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Mechanisms of Groundwater Pollutants Transport in Tulkarm Area / Palestine

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Abstract This study aims at investigating the mechanisms of pollutants transport based on geological formations. The study classifies two sub-aquifers groups. The first group are wells which dogged within Senonian Abu Dis formation, and are mostly used extensively for municipal purposes. The second group are wells dogged with the most top Jerusalem-Hebron formation of Turonian age and mostly used frequently for irrigation purposes. The first group shows a high deteriorated water quality with ionic molar ratios bears the ratios from Wastewater stagnant in adjacent Zomar stream. The stream bed lays directly over Jerusalem formation which promotes the pollutant transport directly to the uptake zone. However, the effect of such stagnant become less in dilution time of winter. Septic tanks surrounded these wells are constructed within the top 5 meters of Senonian formation, which mean that the leakage from septic tanks is not that ease to significantly affect the groundwater quality. The second group are mostly subjected to direct rainfall infiltration this can be indicated through the higher Sodium values which are related to the ion exchange through limestone profile. The results emphasize the need for further procedures to mitigate the pollutants plume migration from Wadi to the surrounded environment.

Keywords Groundwater, Pollution, Palestine, Tulkarm, Karst, Stagnant Water, Transoundary Pollution

1. Introduction

Water is one of the most valuable natural resources in the Middle East. The combination of multiple factors, e.g. population growth, economic and agricultural development, and an arid climate, result in over exploitation of the water resources in the region. The continuous high water demand leads to rapid degradation of the quality of fresh water resources as a result of the salinisation and contamination processes[1-3]. The lack of sufficient water, combined with rapid water quality deterioration, presents a serious challenge to the people in the region. In order to manage and share the water resources under conditions of accelerating degradation, it is crucial to understand the origin and mechanisms of the contamination process.

The salinity that threatens the fresh water resources is derived from different sources, both natural and anthropogenic. In general, over exploitation of fresh aquifers results in a rapid decrease of water level, which then triggers lateral as well as upwelling of deep saline water from adjacent waters from aquifers. Consequently, the overexploited aquifers become saline due to mixing with salinewaters[1-4].

Tulkarm area is located in the north western part of the West Bank. The water resources in the district is limited and restricted only to the shallow aquifer that is subjected to various sources of pollutant ion.

Groundwater in Tulkarm City is being utilized through 10 domestic and 53 irrigation wells with total discharge of 21 MCM per year[5]. Most of the wastewater from the local communities to the east of Tulkarm drained through long stream that extended from Nablus city to the east across Tulkarm city to the Midetranean Sea. The wastewater stream part that pass from Nablus through Tulkarm is called Wadi Zomar. The main objective of this study is to investigate the role of different geological formations in facilitating the transport of the pollutants from Wadi Zomar and different anthropogenic sources surrounding Tulkarm city in Palestine.

2. Study Area

Tulkarm area is located in the north western part of the West Bank - Palestine (Figure 1). The total area of Tulkarm is about 246 km² and its current population is estimated at 166,832 people, representing 12.4% of the total population of the West Bank[6]. Tulkarm lies on the western slopes of the West Bank, which are characterized by gentle slopes. The elevation in the city ranges between 50 to 180 meters above sea level.

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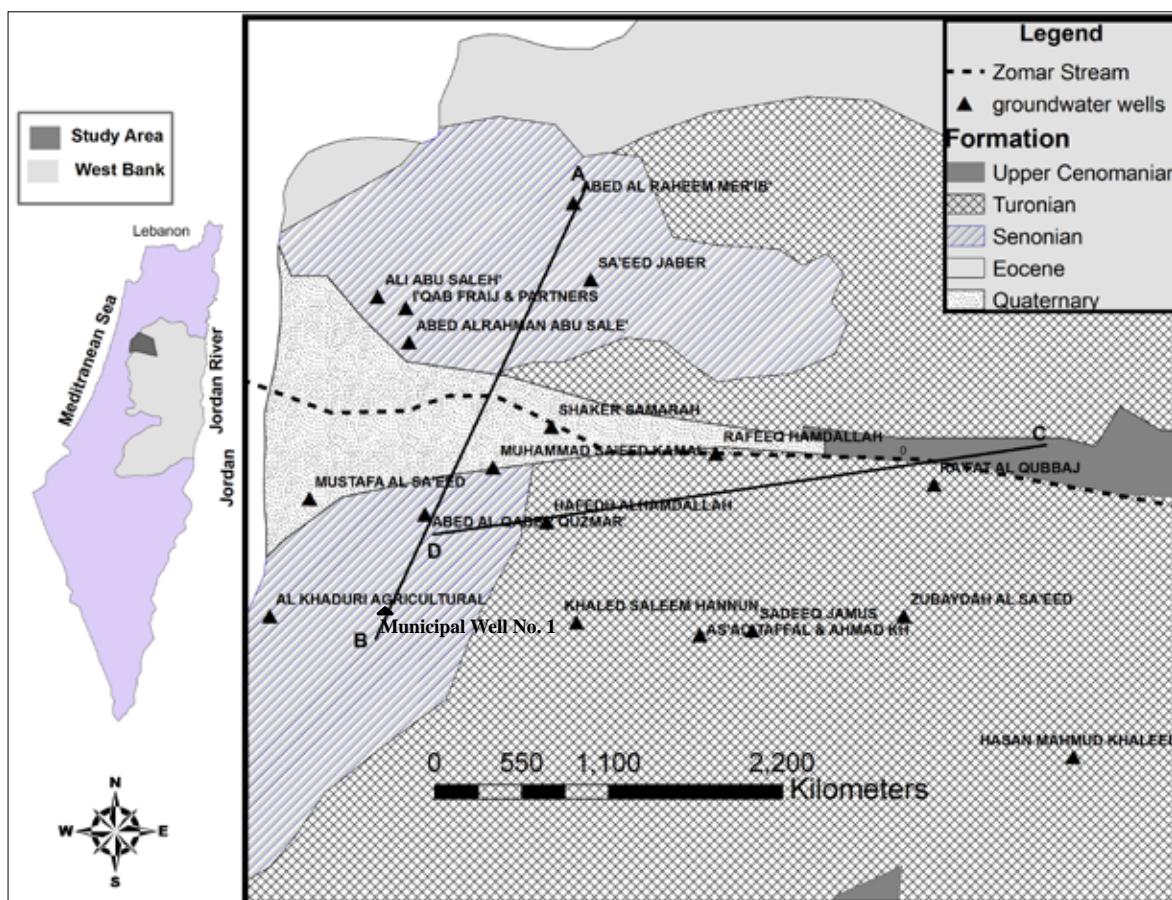


Figure 1. Study Area of Tulkarm, sampled wells are shown with the different geological formations

The climate in Tulkarm is similar to that of the Mediterranean type, which is characterized by long, hot, dry summers and short, cool, rainy winters. Tulkarm is distinguished by the moderating effect the sea breeze has on its climate. Rainfall is limited to the winter and spring months, mostly between November and March while summers are completely dry. The average annual precipitation rate in Tulkarm is about 640 mm[7].

Tulkarm is supplied with water from municipal well no. 1 (Fig.1) with production capacity of 180 m³ / hour, well no. 2 with production capacity of 100 m³/hour, well no. 3 with production capacity of 65 m³/hour and Shwekeh well with production capacity of 110 m³/hour. In summertime, where water consumption increases and production capacity decreases, the Municipality of Tulkarm makes use of few agricultural wells like Al Taffal Well, Hannun Well, Abdel Razeq Well and Al Safarini Well to sublement the increase in water demand. The average water table in the Municipality wells is 90 meters deep. Water consumption is 85 L/Capita/Day.

There are many wadis (streams) located in the district. The main sewage wadi in the region is called Wadi Zomar. The hydrographic catchments area of the Zomar Valley is about 22 km long and 5 km wide[7]. Wadi Zomar exposed to major pollution by human activities, that causes serious health problems and other economic costs related to water treatment, remediation and locating a new water supply,

become evident[8]. The Wadi Zomar is used as drainage for the sewage from the towns of Nablus, Tulkarm and the villages located at the banks of the Wadi.

There are still more than 500 septic tanks/cesspools, which are rarely emptied. Water analysis in the Municipal well no. 1 made three years ago demonstrates pollution of ground water and presence of Fecal Colifrom.

Previous studies for the water quality in the study area shows that there is a big pollution problem with sewage especially for municipal wells which used for domestic purposes[9-16]. These studies try to connect the problem of groundwater pollution to the seepage from the septic tanks. Less were talking about the role of Wadi Zomar in surrounding environment pollution[17]. Moreover, the role of different geological formations in pollution transport still arbitrary.

2.1. Geology

The geological formations of the study area of Tulkarm range in age from Senonian to Quaternary. The stratigraphic section of the West Bank is present in (Fig.2)[18]. The district is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk. The general geology of the Tulkarm area is represented in Figure 1. A brief description of the lithological formations encountered in the Tulkarm district is presented below[18-20].

Period	Age	Graphic Log	Typical Lithology	Formation (West Bank Terminology)	Sub-Formation	Group	Symbol	Formation (Israeli Terminology)	Hydro-stratigraphy	Typical Thickness (m)
Quaternary	Holocene		Nari (surface crust) and alluvium Gravels and fan deposits	Alluvium			Qh-a	Alluvium	Local Aquifer	0 - 100
	Pleistocene		Thinly laminated marl with gypsum bands and poorly sorted gravel and pebbles	Lisan			Qp-l	Lisan/Kurkar Group	"Aquifer"	10 - 200
Tertiary	Neogene		Conglomerates, marl, chalk clay and limestone	Beida			Tnp-b	Seqye Group	Local Aquifer	20 - 200
	Paleogene		Nummulitic reefal Limestone Nummulitic bedded Limestone Nummulitic Limestone, Chalk Chalk, Nummulitic Limestone	Jenin	Jenin 4	Jenin	Te-j4	'Avedat Group	Aquifer	90 - 670
					Jenin 3		Te-j3			
					Jenin 2		Te-j2			
					Jenin 1		Te-j1			
Cretaceous	Paleocene		Marl, Chalk	Khan		Nablus	Ks-n	Mt. Scopus Group	Aquifer (Local Aquifer)	40 - 150
	Maastich-tian Danian		Chalk, Marl	Al-Ahmar						
	Campanian		Main Chert, Phosphate	Wadi Al-Qift						
	Conian-dien-Santonian		Chalk and Chert	Abu Dis						
	Turonian		White Limestone, stichites Limestone and Dolomite Yellow thin bedded Limestone	Jerusalem	Upper Middle Lower	Kc-j	Kc-ju Kc-jm Kc-j	Bina	Upper Aquifer	40 - 190
			Dolomite, soft		Upper					
			Chalky Limestone, Chalk	Bothlehem	Lower		Kc-bu Kc-bl			
	Cenomanian		Karsic Dolomite	Hebron	Upper Middle Lower	Kc-h	Kc-y2 Kc-y1	Amminadav Moza Bait Meir	Lower Aquifer	50 - 210
	Albian		Yellow marl	Yatta	Upper Lower	Kc-y	Kc-ubk2 Kc-ubk1	Kesalon Soreq	Lower Aquifer	10 - 20
			Dolomite Limestone, interbedded with Marl	Beit Kahil	UBK2 UBK1	Kc-ubk2 Kc-ubk1	Kc-ibk2 Kc-ibk1	Givat Yefarim Kefira	Lower Aquifer	60 - 130
			Dolomite	Lower Beit Kahil	UBK2 UBK1	Kc-ibk2 Kc-ibk1	Kc-ibk2 Kc-ibk1	Givat Yefarim Kefira	Lower Aquifer	40 - 90
			Karsic Limestone	Upper Beit Kahil	UBK2 UBK1	Kc-ibk2 Kc-ibk1	Kc-ibk2 Kc-ibk1	Givat Yefarim Kefira	Lower Aquifer	100 - 160
	Aptian		Marl, marly nodular Limestone	Qatana		Kob-r	Ka-q Ka-eq	Qatana Ein Qinya	Aquifer (Local Aquifer)	42 55
			Marly Limestone and Limestone	Ein Qinya		Kob-r	Ka-t Ka-ea	Tammun	Aquifer (Local Aquifer)	300+ 20+
Jurassic	Oxfordien		Shale	Tammun		Kurnub	Ka-rs Kn-r	Hatira	Aquifer	20+ 70+
			Shale and Limestone	Ein Al-Assed		Kurnub	Ka-rs Kn-r	Hatira	Aquifer	20+ 70+
Jurassic	Oxfordien		Marly Limestone, sandy	Nabi Sa'id		Kurnub	Ka-rs Kn-r	Hatira	Aquifer	20+ 70+
Jurassic	Oxfordien		Sandstone	Remail		Kurnub	Ka-rs Kn-r	Hatira	Aquifer	20+ 70+
Jurassic	Oxfordien		Volcanics	Tayasir		Kurnub	Ka-rs Kn-r	Hatira	Aquifer	20+ 70+
Jurassic	Oxfordien		Marl interbedded with chalky limestone	Maleh	Upper Maleh	-	Jo-um Jo-m	'Arad Group	Aquifer	100 - 200
Jurassic	Oxfordien		Dolomitic limestone, jointed and karstic	Maleh	Lower Maleh	-	Jo-um Jo-m	'Arad Group	Aquifer	50 - 100

Stratigraphic Section of the West Bank



LEGEND

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Figure 2. Stratigraphical section of the West Bank (Source:[18])

Table 1. Hydrochemistry of the Pleistocene Wells and springs from Jericho-Palestine area in (mg/l)

SampleID	X	Y	Well Depth (m)	Abstraction rate. (MCM/yr)	NO ₃	pHfield	Conductivity (µs/cm)	PO ₄	SO ₄	Cl	HCO ₃	Mg	Ca	Na	K
Munic. Well	152400	190920	110	0.432689276	64	7.01	1026	7.2	40	95.72	512.6	40.25	96.42	66.07	24.62
Fadilyeh Munic.	152480	191900	118	0.348840931	49	6.95	1104	1.7	39	106.35	512.6	40.44	98.22	70.85	23.15
Shufa Committee	155500	188500	151	0.066066556	28.3	7.1	741	0.13	20	42.54	524.8	38.54	90.15	33.06	2.16
Isma'eel Itair	153750	188800	100	0.18636172	59.4	7.09	815	0.6	43	49.63	414.9	37.04	94.73	40.95	3.57
Izbeh Well 5 Munic	154451	191291	186	0.18636172	54.3	7.06	760	0.7	25	53.18	366.1	32.94	82.25	44.15	4.8
Izbeh Well 6 Munic	153459	190004	200	0.18636172	41	7.06	794	0.2	26	53.18	427.1	22.01	55.55	35.6	1.1
Muhammad Omar	152350	189000	74	0.119719417	23	7.12	667	0.13	16	42.54	451.5	33.15	73.46	35.21	2
Muhd ABED AL HALEEM	152500	187950	165	0.171508167	23.5	7.01	689	0.8	13	46.09	427.1	35.85	72.99	34.59	1.12
As'ad Taffal	154440	190880	136	0.153256042	37.4	7.07	650	0.26	16	42.54	378.3	30	65.99	38.61	1.21
Sadeeq Jamus	154770	190910	157	0.157739458	57.4	7.07	725	0.5	27	53.18	353.9	33.4	75.94	40.78	1.24
Hasan Khaleel	156800	190100	175	0.093099417	32.4	7.27	571	0.08	22	31.91	341.7	29.45	60.62	28.99	2.49
Zubaydah Al Saeed	155730	191000	154	0.141912708	45	7.39	740	0.16	21	67.36	366.1	34.86	71.2	45.85	4.91
Rafeeq Hamdallah	154540	192040	90	0.132879792	53	7.03	889	0.06	23	81.54	427.1	35.15	88.8	63.19	4.36
Hafedh Alhamdallah	153470	191600	80	0.113321625	68	6.84	1062	0.4	21	92.17	549.2	40.59	110.87	62.77	9.16
Municipality Shweikeh	152480	191900	118	0.348840931	45.9	6.93	1033	0.1	36	102.81	500.4	41.96	90.47	69.78	15.49
Almisnawi Munic.	153259	193780	125	0.348840931	57	6.92	947	2.5	23	85.08	475.9	39.56	88.1	60.82	16.7
Ali Abu Saleh	152400	193040	132	0.169933833	32.7	6.95	993	0.06	31	106.34	488.2	40.73	91.4	71.17	8.03
Wadi Zomar Wastewater	153323	193241	-----	52 *	189	6.23	6234	31.2	141	273	1024	87	214	185	53

*For the whole tributaries according the World Bank report on Water status in the West Bank, 2011

2.1.1. Upper Cenomanian

The Upper Cenomanian formation (also known as the Bethlehem formation) consists of limestone, dolomite with some chalk, and marl. Outcrops are found mainly on the flank of the A'nabta anticline. The dolomite forms a rugged morphology on gentle slopes.

2.1.2. Turonian

The Turonian formation (also known as the Jerusalem formation) consists of a series of massive, thick- to- thin bedded limestone to dolomitic limestone and dolomites with a thickness of approximately 70-130 m. The lower part of the Turonian formation consists mainly of limestone and dolomite with marl and some chalk, making it sometimes difficult to be distinguished from the underlying Bethlehem formation. Towards the top of this formation, chalk beds with occasional chert bands are common, and the formation is transitional to the overlying chalk facies. The Turonian formation has a well-developed karst feature and is commonly used as a building stone. It is exposed in the A'nabta anticline and is considered a very good aquifer.

2.1.3. Senonian

The Senonian formation (also known as Abu Dis formation) is mainly made up of Cretaceous Rocks, which are composed of chalk, ranging in age from the Coniacian at the bottom to Paleocene at the top. Outcrops exist in the A'nabat anticline and on the western limb of Nablus-Beit Qad syncline. In the Tulkarm city area, the chalk is thin and consists of marly base and passes upwards through bedded and crystalline limestone that has few marl partings.

2.1.4. Quaternary

Quaternary rocks are divided into the following formations:

a. Lisan Formation: these recent sediments are mainly composed of alluvium consisting of bedded limestone, chert and clay. The thickness of these sediments varies from one place to another. The rock fragments comprising the deposits are mainly derived from rock formations adjacent to the wadi area.

b. Nari Formation: it occurs mainly in high rainfall areas where carbonate rocks are dissolved by percolating water. It forms a thin coating over the limestone.

2.2. Hydrogeology

The Tulkarm district is underlined hydro-geologically by the northern part of the western groundwater basin. It is located in the semi-coastal region. Groundwater flow is directed towards the west and northwest.

2.2.1. Aquifer System

The major aquifers in the area are the Shallow Aquifer and the Upper Cenomanian- Turonian complexes. The Abu Dis acts as an aquitard hence, forming a water barrier. Since

the Upper Aquifer is the predominant aquifer in the region, it is described in full below [19,20].

2.2.1.1. The Upper Aquifer System

The Upper Aquifer is represented by the formations of the age Turonian (Jerusalem formation) and Cenomanian (Bethlehem and Hebron formations).

2.2.1.2. Turonian Aquifer

The Turonian aquifer is part of the Upper Aquifer but can be classified as a distinct local aquifer if the formation beneath it acts as an aquitard as is the case in some areas in the eastern and southern parts of the West Bank. The Turonian aquifer is considered a fairly good aquifer especially where the saturation thickness is in tens of meters. This aquifer is of good thickness and extent in the Tulkarm area (approximately 130 m thick). The water quality of this aquifer is generally good but in some areas there is evidence of deterioration because of sewage and agro-chemical pollution.

2.2.1.3. Cenomanian Aquifer

The formations of this aquifer are the Bethlehem and Hebron. The aquifer is an important regional source of water supply for domestic use. The Cenomanian Aquifer has high recharge values. It is heavily exploited in the areas near Tulkarm and Qalqilya because the aquifer is at a shallow depth in this area. The depth to water is rarely more than 200 m below ground surface.

3. Data Collection and Method

The original aim of groundwater sampling was based on providing a supplement analyses to investigate the gradient of pollution for the aquifer system, according to spatial distribution and the effect of the pollution plume surrounded the wastewater stream banks.

For this purpose, 17 samples from springs and wells, distributed in different geological outcrops, were collected.

The samples were collected in December 2011 (wet season), sampling localities are shown in Fig. 1. Other samples for Nitrate and potassium were obtained 4 months earlier by the end of the dry season.

Onsite measurements for physicochemical parameters (pH, temperature, m-value and redox potential) were done. The samples for anions were preserved using HgCl_2 for prolonged preservation of nitrate. For accurate chloride measurement, the chloride concentration was measured out from the water samples of the cations [3]. Due to the fact that samples were collected in the agricultural season, all the sampled wells had been pumping for a long period of time. Hence, no further purging was needed prior to sampling and the samples were collected immediately. Samples for (Cations and Anions) were collected in 250 ml polyethylene bottles.

Major anions (NO_3 , SO_4 , PO_4 and Cl) were analyzed using HP liquid chromatography. Concentrations of the major cations (Ca, Mg, Na, and K) were determined by ICP-OES. Alkalinity and HCO_3 analysis was measured onsite by titration [21,22].

All chemical analyses were carried out at the Environmental Research Lab. at Al-Quds University – Abu Dis.

4. Results

The chemical data are shown in Table 1. The major cations and anions concentrations of the groundwater from the sampled wells in the study area are plotted on a piper diagram (Figure 3).

The water type is normal earth alkaline water with prevailing bicarbonate for one group and prevailing chloride in other group. The water type varied from

Ca-Mg- HCO_3 which shows less susceptibility to pollution to those have Ca-Mg-Na- HCO_3 -Cl for those wells with high pollutants, the last type bears the sample from Wadi Zomar wastewater (Figure 3). However, both groundwater types reflect dolomite bearing rock from Turonian and sometimes the deeper cenomanian formations.

In general the results shows different NO_3 values in all samples that varied from 64 mg/L in winter season and 81 mg/L in summer season for municipal wells, to 23 mg/L in Muhammad Omar agricultural well. In general most of the nitrate values exceed the WHO standard for safe drinking water which is 50mg/L. While other anthropogenic related ions show variable values which exceed in many cases the WHO standard for drinking water and follow the surrounded activities and the characteristics of the aquifer geology as it will be described in further details later on in the following section.

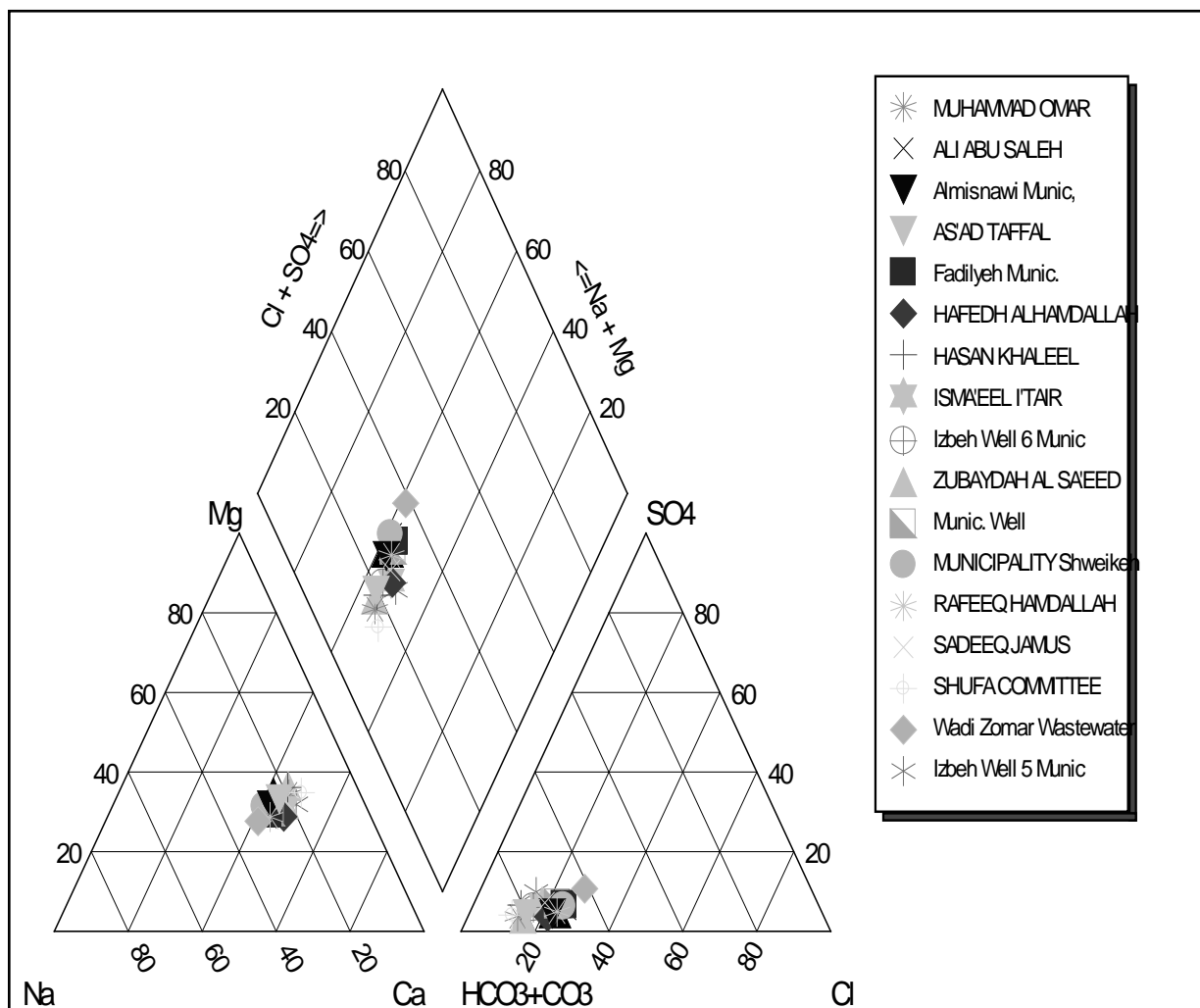


Figure 3. Durov Plot suggests the trend of water from fresh Ca-Mg- CO_3 water in some wells NA-Mg-Cl water in others that are bearing the Wadi Zomar value

5. Discussion

In general, many previous studies for the water quality in the study area show that there is a big pollution problem with sewage especially for municipal wells which used for domestic purposes. These studies mostly refer the problem of groundwater pollution in the area to the seepage from the septic tanks [9-16]. This study shows that these previous results are partially true. In this study, we tried to make further geological investigation to build a conceptual model for pollutants transport, whether it was from septic tanks or from Wadi Zomar. There are some other studies taking

Wadi Zomar as environmental hazards for the surrounding communities from Nablus to the trans-boundary area across green line to the Israeli areas [15,17]. However, the question about the mechanism of pollutants transport from the Zomar stream to the surrounded environment still open. The hydrochemical data from the groundwater in sampled wells surrounding Tulkarm city, show two dominant groups that have different magnitude in pollution and pollution type. In general the high pollution was recognized in the wells that have higher abstraction rate, mainly those wells that used at daily basis for domestic purposes.

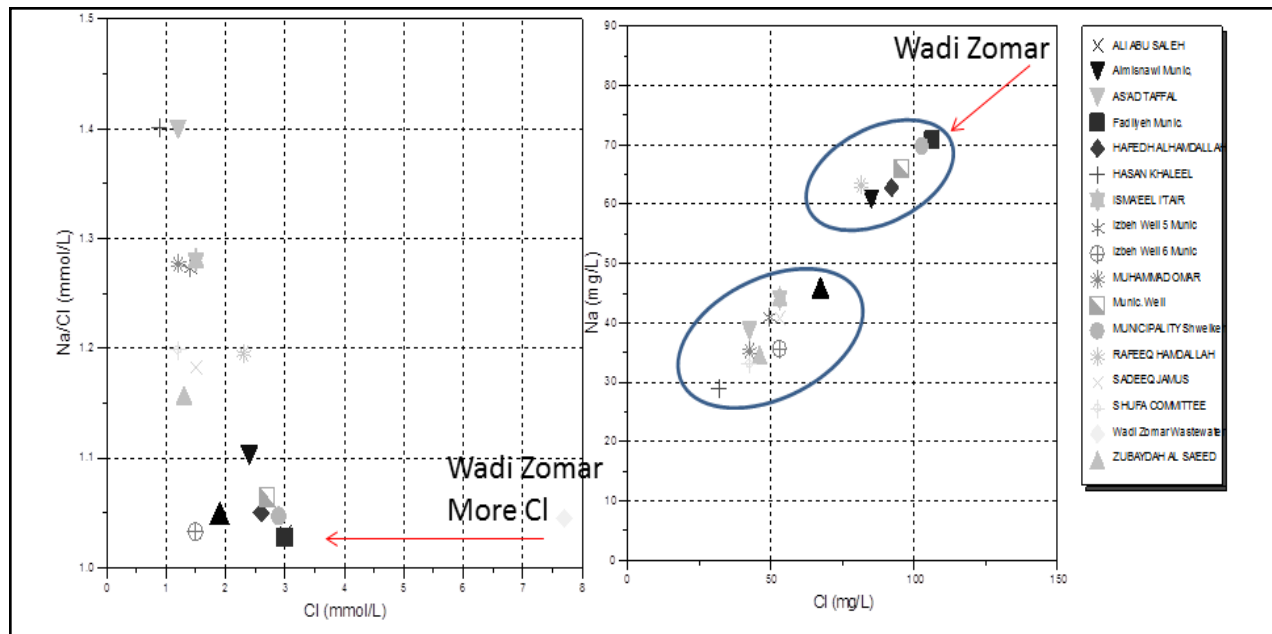


Figure 4. Na vs. Chloride and Na/Cl molar ratios in the samples wells shows 2 major groups, one with high Na and Cl the same as in Wadi Zomar, and the other with relatively lower values

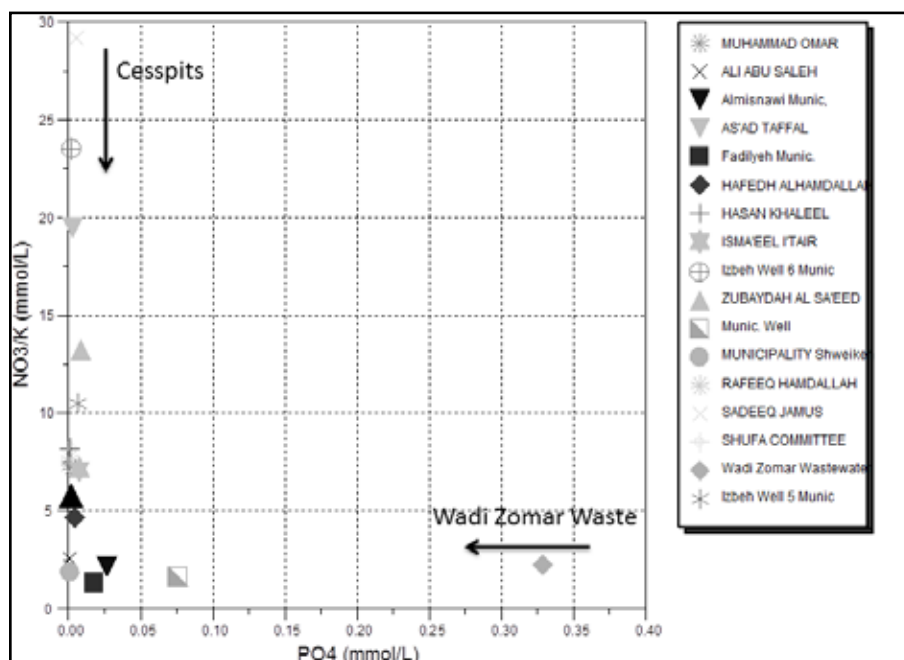


Figure 5. K/NO_3 molar ratio versus PO_4 in mmol/L, classified the samples into Wadi Zomar affected group, septic tanks affected group and wells with mixing effects

According to piper diagram those municipal wells group characterized by higher Na and Cl values that are more closed to those values taken from Wadi Zomar stream (Figure 3). The other group has less Cl content and more Na than chloride which might be due to ionic exchange during the process of recharge (Figure 4). In this context, it is worthy to mention that most of the wells exposed to normal softening are covered with Turonian outcrop which promote the direct infiltration through surface, unlike the other group that is mostly covered by impervious chalky Senonian formation.

The hydrochemical data classified the sampled wells into two groups which are subjected mainly to three pollutants sources (Figures 3, 4, 5). In general the pollutants sources varied according to the geological outcrop, and surrounded activities. These sources can be summarized as follow:

5.1. Wadi Zomar

Wadi Zomar is considered one of the largest wastewater streams that hold the wastewater from the surrounded communities and extend from Nablus city in the east and cross the green-line boundary to Israeli settlements across Tulkarm area. The problem of Wadi Zomar stream varied spatially and temporally, according to the season and the distance from the wastewater inlet and the slope [17]. Two geological profiles in the study area were created depending on the wells lithology (Figure 6, 7). The profiles show that most of the wells in the study area are drained from the Turonian- Cenomanian layers (Jerusalem-Hebron formation) (Figures 2). The Turonian Jerusalem formation is exposed in the area surrounded the Zomar stream, while the Cenomanian Hebron formation is found on the flank of the A'nabta anticline upper part of the stream (Figure 1,2, 6, 7). The direct seepage from Hebron formation allowed the sewage to mix directly through with fresh recharge water and leaks to the zone of uptake (Figure 7).

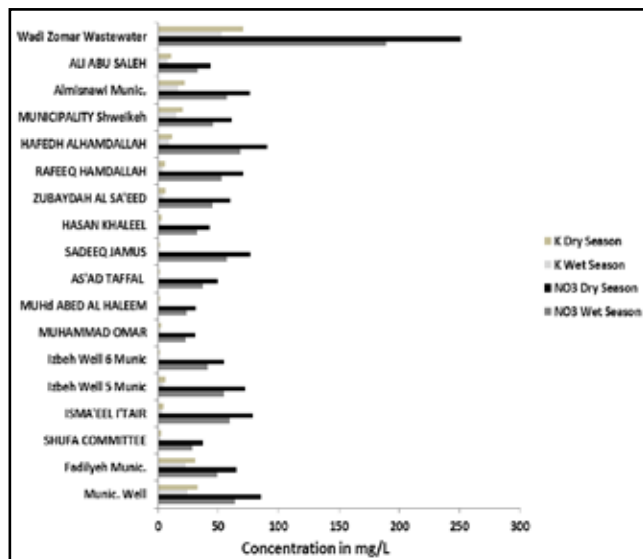


Figure 6. Concentration of Potassium and Nitrate (in mg/L) in Summer and Winter season, show an increase in concentration in the dry season

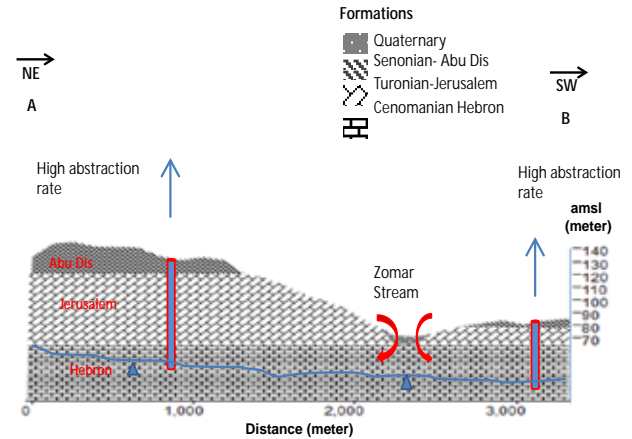


Figure 7. A-B geological cross section from the North East to the South West of the study area

Two main factors increase the problem of wastewater leakage, these factors can be summarized as the increasing the abstraction pressure in the nearby municipal wells, and formation of wastewater stagnant, where the slope of the wastewater stream become more gentle and semi-straight in the study area, allowing the formation such wastewater stagnant which promote the wastewater to infiltrate slowly to the groundwater. This can be indicted through the variation of Potassium and nitrate values from winter to summer season (Figure 8), where in winter the stream receive additional runoff amount from the precipitation that prevent the formation of wastewater stagnant across the flow path.

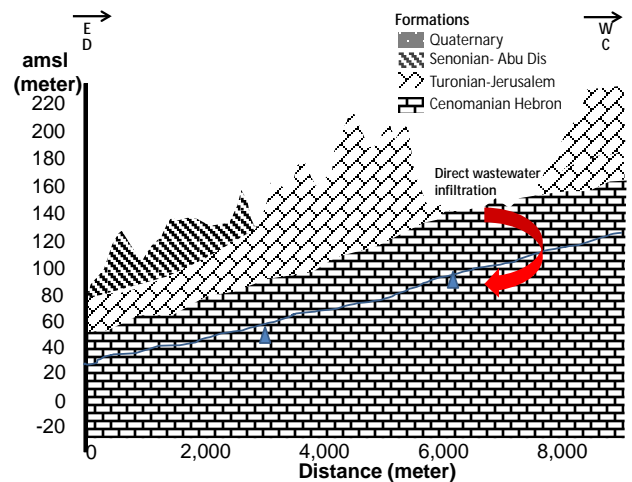


Figure 8. C-D geological cross section from the East to the West of the study area

In general, both conditions favoured an environment where the pollution plume surrounded the wadi stream pulls in toward the zone of uptake through Jerusalem Hebron formation (Figures 6, 7). The most highly abstracted wells group (containing Municipality 1, Municipal Fadilya 2, Shweikeh Municipality well 3, and Misnawi Municipality well, in addition to two wells lay directly near the Zomar stream) are characterize by higher amount of Cl, PO₄, and K.

The values for these elements are bearing the values from samples obtained from wadi Zomar wastewater (Figure 5).

5.2. Septic Tanks

As mentioned above, several studies and reports connected the problem of high nitrate in the groundwater from the study area to the septic tanks distributed over the study area. Septic tanks, naturally, play an important role in the pollution process but the complete story is not only related to the septic tanks and it is not definitely the main cause of groundwater pollution as this study pinpoint. The data of this study suggest more important role for Wadi Zomar in the pollution process rather than the effect of cesspits. As mentioned above, this suggested role for the Wadi Zomar is clear in the wells of high abstraction rate and which are dogged in the impervious layers of Senonian (Figure 1). Normally septic tanks are present in the top 5 m below surface; therefore, the evidence of leakage from septic tanks through the Chalky Senonian layer is very low. However, a significant evidence of pollution from septic tanks was noticed in the wells dogged in the Turonian layer, these wells shows higher nitrate over Potassium values with relatively low PO_4 which found higher in wastewater from Wadi Zomar (Figure 5). These wells (dogged in Turonian) also show surplus Na in most cases which might indicate softening during the direct recharge through Jerusalem formation or might due to additional source of Na from Septic tanks with Na/Cl molar ratio higher than this ratio taken from Wadi stream (Figure 4).

5.3. Agricultural Activities and Irrigation Feedback

The protected agriculture is widely common all over Tulkarm area, where the drip irrigation practices are mostly used; however, some farmers are still using direct water application for irrigation. Moreover, there are a lot of agrochemicals and fertilizers applied in considerable amount in the study area[10]. In general, there are many indicators about the presence of irrigation feedback to the groundwater. Most of the farmers use Potassium nitrate and natural manure as fertilizers. This resulted in a surplus amount of potassium and nitrate in the groundwater. However, the data shows a wide range of both potassium and nitrates in the groundwater samples. In this context, it was difficult to differentiate between those values that are coming from the pollution plume of the Wadi Zomar, septic tanks or the agricultural feedback. Figure 5 shows that there are some wells (s. a. Rafeeq Hamadallah, Izbeh wells, and Ismael Itair) which are less affected by Zomar sewage plume, where the contribution of agricultural pollutants are clearer with higher potassium and relatively low PO_4 . This means that most of the wells are subjected to such kind of pollution, but the presences of more effective sources are dominated over the agricultural sources.

6. Conclusions

The problem of groundwater pollution in the upper aquifer of Turonian Cenomanian age is the most common problem for the groundwater in the study area. Previous studies connected the source of pollution by the presence of common used septic tanks, agricultural activities and to limited extend the wastewater discharge in Wadi Zomar. Unlike other studies, this article classifies the pollution sources and the predominance effect of each source on each wells group. The study connects the different mechanisms of pollutants transport to the different geological pollution that characterize the surrounded aquifer media. In general, the study classifies two wells groups according to its location within geological outcrops. These are wells which dogged with the most top Senonian Abu Dis formation, which are mostly municipal with high daily abstraction rates, and the wells dogged with the most top Turonian Jerusalem formation and mostly used frequently for irrigation purposes. The first well group show a high deteriorated water quality that mostly related to the pollutant transport from Wastewater stagnant in Wadi stream. The stream bed lays directly over Jerusalem formation which promote the pollutant transport directly to the uptake zone of these wells (especially municipal one with high abstraction rate), and overcome any other pollution sources that might affect the quality of groundwater in these wells. Moreover, the septic tanks surrounded these wells are present in the most top 5 meters of impervious Senonian Abu Dis formation, which mean that the pollution from septic tanks has less effect on the groundwater from it. Moreover, the flatten slope of the Wadi stream surrounding Tulkarm enhance the formation of wastewater stagnant that infiltrate slowly through the alluvial deposits to Jerusalem formation and finally to the surrounded aquifer. The formation of such wastewater stagnant is mostly predominant in Sumer season with the absence of sufficient waste dilution or precipitation runoff that wash out the Wadi flow.

On the other hand, the second wells group shows higher sodium values which are related mostly to the ion exchange or softening that occurs with direct infiltration through Jerusalem formation cover the top of these wells locations. However, this group show less values of pollutant, and accordingly the effect of other pollution sources was easily noticeable. This group characterize by more effect from the septic tanks, then the pollutants from irrigation feedback.

7. Recommendations

The process of pollutants plume migration from Wadi Zomar through the geological formations to the adjacent uptake zone, can be controlled through lining the wastewater stream with suitable impervious material that prevent the leakage from the Wadi along the Stream path.

The daily heavy abstraction rate from the adjacent municipal wells must be regulated and the change in water quality should be monitored with respect to fluctuation of

water table.

The effect of wastewater stagnant formation especially in summer season must be mitigated by injecting the stream with a suitable amount of treated wastewater that accelerate the stream flow and wash these stagnant out along wadi path.

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