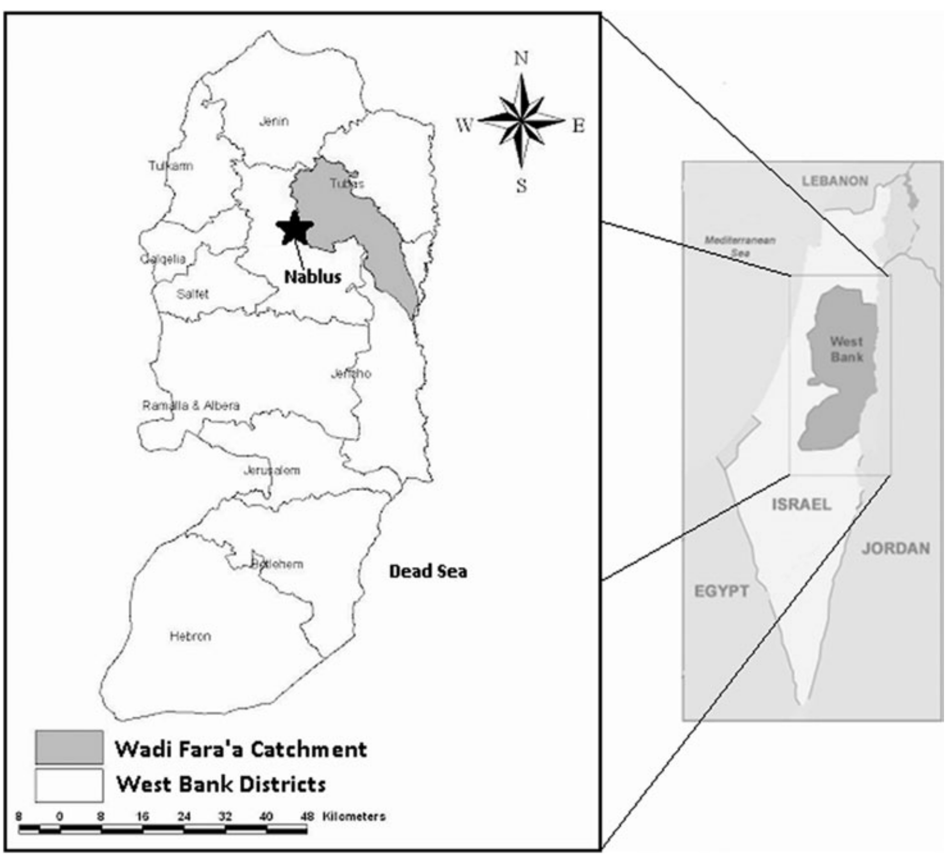

Figure 1. Location of Nablus and Fara'a Catchment within the West Bank (Abedel-Karrem 2005).

Description of study area

The Wadi Fara'a catchment is a semiarid to arid catchment in the north-eastern part of the West Bank (Figure 1) that is renowned for its prolific springs and wells. The catchment drains to the Jordan River and is part of the Dead Sea basin. The eastern side of the city of Nablus is the only major metropolitan area in the catchment. The remainder of the catchment is made up of Palestinian villages, Israeli settlements, military areas, and agricultural land.

The city of Nablus, with a population of 154,371, houses three refugee camps and is one of the largest and oldest cities as well as one of the most densely populated areas in the West Bank (PCBS, 2009a). Collected sewage is discharged directly into nearby wadis, with the city being divided hydrologically into two major surface water catchments: the western catchment flowing into Wadi Zeimar and the eastern catchment flowing into Wadi Fara'a, the case study area. Conventionally, the water authorities in Nablus divide the city by these two major water catchments, referring to Nablus-West and Nablus-East respectively, as the city's sewage network drains by gravity in differing directions. The terms Nablus-West and Nablus-East will be used from here on in this paper to refer to the different drainage areas within the city of Nablus. While the majority of the city's commercial centre and much of the residential area falls in Nablus-West, Nablus-East holds the largest two of the city's three refugee camps, which are the most densely populated areas of Nablus. Nablus-East also includes the city's industrial area.

The entire study area included Nablus-East, Balata and Askar refugee camps, and the villages of Rujeib and Kafr Qalil, which are directly adjacent to the city (Figure 2). Balata and Askar camps are within the municipal borders of Nablus but are serviced by UNRWA (United Nations Reliefs and Works Agency) rather than the municipality and are therefore accounted for separately.

Materials and methods

Data collection

The study was carried out by compiling existing reports, studies, data, and documents from local authorities detailing the environment of Nablus-East and the state of the wastewater. Field work in the West Bank took place between November 2010 and February 2011. Hard and soft copies of existing studies, reports, and other data were collected primarily by personal visits to local authorities and NGOs in the West Bank in Ramallah and Nablus. Data sources included the City of Nablus Water Supply and Sanitation Department (WSSD), the Palestinian Water Authority (PWA), the Water and Environmental Studies Institute (WESI) at An Najah University, the Palestinian Central Bureau of Statistics (PCBS), and the Ministry of Local Governments (MLG).

The City of Nablus's (WSSD) provided the majority of the data used in this study. This data included shape files of buildings, roads, water mains, and sewers, the first 10 months of water use data for 2010, and population density and zoning maps, which were abstracted as image files from

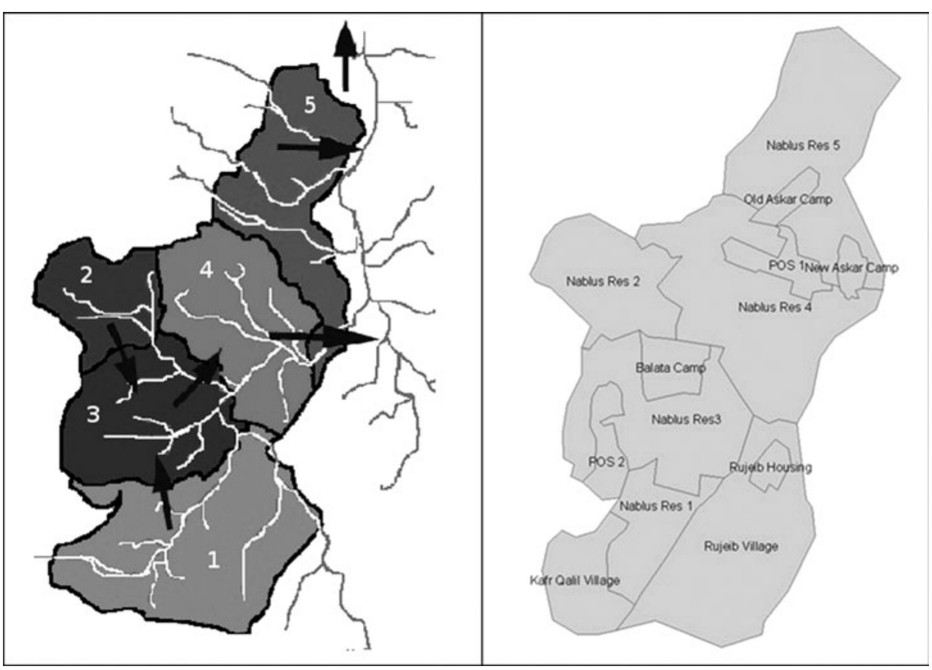

Figure 2. The study area: a) Wadi network and the 5 subcatchments, derived from flow analysis in ArcMap. Arrows indicate flow direction from one subcatchment to another; b) Map of the 13 designated miniclusters (MCs).

Lahmeyer International *et al.* (2005). A Garmin® handheld GPS device was used to obtain the spatial coordinates of the sewage outfall location. A Digital Elevation Model (DEM) was obtained from WESI at An Najah University. Population and housing data from the 2007 census was obtained from PCBS, and a satellite image was obtained from the MLG. Several feasibility studies for water projects in Nablus were obtained from the PWA. A literature search was conducted to fill gaps in the data available on-site.

Data input and analysis in ArcMap 9.2

Spatial data was input into ArcMap 9.2 along with attribute data for compilation and analysis. Maps obtained as image files were geo-referenced and then digitized into shape files in ArcMap. Calculated 2007 and 2010 population figures (see below) were added to the attribute tables of the population density map to create updated population density maps. The satellite image was used to update the building layer and digitize new buildings not in the existing building layer. The DEM was used to determine flow accumulation, flow direction, and stream (wadi) networks using ArcMap hydrology tools. The watershed tool in ArcMap 9.2 hydrology tools was used to determine five specific subcatchments in the study area (Figure 2). This subcatchment map layer was then overlaid onto the population density and zoning layers to determine approximate population and major land use of each subcatchment area. The five subcatchments were further divided in 13 "miniclusters" (MCs), smaller units of area for which detailed population density and land use data was available (Figure 2). The refugee camps and villages were treated as separate miniclusters.

The 2007 census recorded the number of cesspits in the municipality of Nablus, however no spatial data was available to determine how many of these cesspits were located in Nablus-East. Therefore, a proximity analysis was conducted in ArcMap to determine the distance of each building to the sewer network, in order to infer buildings not connected to the sewage network. This was done by converting the building polygon layer to points by using the centroid of each building. The proximity analysis "near" tool was then used to determine the distance of each point (building) to the nearest sewer line in meters. The chief assumption was that a building more than 150 m from the nearest sewer line was unsewered. This was considered a conservative estimate of unsewered buildings. A distance of 50 m from a tertiary sewer line should be an adequate distance to assume no connection, however it was unclear whether the spatial distribution of sewer lines collected from the municipality represented tertiary, secondary, main lines, or some combination of all three; sewer diameters suggested the known sewer lines were primarily secondary and main lines. Therefore, it was assumed a distance of 50 m would overestimate the number of unconnected buildings. A proximity analysis was conducted for distances of 50 m, 100 m, and 150 m, and the 150 m distance gave the most realistic estimate according to census and municipality figures.

Chemical loading was calculated in ArcMap for each 1000 m^2 based on the number of housing units times the occupancy rate, times the per capita chemical loading rate. The occupancy rate was calculated as the population of the MC divided by the total number of housing units in the MC. The per capita loading rates were calculated by multiplying the mean wastewater concentrations (see below) by the total wastewater production per capita.

Calculations and data transformations

Census information was available from the PCBS for the years 1997 and 2007. The population density map obtained was from 1997; population densities for Nablus for 2007 could not be obtained. Therefore, 1997 proportions were applied to 2007 population numbers to estimate population of each minicluster (MC) in 2007, with the assumption that relative population densities had not changed. For a given minicluster on the 1997 population density map, the 2007 population was calculated as follows, where $\text{Popln}_{\text{year}}$ is the population of a given year:

$$(\text{Popln}_{1997}\,\text{MC}/\text{Popln}_{1997}\,\text{Nablus city}) \times \text{Popln}_{2007}\,\text{Nablus city} = \text{Popln}_{2007}\,\text{MC} \tag{1}$$

For villages and refugee camps, 2007 population figures were obtained directly from the 2007 census. 2010 population figures were further estimated from 2007 figures by calculating the growth rate over the ten year period from 1997 to 2007 for the total area serviced by the City of Nablus's water network and projecting the population figures to 2010 based on that growth rate, as follows, where GR is growth rate and $\text{Popln}_{\text{year}}$ is population of a given year:

$$\text{Popln}_{2007} = \text{Popln}_{1997}(1 + \text{GR})^{10} \tag{2}$$

$$\text{Popln}_{2010} = \text{Popln}_{2007}(1 + \text{GR})^{3} \tag{3}$$

Growth rates were determined separately for the municipality of Nablus, villages, and refugee camps.

The city's water use data did not discriminate between residential, commercial, and industrial use, nor did it discriminate by location. Thus, water use was proportioned to the study area based on population. Per capita water use was assumed to be constant across the study area, and residential, commercial, and industrial water use were included in per capita consumption. Given that the Nablus-East study area excludes most of the central commercial district (which lies in Nablus-West), and that the industrial water use is relatively low and similar in comparison to residential water use rates (see results), these assumptions may not compromise the accuracy of the results as much as it might in another study area. Per capita water use was calculated as follows:

$$\text{Per cap water use} = \text{Total Water Use Serviced Area} / \text{Popln Total Serviced Area} \quad (4)$$

The total serviced area was the population of the total area served by the municipality's WSSD.

Recharge and pollutant load estimations

Wastewater samples from the Nablus-East main sewage outlet have been analysed for a thesis from An Najah University in 2007 (Abu Baker 2007). The samples were taken twice a month for a year. In addition, a design report for the implementation of a sewerage project in Nablus-West analysed wastewater samples from Nablus-West outlets on 10 different days over a period of 3 months, also in 2007 (Lahmeyer International 2007). Total phosphorus (TP) and biological oxygen demand (BOD_5) loading for this case study were estimated from mean wastewater concentrations at Nablus-East (Abu Baker 2007), and mean total nitrogen (TN) figures from Nablus-West wastewater (Lahmeyer International 2007) were used to estimate the N loading in the study area, because the data from Nablus-East did not record TN. The wastewater characteristics used for calculations in this study are detailed in Table 1.

Total wastewater loads and contaminant loads for TN, TP, and BOD_5 were calculated based on per capita water use and occupancy for the study area and chemical parameters from Nablus wastewater (Table 1). Fractions of wastewater and TN, TP, and BOD_5 discharged to the ground (via cesspits and leakage from sewer pipes) were distinguished from those discharged to the wadi (at the sewage outlet). These were estimated based on actual and predicted numbers of cesspits and the estimated leakage fraction for the sewer network. The outdoor water use (garden) and water consumption (cooking and drinking) fractions were estimated from a study that investigated domestic water use habits in the West Bank by Nazer *et al.* (2008). The primary assumptions made for the calculations were:

- In sewered areas, 70% of total metered water used in sewered areas reaches the sewage outlet point as wastewater. This figure was based on personal conversations with engineer Sulieman Abughosh at the Nablus WSSD (Jan 2011), who cited a study (not found by the author) that determined the amount of sewage reaching the outlet as a fraction of total metered water used was 70%. This figure falls within the range of standard assumptions used in designing wastewater treatment plants, which estimate 60 to 85% of per capita consumption becomes wastewater (Lin and Lee 2001, p. 487).
- Of the remaining 30% of recorded metered water used in sewered areas:
  - 15% was attributed to outdoor (garden) use (Nazer *et al.* 2008)
  - 4% was attributed to cooking and drinking (Nazer *et al.* 2008)
  - 11% was attributed to sewer exfiltration
- For unsewered areas, the fate of metered water usage was calculated as follows:
  - 15% was attributed to outdoor (garden) use (Nazer *et al.* 2008)
  - 4% was attributed to cooking and drinking (Nazer *et al.* 2008)
  - The remaining 81% was assumed to be deposited in cesspits
- All pollutants input to the ground were assumed to remain in the ground or groundwater; emptying of cesspits was not taken into account because of lack of data.

Figures were calculated individually for each MC as:

$$MC_{\text{water use}} = \text{per cap water use} * \text{PoplnMC} \quad (5)$$

$$\text{Garden} = MC_{\text{water use}} * 0.15 \quad (6)$$

$$\text{Consumption} = MC_{\text{wateruse}} * 0.04 \quad (7)$$

$$WW_{\text{total}} = MC_{\text{water use}} - \text{Garden} - \text{Consumption} \quad (8)$$

$$WW_{\text{ground}} = [(MC_{\text{wateruse}}/HU_{\text{total}}) * HU_{\text{sewer}} * 0.11] + [(MC_{\text{wateruse}}/HU_{\text{total}}) * HU_{\text{cesspit}} * 0.81] \quad (9)$$

$$WW_{\text{wadi}} = (MC_{\text{water use}}/HU_{\text{total}}) * HU_{\text{sewer}} * 0.7 \quad (10)$$

$$TN_{\text{ground}} = WW_{\text{ground}} * \text{TN concentration in wastewater} \quad (11)$$

$$TN_{\text{wadi}} = WW_{\text{wadi}} * \text{TN concentration in wastewater} \quad (12)$$

Where MC_{wateruse} is the total water consumption for the MC, "garden" is the water lost via outdoor water use,

Table 1. Chemical parameters of Nablus wastewater used in load calculations.

		Min	Max	Mean	Source
TN	mg/l	94	134	111	Lahmeyer International 2007
TP	mg/l	2.2	19	10	adapted from Abu Baker 2007
BOD_5	mg/l	102	940	600	Abu Baker 2007

Table 2. Comparison of (A) per capita chemical pollutant loads calculated for the study area using the primary method based on wastewater characteristics and water use, (B) per capita pollutant loads caculated for the occupied Palestinian Territories (oPT) based on local diet using the method by Jönsson *et al.* (2004), and (C) average per capita loads from the literature.

	A Calculated per capita load Nablus-East kg/(p*yr)	B Calculated per capita load oPT; comparison method kg/(p*yr)	C Per capita loads from the literature kg/(p*yr)
Total Nitrogen	3.5	2.6	4 to 5 (Gajurel *et al.* 2003)
Total Phosphorous	0.2	0.3	0.75 (Gajurel *et al.* 2003)
BOD_5	18	N/A	20 (Arceivala and Asolekar 2007)

"consumption" is the water lost via consumption, WW_{total} is the total amount of WW produced in the area (m^3/day), WW_{ground} is the total amount of wastewater infiltrating the ground (m^3/day), WW_{wadi} is the total amount of wastewater reaching the sewer outflow point (m^3/day), HU_{total} is the total number of housing units (buildings), HU_{sewer} is the total number of housing units with sewer connections, $HU_{cesspit}$ is the total number of housing units with cesspits, TN_{ground} is the total load of nitrogen discharged to the ground (kg/day), and TN_{wadi} is the total load of nitrogen reaching the sewer outflow point (kg/day). Figures for TP and BOD_5 were calculated identically as TN values.

In order to assess the integrity of the calculated per capita chemical loading, comparisons were made to values in the literature (Table 2). In addition, for comparison purposes, TN and TP loading per capita were calculated using a second method based on nutrition data developed and described by Jönsson *et al.* (2004). These calculations were based on protein consumption using FAO nutrition data for the Occupied Palestinian Territories. Country data was obtained from FAO-Stat website under "Nutrition Data - > Food Supply - > Crops Primary Equivalent". Results of these secondary calculations based on the local diet are also in Table 2 and are labeled "comparison method" to avoid confusion with loads calculated using the primary method.

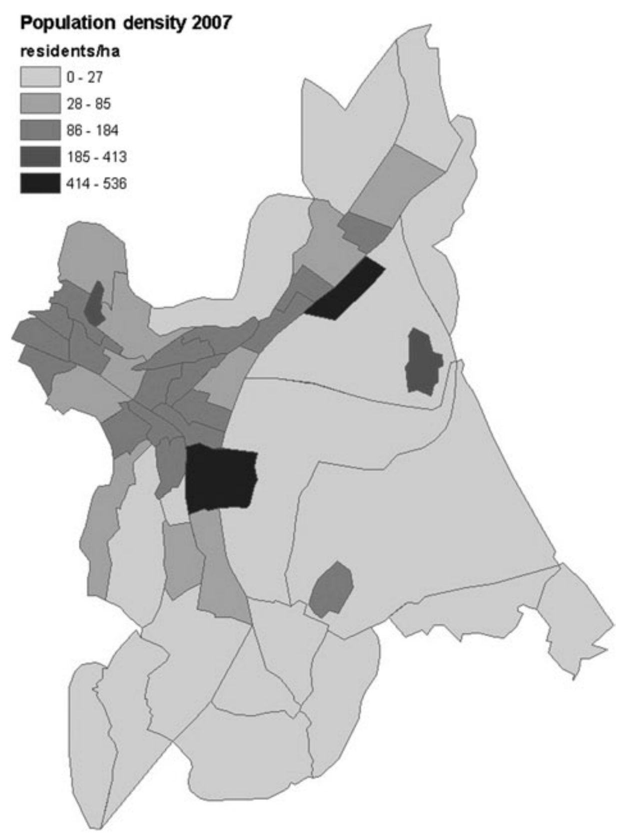

Figure 3. Updated population density of the study area, based on population density map from Lahmeyer International, SETEC and ACE (2005).

Results

Population and zoning

Nablus-East is characterized overall by low density housing with large swaths of industrial areas and open spaces (including agricultural land) and small pockets of very densely inhabited areas where the refugee camps are located. The total population of the study area was calculated to be 66,490 in 2010. The majority of the study area is residential (53%). Another 15% of the study area is zoned as industrial and 5% is refugee camps. Figure 3 shows the spatial distribution of population densities in the study area. Notably, the Balata and Askar refugee camps make up 40% of the population in the study area but take up only 5% of land area.

The population growth rate in the municipality of Nablus over the 10 year period between 1997 and 2007 was extremely low (0.1% growth; Table 3). Conversations with local residents revealed anecdotally that many residents moved out of Nablus during the 2nd Intifada (roughly from 2000 to 2006), because the borders were tightly sealed by Israeli checkpoints and it was very difficult to get in and out. This likely explains the low growth rate of the city. A previous study (Dahlem and

Table 3. Area and population figures for the different municipal regions of the study area. 1997 and 2007 figures are actual census figures or derived from census figures; 2010 figures are projected.

	Nablus-East	Kafr Qalil village	Rujeib village	Askar camp	Balata camp	Study area total
Area (m^2)	$7668*10^3$	$5956*10^2$	$1984*10^3$	$2568*10^2$	$2912*10^2$	$1080*10^4$
% Study Area	71%	6%	18%	2%	3%	
Popln 1997	$2717*10^1$	1862	2926	9,496	$1319*10^1$	$5464*10^1$
Popln 2007	$3201*10^1$	2414	4138	$1143*10^1$	$1501*10^1$	$6500*10^1$
Popln 2010	$3213*10^1$	2607	4588	$1157*10^1$	$1560*10^1$	$6649*10^1$
Annual growth rate	0.1%	2.6%	3.5%	1.9%	1.3%	1.8%

Jardaneh 2008) noted that a large percentage of newly built (high-rise) apartment buildings in Nablus are mostly uninhabited, and personal observation in the field confirmed that this is still true.

The two refugee camps in the study area, on the other hand, with 40% of the population of the study area, had ten-fold higher annual growth rates than the municipality of Nablus itself, with 1.3% and 1.9% in Balata and Askar camps, respectively. The growth rates of the two villages in the study area were higher yet – close to double those of the refugee camps (2.6% and 3.5%; Table 3).

Sewerage and cesspits

Nearly all of Nablus-East is covered by the sewer network (Figure 4). The refugee camps are also sewered, although the sewer lines are not displayed on the map. The major sewage outlets are also shown on the map in Figure 4. According to several sources, the sewage network in Nablus-East has more than one outlet, however the primary outlet is located near the slaughter house in the industrial area, and carries the vast majority of Nablus-East's sewage (GTZ and Arabtech Jardaneh 2006). The subcatchments and flow directions determined in ArcMap indicate that sewage from subcatchments one and two flow into three, which then flows into subcatchment four, and is discharged at a single outlet point marked with a star in Figure 4. Subcatchment five's wastewater is believed to have a secondary outlet to the wadi downstream of the primary Nablus-East outlet, based on the flow analysis and personal communication with WSSD engineers in Nablus (January 2011). A possible secondary outlet for subcatchment 5 is shown in Figure 4. All of Nablus-East's wastewater flows to the wadi toward Wadi Fara'a untreated.

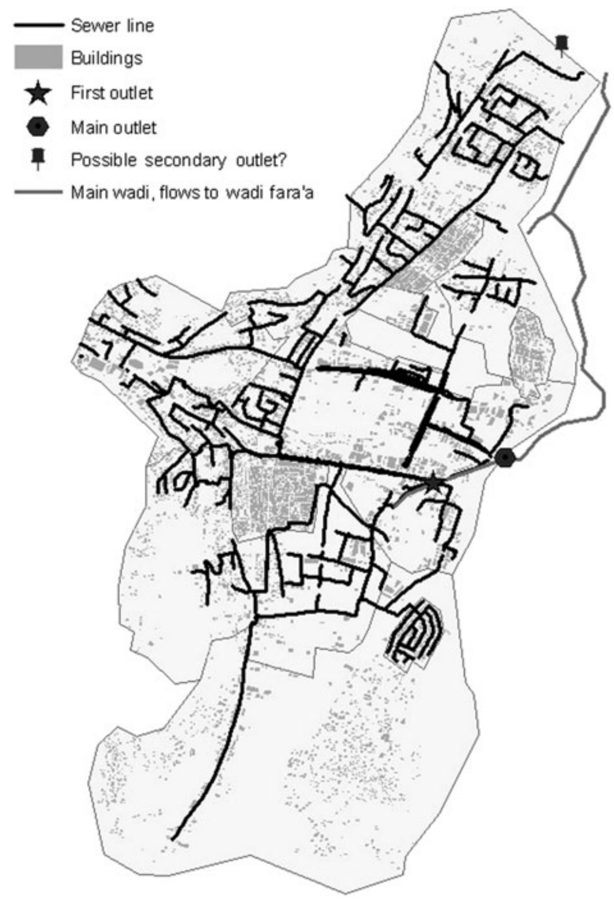

Figure 4. Sewer network and sewage outlet map. Flow direction of the study area is primarily west to east, while the flow direction of the wadi is north.

Records from the 2007 census show that 99.7% of the households in the municipality of Nablus use the city's water mains, and that furthermore 97.2% are connected to the public sewage network (PCBS, 2009b). The 2007 census recorded a total of 637 cesspits in the municipality of Nablus. The proximity analysis in ArcMap revealed that as many as 189 buildings in Nablus-East may be unsewered. This figure includes only buildings within the study area that fall inside the municipal boundaries of the city of Nablus; actual numbers of cesspits for the villages and camps are known from the census (circa 2007). Table 4 details actual (villages and camps) and estimated (Nablus-East) numbers of cesspits in the study area. Balata and Askar refugee camps are nearly 100% served by sewage networks, with only a total of seven cesspits (amongst about 4800 households). The villages of Rujeib and Kafr Qalil both have a high percentage of unconnected households; notably, Rujeib is 100% unsewered. A map highlighting actual (villages) and predicted (Nablus-East) locations of cesspits is displayed in Figure 5. Table 5 provides an overview of the data available about cesspits from the 2007 census for the northern West

Table 4. Water and sewerage connections in the study area, based on 2007 census data by housing unit (HU) (PCBS, 2009b). Nablus-East figures are estimated based on distance to the nearest sewer line using proximity analysis in ArcMap.

	Total # HUs	Total popln. 2007	% Study area	% Public water	# Private wells	% Public sewage	# Cesspits (actual)	# Cesspits (est.)	%HUs with cesspits
Nablus-East	6403	$3213*10^1$	71%	100%	?	97%	unknown	189	3%
Rujeib	758	4138	18%	100%	1	0%	756		100%
Kafr Qalil	417	2414	6%	100%	41	72%	115		28%
Balata camp	2717	$1501*10^1$	2%	100%	3	100%	3		0%
Askar camp	2082	$1143*10^1$	3%	100%	2	100%	4		0%
Total	$1238*10^1$	$6,512*10^1$		100%	47	$<88\%$	1515	1704	$>12\%$

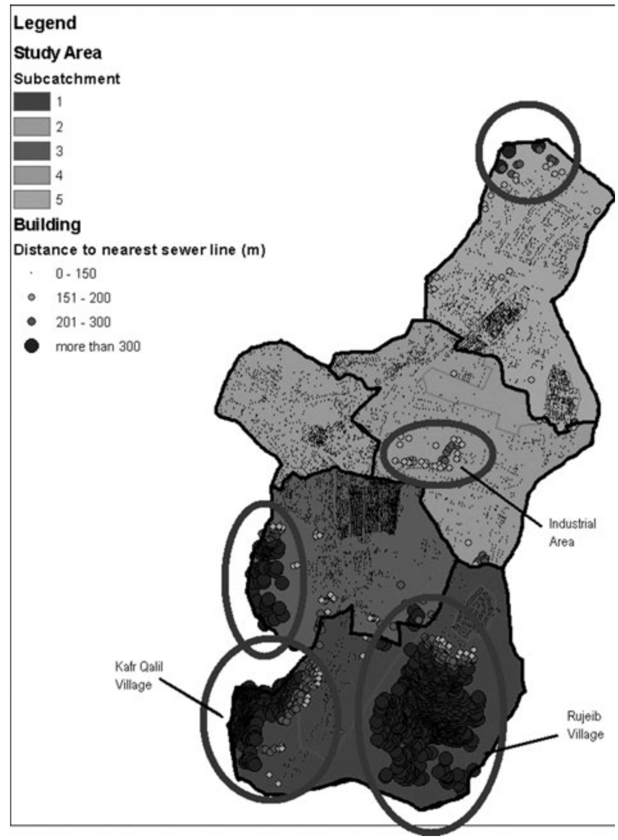

Figure 5. Predicted locations of cesspits in study area based on analysis of each building's proximity to sewage line. Areas with known or predicted concentration of cesspits are circled.

Bank. According to the census, the majority of cesspits are less than 20 m^3 in volume, and more than 97% of them have "porous" lining.

Water use

The city of Nablus's water supply comes from four deep water wells outside the city and six springs inside the municipal boundaries. The wells outside the city provide the vast majority (about 80%) of current production (Lahmeyer International et al. 2005). Two of the springs within the city limits lie within the Nablus-East study area, near the Western limits of the catchment and close to the city centre.

Records from the financial section of the municipality of Nablus's WSSD show that a total of 6,595,334 m^3 of water was consumed in the first 10 months of 2010 for the entire service area. The total serviced area had an estimated population of 205,820 in 2010. These figures result in an estimated 106.4 L $capita^{-1}day^{-1}$ water use, including residential, commercial, and industrial use. Table 6 shows the estimated water use for each of the 5 subcatchments in the study region. Subcatchments 3 and 5, with the refugee camp populations, have the highest total

Table 5. 2007 census figures related to cesspits, reported for the northern West Bank (PCBS, 2009b).

Cesspit volume	61%	less than 20 m^3
	38%	from 20–50m^3
Single household or multi-household	51%	single household use
	47%	used by 2–4 households
Type of lining	97%	"porous"
	3%	"tight"
% households having both cesspit and well		40%
Of those households, distance between cesspit and well	38%	less than 15m
	41%	from 15 to 25m

Table 6. Calculated annual water use and wastewater quantities by subcatchment number, including estimates of fraction going to ground and discharged to the wadi at the sewage outlet point, expressed in absolute quantities and as a function of area.

			Wastewater (m^3/day)			Wastewater (m^3/ha*day)		
Subcatchment	Estimated total water use (m^3/day)	Estimated water use per hectare (m^3/ha*day)	Total	To ground	To wadi	Total	To ground	To wadi
1	877	3	711	446	264	2.2	1.4	0.8
2	1175	11	951	129	822	9	1.2	7.8
3	2366	12	1917	334	1583	9.6	1.7	7.9
4	590	3	478	81	397	2.1	0.3	1.7
5	2066	9	1673	252	1421	7.6	1.2	6.5
Study area total	7075	7	5730	1242	4488	5.3	1.2	4.2

water usage (Table 6). The estimated total water usage for the study area per day was 7070 m^3.

Wastewater characteristics and estimated pollutant load

Chemical characteristics of Nablus wastewater used in this study are summarized in Table 1. Strong pollutant concentrations in Palestinian sewage are explained by low water usage, which is common in developing countries (Foppen 2002, Mahmoud *et al.* 2003). Wastewater quantities and pollutant loads for the study area are shown in Table 6 and Table 7. Based on calculations, an estimated 22% of total wastewater and associated pollutants go directly to the ground in the study area, while the remaining 78% is discharged to the wadi and flows towards Wadi Fara'a. Notably, a higher percentage of the estimated wastewater infiltrating the ground results from sewer exfiltration (57%) than from cesspits (43%).

Table 2 shows the comparison of the calculated per capita pollutant load values and also compares them to published values in the literature. The calculated loads of 3.5, 0.2, and 17.9 kg $cap^{-1}yr^{-1}$ for TN, TP, and BOD_5,

Table 7. Calculated watewater quantities and pollutant load per day by subcatchments. a. absolute loads and b. loading per day as a function of area.

		Total nitrogen (kg/day)			Total phosphorus (kg/day)			BOD_5 (kg/day)		
a)	Subcatch	Total load	To ground	To wadi	Total load	To ground	To wadi	Total load	To ground	To wadi
	1	79	50	29	7	5	3	253	94	159
	2	106	14	92	10	1	8	583	89	494
	3	213	37	176	20	3	16	1066	116	950
	4	53	9	44	5	1	4	322	83	238
	5	186	28	158	17	3	15	1032	179	853
	Total	638	138	500	59	13	46	3256	562	2694
		Total nitrogen (kg/ha*yr)			Total phosphorus (kg/ha*yr)			BOD5 (kg/ha*yr)		
b)	Subcatch	Total load	To ground	To wadi	Total load	To ground	To wadi	Total load	To ground	To wadi
	1	90	56	33	8	5	3	286	107	180
	2	365	50	315	34	5	29	2009	308	1701
	3	390	68	322	36	6	30	1952	212	1739
	4	83	14	69	8	1	6	505	131	374
	5	310	47	263	29	4	24	1719	298	1421
	Total	216	47	169	20	4	16	1101	190	911

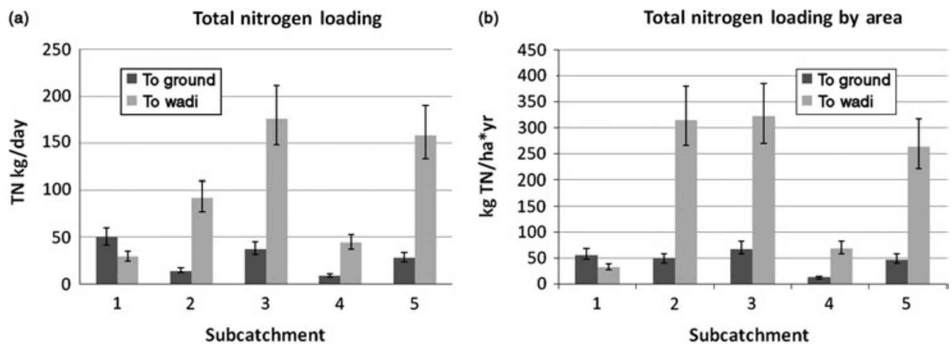

Figure 6. Estimated nitrogen loading by subcatchment (figures from Table 7): a) absolute nitrogen loading (kg/day) and b) loading by area (kg/ha*yr). Bars indicate the uncertainty range based on the min and max TN concentrations of Nablus-East wastewater.

respectively, are slightly lower than other published rates, but seem quite reasonable given the expected loading based on the local diet (Table 2).

Figure 6 shows the estimated nitrogen loading by subcatchment. Subcatchment 3 has the highest absolute N loading while subcatchment 1 has the highest absolute N loading to the ground. Subcatchment 3 has the highest total N loading by surface area as well as the highest N loading to the ground by surface area. Interestingly, estimated N loading to the ground by surface area was comparable for all of the catchments (hovering around 50 kg/ha*yr; Figure 6), with the exception of the sparsely populated industrial area of subcatchment 4. This was true regardless of whether the area was predominantly sewered or not. Figures for subcatchment 4 should be interpreted cautiously, since they were based on calculations for domestic loading by population density and did not consider additional industrial loading.

Figure 7 further illustrates the spatial distribution of nitrogen loading to the ground by source origin. Interestingly, the loading is heavily concentrated in the refugee camps, which are connected to the sewer network, but have extreme population density, whereas loads from (unsewered) villages in subcatchment 1 were also high, but more spatially spread out. Subcatchment 4, containing the industrial area, again shows low loading due to low population density.

Maps of estimated loads of other pollutants would mirror the image in Figure 7, because calculated loads were all based on the same fractions of wastewater going to the ground; they are therefore not presented here.

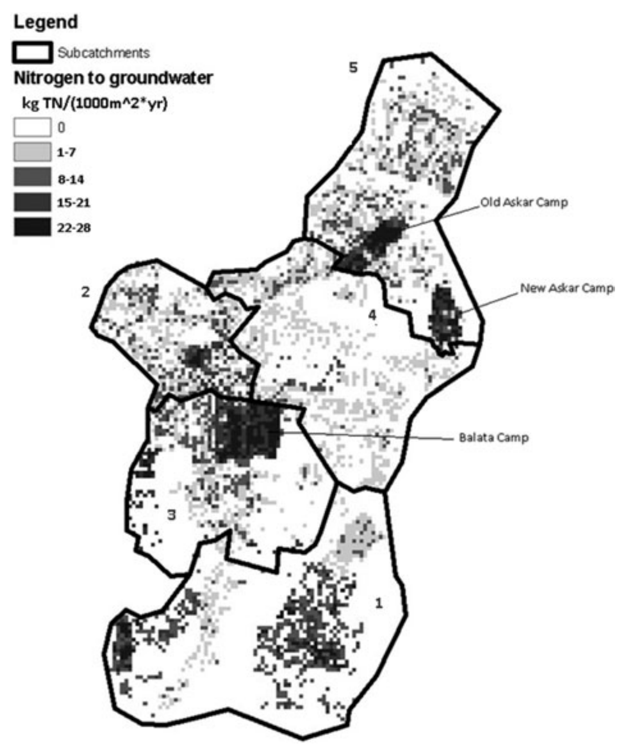

Figure 7. Spatial origin of nitrogen loads to groundwater, expressed in kg of TN per decare (1000 m^2) per year.

Industrial wastewater

The industrial zone in Nablus-East includes a number of factories, including stone cutting, tahini, textile, concrete, cosmetic, and soap. It also includes a slaughter house, a dairy, and a tannery. The major contributors to industrial wastewater and their estimated BOD input are summarized in Table 8. It should be emphasized that these figures are estimates only and could be overestimates, as they were used to help guide decisions about wastewater treatment plant design. However, the figures are based on quantities of items produced (i.e. number of sheep slaughtered per day), and therefore help to give an understanding of ratios and major contributors to industrial wastewater. Significant contributors of organic waste are the tahini industry, the dairy, the textile industry, and the slaughter house, which are located inside the study area.

Based on the figures of wastewater production from the different industries, values from the literature were used to estimate the pollutant loads of the major industrial contributors to organic wastes, which are summarized in Table 9.

Table 8. Estimated wastewater quantities and BOD input from the major industries producing organic wastes in Nablus-East (JV Dahlem and Jardaneh 2008).

	# of factories	Estimated wastewater production (m^3/day)	BOD input (kg/day)	Wastewater disposal method
Slaughter house	1	158	236	Sewer network
Dairy	1	205	251	Sewer network
Tahini	7	49	335	Sewer network (5) Cesspits (2)
Textile	2	242	184	Sewer network
Tannery	1	17	30	Sewer network
Cosmetic	3	3	Not estimated	Sewer network
Soap	2	Not estimated	Not estimated	Sewer network
Stone cutting	17	Not estimated	Not estimated	Open dumping
Concrete	13	Not estimated	Not estimated	Sewer network

Table 9. Estimated pollutant loads from major organic waste polluting industries in Nablus-East, based on wastewater quantities predicted from JV Dahlem and Jardaneh (2008) and pollutant concentrations from the literature.

	TN (kg/day)	TP (kg/day)	BOD_5 (kg/day)	TN (g/m^3)	TP (g/m^3)	BOD_5 (g/m^3)	Reference
Slaughter house	16	1.6	160	100	10	1000	Van Oostrom 2001
Dairy	16	2	170	80	10	816	Goel 2006
Tahini	no data	no data	330	no data	no data	7000	Dahlem and Jardaneh 2008
Study area total	32	3.6	660				

Discussion

The total wastewater calculated as recharge in this study was 453,600 m^3/year. According to the SUSMAQ study (a joint project of Newcastle University, the PWA, and several other UK and West Bank partners from 1999 to 2005), the total annual rainfall recharge for the region is between 0.09 and 0.12 MCM/km^2 (Najem 2008), which amounts to between 923,954 and 1,334,600 m^3/year, or roughly 1,000,000 m^3/year for the study area. Therefore, wastewater recharge in the study area may amount to as much as 50% of total recharge from precipitation, making sewage a highly significant source of recharge. Most of the municipal wells lie outside of the study area to the northeast of the city, but sewage infiltration within the study area may threaten municipal water wells, because the city of Nablus lies above the Eocene aquifer, which flows northeast (Qannam 2003, Najem 2008). The flow direction of surface water is also north-easterly. The most recent chemical analysis of groundwater samples from municipal wells confirm increasingly high levels of nitrate in groundwater, measuring 22 and 25 mg/l NO_3^- at wells of depth 670 ft and 675 ft and 11 mg/l NO_3^- at a well of depth 413 ft (Mahmoud *et al.* 2012). The municipal springs are on the westernmost side of the study area, and therefore may be less susceptible to contamination, however, the census indicates at least 25 private wells within the city and 41 private wells in the village of Kafr Qalil (PCBS, 2009b), an area with a high density of cesspits. These shallower private wells are highly susceptible to sewage infiltration.

If we compare the calculated N loadings from sewage in Nablus-East to N loading from agriculture in the area, sewage seems to be at least a comparable contributor to agriculture. Najem (2008) interviewed farmers in the Wadi Fara'a region outside of Nablus, and subsequently estimated average fertilizer loads were 20 kg per donum (also spelled dönüm, dunam, donom**,** a non-SI unit of area used in the Ottoman Empire, equal to 1000m^2) per month in the area. The study reported that the three types of fertilizers used in the area are urea, ammonium sulphate, and calcium nitrate (Najem 2008), which are 46.6%, 21.2%, and 17% nitrogen by mass, respectively. This indicates that nitrogen loading by agriculture in the region is somewhere between 3.4 and 9.2 kg per donum per month, or between about 1 and 3 kg $ha^{-1}day^{-1}$. The results of this study estimate a total loading of 0.6 kg nitrogen $ha^{-1}day^{-1}$, or 1.8 kg per donum per month from sewage in the study area. Thus, sewage may contribute up to 60% as much nitrogen loading by area as agriculture. Furthermore, because of the extremely high population densities, the N loading from the refugee camp wastewater ranges from about 4 to 5 kg N $ha^{-1}day^{-1}$, a figure that could be up to 4 or 5 times the amount of N loading from agriculture by area.

The urban nitrogen loading rate of 216 kg N ha^{-1} yr^{-1} calculated for Nablus-East is greater than the rate of 21 kg N ha^{-1} yr^{-1} reported by Wakida and Lerner (2005) for the city of Nottingham (UK), however the loading rate for Nablus-East should be expected to be significantly higher because of the high density of unlined cesspits. Ideally, the estimates of recharge and pollutant loading presented here should be compared with field data for validation, however as is common with estimates of urban nitrogen loading to groundwater, lack of information and suitable sampling points make this challenging (Lerner 2003). Because the sampling points (wells) are outside the city, validation of results with groundwater samples would require large amounts of additional data for a wider catchment area including non-urban nitrogen loads, which is outside the scope of this study. Furthermore, an urban borehole is unlikely to reflect current nitrogen loading, unless the nitrogen loading rate has been constant for the entire turnover time of the aquifer, which is highly improbable due to population and land use change over time (Lerner 2003). Validating sewer exfiltration rates with field data is equally problematic, as there is currently no single, reliable method of measurement, and different experimental methods have produced widely varying results (Rutsch *et al.* 2008). A validation of wastewater flow estimations with experimental flow measurements at Nablus-East outlets, however, is recommended for a future study.

Conclusion

Wastewater as recharge in the Nablus-East study area may be as much as 50% of total recharge from precipitation, and nitrogen pollutant loads from sewage are up to 60% as much as loads from agriculture by area. Validation of the results of this study are problematic due to lack of reliable methodology, information, and sampling points to monitor wastewater flow to groundwater in the field. Nevertheless, most recent chemical analysis of groundwater samples near the study area confirm high nitrate concentrations in groundwater. Results suggest that sewage poses a serious threat to groundwater in Nablus-East and that current loading to the ground via cesspits and leakage amounts to 22% of total wastewater flow. Spatial analysis shows that pollutant loads are concentrated in dense pockets, and population growth rates in unsewered and densely populated areas suggest that that the loads uncaptured by sewerage will continue to increase over time.

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