

Review

A Review of Groundwater Contamination in West Bank, Palestine: Quality, Sources, Risks, and Management

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Abstract: The contamination and shortages of drinking water in the West Bank are among the most important challenges facing the Palestinian National Authority (PA) and the population residing in all sectors. In general, the contamination of water sources makes it difficult to obtain a sufficient quantity of drinking water of suitable quality, since contaminated water has a harmful effect on health, which profoundly impairs the quality of life. Despite knowledge of the adverse health effects of chemical and biological groundwater contamination, few studies have been conducted to suggest measures that can be taken to overcome the contamination and shortages of water. In our review, four levels of domains are used to evaluate the groundwater situation/condition in the West Bank, including (i) assessing the groundwater quality in the West Bank, (ii) identifying the sources of groundwater pollution, (iii) determining the degree of health risks associated with groundwater pollution, and (iv) determining the role of groundwater management in maintaining the quality and sustainability of these sources. To this end, the previous literature on groundwater status was reviewed for the past 27 years. In order to analyze the existing literature, a review matrix based on these four core domains was developed. Our findings revealed only 5 studies corresponding to the first nine years and 9 and 16 studies in the second and third periods, respectively. Furthermore, we found that only a few studies have examined the degree of health risk of groundwater in the West Bank. Although the government of Palestine has made access to safe drinking water a priority for its population, the PA struggles to provide sufficient and clean water to its residents, with a number suffering from water shortages, especially in dry seasons.

Keywords: groundwater; health risks; management; West Bank; Palestinian National Authority



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1. Introduction

Most of the world's population suffers from a lack of safe water supplies [1]. As the population of the world grows and the environment becomes further affected by human activity, access to fresh drinking water dwindles, and Palestinians in the West Bank, similarly to the rest of the world, suffer from a lack of potable water [2]. PA in the West Bank use groundwater as the main source of water, representing more than approximately 90% of the total water supply [3]. Groundwater, in the form of wells and springs, comprises the main sources of water in the West Bank, the land of which is limestone with karstic characteristics [4]. Spring water is naturally found where ground water emerges from the Earth's surface in a defined flow [5]. While water from natural spring represents an important source of drinking water, its quality is currently being seriously threatened by microbiological and chemical contamination. A spring's water can be described as any natural occurrence where water flows onto the surface of the Earth from below. Springs are key elements of the natural environment that respond sensitively to any changes occurring in natural ecosystems and can therefore be classified as important hydrogeological indicators [6]. However, this form of groundwater is incredibly vulnerable to pollution given the karstic nature of the aquifer and due to various human activities

resulting in untreated wastewater, pesticides, chemical fertilizers, livestock farm waste, and unsanitary landfills [2]. Importantly, an increase in any one of the physico-chemical and biological parameters in groundwater beyond the permissible limits indicated by the World Health Organization (WHO) guidelines and the Palestinian national standards (PSI) may result in damage to human health [5,7,8] (Table 1).

Table 1. The Palestinian national standards (PSI) and World Health Organization (WHO) permissible limits for water [7,8].

WHO	PSI	Unit	Water Tests (Physicochemical Parameters)
-	-	$\mu\text{S}/\text{cm}$	Conductivity of water (EC)
1.5	1.5	mg/L	Fluoride in water (F)
50	50	mg/L	Nitrate in water (NO_3)
NA	NA	mg/L	PO_4 (as P)
6.5–8.5	6.5–8.8		pH of water
250	200	mg/L	Sulfate in water (SO_4)
1000	1000	mg/L	Total dissolved solids (TDS) in water
500	500	mg/L	Total hardness of water (TH)
1.5	-	mg/L	Ammonia in water (NH_3)
250	250	mg/L	Chloride (Cl)
-	100	mg/L	Calcium (Ca)
-	100	mg/L	Magnesium (Mg)
-	200	mg/L	Sodium (Na)
-	10	mg/L	Potassium (K)
-	0.2	mg/L	Aluminum (Al)
-	0.3	mg/L	Iron (Fe)
-	0.1	mg/L	Manganese (Mn)
2	1	mg/L	Copper (Cu)
-	5	mg/L	Zinc (Zn)
0.05	0.05	mg/L	Total chromium (Cr)
0.003	0.005	mg/L	Cadmium (Cd)
0.07	0.05	mg/L	Nickel (Ni)
0.7	-	mg/L	Barium (Ba)

Several studies have shown that there are rising concentrations of some chemicals, such as nitrate, in groundwater, which affects the sustainability of this limited water resource [9–11]. Monitoring the sources of pollution in the water recharge areas of the aquifers is extremely important and would help in managing water resources in a highly effective way, thereby enhancing governance of the entire sector [12]. The Oslo I and II Accords provide broad guidelines for how water is used in the West Bank, including pollution management, waste treatment, the extraction and use of natural resources, and the prevention of harm to water infrastructure [13]. It has become necessary to protect water sources from pollution in order to maintain the quality and sustainability of these sources.

The assessment of water quality provides baseline information on water safety, and continuous monitoring of water is essential because water quality in any source of water and at the point of use can change with time and other factors [14]. However, the list of parameters to be tested in any water assessment and monitoring program may vary according to the local conditions of the area. Parameters that are basic and generally considered priorities in any water quality assessment may include physico-chemical, harmful chemicals, and microbiological parameters [15].

Groundwater contamination is often the result of human activity. In areas where population density is high and there is intensive human land use, groundwater is especially vulnerable. Generally, most activities whereby chemicals or wastes may be released to the environment, either intentionally or accidentally, has the potential to pollute groundwater. When groundwater becomes contaminated, cleanup or remediation become difficult and expensive [16]. Biological and chemical pollutants, when they reach groundwater, may cause harm to humans and the environment. An increase in the incidence of waterborne human diseases, such as diarrhea and emesis, occurs due to drinking of polluted water [17]. These waterborne diseases can lead to death if correct treatment is not provided [18]. As-suring the safety of drinking water has been a crucial challenge for public health. Water contamination with pathogenic microorganisms represents a seriously increased threat to human health [6]. Agricultural activities, such as the addition of pesticides and fertilizers, soil washing, and evaporation processes [16], could lead to the emergence of many pollutants, such as nitrate, in groundwater. Moreover, groundwater quality is widely affected by various factors, including human—i.e., agricultural and industrial—activities and, importantly, insufficiently treated sewage [19]. In West Bank, Palestine, cesspits are considered an important source of groundwater pollution, mainly in rural areas, where connection to the mains sewerage network system is inaccessible, impractical, and costly. Cesspit effluents contain a wide variety of chemical and biological pollutants [2,20].

Population growth and urban expansion affect the quantity, quality, and sustainability of water resources. The pressure on water resources in the coming years due to the expected population increase will affect the quantity and quality of water in the sources, and this will undoubtedly affect the sustainability of these sources [21]. Furthermore, the hydrological status in Palestine is unique due to both political and natural conditions. The main natural conditions include (i) scarcity and uneven distribution of rainfall due to extreme topographic variations within the region and (ii) the hydrogeological location of the West Bank, which extends from the upstream portion of the Shared Carbonate Aquifer System to downstream of the Jordan River Basin.

According to the Palestinian Central Bureau of Statistics (PCBS) and Palestinian water authority PWA, the per capita use of water in the West Bank is 73 L/capita/day, which is the share of water for Palestinians and is considerably lower than the 100 L/capita/day minimum recommended by WHO. In some communities in area C, Palestinians survive on as little as 20 L/capita/day [22,23]. All water resources in the Occupied Palestinian Territory were placed under military control by Israel when it occupied the Palestinian territories in 1967 (Military Order No. 92, 1967); these orders are still in effect, but they only apply to Palestinians and not to Israeli settlers who are subject to Israeli law [24]. Some water management responsibilities were issued to the Palestinian Authority in accordance with the Oslo Accords, in accordance with Article 40 of the environmental provisions in the Oslo II Accord, where approximately 80% of the waters pumped from the aquifers were allocated for Israeli use and the remaining 20% for Palestinian use [25]. Despite the lack of water, meeting the basic needs of the Palestinian population is a national priority, and the government is struggling to expand access to safe drinking water and sanitation. The proportion of the population using safely managed drinking water services in Palestine was 59.1% in 2017 [26].

Monitoring water quality is an essential step to enhance its public use. Therefore, this study aims to shed light on groundwater pollution in the West Bank in terms of quality, sources, risks, management, and the relationships among them in addition to providing a description of the groundwater situation. An analysis of the existing literature was conducted on the past 27 years of literature, which was reviewed using a review matrix based on the four core categories developed for this purpose. Importantly, this review matrix will provide an idea of the number of studies that have been completed during the specified period, which is expected to offer a clear idea about groundwater contamination in the West Bank, the degree of health risks, and the role of sound management in maintaining the quality and sustainability in groundwater. Studies were classified according to the four

abovementioned categories, which can offer an idea of the sort of studies required in the future (Table 2). It is impossible to guarantee adequate groundwater quality if there is no appropriate environmental management of pollution sources. To ensure the sustainability and sustainable availability of fresh water sources in the future, more water quality studies need to be conducted over a period of time. The availability of water quality monitoring data for periods of at least a few years is very useful for comparisons of different ion concentrations [27].

Table 2. Review matrix of groundwater research in West Bank, Palestine, for the years 1994–2022.

Author(s)	Year	Groundwater Quality	Sources of Pollution	Health Risks	Groundwater Management
J. Isaac, V. Qumsieh, and M. Owewi [28]	1995	x			x
J. Isaac and W. Sabbah [29]	1997				x
PWA [30]	2000	x		x	x
L. J. Froukh [31]	2003				x
M. Ghanem [32]	2005				x
R. M. Stephan [33]	2007				x
A. Mohammad S. Juaidi [34]	2008				x
F. M. Anayah and M. N. Almasri [10]	2009	x	x		x
G. A. Daghrhah [35]	2010	x			
M. Ghanem, S. Samhan, E. Carlier, and W. Ali [36]	2011	x	x	x	
Z. A. Mimi, N. Mahmoud, and M. A. Madi [37]	2012		x		
D. A. Shreim [38]	2012		x		
B. Borst, N. J. Mahmoud, N. P. van der Steen, and P. N. L. Lens [39]	2013		x		
H. Malassa, M. Hadidoun, M. Al-Khatib, F. Al-Rimawi, and M. Al-Qutob [40]	2014	x			
A. Aliewi and I. A. Al-Khatib [11]	2015	x	x	x	
T. Judeh, M. Haddad, and G. Özerol [12]	2017				x
A. H. D. M. G. Atta [41]	2017	x	x		
World Bank [42]	2018				x
H. Jebreen, A. Banning, S. Wohnlich, A. Niedermayr, M. Ghanem, and F. Wisotzky [9]	2018	x			
A. Daghara, I. A. Al-Khatib, and M. Al-Jabari [43]	2019	x			
M. Rudolph [44]	2020				x
M. N. Almasri, T. G. Judeh, and S. M. Shadeed [45]	2020	x	x		x
B. Hejaz, I. A. Al-Khatib, and N. Mahmoud [2]	2020	x			
D. H. M. A. Daajna [46]	2020	x			x
M. N. Almasri, T. G. Judeh, and S. M. Shadeed [45]	2020	x	x		x
W. Ahmad and M. Ghanem [47]	2021	x	x		
T. Judeh, H. Bian, and I. Shahrour [48]	2021	x			x
M. Ghanem, W. Ahmad, Y. Keilani, F. Sawaftah, L. Schelter, and H. Schuettrumpf, [49]	2021	x			
N. Mahmoud, O. Zayed, and B. Petrusevski [27]	2022	x			
R. A. Thaher, N. Mahmoud, I. A. Al-Khatib, and Y. T. Hung [50]	2022		x		

2. Groundwater Quality in West Bank, Palestine

Groundwater contamination is the addition of undesirable substances to groundwater caused by human activities, and this contamination can render groundwater unsuitable for use [51]. The major contaminants in the West Bank are NO_3 , Cl, Na, NH_4 , PO_4 , TDS, salinity, and FC [27]. There are many classes of contaminants detected in groundwater, but chemical and biological contaminants are the most important. These contaminants can come from natural and anthropogenic sources [52]. Anthropogenic activities are increasingly threatening groundwater quality due to the large amounts of nitrogen, phosphorus, and heavy metals that infiltrate the soil when precipitation and irrigation and reach the groundwater [53]. Unsanitary landfill and agricultural areas scattered in the northern West Bank may lead to the deterioration of groundwater [54]. In recent years, nitrate contamination in groundwater has been reported in many countries (e.g., Spain [55], Italy, Morocco, Tunisia [56], Syria [57], Iran [58], Pakistan [59], Thailand [60], China [61], Mexico, and Brazil [62]), and Palestine also suffers from the same problem [2]. Importantly, nitrate (NO_3) is one of the most important chemical parameters by which water quality is measured. A recent study in the northern West Bank has shown that 18% of the samples examined from groundwater were above the permissible limit for the WHO guidelines and PS Table 1. Likewise, fecal coliform (FC) and total coliform (TC) results showed that 1.3% of the samples were low-risk [2]. Concentrations of nitrate in groundwater can generally be affected by wastewater, cesspits, farming activities (fertilizers), septic tanks, and animal manure [10]. In the West Bank, the high to very high level of phosphate additionally confirmed that the occurrence of groundwater pollution with untreated or insufficiently treated wastewater is extremely likely [27]. In different regions of the world, such as the rural areas of northern China, groundwater is polluted by large amounts of nitrogen fertilizers, which are used by humans in agricultural activities [63]. On the other hand, the large-scale use of fertilizers in the West Bank led to an increase in the concentration of nitrates in groundwater.

The presence of a certain concentration of nitrogen in groundwater is an indicator of the pollution of this water. Nitrogen leaks into the groundwater from various sources, such as cesspits, urban sewage collection lines, dry and wet sedimentation, the flow of treated and raw wastewater into valleys and waterbodies, fertilizers (chemical and manure), and irrigation with polluted water [45]. According to the study of Qana valley springs in Salfit governorate, Palestine biological tests indicated that all the springs are not suitable for drinking purposes because of their contamination with *E. coli* and fecal bacteria, and the reason for this contamination is untreated wastewater [64]. Previous studies in the West Bank have shown that 10% of the samples had a hardness value above the permissible limit of the PSI, 15% had a sodium content exceeding the permissible limit of the PSI, and only a very small fraction of the samples (3%) were contaminated with fecal coliforms [43]. Mahmoud pointed out in his study that the concentration of ions and treatments (such as Cl^- , Na^+ , NH_4^+ , TDS, and NO_3) affect the quality of water related to aesthetics and health, and those of heavy metals (such as Cr, Cu, Fe, Mn, Pb, Cd, and As), are within the recommended limits for drinking water (Table 3). However, signs of contamination, namely elevated levels of nitrate and ammonium, have been observed even in some deep wells [27]. About 41% of the selected wells in the Tulkarm and Qalqiliya were demonstrated to have nitrate concentrations higher than the limits in the WHO and Palestinian standards, while the chloride concentration was within the acceptable limit [4] (Figure 1).

Table 3. Physicochemical parameters of the groundwater from 29 wells in West Bank, Palestine [27].

Parameter	Average (STD)	Range	PSI	WHO
pH	7.4 (0.2)	6.8–7.9	6.5–8.5	NA
TDS (mg/L)	340 (56)	265–449	1000	NA
F (mg/L)	0.3 (0.2)	0.1–1.2	1.5	1.5

Table 3. Cont.

Parameter	Average (STD)	Range	PSI	WHO
Cl (mg/L)	59.8 (27.3)	33–132	250	NA
SO ₄ (mg/L)	17.1 (8.7)	8–48	200	NA
HCO ₃ (mg/L)	246 (8.8)	226–259	NA	NA
NO ₃ (mg/L)	21.5 (10.9)	0–46.2	50	50
PO ₄ (mg/L as P)	0.8 (0.7)	0.0–3.0	NA	NA
Ca (mg/L)	50.7 (3.3)	46–59	100	NA
Mg (mg/L)	20 (1.7)	17–25	100	NA
Na (mg/L)	39.8 (18.8)	21–91	200	NA
K (mg/L)	2.7 (4.5)	0–19	10	NA
TH (mg/L)	208.5 (13.4)	187.2–250	500	NA
NH ₄ (mg/L) as N	1.6 (2.4)	0–8.5	NA	

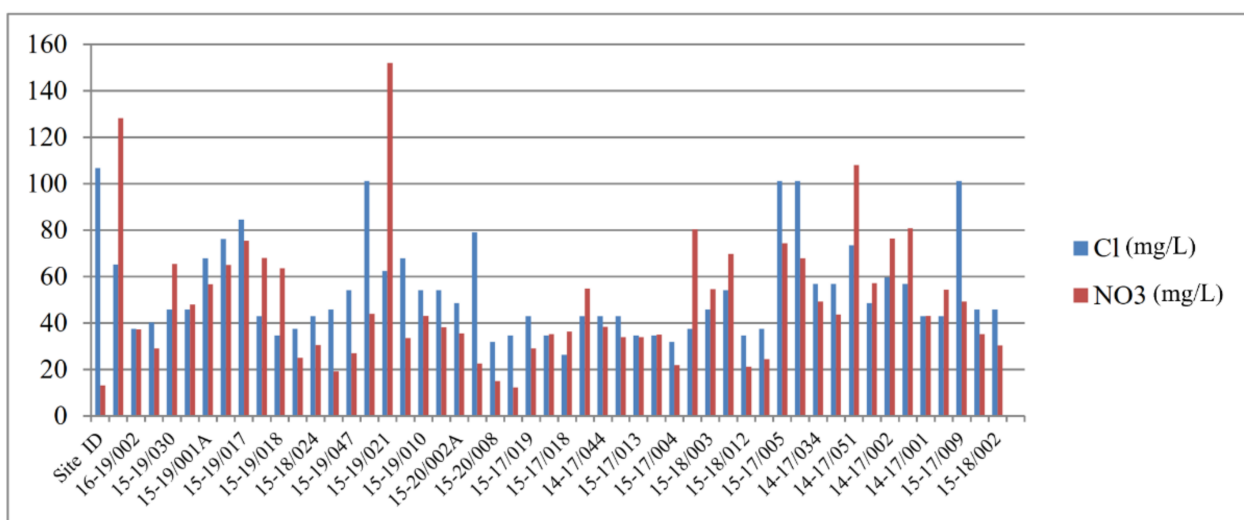


Figure 1. Annual average chloride and nitrate content in selected wells in Qalqilia and Tulkarm in the West Bank 2013 [4].

3. Sources of Groundwater Pollution in West Bank, Palestine

Raw wastewater is considered one of the potential sources of groundwater pollution in the West Bank, where sewage flows into the nearby valleys and waterbodies, leaving behind large amounts of pollution [11]. Cesspits, agricultural activities, and the random dumping of solid waste are also considered sources of groundwater pollution [11,39,45,50]. The high concentrations of chemical and biological parameters of groundwater above the permissible limits of WHO and PSI will have direct effects on public health [65,66].

More than 200 Israeli settlements and outposts discharge a large quantity of wastewater into the valleys of the West Bank every year [29,46,47,64,67] (Figure 2). In a recent study that assessed the impact of untreated wastewater discharged to Sarida Valley in the West Bank, a strong relation was found between the wastewater flow in Sarida valley and the spring water quality system in the drainage catchment [47]. Another study in the West Bank found that the reason behind the high nitrate pollution in spring water could be attributed to agricultural activities in addition to the high groundwater recharge. However, leaking septic and sewer systems are considerably causing the nitrate contamination of groundwater in populated areas [68]. In another study of the quality of spring water in the central West Bank, the cause of the high levels of K and Na was found to be the intensive

farming around these springs [49]. It is clear that the springs have high concentrations of total and fecal coliform bacteria, which indicates the presence of pollution hotspots in that area, such as the cesspits or due to sewage water flowing near the springs (Table 4) [49].

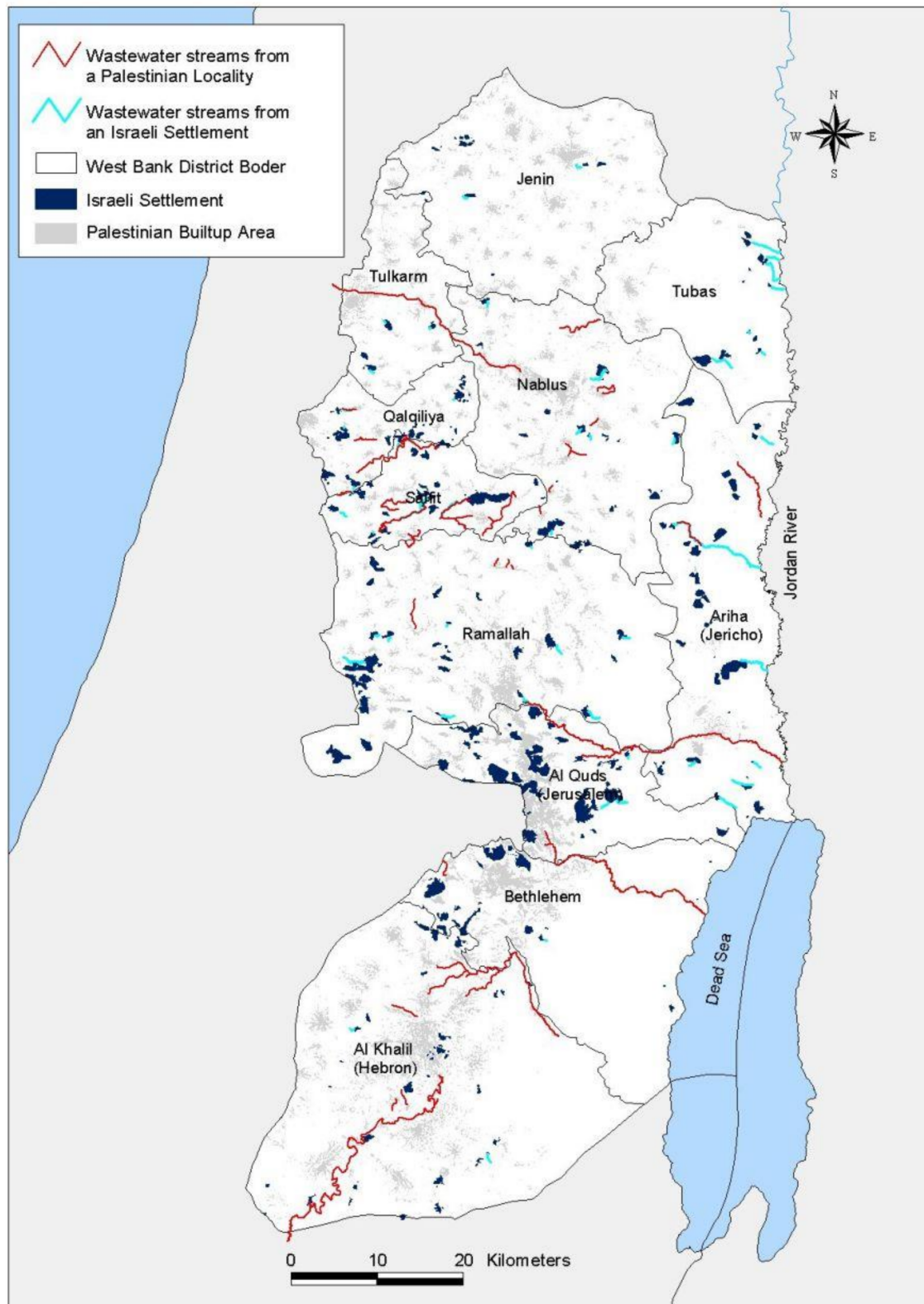


Figure 2. Wastewater streams from Palestinian location and Israeli settlements (ARIJ, 2008).

Based on the per capita wastewater generation in the West Bank, the total volume of wastewater generated for the year 2015 was estimated to be approximately 66 MCM/year [69]. Wastewater treatment plants are mainly present and used in urban centers, where approximately 60% of the population are using the public wastewater network, while the remainder use cesspits and septic tanks to dispose of wastewater [23,70]. The percentage of the population served by cesspits and the sewage network in the northern West Bank is 54.5% and 45.5%, respectively [71]. Table 5 shows the governorates, population, percentage of the population served by cesspits and the sewage network and the amount of water supply and wastewater generated in northern West Bank. Wastewater seeps through the soil and rocks to reach the groundwater, which is considered as the main source of drinking water in the West Bank, and thus experiences considerable contamination and pollution [46].

Table 4. Overview of the results for analysis of 50 springs in the West Bank sampled for major cations and anions and comparison with the limits of WHO and PSI standards.

	Ca	Mg	Na	K	Cl	NO ₃	SO ₄	HCO ₃
Mean (mg/L)	91.64	39.25	53.60	26.03	40	5	27.7	200.8
Max (mg/L)	132.3	69.68	122.9	170.7	57.5	12.5	40.5	241
Min (mg/L)	26.48	15.56	11.12	0.204	28.5	1.9	15.8	156
Median (mg/L)	79.62	25.7	19.04	0.624	39.15	4.2	27.8	203
WHO Standard (mg/L)	NA	NA	NA	NA	250	50	250	NA
PSI Standard (mg/L)	100	100	200	10	250	50	200	NA

Table 5. Governorate, area, population, wastewater disposal systems, generation of solid waste, quantity of water supply, and quantity of wastewater generated in the northern West Bank [23,70,71].

No	Governorate	Area (km ²)	Population	% Population Served by Cesspits	% Population Served by a Sewage Network	Quantity of Water Supply (Million m ³)	Quantity of Wastewater Generated (Million m ³)	Generation of Solid Waste Ton/Year
1	Salfit	204	80,000	90% 73,889	10%	5.4	3.51	29,200
2	Qalqiliya	166	120,000	55% 66,919	45%	8.3	5.4	43,800
3	Tulkarm	246	200,000	57% 113,347	43%	10.1	6.57	73,000
4	Jenin	583	335,000	60% 203,351	40%	8.2	5.33	122,275
5	Tubas	402	65,000	65% 42,844	35%	4	2.6	23,725
6	Nablus	605	410,000	52% 216,115	48%	15.7	10.21	149,650
Total		2206	1,210,000			51.7	33.7	441,650

One of the main causes of groundwater contamination in the West Bank is the effluent (outflow) from septic tanks and cesspits. Approximately 28% of residential homes rely on cesspits and 10% on septic tanks [23]. The large number and widespread use of these systems means they are a serious source of pollution. Sewage systems can contaminate groundwater with bacteria, viruses, nitrates, detergents, oils, and chemicals [39,72]. Most of the communities in the rural areas of the West Bank suffer from a lack of adequate sewage

systems for the disposal of sewage. Rural systems in Palestine are limited to cesspits and septic tanks [73]. On the other hand, the US Environmental Protection Agency has specific and mandatory legislation governing the operation of septic tanks and cesspits in the US, whereby it assists in lowering groundwater contamination levels [74]. In a recent study on the quality of spring water, 127 samples were collected from 300 springs distributed across the West Bank, Palestine. Most of the physical and chemical characteristics for water from springs were within the acceptable standard limits, with the exception of turbidity, chloride, and nitrates. Regarding biological contamination limits, 97% of the samples were classified as possessing no risk, and only 2% were classified as possessing a simple risk and thus require chlorination treatment [43]. The development of sewage networks, wastewater treatment plants, and reduction in cesspits in rural areas significantly reduces nitrate concentrations and biological contamination in spring water.

The West Bank's soils are exposed to a wide range of human activities, including agricultural and industrial operations, which have a negative impact on arable land fertility [41]. Fertilizer and pesticide overuse is one of the most serious problems affecting the land in the West Bank, where farmers are forced to use increasing amounts of fertilizers and pesticides to boost the productivity of agricultural land due to the enormous rise in population and the limited agricultural area. In the West Bank, the annual rate of agricultural fertilizer use has reached up to 30,000 tons of chemical fertilizers and manures [75]. Likewise, annual rates of pesticide use in agricultural activities has reached up to 502.7 tons, a considerable amount that is internationally banned for health reasons [75]. Agricultural fertilizers and pesticides have caused high levels of nitrate and potassium in the groundwater [45].

West Bank, Palestine, is facing the problem of solid waste for several reasons: (i) increasing population, (ii) lack of materials and resources needed for solid waste management, and finally (iii) weak technical expertise [46,76]. Both Israeli settlements and Palestinian communities use non-engineered solid waste dumping sites in the West Bank [11]. This waste is mostly industrial or domestic and poses a high risk to the environment and to both surface and groundwater. In 2017, it was estimated that an individual generates approximately 1.9 kg of solid waste per day in Israeli settlements in the West Bank [77]. In 2019, Palestinians produced roughly 4333 tons of solid waste per day, totaling around 1.58 million tons for the year or around 0.9 kg per capita per day. However, 441,650 ton/year was produced north of the West Bank (Figure 3) [78,79].

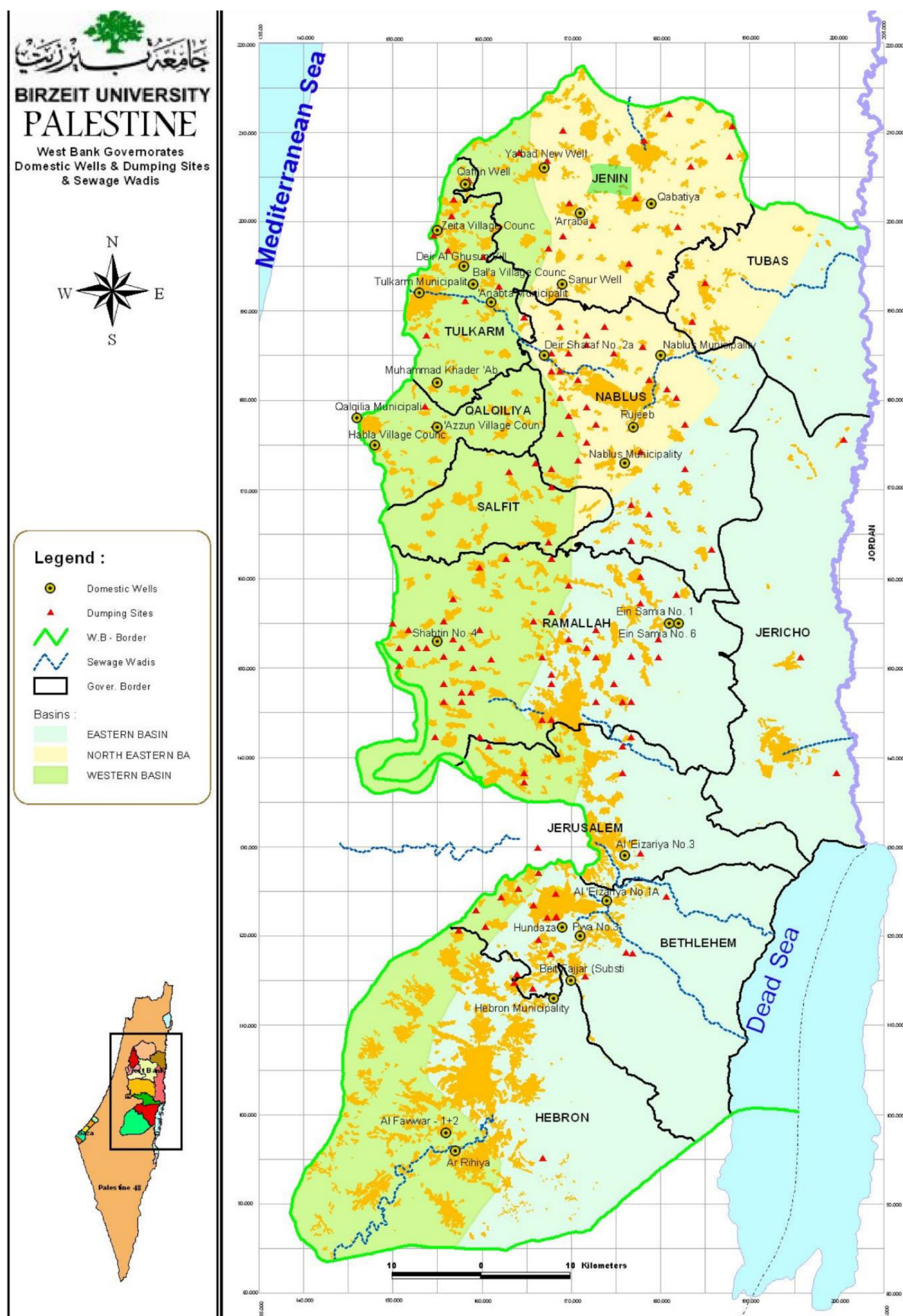


Figure 3. The non-engineered solid waste dumping sites in the West Bank—Birzeit University, Palestine [27].

4. Health Risk

The contamination of groundwater either from anthropogenic or natural sources poses risks to human health and results in the occurrence of waterborne diseases in humans, such as diarrhea and vomiting [80]. Biological contamination is considered the main cause of death worldwide, especially in poor and developing countries [18,81]. FC and TC results have shown that 1.3% of groundwater samples are contaminated in the northern governorates of the West Bank, Palestine [2]. In the study of water quality in Wadi al-Qilt area, the results showed that 47% of the samples are contaminated with FC bacteria, which indicates the leakage of pollutants in the area feeding the springs [35]. However, in 2019, a study of the quality of drinking water from springs in Palestine found that only 3% of the samples were contaminated with FC bacteria [43].

Chemical pollutants in groundwater have been a major concern due to health risks. Water contaminated with nitrates is not suitable for domestic use, since it causes diseases and health problems, such as shortness of breath, methemoglobinemia or (blue baby) syndrome, an increase in starchy deposits, and hemorrhaging at the spleen [82]. In the study of Dagbara et al. (2019), 21% of West Bank groundwater samples were found to have a nitrate concentration above the permissible limit [43]. On the other hand, the high concentrations of sodium and potassium in drinking water may cause high blood pressure in humans [83]. Pollutants, such as heavy metals, affect waterbodies due to their strong toxicity even at low concentrations. For some minerals, such as Ca, Mg, K, and Na, their presence in normal proportions is important for sustaining life, but extensive exposure to heavy metals can cause poisoning with serious health effects [84] (Table 6).

Table 6. Study on diseases associated with chemical and biological contamination of drinking water around the world.

Chemical and Biological Contaminants	Disease	Country	Source	Remarks
Fluoride	- Dental and skeletal fluorosis - The results of non-carcinogenic health risk indicate health risk was higher in infants and children as compared to the adults	Global scale and India	[85,86]	Fluorosis still represents a serious and widespread health problem, particularly in rural communities, which depend on untreated water supplies
Nitrate (NO ₃)	- Methemoglobinemia or “blue baby” syndrome, birth defects, thyroid disease, and colon cancer - Health risk was higher in infants and children compared to adults	United States, Europe and Global scale and India	[86–88]	Fertilizer and cesspits are the main source of NO ₃ in groundwater
Sodium (Na) and potassium (K)	May cause high blood pressure in humans	Coastal areas in Southeast Asia (coast of Bangladesh)	[83]	Drinking water salinity that contains high concentrations of sodium may affect pregnant women, which increases risk of hypertension and associated diseases
Arsenic	Cancer of the skin, lung, bladder, and probably liver	Global scale	[88]	Arsenic is responsible for a range of adverse effects, including hyperkeratosis and peripheral vascular disease

Table 6. Cont.

Chemical and Biological Contaminants	Disease	Country	Source	Remarks
Lead, cadmium and chromium	- Cognitive and developmental impairment, and hypertension - Kidney disfunction and bone toxicity - Cancer	Global scale	[89]	Chemical contamination in drinking water is a global issue affecting more than one billion people, placing them at risk of adverse health impacts and water scarcity
Zinc	Stomach cramps, nausea, and vomiting may occur	Global scale	[90]	Ingesting high levels of zinc for several months may cause anemia, damage the pancreas, and decrease levels of high-density lipoprotein (HDL) cholesterol
Fecal coliform (FC)	The occurrence of waterborne diseases to humans, such as diarrhea and vomiting	African countries and Ethiopia	[17,18]	Biological contamination is considered the main cause of death worldwide, especially in poor and developing countries

5. Contamination of Drinking Water

The water analysis of wells and springs conducted by the PWA in 2016 in the West Bank has shown that 15% of the water sources used for drinking contain nitrate concentrations higher than the permissible levels (50 mg/L) according to the Palestinian standard. In addition, the microbial tests showed concentrations around or below 19% [21]. Poor drinking water quality results in many waterborne diseases. Understanding the factors that affect drinking water quality is very important and also essential for informing decisions aimed at protecting drinking water sources. The quality of drinking water is usually affected by the quality of the source. In rural areas, drinking water is usually pumped directly from wells and rivers without adequate treatment and, therefore, the quality of the source water plays a critical role in determining the quality of the drinking water [91,92].

Heavy metals, such as Mn, Fe, Co, Ni, Cu, Zn, Se, and Cr, are essential for the growth of organisms, while Pb, Cd, Hg, and As are not only biologically nonessential, but definitely toxic [93–95]. After entering the water, metals may precipitate, be adsorbed onto the solid surface, remain soluble or suspended in water, or be taken up by fauna. A very important biological property of metals is their tendency to accumulate [84]. Common water contaminants iron and manganese are not health hazards but can cause offensive taste, appearance, and staining [96]. The groundwater in the West Bank is potable, except for some cases where the water is not suitable for drinking due to excessive salinity, high nitrate concentration, and bacterial contamination. Importantly, the levels of heavy metals in the water, including Cr, Cu, Fe, Mn, Pb, Cd, and As, are well below the limits advised for human consumption [27].

6. Drinking Water Management

Under Palestinian law, the PWA is considered primarily responsible for managing the water sector in the West Bank and Gaza. The ministry of health (MoH) participates in monitoring water quality, and the Ministry of Local Government (MLG) participates through local authorities and Joint Service Councils (JSC) in providing the population with water and sanitation services [97]. There are different local government institutional entities that provide water services in the West Bank, within which around 17% of the population is served by independent utility firms that are formally established under their own law and are accountable to the board of directors of the local units they own. However, the services are provided to the rest of the West Bank residents and families by service

providers under the auspices of the Ministry of Local Government. Large cities have municipal water departments that provide water and/or sewage services (76 in the West Bank). A number of smaller municipalities and villages joined together to form the Joint Service Boards (JSBs), which provide water and/or wastewater services to these localities. Likewise, another 162 village councils provide water and sanitation services directly to their residence. Currently, there are moves to begin with aggregation smaller service providers and to encourage service providers to strengthen transparency, accountability, and financial independence [42].

There has been a rapid increase in the Palestinian population in the West Bank and a decline in water security in recent years, with increasing demand for water and the dwindling of water resources, where the demand is already outstripping the supply. The situation is constantly deteriorating [42]. The internal renewable water resources are exploited to such a large extent that the quality of groundwater in the Gaza Strip is qualified as undrinkable because of seawater intrusion and wastewater discharging areas and solid waste dumping sites [98,99]. The Palestinians' access to additional water sources has become very difficult due to the political situation [100]. The residents of the Gaza Strip depend on desalination as a non-traditional water resource to cover the massive shortage of fresh water, and it also contributes to addressing global water scarcity issues [101,102]. Ensuring water security is a priority. Water security requires adequate and well-managed water resources, including risk management and water resources that provide sustainable, efficient, and equitable services to improve water security in the Palestinian water sector [42].

A well-managed drinking water system must be managed from source to end-users (i.e., from wells and springs to the drinking taps). Drinking water is more likely to be safe if all steps of the process (e.g., extraction, treatment, and distribution) are working as they should [103]. This requires proper management of the water sources during the planning, construction, installation, operation, and maintenance of the entire system (i.e., management of the catchment as a whole unit). A good understanding of these processes facilitates the early identification of potential vulnerabilities. Inadequate wastewater management in urban and rural areas means that drinking water may be at risk, and this will negatively affect public health [15,104].

Commitment to a future with sustainable management of water resources is a matter that requires integrated management and planning of water resources, which should involve all stakeholders [105]. The commitment of stakeholders is important because of their impact on water management through their joint efforts [105]. Addressing water scarcity, protecting ecosystems, preserving human health, and raising the level of economic development are among the most important factors to handle in the process of evaluating the integrated management of water resources [106]. The sound management of water resources is extremely important and has a significant impact on water quality and the health of end-users [65]. The process of monitoring groundwater quality that starts at the source and ends at the water networks and includes disinfection activities and supervision of water distribution to beneficiaries with fairness, equity, transparency, and governance of the water sector through integrated and sustainable management is important [107].

In the last decade, the expansion and diversity of water providers (e.g., private companies, municipalities, village councils, joint services councils, and others) underpin the importance of stakeholder involvement as a necessary tool to regulate and organize the sector. Working to establish a unified entity for water service providers could help to reduce financial, administrative, and technical burdens [108].

Access to an adequate amount of water is an important goal that countries aspire to achieve because of its importance to human development. Much of the world's population lacks access to water as a result of the great pressure on water resources and their pollution. Population increase, economic growth, and pollution have led to considerably increased competition and conflicts over fresh water [107]. There is currently a greater need to manage the available water resources rather than searching for new ones that may not be available at all. In light of climate change, drought, and complex political conditions, it has become

demanding to implement an integrated and sustainable approach for the management of water resources [109]. A sound approach for the management of water resources should include governance, involvement of stakeholders, and the protection of ecological systems (e.g., controlling of water pollution, wastewater treatment, and the recycling and treatment of solid waste), the organization of agricultural sectors, and rationalized use of agricultural pesticides and fertilizers [109].

Human activities in the catchment area of water sources can lead to water pollution and negatively impact public health. Water catchment protection is therefore also important in securing clean and safe drinking water. The prevention of pollution is essential, and regular sanitary inspections to detect any sources of contamination will help in securing good quality drinking water year round [110].

As the human population increases, there is an increase in pollution and catchment destruction, inadequate sewage collection and treatment, and increase in the use of fertilizers to grow more food, which together result in increased water contamination. Catchment management is playing an increasingly important role in reducing the levels of potential contaminants in raw waters. An efficiently managed scheme will help to reduce pollution from agriculture and also help to control urban and chemical pollution from sites within a catchment. Due to the complex interactions between the natural environment and human action, which determine the quantity and quality of water resources, knowledge of water resources and (possible) pollution is often very low [111]. Determining the sources of pollution first and then linking their impact on water sources through water tests and studying the nature of waterbodies, with the help of GIS, will directly help in the good management of drinking water sources. Sufficient groundwater quality for future drinking water supply cannot be ensured unless the appropriate and effective environmental management of the pollution sources is implemented to ensure the sustainable availability of this fresh water sources also in the future [27].

7. Conclusions

The main reasons for water scarcity in the West Bank are the unique hydrological situation and diverse political and natural conditions, where the main natural conditions include scarcity and uneven distribution of rainfall due to extreme topographic variations within the region and the hydrogeological location of the West Bank. As for the political conditions, the Israeli government has virtually complete control over all West Bank. Although the PA has made it a priority to obtain safe and adequate drinking water, it is still struggling to achieve this goal, which is considered difficult in the light of the uncontrolled of PA over the groundwater sources. Furthermore, groundwater contamination from untreated wastewater, cesspits, solid waste dumping sites, and fertilizers has increased this problem. It is crucial to solve the problem of cesspits in Palestinian rural areas and replace them with sewage networks. Furthermore, solving the problem of untreated wastewater from Israeli settlements is important for reducing groundwater contamination.

The West Bank's groundwater is nevertheless drinkable, with the exception of a few instances where it is unfit for consumption due to high nitrate concentrations, excessive salinity, and bacterial contamination. It is important to note that the concentrations of heavy metals in the water, including Cr, Cu, Fe, Mn, Pb, Cd, and As, are significantly lower than the levels recommended for human consumption. Increasing the Palestinian share of drinking water is important, especially in light of the large growth in the population and the increase in water demand. A considerable group of West Bank residents is still struggling to obtain the minimum amount of drinking water stipulated by the World Health Organization, especially during the dry seasons. The quality of the groundwater and the health of end users are impacted by effective management of the available water resources. For this end, it is crucial to monitor the quality of groundwater from its source to its final destination. This process also involves disinfection procedures and the supervision of water distribution to beneficiaries with fairness, equity, transparency, and water sector governance. Sufficient groundwater quality for future drinking water supplies cannot

be ensured unless the appropriate and effective environmental management of pollution sources is implemented to ensure the sustainable availability of this fresh water source also in the future. Future directions in research should look for new and creative methods for managing and monitoring groundwater, such as the use of smart technology that would enhance the protection of these sources from contamination and reduce health risks and thus maintain their sustainability. Detailed information on the quality of groundwater should be provided, and the data and information should be made publicly available, which will encourage scientific research aimed at providing more creative solutions for water shortage in the entire region.

In the West Bank, the number of Israeli settlements has exceeded over two hundred. According to the Israeli Beit Salem Foundation for Human Rights, the highest number of Israeli settlers was registered in 2020, with more than 900,000 living in the West Bank, where they consume vast amounts of groundwater and produce large quantities of contamination (Figure 4). On the other hand, the Palestinian communities need more water but generate different types of contamination. To date, in the West Bank, there has been a lack of studies that focus on developing suitable groundwater management solutions in terms of water quality and vulnerable zones considering the pollution sources and the degree of health risk. Therefore, the problem of access to safe drinking water persists. The recently announced Sustainable Development Goals (SDGs) also highlight the importance of universal and equitable access to safe and affordable drinking water, which was established as one of the 17 global goals (SDG 6) to be achieved by 2030. Unfortunately, these goals may not be achievable under these complex political and natural conditions. Finally, conducting more research in groundwater field is important and may contribute to protecting it from pollution and maintaining its sustainability.

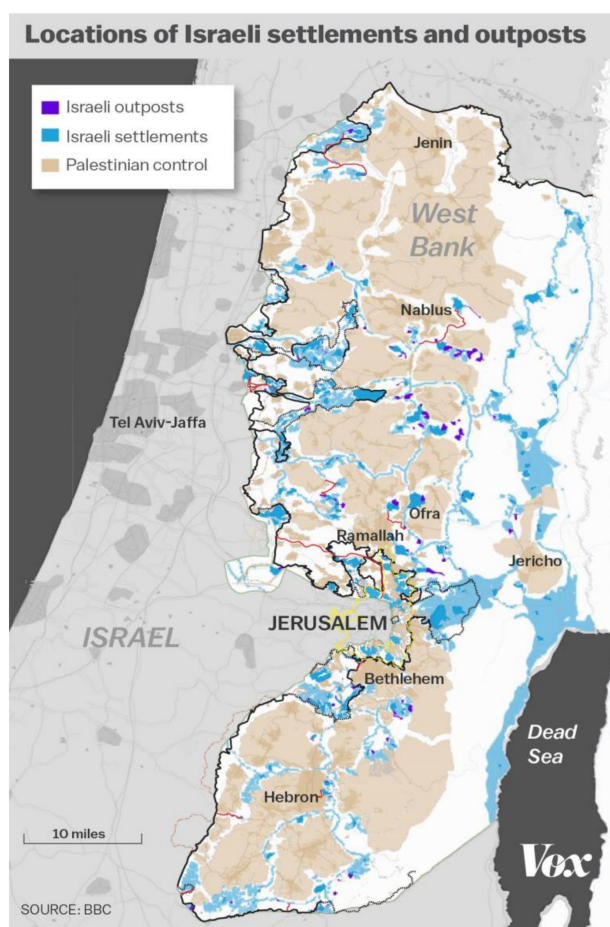


Figure 4. Israeli settlements in West Bank, Palestine [112].

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