Spatial quality of municipal wastewater flowing in wadi Al Zomar and infiltrated through wadi bed

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جودة المياه العادمة المتدفقة في وادي الزومر و الراشحة خلال قاع الوادي

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This thesis was prepared under the supervision of Dr. Nidal Mahmoud and has been approved by all members of the Examination Committee

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DEDICATION

My parents, Sisters and Brothers

For all those who supported me all the time

Ahmed Al Daraowsheh

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الخلاصة

يهدف هذا البحث الى دراسة التنقية الذاتية لوادي الزومر اثناء جريان مياه الصرف الصحي من المصب الواقع غرب مدينة نابلس وصولا الى جدار الفصل غرب مدينة طولكرم ويركز البحث ايضا على الملوثات الراشحة او المتسربة من قاع الواد عبر طبقات التربة السطحية على عمق يتراوح بين (1-2) م على طول الوادي . حيث تم دراسة كمية ونوع الملوثات في المياه المتسربة وتأثيرها على جودة المياه الجوفية.

تم اخذ عينتين من الوادي عينة في فترة الجفاف (الصيف) وعينة في الفترة الرطبة (الشتاء)، حيث تم اخذ ثلاث عينات من الوادي في فترة الصيف (فترة الجفاف) وثلاث عينات في فترة الشتاء (الفترة الرطبة) حيث شملت كل عينة على عينة سطحية (من المياه الجارية) وعينة من المياه المتسربة على عمق (1-2) م تحت قاع الوادي في اربع مواقع مختلفة على طول الوادي ، وتم اجراء الفحوصات الفيزيائية (DO, TSS,TDS, pH, EC and Turbidity) والكيميائية (COD, BOD, NH_4, NO_3, PO_4, fecal coliforms and heavy metals) لكل عينة.

من نتائج الفحوصات يمكن تقييم عملية التنقية الذاتية في الوادي في المنطقة بين (ST.1) و (ST.3) فقط، وذلك لعدم وجود اي مصادر اخرى للمياه العادمة حيث ان المصدر الوحيد للوادي هو منطقة المصب غرب مدينة نابلس، ماعدا مجموعة صغيرة من المنازل في قرية عنبتا التي تصب مياهها العادمة في الوادي مباشرة .

من النتائج فان تراكيز (COD,BOD) انخفضت بشكل ملحوظ (جوهري) خلال جريان المياه العادمة من ST.1 الى ST.2 (10 كم) وانخفضت بعد ذلك بشكل هامشي من ST.2 الى ST.3 حيث كانت نتائج (COD,BOD) [514,257], [259, 139] و [298, 135] ملغرام/ لترعلى التوالي، هذه النتائج تظهر ان تراكيز المواد العضوية تقل باستمرار التدفق من ST.1 الى ST.2.

من ناحية اخرى فان نسبة (COD/BOD) لكل من (ST.(1, 2, 3&4 كانت (2.3)-(2.4)-(1.9)-(2.0)، حيث ان نسبة COD/BOD في ST.1+2 متطابق مع النسبة النموذجية للمياه العادمة الخاصة بالمنازل وهي (2.0) مما يدل على درجة قابلة لتآكل المواد العضوية بشكل جيد.

بعد ذلك فأن النسبة تزداد بالاتجاه الى ST.3 وST.4 هذه الزيادة ناتجة عن ازالة معظم المواد العضوية القابلة للتآكل من خلال عملية التنقية الذاتية للمواد العضوية.

بالنسبة للامونيا فأن التراكيز كانت متغيرة بشكل واضح بين ST.01 و ST.3 حيث كانت التراكيز كما يلي 76 و64 و 50 ملغرام/لتر على التوالي. بنفس الوقت لا يوجد نترات في العينات المفحوصة مما يدل على ان بكتيريا (heterotrophic) هي التي كانت سائدة بين ST.1-ST.2، بينما بكتيريا (autotrophic) هي التي كانت سائدة بين ST.2-ST.3 وبالتالي فان انخفاض الامونيا كانت نتيجة عملية (nitrification and de-nitrification) بشكل متزامن.

كانت نتائج الاكسجين الذائب (DO) و درجة الحموضة (pH) في (ST.1+ST.2+ST.3) كما يلي (7.9 -0.4) (7.8- 3.3) (7.7 – 0.3) ملغرام/لتر.

ان تركيز الفسفور (PO_4) لم تظهر اختلافات كبيرة على طول الوادي حيث كانت التراكيز في (ST.1+ST.2+ST.3)على التوالي (2.5-3.0-4.0) ملغرام/لتر.

تراكيز (Fecal Coliforms) كانت في ST.2, ST.1 و ST.3 كما يلي 10^5*(2.08-7.36-13.2) cfu/100ml.

نتائج المعادن الثقيلة (Heavy metals) اظهرت وجود ثلاث معادن وهي الزنك (Zn) ،الحديد (Fe) و المنغنيز (Mn) في ST.1+2+3 حيث كانت النتائج كما يلي (0.096،0.089،0.145)-(0.284،0.127،1.236)-(0.054،0.241،0.117) ملغرام/لتر. اما بقية المعادن المفحوصة وهي النحاس والنيكل والكروم والرصاص فكانت تراكيزها صفر.

اما في ST.4 فان التراكيز كانت أعلى وذلك بسبب مغذيات من مصادر اخرى للمياه العادمة من مدينة طولكرم.

نتائج COD و BOD في عينات فصل الشتاء اظهرت انخفاض جذري في تركيز COD و BOD من ST.1 الى ST.3 حيث كانت النتائج كما يلي (220- 509) (138- 439) (67-242) ملغرام/ لتر على التوالي اما في ST.4 فان نتائج COD و BOD كانت (92- 246) ملغرام/ لتر وهي اقل من النتائج المتوقعة مقارنة بفصل الصيف وسبب ذلك التخفيف الناتج من مياه الامطار المتدفقة الى الوادي.

نسبة COD/BOD تدل على ان عملية التآكل للمواد العضوية (biodegradation) كانت ضعيفة و ذلك نتيجة عن اختلاط مياه الصرف الصحي مع مياه الامطار خاصة في المناطق الزراعية التي تمثل ST.2 و ST.3 .

اما الامونيا فأظهرت النتائج في فصل الشتاء انخفاض حاد حيث كان تركيز NH_4-N في ST.1 (50) ملغرام/ لتر انخفضت الى (27) ملغرام/ لتر وبعد ذلك ثبت التركيز تقريبا بالاتجاه الى ST.2 وهذا عكس ما حصل في فصل الصيف.

النترات ظهرت في تراكيز عالية نسبيا في فصل الشتاء في كل من ST.1+2+3 حيث كانت النتائج كما يلي على التوالي (1.0-5.6-44-2.6) ملغرام/ لتر بتوافق عن ارتفاع نسبة تركيز الكسجين الذائب (DO) في المياه العادمة حيث كانت نتائج (DO) تتراوح بين (4.5-5.5) ملغرام/ لتر. من ناحية اخرى فان ارتفاع (DO) ادى الى اعاقة عملية (nitrification).

تراكيز (PO_4) كانت قليلة على طول الوادي حيث كانت التراكيزفي (ST.1+ST.2+ST.3+ST.4) على التوالي (1.8-1.6-3.2-3.4) ملغرام/ لتر.

نتائج (Zn-Fe-Mn) كانت شبه ثابتة في كل المحطات ولم يظهر اي وجود للمعادن الاخرى.

من قياسات التدفق للتيار في الوادي تم قياس معدل التسرب الى الارض حيث تم اجراء الحسابات في المقطع بين (ST.1+ST.2) وذلك لعدم وجود مصادر اخرى للتغذية وايضا بسبب قلت الغطاء النباتي، حيث كان معدل التسرب (0.09) سم/دقيقة وتم تاكيد هذه القيمة باجراء فحص (Double ring infiltration rate)، اما المقاطع المتبقية فتم حساب معدل التسرب بالاعتماد على فحص معدل التسرب.

تقييم توازن كتلة الماء (Water mass balance) للوادي للمقطع الاول الذي تم اختياره كمقطع نموذجي حسث انه لا توجد مصادر ثانوية اخرى تصب في المقطع و لقلة الغطاء النباتي في هذا المقطع و بالتالي تكون عملية (evapotranspiration) اظهر ان 11800 و 10000 متر مكعب تتسرب الى الارض خلال اليوم في كل من الفترة الجافة والفترة الرطبة على التوالي. 1 % من هذه الكمية يمكن تفسيره بسبب التبخر وبالتالي فان 43 % في فصل الصيف و 16 % في فصل الشتاء من المياه الجارية في الوادي تتسرب الى طبقات التربة، وهي كمية كبيرة لها تأثير سلبي على المياه الجوفية في المدى المتوسط و البعيد لما تحملة من ملوثات في اثناء تسربها.

من أجل تقديم درجة التلوث للمياه العادمة بعد تسربها الى قاع الوادي تم تركيب اربع محطات في اربع مواقع مختلفة على عمق يتراوح بين 1-2 م، حيث تم أخذ عينات في كل من فصل الصيف و الشتاء بالتزامن مع العينات السطحية.

أظهرت نتائج الفحوصاتللعينات المتسربة درجات مختلفة من التنقية و المعالجة و انخفاض في تراكيز الملوثات ناتجة من العمليات الفيزيائية و الكيمائية و الحيويةفي جسم التربة.

أظهرت نتائج المواد العضوية في فصل الصيف انخفاض في التراكيز بنسبة تتراوح بين 35% الى 59% ل BOD، و بنسبة تتراوح بين 31% الى 72% ل COD. أما في فصل الشتاء فقد كانت نسبة الانخفاض في التراكيز لكل من COD, BOD بين 25% الى 89% لكلاهما.

أما الامونيا فان الإنخفاض في التركيز قليل بنسب تتراوح بين 9% الى 29% في كل من المحطة رقم (1) و المحطة رقم (4) و ارتفاع في المحطة رقم (3) بنسبة 35% وذلك في فصل الصيف. أما في فصل الشتاء فإن النخفاض في تركيز الأمونيا أكثر حيث تراوح بين 14% الى 81%. بالنسبة للنترات فقد ظهرت في العينات المتسربة في فصل الصيف بتراكيز تراوحت بين 15-33 ماغرام/لتر حيث لم تظهر تراكيز للنترات في العينات السطحية. ويمكن تعليل ذلك بإرتفاع تركيز الاكسجين الذائب في المياه المتسربة. في فصل الشتاء فان تركيز النترات إنخفض في العينات المتسربة بالمقارنة بالعينات السطحية في كل من ST.1 و ST.3 بنسبة تتراوح بين 22-40%.

انخفضت التراكيز للمعدني الزنك و الحديد في العينات المتسربة مقارنة بالعينات السطحية حيث كانت نسبة النخفاض بين 48% الى 73%، على عكس معدن المنغنيز الذي اظهر ارتفاع كبير في تركيز المعدن في المياه المتسربة وذلك في كل من فصلي الصيف و الشتاء.

بناءا على ما سبق يتبين ان التربة تعمل على تخفيف تراكيز الملوثات من المياه العادمة اثناء تسربها وذلك بسبب العمليات الكيميائية و الحيوية، ولكن هذا الإنخفاض لم يكن بشكل كبير حيث بقيت بعض التراكيز بقيم عالية على عمق (2) م من قاع الوادي، مما يدل ان عملية التسرب غير كافية لتنقي المياه العادمة النتسربة مما قد يسبب بوصول المياه المتسربة و هي ملوثة و خاصة بعنصر النيتروجين و المعادن الثقيلة مما قد يؤدي الى تلويث المياه الجوفية.

من جهة اخرى تم احتساب حمل المواد الملوثة الذائبة في المياه العادمة حيث عبر عنها بوحدة (كغم/اليوم) ، حيث تمت الحسابات للمقطع رقم (1) الواقع بين ST.1 – ST.2.

الملوثات التي تم اخذها بعين الاعتبار هي النتروجين والفسفور والمواد العضوية الممثلة ب (COD - BOD) والمعادن الثقيلة.

بالنسبة للنتروجين والفسفور فان نسبة الكمية المتسربة كانت 31% و 34% على التوالي من الكمية الكلية الداخلة الى النظام المائي المقاسة في ST.1 ، اما نسبة المواد المزالة عن طريق العمليات الحيوية في مجرى الوادي فتقدر ب 22% من الكمية الكلية لكلا العنصرين.

ان كمية النتروجين الداخلة الى النظام المائي عند ST.1 كانت حوالي 2000 كغم/اليوم خرج منها (933) كغم/اليوم عند ST.2 وتسربت 623 كغم/اليوم الى التربة والباقي هو 447 كغم / اليوم ازيل بالعمليات الحيوية.

ان كمية الفسفور المتسربة الى التربة فكانت 37 كغم/اليوم في المقطع (1)، اما بالنسبة للمواد العضوية فكانت كمية (COD - BOD) المتسربة للتربة (1423و3653) كغم/اليوم من كامل الكمية الداخلة الى النظام المائي ،

مما يدل على نسبة كمية كبيرة من الملوثات قد تسربت الى العمق اسفل قاع الوادي وتمثل نسبة 28% من الكمية الكلية الداخلة الى النظام لكل من (COD وBOD) .

اما في فصل الشتاء فلوحظ اختلاف جذري في كمية الملوثات المتسربة عنها في فصل الصيف حيث كانت كميات N-COD-BOD (1391-379-174) كغم/يوم، وهي اقل مقارنة بفصل الصيف وكانت كمية الفسفور ثابتة في كلا الفصلين.

من النتائج تبين كمية الملوثات الذائبة الداخلة الى النظام في فصل الشتاء اكبر منها في فصل الصيف بسبب وجود مصادر اضافية للملوثات ناتجة عن تدفق مياه الامطار الى الوادي وبالرغم من ذلك فان كمية الملوثات المتسربة الى قاع الوادي كانت اقل في فصل الشتاء مقارنة بفصل الصيف.

تم اخذ عينات من التربة والرواسب لدراسة (TSS & VSS) والمعادن الثقيلة في الرواسب واظهرت النتائج ان ارتفاع في تركيز بعض المعادن الثقيلة عن ما هو مسموح به وهذه المعادن هي النحاس و النيكل و الرصاص و الكروم. اما باقي المعادن فكانت ضمن الحدود المسموح بها.

Abstract

The Wadi Al Zomar has suffered for over fifty years from a variety of domestic, agricultural and industrial pollution sources together with development pressures in the open spaces that surround the river. The major point pollution sources are effluents that enter the stream through Wadi Al Zomar, the largest of the stream tributaries, beginning with deposition of raw sewage from the western side of Nablus. The wadi receives about seventy pollution sources along its route. These include sewage and effluents from towns, Tulkarem City, stone-cutting industries, landfills, leather factories.

This research focused on self purification in the wadi and also pollutants infiltration from untreated wastewater through top soil at different longitudinal sections in a wadi stream, on the other hand, to identify and quantify the degree of pollutants in the infiltrated water and to identify their potential effect on groundwater quality.

The wadi was sampled during two seasons in order to evaluate variations of wastewater quality under different flow conditions and to evaluate the degree of dilution during winter season as a result of rain runoff. Sampling was performed from February 2012 to March 2012 for winter (wet) samples; three samples from four stations along the wadi were collected during wet period after rainfall event on 22/2/2012, 9 & 19/3/2012. Three samples were taken during dry period on 11, 16 & 29/9/2012.

The discharge of sewage from Nablus City into Wadi Al Zomar (~ 25,000-33,000 m^3/day) is the main point source of pollution into the system.

The quality of wastewater flowing in wadi Al Zomar was assessed during dry season in terms of (COD, BOD, NH_4, NO_3, PO_4, fecal coliforms and heavy metals), in addition to physical parameters DO, TSS,TDS, pH, EC and Turbidity. The average concentration of these parameters at the first measuring starting point, St.1 at 4 km from the Nablus west outfall of COD, BOD, NH_4-N, NO_3-N, PO_4 and fecal coliforms were 514 mg/l, 247 mg/l, 74 mg/l, BDL, 4.1 mg/l, 1.32E06 cfu/100ml, respectively. Out of the tested heavy metals (Zn, Fe, Mn, Cu, Cr, Ni and Pb) only Zn, Fe and Mn were detected with value of 0.42, 1.24 and 0.12 mg/L, respectively.

The self purification of the wadi during dry season could only be assessed between St.1 and St.3 because along this part of the wadi there are no pollution inputs, with the exception of a few houses in Anabta who discharge their wastewater ahead of St.3. The COD and BOD concentrations decreased substantially while travelling from St.1 to St.2 (10 km from Nablus West outfall) and marginal change was noticed afterwards till St.3 of "COD and BOD" values at St.1, St.2 and St.3 of (514 and 257 mg/L), (259 and 139 mg/L) and (298 and 135 mg/L), respectively. This shows that the organic matter was removed while travelling from St. 1 to St. 2, especially that the calculated incremental increase of BOD and COD from Anabta houses were 12 and 24 mg/L, respectively. The changes in COD/BOD ratios at ST.1, 2, 3 and 4 were (2.0, 1.9, 2.4 and 2.3) respectively. The COD/BOD ratios at St.1 and St.2 are in conformity with typical ratios of domestic sewage of 2, indicating high biodegradability of organic matter. Meanwhile, the ratio increased afterwards due to removal of readily biodegradable via self purification processes of organic matter.

Different from the course of the organic matter changes, NH_4-N concentration was marginally changed between St.1 and St.2 of respectively 76 mg-N/L to 74 mg-N/L, but afterwards was substantially reduced to 50 mg-N/L at St.3. NO_3 was not detected at St1, St2. Nor St.3. Apparently between St.1 and St.2 heterotrophic bacteria were dominant, while autotrophic bacteria was dominant between St.2 and St.3, and NH_4-N reduction was due to simultaneous nitrification - de-nitrification. The DO and pH measured at St.1, St.2 and St.3 were respectively (0.40 mg/L, 7.9), (3.3 mg/L, 7.8) and (0.3 mg/L, 7.7). The PO_4 was marginally changed as the PO_4 concentration at St.1, St.2 and St.3 were 4, 3 and 2.5 mg/L, respectively.

The Fecal Coliforms concentration at ST1, St.2 and St.3 of 1.3E+06, 7.4E+05 and 2.1E+05, respectively, were not significantly different at the 95% confidence interval.

The Zn, Fe and Mn were reduced all the way through from St1. till St.4 from 0.42, 1.24 and 0.12 mg/L to 0.08, 0.11 and 0.04 mg/L, respectively. The other measured heavy metals of Cu, Cr, Ni and Pb were not detected anywhere.

These parameters (COD, BOD, NH_4-N, PO_4, FC) were increased at ST.4 due to additional sources of domestic sewage from Tulkarem City, and NO_3 remained zero.

The quality of wastewater flowing in wadi Al Zomar was assessed during dry season in terms of (COD, BOD, NH_4, NO_3, PO_4, fecal coliforms and heavy metals), in addition to physical parameters DO, TSS,TDS, pH, EC and Turbidity. The average concentration of these parameters at the first measuring starting point, St.1 at 4 km from the Nablus west outfall of COD, BOD, NH_4-N, NO_3-N, PO_4 and fecal coliforms were 509 mg/l, 128 mg/l, 50 mg/l, 1 , 3.4 mg/l, 2.2E06 cfu/100ml, respectively. Similar to the results of the dry period, out of the tested heavy metals (Zn, Fe, Mn, Cu, Cr, Ni and Pb) only Zn, Fe and Mn were detected with value of 0.10, 0.23 and 0.07 mg/L, respectively.

The self purification of the wadi during wet season could only be assessed between St.1 and St.3 because along this part of the wadi there are no point sources of pollution, with the exception of a few houses in Anabta who discharge their wastewater ahead of St.3. The COD and BOD concentrations decreased substantially while travelling from St.1 to St.3 (18 km from Nablus West outfall) of “COD and BOD” values at St.1, St.2 and St.3 of (509 and 220 mg/L), (439 and 138 mg/L) and (242 and 67 mg/L), respectively. At St.4 the COD and BOD concentrations were 246 and 92, respectively, which are less than expected as of the dry season results, most likely due to dilution with rain water. The changes in COD/BOD ratios at St.1, St.2, St.3 and St.4 were 2.3, 3.2, 3.6 and 2.7, respectively. The relatively high COD/BOD values indicate the poor biodegradability of organic matter due to mixing of wastewater with runoff, especially in the un-urban middle part of the wadi coinciding St.2 and St.3.

NH_4-N concentration was sharply decreased from 50 mg-N/L at St.1 to 27 mg-N/L at St.2 and remained almost stable afterwards. Unlike the dry period, nitrate concentration were present at relatively high concentrations at St.1, St.2, St.3 and St.4 of 1.0, 5.6, 4.4 and 2.6 mg-N/L, accompanied with high DO of respectively 4.0, 5.0, 5.0 and 5.0 mg/L. the high DO concentrations had apparently hindered the nitrification processes. Noticeably, nitrate concentration at St.1 which is the closest to Nablus west outfall and St.4 in Tulkarem city are the lowest indicating de-nitrification.

The wastewater temperature at the four stations was around 15°C, the relatively high concentration of nitrate. The pH measured at St.1, St.2, St.3 and St.4 were respectively 7.9, 7.8, 7.7 and 7.7. The PO_4 was marginally changed as the PO_4 concentration at St.1, St.2 and St.3 were 4, 3 and 2.5 mg/L, respectively. The PO_4 was marginally changed as the PO_4 concentration at St.1, St.2, St.3 and St.4 were 3.4, 3.2, 1.6 and 1.8 mg/L, respectively.

The Fecal Coliforms concentration at St.1, St.2, St.3 and St.4 of 2.2E+06, 3.5E+06, 8.2E+05 and 3.4E+05, respectively, were not significantly different at the 95% confidence interval.

The Zn, Fe and Mn concentrations were stable all the way through from St1. till St.4 from 0.1, 0.23 and 0.07 mg/L to 0.06, 0.18 and 0.05 mg/L, respectively. The other measured heavy metals of Cu, Cr, Ni and Pb were not detected anywhere.

The rate of infiltration (cm/min) into subsurface was generated based on flow measurement at St.1 and St.2 only and generalized to the whole wadi. This is because along this section of the wadi (St.1 to St.2) (1) there is no pollution input from human activities, (2) vegetation cover is minimal so evapotranspiration could be neglected. The obtained infiltration rate of 0.09 cm/min was also confirmed by double ring infiltrate rate test. Accordingly infiltration rate for other sections of the wadi are calculated based on the double ring infiltration rate test.

The water mass balance assessed for section (1), located between St.1 and St.2, showed that about which 11800 m^3 and 10000 m^3 were lost during dry and wet season, respectively. Out of this lost water, only 1% was due to evaporation during both seasons, while 43% and 16% were infiltrated into the sub soil during the dry and wet seasons, respectively.

The BOD and COD concentrations during dry season at ST 1, 3 and 4 were respectively [73(4.95), 67(4.95) and 149(8.5)] mg/l and [304.7(62), 212.5(86) and 173(24)] mg/l. These concentrations showed reduction in the measured pollutants COD (35-59) %, BOD (31-72) %.

The ammonia NH_4-N concentrations at St.1, St.3 and St.4 were [55 (4), 68.0(3) and 67.1(15)] mg/l. The results showed substantial decreases in NH_4-N concentrations in St.1 and St.4 by percent of (9-28) %, but in the St.3 the concentration were higher than for surface concentrations by 35 %. The NH_4-N increased from 50.3(2) to 68.0 (3) mg/l.

Fecal coliforms concentrations were sharply decreased at St. 1, 3 and 4 were [5.66(5.5), 26.5(5.6) and 21.3(19.2)]*10^3 cfu/100 ml with reduction percent range from 87 to 100%.

The nitrate NO_3-N were presence in infiltrated samples at St.1, St.3 and St.4 were [33(35), 20(18) and 14(13)] mg/l, respectively. In same time the dissolved oxygen increased by 3-folds to 4- folds of DO concentrations of surface wastewater.

Phosphate (PO_4) concentrations increased in St.1 and St.3 and decreased in St.4 in dry season, but in wet season the phosphate increase at St.3 and St.4 (48-200) % and increased in St.1.

The heavy metals in infiltrated samples decreased in case of Zn and Fe in the range of (48-73) % at all stations in the dry season, but for Mn the opposite occurred, the Mn concentrations increased from 1-fold to 6-folds of the Mn concentrations in the surface wastewater.

In wet season, the BOD and COD concentrations at stations 1, 3 and 4 were respectively [33(1), 61(42) and 20(1)] mg/l and [80(8), 181(25) and 157(42)] mg/l. These concentrations showed reduction in the measured pollutants COD (25-84) %, BOD (31-89) %.

The ammonia NH_4-N concentrations at St.1, St.3 and St.4 were [9 (2.5), 24(15.5) and 16(6.6)] mg/l. The results showed substantial decreases in NH_4-N concentrations in ST.1 and ST.4 by percent of (14-81) %.

Fecal coliforms concentrations were sharply decreased at stations 1, 3 and 4 were [9.53(8.0), 175(28.5) and 7.17(7.4)]*10^3 cfu/100 ml with reduction percent range from 79 to 100%.

The nitrate NO_3-N concentrations were decreased in the infiltration samples at St.1, St.3 by percent range from 22% to 40%, but for ST.4 the concentration increased by from 2.6 mg/l to 4.4 mg/l .

The concentration of PO_4 in the infiltrated wastewater was range of (1.7-4.9) mg/l in both seasons, the results showed increase in PO_4 at most stations except St.4 in dry season and at St.1 in wet season.

The heavy metals were decreased in case of Zn and Fe in the range of (48-73) % at all stations, but for Mn the opposite occurred, the Mn concentrations increased from 1-fold to 6-folds of the Mn concentrations in the surface wastewater.

Chemical mass balance was used to evaluate pollution fluxes lost or added to the system by calculating the difference in fluxes between St.1 and St.2.

The calculated surface flowing fluxes loads in terms of Kg/day of COD, BOD, N and P along the wadi in wet and dry seasons at the four stations showed reduction in the loads due to self purification processes and infiltration into subsurface occurring through the flowing along the wadi. In dry season, the reduction in the fluxes loads from St.1 to St.3 range from (57-69) %. In wet season, the reductions were less than in dry season. The reduction percent from St.1 to St.3 range from (40-70) %. These pollutants relatively increased at downstream (St.4).

The penetrated loads for N, P, COD and BOD loads in section (1) were respectively (623, 37, 1423 and 3653) Kg/d in the dry season and (174, 37, 379 and 1391) Kg/ day in the wet season, these represented percent of (31, 34, 29 and 27) % for total loads enter the system (wadi) in the dry season and (7, 21, 3 and 5) % in the wet season, which indicate large quantities of organic matter, nitrogen and phosphorus infiltrated through soil bed up to 2.0 m deep, these pollutants may be go deep in the ground depend on the chemical and biological processes and finally reach the groundwater.

The sediments samples results at ST.1 and ST.2 showed high values of some heavy metal such as (Cu, Ni, Pb and Cr); Heavy metals may be very mobile in the soil if they are present in the leachate as organic metal complexes.

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Chapter One

Introduction

1.1 Background

Water resources in the West Bank are scarce. This is due to the fact that, geographically, the West Bank is located in an arid to semi-arid region. Therefore, societies in the West Bank are very vulnerable to variability of water resources availability. This vulnerability is caused by the strong constraints on the use of natural resources due to limited and low reliable water resources availability in addition to an often high population density and growth rate. In addition to the excessive exploitation of the scarce water resources, the water quality of these natural resources is jeopardized by the discharge of untreated wastewater. Alarming signals have been reported in some places of groundwater pollution with high concentrations of chloride, e.g. up to 250 mg/l, in both the West Bank and Gaza Strip (Ghanem *et al*., 2002). In many areas, groundwater and surface water are now contaminated with heavy metals, POPs (persistent organic pollutants), nutrients and microorganism that have an adverse affect on health (Ghanem *et al*., 2002).

On a one hand, the long residence times are important for the degradation and natural purification within the aquifer, on the other hand, groundwater has a long-term memory for resistant contamination. In order to avoid an extraordinary burden on the drinking water sources it is important to protect this vulnerable system at the source of pollution. The infiltration from wadi bed plays important role regarding groundwater and drinking water quality. On both sides of this system – rivers or streams and within the aquifers system – the flow processes of water as well as the main contaminants transport processes are known, but the linkage between the components are still not well understood. The interaction between the surface water and groundwater is quite complex and depend on many influencing factors and vary significantly in space and time Sophocleous (2002). While very interesting process-based models were developed to stimulate hydrologic fluxes in wadis (Lange *et al*., 2003; Shadeed, 2008), these developed models are very catchment specific and regionalization approaches to make them applicable in other catchments need to be developed. So far, the hydrological models were not coupled with contaminant transport models or water quality models.

The discharge of untreated wastewater into streams leads to increased contamination from organic and inorganic substances. Additionally, wastewater contains a variety of potential human pathogenic parasites, bacteria, and viruses. Therefore, permanent contamination may occur in stream below municipal discharges. Under these conditions, self purification is a process for the preservation of the ecological balance. Self purification power is therefore a main parameter for describing the function ability of the ecosystem. The ability of ecosystem to respond to external pollution and external materials and to preserve ecological structures is named stability (Kalbe, 1996).

Self purification describes as all physical, chemical and biological processes by which the quantity of the pollution in the stream is decreased. The biodegradation and de-nitrification leads to self purification in stream reaches. The assimilation of the dissolved organic substances and nutrients in the water by bacteria, plants, and animals, as well as dilution and mixing process are assigned to self purification (Wuhrmann, 1990).

The problem of urban effluent discharge in wadis represents the thorny question of their impact on the groundwater. This aspect becomes crucial when several drinking water-catchments are located nearby the wadi banks.

Climate change will have a significant impact on water resources and their management. Lower levels of precipitation, a modification in frequency, intensity and spatial distribution of the precipitations and a rise in temperature are expected consequences. Climate change will contribute towards a decreasing availability of water, water quality degradation, and extreme flood and drought events. Climate change will add pressure on water and environmental resources in the semi-arid region and threat ecosystems (Rusteberg, 2001).

Runoff accumulates pollution loads, which are transported either in the dissolved or in the solid phase. The length of the dry period may also influence the patterns of contaminant transport and redistribution in dry land channel. Large storms following long dry periods can facilitate rapid fluvial reconnection with the aquatic component of the watershed. It has been recognized that suspended particulate matter is a significant transport agent for trace element contaminants in stream environments (Characklis and Wiesner, 1997).

As waste treatment practices in semi-arid communities shift from septic tanks and cesspools to central sewage systems, ephemeral steams have increasingly come to serve as conduits to collected treated effluents and to raw wastewater. Wastewater discharge into the stream has considerable impact on the channel bed morphology and functionality by transforming a dry ephemeral stream with intermittent flood to one of continuous flow (Hassan *et al.,* 2001).

The West Bank has been classified into different sensitive areas based on the degree of sensitivity to pollution. Most of the sensitive areas are located in the north of the West Bank while the south and the east are less sensitive. The area of Tulkarem in the north of the West Bank is considered as highly sensitive area due to the shallow aquifer system where pollutants are being increasingly added to the groundwater system through various human activities and natural processes (MOPIC, 1998).

Effluent concentrations produced by municipal wastewater treatment are typically set with the full dilution associated with perennial streams in mind, while the flow conditions in ephemeral streams present completely different hydrological and ultimately ecological requirements (Tal *et al.*, 2006).

Moreover, point source pollution in ephemeral streams has been shown to be highly variable. In a recent study (Stein, 2007) it was found that inter-annual concentrations of metals varied fivefold, and bacteria count varied by five orders of magnitude. This trend is confirmed by other studies (Hatje, 2001; Nimick, 2003). Moreover, dry weather base flow in arid, urban watersheds has been observed to vary in a predictable manner by up to 40% in a single day. Finally, the composition of wastewater is increasingly recognized as complex. Contaminants that were not previously addressed, (e.g. pharmaceuticals) may have substantial impact on potential water quality, especially in watersheds where ephemeral streams play important roles in aquifer recharge. As wastewater comes to dominate such water resources, it is important that regulations and management strategies accommodate the actual field conditions, and address the full range of pollution sources.

The infiltration of wastewater has important resource benefits, both improving its quality and storing it as groundwater for future use, but also represents a potential health hazard because it can pollute aquifers used for potable water supply (Foster and Chilton, 2004). The range of potential groundwater pollutants from wastewater infiltration includes pathogenic microorganisms, excess nutrients and dissolved organic carbon (Ronen *et al*., 1987) and, particularly where a significant component of industrial effluent is present, toxic heavy metals and xenobiotic organic compounds. However, the actual effect on groundwater can vary widely (Foster *et al*., 1997, 2002). The accumulation of organic carbon on sediment surface as a result of contaminant sorption during wastewater sorption has been reported by(Barber Ii et al., 1992) Barber *et al*. (1992 and 1994). Once the wastewater is removed the outcome may be reversed and the sediments serve as a net source rather than a net sink of dissolved constituent (Smith *et al*., 2012).

However, a faster than expected process of grown water contamination can occur as a result of (1) existing fractured formation in the soil matrix (2) presence of surface active (surfactant) in the waste and flood water reaching the soil (3) reality of wetting/drying cycles of water infiltration into soil.

The Al Zomar Wadi, the case study of this research, has suffered for over fifty years from a variety of domestic, agricultural and industrial pollution sources together with development pressures in the open spaces that surround the river (Restoration of the Alexander River, 2001). The major point pollution sources are effluents that enter the stream through Wadi Zomar, the largest of the stream tributaries, beginning with deposition of raw sewage from the western side of Nablus. The Zomar wadi receives about seventy pollution sources along its route (Tal *et al.*, 2006). These include sewage and effluents from towns, Tulkarem City, stone-cutting industries, landfills, leather factories.

1.2 Problem description

In urban centers, 70% of the population is connected to sewage networks (UNEP, 2003). In the vast majority of cases, however, these networks discharge the sewage without treatment into streams in the open environment. Where sewage networks are not in place, sewage runs in open canals or are also disposed of in cesspits. Whether disposed of in cesspits or discharged into streambeds, untreated sewage percolates into groundwater, threatening the future availability of good-quality, safe drinking water from the Mountain Aquifer.

Nowadays, wastewater treatment in Palestine is high on the official agenda. There are several centralized wastewater treatment plants which are planned to be constructed in the coming near future. That will be the end of untreated wastewater discharge in the wadis. Nonetheless, the long term polluted soil is expected to keep releasing the pollutants particularly leaching during the rainy season. The amount and time course of such pollution emanation is still to be elucidated.

This research focused on self purification in the wadi Al Zomar and also pollutants infiltration from untreated wastewater through the top soil of wadi bed at different longitudinal sections in the wadi stream, to identify and quantify the degree of pollutants in the infiltrated water and to speculation their effect on groundwater quality.

1.3 Aim and Objectives

The specific objectives of this research are:

1. Investigate the alterations of wastewater quality, in terms of chemicals parameters (COD, BOD, NH_4, NO_3, PO_4, fecal coliforms and heavy metals) and physical parameters (pH, temperature, DO, TSS, TDS, EC and turbidity), at several longitudinal sections during wet and dry seasons (*self purification*).

2. Investigate the alteration of surface wastewater quality in terms of chemicals parameters (COD, BOD, NH_4, NO_3, PO_4, fecal coliforms and heavy metals) and physical parameters (pH, temperature, DO, TSS, TDS, EC and turbidity), after infiltrate through top soil of wadi bed at several longitudinal sections.

3. Investigate the alteration of infiltrated wastewater quality at several longitudinal sections during wet and dry seasons (*in response to surface self purification*).

4. Assess pollution fluxes to groundwater.

5. Assessing wadi bed polluted soil quality (TSS, VSS and heavy metals) at speculation of the potential of long term release of pollutants from the polluted soil when untreated wastewater discharged is terminated.

Chapter Two

Literature Review

2.1 Introduction

Rapid growth in urban population and water demand in the last few decades have resulted in greatly increased water-supply provision and, thus, wastewater generation. It has also become apparent that common wastewater handling and reuse practices incidentally result in high rates of infiltration to underlying aquifers. Volumetrically, this is often the most significant local 'reuse' of urban wastewater, but one that is rarely planned and may not even be recognized. The infiltration of wastewater has important resource benefits, both improving its quality and storing it as groundwater for future use, but also represents a potential health hazard because it can pollute aquifers used for potable water-supply (Foster and Chilton, 2004).

There has been a little concern about pollutant assimilation capacity of receiving watercourses, and in more arid region because the bulk of dry season flow downstream of urban centers will be raw sewage (Foster and Chilton, 2004).

The ephemeral stream basins are similar to the watersheds in perennial streams. The two are characterized by a heterogeneous variety of sources. These include point sources and non-point sources. Point source pollution typically includes industrial effluents, treated water, or raw sewage from a discrete source discharging and contaminating the water. The fate and impact of point source pollutants is fundamentally different in ephemeral streams than it is in perennial streams. As waste treatment practices in semi-arid communities shift from septic tanks and cesspools to central sewage systems, ephemeral steams have increasingly come to serve as conduits to collected treated effluents and to raw wastewater. Wastewater discharge into the stream has considerable impact on the channel bed morphology and functionality by transforming a dry ephemeral stream with intermittent flood to one of continuous flow (Hassan and Egozi, 2001).

The environmental conditions in such streams frequently are extremely poor, since a cleaner water body does not dilute effluent being discharged into these streams. The high concentrations of BOD, nutrients and bacteria frequently have a more direct and severe impact on the ecosystem than in naturally perennial streams. Effluent concentrations produced by municipal wastewater treatment are typically set with the full dilution associated with perennial streams in mind, while the flow conditions in ephemeral streams present completely different hydrological and ultimately ecological requirements (Tal *et al*., 2006). In addition, effluent discharge introduces a continuous input of water into an ecosystem which is mostly dry. This shift affects vegetation cover, bank and bed stability, sediment transport and storage. The associated hazards of mosquitoes, odors and, of course, groundwater contamination can be substantial. The natural vegetation and fauna are often replaced by invasive species that are better adapted to contaminated wet environments (Tal *et al*., 2006).

Within the West Bank, there are fifteen streams that cross the Green line. Twelve of these are major streams that flow year-round in a westward direction toward the Mediterranean Sea. All of these involve watersheds that are partially located in the West Bank. At least part of each of these streams can be defined as highly polluted, posing a health hazard to users, endangering flora and fauna and unfit for recreational or consumptive uses (Alon Tal, 2007).

The Palestinian streams differ fundamentally from those in Europe and most parts of the United States. These channels are not naturally perennial but flow year round due to the constant discharge of untreated wastewater (Tal *et al*., 2006).

Understanding the full menu of pollution loadings and adopting a comprehensive watershed strategy is critical for designing and implementing an effective water management strategy. Part of the failure thus far in stream restoration activities involves an inability to move beyond unilateral chemical characteristics of pollution sources and the capability to respond to in-stream condition. The growing recognition, that surface water resources should play a critical role in Palestinian's long term environmental strategy. These water surface resources can and should provide key sources of drinking water, aquatic habitats, commercial waterfront and places of recreation (Tal *et al.*, 2006).

Deterioration of groundwater quality rarely occurs naturally and is usually caused by human activity. There are two main reasons for deteriorating groundwater quality: (a) overpumping (which can lead to saline water being drawn into the aquifers); and (b) direct contamination through the leaching of wastes and chemicals from the land surface down into the aquifers. This issue is most importance in the West Bank (SUSMAQ, 2003).

2.2 Aquifer vulnerability

Groundwater vulnerability is defined as: "The tendency and likelihood for general contaminants to reach the water-table after introduction at the ground surface".

With this definition, the vulnerability of an aquifer to pollution is dependent on the intrinsic characteristics of the strata separating the saturated aquifer from the ground surface, and is largely independent of the transport properties of specific contaminants. Intrinsic vulnerability is independent of the saturated aquifer itself. It only deals with the unsaturated strata between the ground surface and the water-table (Fig. 2.1). Once the contaminants have arrived at the water-table the resource is polluted (SUSMAQ, 2003).

The main groundwater aquifers in the West Bank are karstic. This means that the groundwater flows rapidly within discrete fissures rather than slowly through pore spaces and small fractures (see Figure 2.2) (SUSMAQ, 2003).

Most of the Mountain Aquifer's recharge area is vulnerable to groundwater pollution due to its hydrological characteristics. The Mountain Aquifer is a *karst* geological system, which provides little protection to its groundwater. Over the years, the limestone ground was subject to dissolution by water containing acidic elements, developing a wide system of underground channels inside the rock. This system allows for relatively fast and unhindered percolation of surface water, both rain and sewage, into the ground. Pollutants on the surface of the Mountain Aquifer thus pose a very serious threat to the quality of groundwater, far more than in the case of the Coastal Aquifer, where the sandy soil filters or absorbs pollutants, and allows for biological processes that decompose organic matter (Gvirtzman, 2002).

Groundwater pollution due to point and nonpoint sources is caused mainly by agricultural practices (noticeable is the use of inorganic fertilizers, pesticides, and herbicides), localized industrial activities (organic and inorganic pollutant and heavy metals), and inadequate or improper disposal of wastewater and solid waste including hazardous materials (Hall *et al*., 2001; Delgado and Shaffer, 2002; Shrestha and Ladha, 2002; UNEP, 2003; Almasri and Kaluarachchi, 2004; Dunn *et al*., 2005).

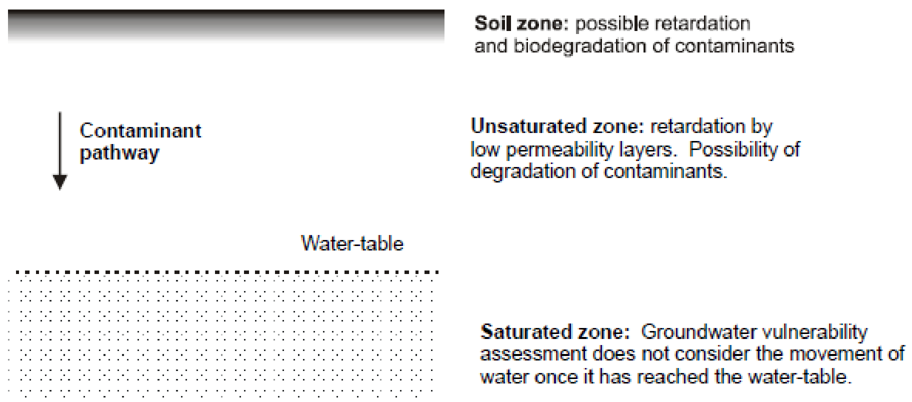


Figure 2.1: The contaminant route generally assumed for groundwater vulnerability assessment (SUSMAQ, 2003)

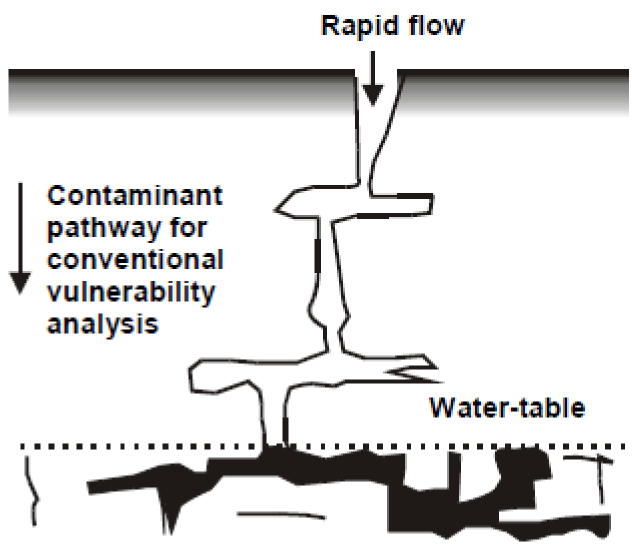


Figure 2.2: Groundwater flow in karst areas (SUSMAQ, 2003)

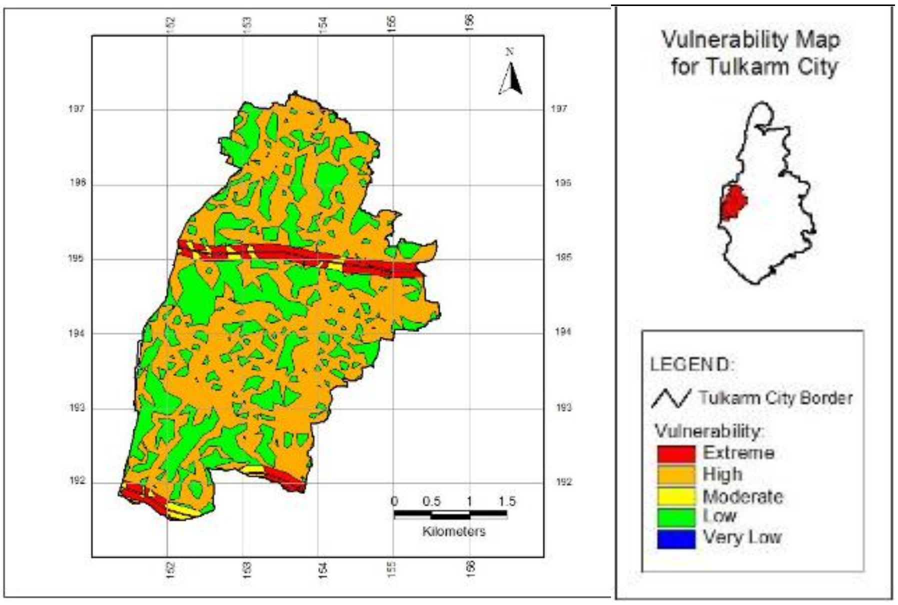


Figure 2.3: Vulnerability map of Tulkarem city (Aliewi, 2008)

The rarely challenged, conceptual model, on which the current management of groundwater is based, presupposes effective buffering and protecting properties of the aquifer matrix, and slow rates of water vertical velocity, typically *ca*. 0.7 and 2.3 m/year in clay loam and sandy sediments respectively for the Mediterranean climate region (Gvirtzman *et al*., 1986).

Therefore, groundwater contamination by water-soluble and insoluble pollutants has been conceptualized only as a remote, long-term possibility that, for the time being, one should not be worried about. However, a faster than expected process of groundwater contamination can occur as a result of: (a) existing fractured formations in the soil matrix; (b) presence of surface active agents (surfactants) in the waste and food waters reaching the soil; and (c) reality of wetting/drying cycles of water infiltration into soil (precipitation, agricultural irrigation and aquifer recharge). Thus, the actually observed enhanced groundwater contamination contradicts the currently, commonly accepted, ``buffer model'' of the vadose zone. In view of the effects of the above parameters mostly ignored in contemporary practice and data analysis, the output predicted by modeling is very far from actual reality (Konikow and Bredehoeft, 1992).

2.3 Wastewater Management in the West Bank

According to ARIJ (2011) the total volume of wastewater generated in the West Bank in the year 2008 was estimated at 47.31 MCM. Of this 13.5 MCM (30.1 %) is collected by the sewage network. Only 63 localities, out of 510 localities, are served by a sewage network. However, wastewater collection network is limited to the major cities and refugee camps in the West Bank. These are outdated, often leak, and are incapable of handling the current amount of wastewater that they receive. Lacking wastewater facilities, the remaining 70 percent of Palestinians deposit their wastewater in cesspits, from where it largely seeps into the groundwater. Palestinians personally pay to empty the cesspits, and due to the poor state of the economy, many families do not have the financial resources to bear the expense. Around 90-95 percent of the Palestinian wastewater in the West Bank is not treated at all. Due to the lack of treatment plants, even when residents empty the cesspits, the wastewater ends up in valleys, sewers, irrigation channels or refuse dumps.

The main wadis that convey wastewater are Wadi Zomar, Wadi El sajour, Wadi Batunia, Wadi As Samen and Wadi En Nar.

The north-western strip of the Mountain Aquifer’s recharge area, around the cities of Tulkarem and Qalqiliya, is particularly vulnerable to pollution. Groundwater in that area is closer to the surface, requiring a shorter period of time for pollutants to percolate and reach it (Guttman, 1999). Some of the most abundant water extractions from the Mountain Aquifer are located in that area (Gvirtzman, 2002). Alarmingly, it is also the location of some of the most serious pollution spots (IWC, 2003a, 124).

2.3 Vadose (unsaturated) zone

The vadose zone or unsaturated zone is defined as "the part of the earth between the land surface and the top of the groundwater table".

The unsaturated zone is only partly saturated with water; the remainder of the pore space is filled with air. It is through this vadose zone that the water and/or wastewater moves down to the water table, transported soluble and particulate materials which can pollute groundwater (Blum *et al.*, 2012).

The vadose zone is biological active because the soil pores contain both air and water. Contaminants can be transformed by geochemical, radiological, and microbiological processes as they are transported through various environments within the groundwater system (Blum *et al*., 2012). Some chemical transformations can change harmful contaminants into less harmful chemical species, while other processes can produce compounds that are more harmful to ecosystems or human health than the parent compound. The natural decay of some radio nuclides can produce daughter products with different transport properties and health effects than the parent product (Focazio *et al*., 2000).

The relative importance of the different processes that are operative is summarized in Figure. 2.4. The most active zones for contaminant attenuation and elimination are the soil and unsaturated zone. The processes continue, to lesser degree, at greater depth, especially were unconsolidated sediments as opposed to consolidated fissures rocks are present in the saturated zone. Additionally, the hydrodynamic dispersion accompanying groundwater flow will bring about dilution of persistent and mobile pollutants, in the saturated zone of aquifers (Foster *et al*., 1994).

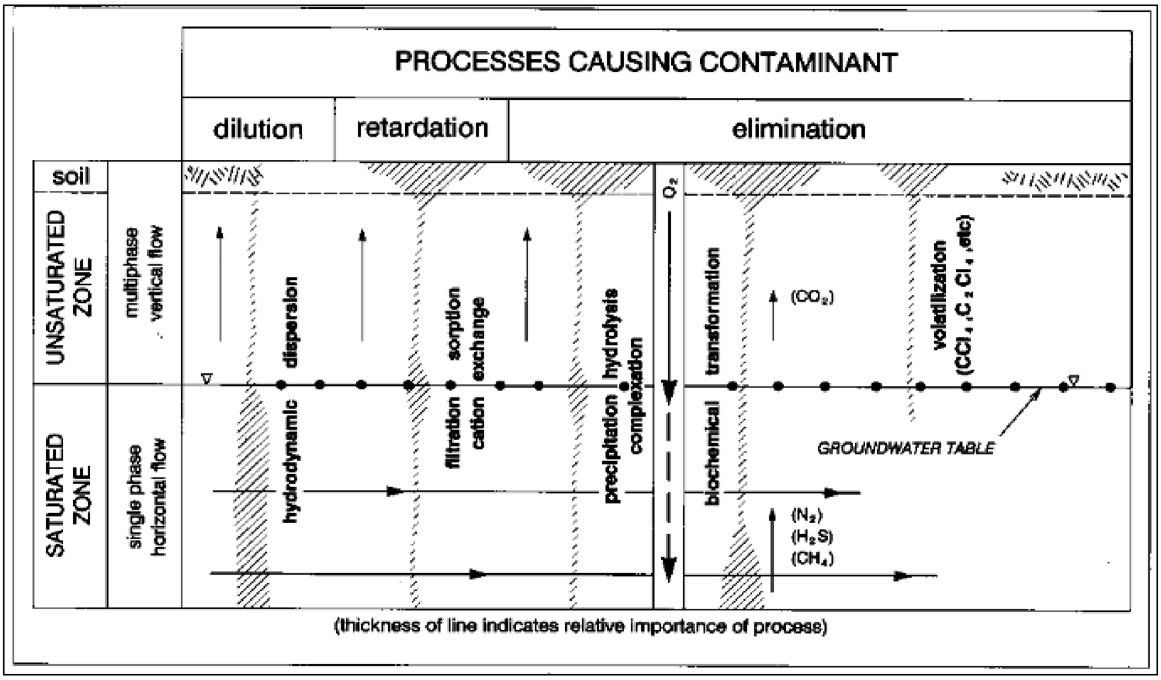


Figure 2.4: Summary of processes of attenuation in groundwater system (Foster and Hirata, 1988).

The soil has a capacity to filter, buffer and transform materials between the atmosphere, the plant cover and the water table (Blum *et al*., 2012). They strongly influence the water cycle of the earth's surface:

(1) Mechanical process: indicating the filtration of solid and liquid compounds in the pore spaces,

(2) Physico – chemical reaction: buffering capacity through absorption and precipitation of all kinds of organic or inorganic compounds,

(3) Microbiological and biochemical capacity for transformation, through the alteration and decomposition of organic materials by mineralization and hydrolytic processes (Blume *et al*., 2006).

The soil can maintain those capacities, thus a little danger that pollutants will reach the soil solution. However, if these functions cannot be fulfilled any more, higher quantities of the heavy metal will reach the soil solution and leach beneath the profile and thus contaminating the groundwater (Blume *et al*., 2006).

In some hydrological conditions, notably with shallow water table or near surface fractured aquifers, there is likely to be significant penetration of pathogenic bacteria and viruses to aquifers (CAN *et al*., 1987), but in the most other conditions vadose zone attenuation (over percolation depths of 2-5m) will be effective in eliminating most pathogens (Foster *et al.,* 1994).

Unsaturated zone water movement is normally slow and restricted to the smaller pores with large specific surface area; there is thus major potential for (Foster *et al.,* 1994):

1. Interception, sorption and elimination of pathogenic bacteria and viruses.

2. Attenuation of heavy metals, and other inorganic chemical, sorption or cation exchange.

3. Sorption and biodegradation of many hydrocarbon and synthetic organic compounds.

2.4 Groundwater Pollution by Infiltrated Pollutant

Foster *et al*. (1994) studied the effects of wastewater recharge on aquifer water quality and they showed that the movement of wastewater through the soil, unsaturated zone and saturated aquifer improves its quality. Natural soils actively attenuate many, but not all, pollutants. They indicated that not all hydrogeological environments are equally effective in contaminants attenuation. They showed that the total and dissolved organic carbon concentrations, together with biochemical oxygen demand, have been determined beneath a number of wastewater recharge sites in Britain. A high degree of removal following infiltration is achieved for all these parameters. TOC removal is reduced by 70-90% was observed by the researchers, and the BOD of primary effluent is reduced by 90-98% following infiltration. DOC reported to be reduced by about 60 percent.

Singh *et al.* (2000) studied the heavy metals that transport from dredged sediment disposal sites in a laboratory rainfall simulation experiment the region of Ghent, Belgium.

A rainfall simulation experiment was conducted to estimate heavy metal transport from dredged sediment derived soils by surface runoff and percolating water. Both runoff rate and sediment yield were high in the sandy loam soils, characterized by relatively low organic matter contents. Mean metal concentrations in runoff water exceeded the Netherlands values for ground water quality. The total metal load exported by both runoff and percolating water was largest for the most contaminated soil. For most metals, transport by percolating water was several times higher than the metal load exported by surface runoff water

Al Kharabsheh (1999) investigated the effects of the Kherbet Es Samra wastewater treatment plant (KS), on the deterioration of groundwater quality at Seil Zarqa –

Jordan. He found the chemical characteristics of soil water solution with different depths up to 140 cm (measured using suction cup) that the electrical conductivity, cation and anions increase readily with depth, Ca, Cl, Mg, Na and SO_4 have increased by 34, 29, 17, 12 and 9 times, respectively, which mean that the soil contains minerals and solids $CaCl_2$ and $MgCl_2$. The clayey minerals of the soil did not allow the nitrification process to occur. NH_4 decreased and NO_3 increased to beyond a depth of 140 cm. The COD decreased during the oxidation process after 140 cm depth and the PO_4 decreasing during the precipitation process of the soil. The research found by that the soil water is highly affected by the treated water. The results of the study showed that there is a leakage of wastewater from the basin of KS, and from Seil Zarqa into the groundwater of the upper aquifer complex.

Gaiero *et al.* (1997) found that the anthropogenic activities can cause elevated levels of heavy metals in various parts of the ecosystems. Heavy metals of river sediments in hydrological systems are more sensitive than dissolved concentrations indicator of contamination.

The CH2MHill report (1999) for the Palestinian Water Authority concerns the West Bank aquifers and focuses on Wadi Al Qilt catchment in order to understanding the potential of wastewater pollution sources to the groundwater. The results revealed that ammonia, potassium, nitrate, chloride, and Total Dissolved Solid (TDS), and the trace metals such as antimony, lead, selenium, thallium, mercury, cadmium, and arsenic classified as pollutants at Al Quilt.

Qannam (2003) studied the Wadi Al Arroub drainage basin/Palestine. The study focused on identifies the different pollutants, their possible sources and impact on the water resources. He also studied the changes in the chemistry of the recharge water from wastewater conduit and rain water during the infiltration through the vadose zone by collecting soil water samples using suction cup method at two different locations with different depths 30, 60 and 90 cm in each location. He showed that the increase of concentrations of the main chemical components becomes less with depth.

Ghanem (2005) studied the effect of hydro-chemical changes at the water quality allocation in the West Bank and the negative impacts of pollutants at solid waste dump sites and the liquid wastes in some selected areas on the quality of groundwater.

He found that the level of trace metals in groundwater depends on the ion exchange capacity of the soil layers that will attenuate the down gradient movement, but the level of organic matter in groundwater depends on the organic content of the soil and biodegradation rate. Natural filtration through geological formation will affect the presence of trace metals, organic matter and the physical parameters such as TDS, EC, pH, temperature and total hardness.

Abdul-Jaber *et al.* (1999) studied the effect of contamination from wastewater on the shallow aquifer in the northern West Bank. The outcomes from this study showed that most of the springs and wells within the high density residential areas were contaminated with wastewater by infiltration from cesspits and the open conduits of raw sewage.

Samhan *et al.* (2010) assessed the water quality in the West Bank aquifers for major parameters such Chloride, Nitrate, Sodium, Potassium, Sulfate, and other biological indicators such as T. Coliform and F. Coliform. About 90 springs and wells used for domestic purposes were analyzed. The study showed that the main sources of contamination encountered in domestic sources in the West Bank aquifers are from domestic wastewater, agriculture activities and direct discharge of wastewater in wadis without any type of treatment.

Al Zomar watershed contains about seventy pollution sources, including sanitation effluents and raw sewage from the communities, stone-cutting industries, and different factories, as well as seepage from solid waste dumping sites, and gas stations, etc. During the olive picking season from October to December each year, wastewater from the surrounding olive mills adds to the pollution loading in the stream. The total quantity of effluents that enter the stream is estimated to be 3 million cubic meters yearly. About half of this quantity of effluents generated in the catchment penetrates to the groundwater, which is the main source of water supply in the area, adding another aspect to the problem (Tal *et al.*, 2006).

Khyat *et al*. (2012) studied the mechanisms of pollutants transport in Wadi Al Zomar based on geological formations. The study classified two sub-aquifers groups. The first group, are wells which dug within Senonian Abu Dis formation, and are mostly used extensively for municipal purposes. The second group, are wells dug 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. They found that septic tanks surrounded these wells are constructed within the top 5 meters of Senonian formation, which means that the leakage from septic tanks is not that ease to significantly affect the groundwater quality. The results emphasize the need for further procedures to mitigate the pollutants plume migration from Wadi to the surrounded environment.

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 (Khyat *et al.*, 2012). They found that 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, that classifies the pollution sources and the predominance effect of each source on each wells group. 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 Tulkarem 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 summer season with the absence of sufficient waste dilution or precipitation runoff that washes out the Wadi flow.

Rumman (2003) found in her research that the quality of groundwater in Tulkarem Area indicates a gradual increase in chloride and nitrate with time. Figure 2.5 shows the spatial distribution of nitrate concentration across the West Bank for the year 2004. This distribution was developed to assess the possible anthropogenic effects on groundwater quality, nitrate concentrations were classified into four groups based on the work of Cox and Kahle (1999) and Madison and Brunett (1985).

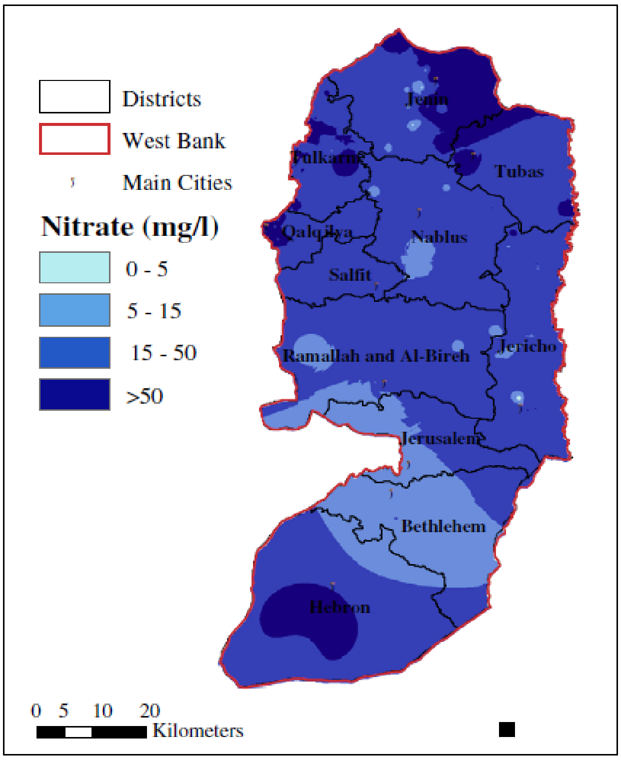


Figure 2.5: The distribution of nitrate concentration across the West Bank for the year 2004 as interpolated using the IDW method (Anayah and Almasri, 2009)

The ranges of nitrate concentrations in the West Bank districts were analyzed by Anayah and Almasri (2009). The results reflect the intensive agricultural activities as well as the existence of other possible sources including the cesspits and the disposal of untreated wastewater. It can be concluded that the most vulnerable groundwater basin to contamination is the Western Basin. This result can be attributed to the agricultural activities along with the high groundwater recharge.

SUSMAQ (2001) found in their report that about 97 wells have concentrations exceeding the WHO standards for drinking water (45) mg/l, 13 of which are domestic wells. The maximum nitrate concentration in the domestic wells measured at 112 mg/l in the Tulkarem area tapping the Cenominian – Turonian aquifer.

Aliewi *et al.*, (2008) studied the impact of the untreated wastewater of Wadi Zomar on the Groundwater system of the Tulkarem area. They found that the wastewater infiltration from the wadi to the groundwater usually contains high contaminant concentrations of Chloride, BOD, TSS, and Bacteria. The results of pollution model indicate a general trend and distribution of pollution plume to east from Wadi Zomar, which is one of the main pollution sources in the region. The spatial distribution of concentration is parallel to the input source. The effects of pollution plume after 300 days cover an area of 9.0 km^2, and about 14 km^2 after 6000 days of simulation.

2.5 Infiltration

Reductions in flow volume between upstream and downstream points are caused by evapotranspiration and infiltration into the bed, the banks, and possibly the flood plain. These losses (called transmission losses) reduce not only the volume of the hydrograph, but also the peak discharge. Transmission losses not only cause reductions in discharge but can also dry up the channel completely. Transmissions losses through the bed of streams in arid and semiarid regions can account for a large proportion of the total amount of runoff generated upstream (Hughes and Sami, 1992) and of course are reflected in decreased groundwater recharge and increased contamination (Tal *et al.*, 2007).

In many semi arid areas wadi bed leakage is the dominant recharge mechanism, the leakage of water through wadi bed depend on flow rate, bed lithology and the underlying aquifer characteristics (SUSMAQ, 2001).

Infiltration will not necessarily be linearly related to flow, for instance at extreme low flows sedimentation may seal the wadi bed. At high flows the wadi bed may be scoured, improving infiltration, or alternatively sealed by suspended sediments. When flow rates exceed the capacity of the wadi channel and spill over onto adjacent plains infiltration characteristics will change significantly (SUSMAQ, 2001).

For the estimation of losses water in the wadi, a water balance approach was used. Water loss is caused by three main processes: Infiltration in the groundwater, evaporation and evapotranspiration (Tal *et al.*, 2007).

The rate of evapotranspiration depends on many factors including plant species, stage of growth, leaf area, and plant density and can vary seasonally with surface water availability and depth to groundwater (Snyder and Williams, 2000). Therefore, the complexity and difficulty in evaluating evapotranspiration involves large uncertainties and imprecision (Goodrich et al., 2000)

2.6 Study Area

Wadi Al Zomar/Alexander watershed begins in the hills of Nablus and continues to flow throughout the central coastal plain. The watershed spans over 556 km^2 of land and is forty-four km long from Nablus Mountain to coastal plain. The eastern most border flows from the city of Nablus in the West Bank Mountain Ridge continuing down to its estuary in the west, where it meets the Mediterranean Sea. The hydrographic catchments area is approximately 28 kilometers long continuing to green line. The stream comes down in its first 10 Km from the height 740 m to 210 m, an average slope of 45 m per Km and 9 m per Km in the remaining length (Brandies, 1996)

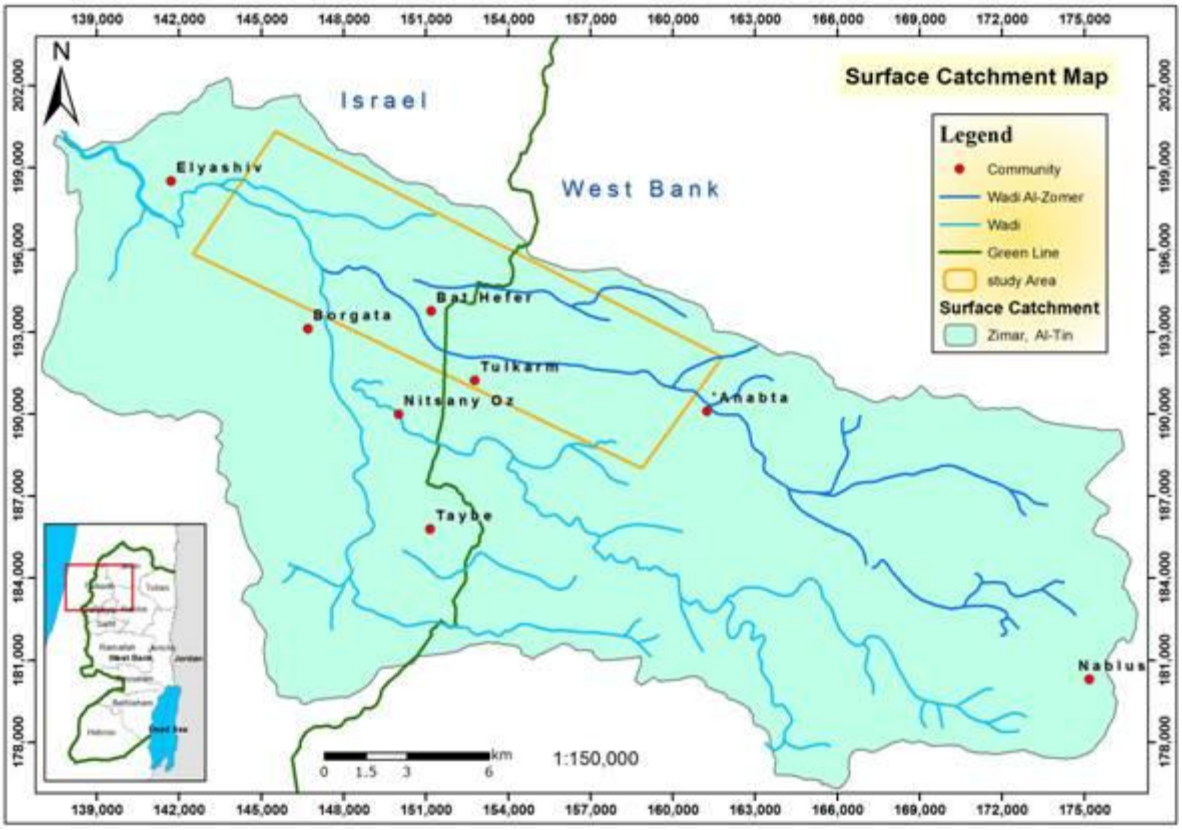


Figure 2.6: Alexander basin and catchment area of Al Zomar wadi in the rectangle (Tal *et al*., 2006)

2.7 Climate

The climate of Wadi Al Zomar catchment is typical Mediterranean (subtropical to semi arid). The average temperature ranges from 8 to 14 °C, while the average temperature in the summer ranges from 21 to 40 °C. The average relative humidity ranges from 39 % in May and 84% in January. The mean annual precipitation in the catchment area is 650 mm (OPTIMA, 2007).

2.8 Precipitation

The mean annual rainfall in the Tulkarem city is 623 mm for the period from 1952 to 2010 (Tulkarem Agricultural Department, 1996 & Palestine Central Bereau of

Statistics, 2012). The amount of mean annual rainfall in the Tulkarem Area varies from year to year and rain may fall with great intensity in wet years. The rainy season in the Tulkarem Area usually starts in October and continues through May. Between December and February, almost 70% of annual rainfall occurs, while 20% of annual rainfall occurs in October and November.

2.9 Topography

The soil cover in stream area varies to three types:

- Brown Rendzinas and pale Rendzinas: this type of soil cover the area from effluent point in west of Nablus city to Anabta village.
- Terra Rossa, Brown Rendzinas and pale Rendzinas: This type of soil covers the area from Anabta village to Tulkarem City.
- Grumusols: Small Area closed to green line nearest Tulkarem City (Rofe and Raffety, 1963-1965)

2.10 Geology

The geological formations of the study area of Wadi Al Zomar range in age from Senonian to Quaternary. The stratigraphic section of the West Bank is presented in Figure 2.7. The catchment area is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk.

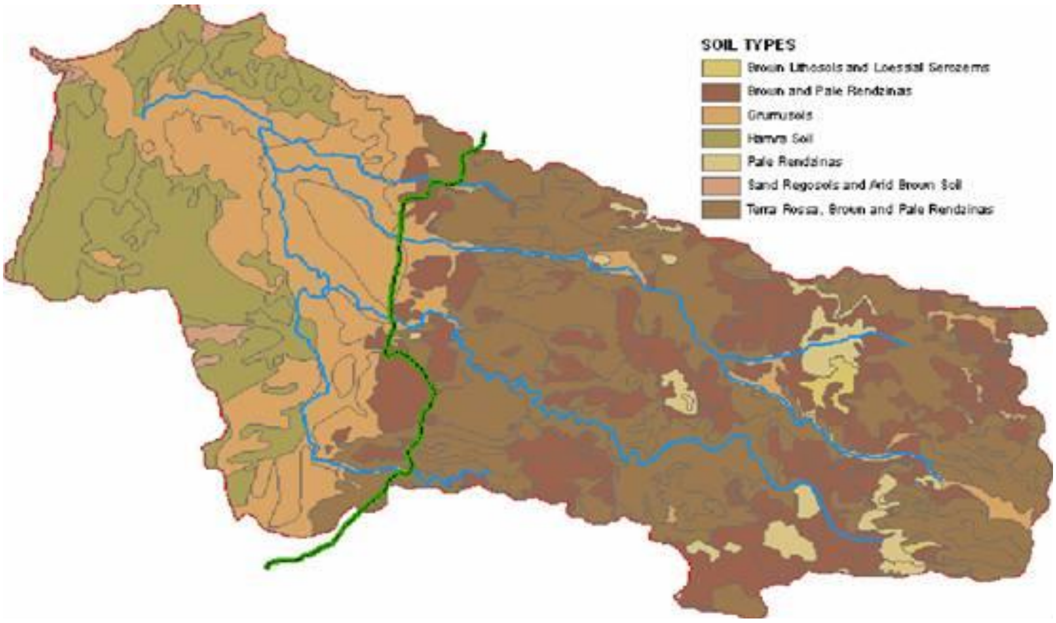


Figure 2.7: Soil classification map of the Tulkarem District (Tal *et al.*, 2007)

The general geology of the Catchment area is represented in Figure (2.8). A brief description of the lithological formations encountered in the Tulkarem district is presented below (SUSMAQ, 2001; Aliewi *et al*., 2003).

1. Upper Cenomanian (Bethlehem formation)

The Upper Cenomanian 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 slope.

2. Turonian (Jerusalem formation)

The Turonian 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 (Al Khayat *et al.*, 2012).

3. Senonian (Abu Dais formation)

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

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 Figure 2.8

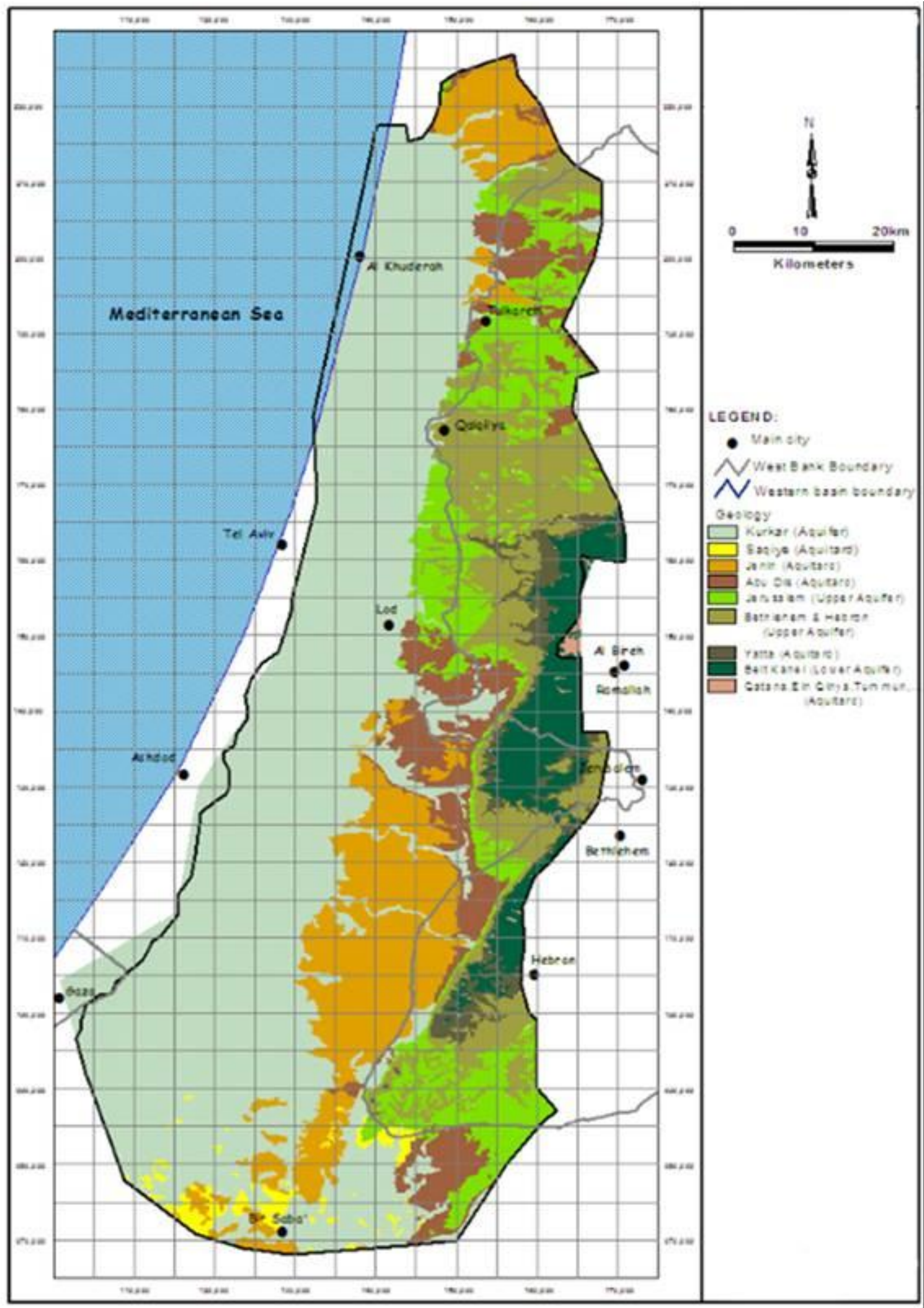


Figure 2.8: Wadi Al Zomar Lithology (HWE, 2006)

2.11 Hydrology

Figure 2.9 is a hydrogeological map of the Western Aquifer Basin (WAB), with formations divided into relevant hydrostratigraphic units. The WAB is built (West Bank group) formations of Upper Albian to Turonian age. It consists of two thick carbonate sequences, divided by a more marly and chalky section of Lower Cenomanian age (Table 2.1). Both carbonate series, the aquifers, contain limestone and dolomite, with the lower being limier and the upper more dolomitic in lithology.

The bottom below the West Bank group (West Bank group) is a thick sequence of shale and marl called Kobar group or sometimes also referred to as Kurnub group. In the coastal plain, where the Upper Aquifer is not exposed, it is covered mainly by Senonian chalks, in restricted areas also by Eocene chalk and limestone series or directly by sub-recent alluvial.

Accordingly, the relevant formations can be summarized from top to bottom as:

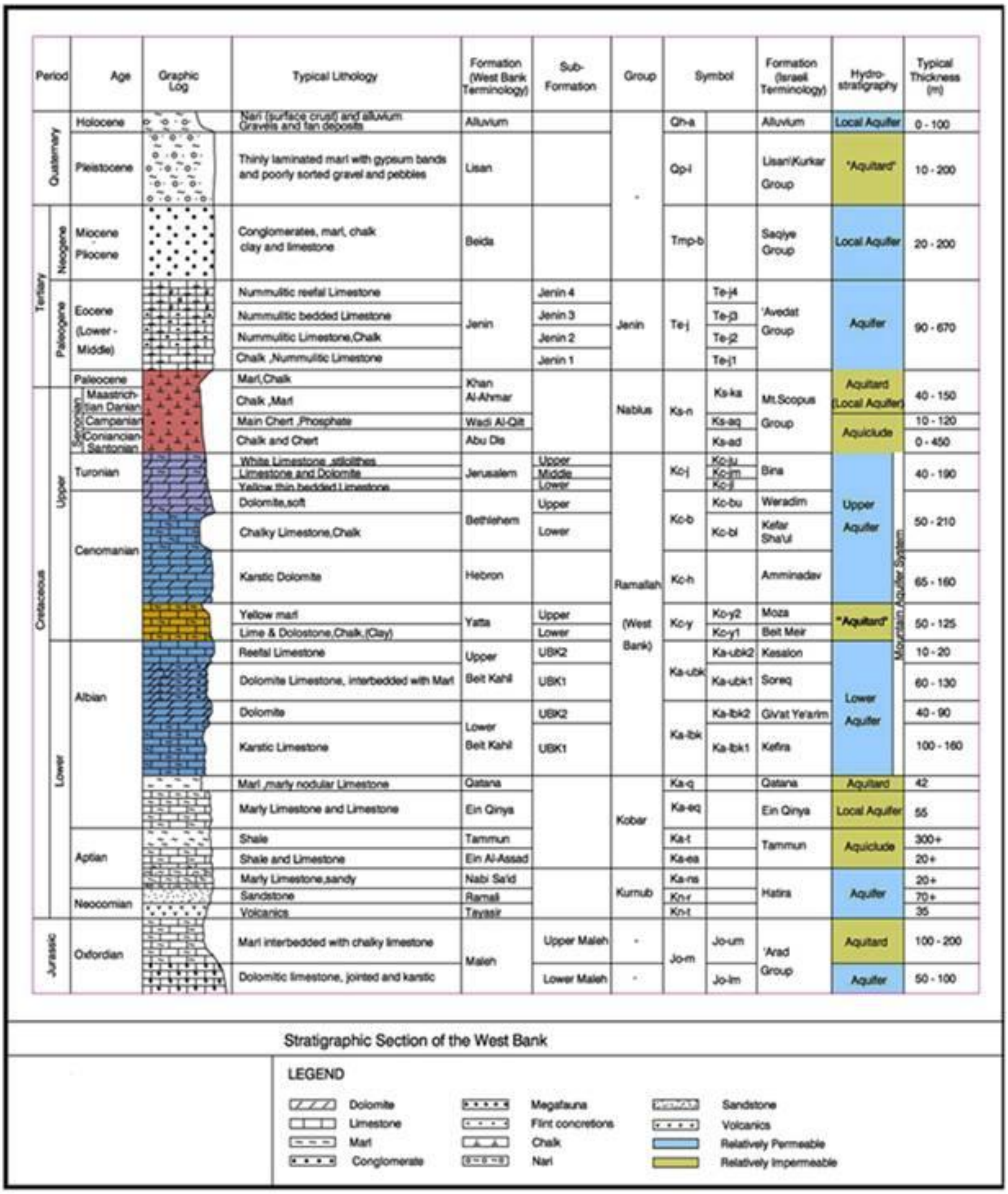
Layer 5: Top Aquiclude (Abu Dies or Mt.Scopus Group and younger sediments) of predominantly chalk and marl

Layer4: Upper Aquifer (Jerusalem, Bethlehem, Hebron formations) of mainly dolomite

Layer 3: Middle Aquitard (Yatta formation) simplified as one confining unit with several horizons dominated by marl, or sometimes chalk

Layer 2: Lower Aquifer (Upper and Lower Beit Kahil formations), of predominantly limestone.

Layer 1: Bottom Aquiclude (Tammun, Ein Qinya, Qatana or in geophysical terms Yakhini) of marl and shale.



Period	Age	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	"Aquitard"	10 - 200
Tertiary / Neogene	Miocene Pliocene	Conglomerates, marl, chalk clay and limestone	Beida			Tmp-b		Saqiye Group	Local Aquifer	20 - 200
Tertiary / Paleogene	Eocene (Lower - Middle)	Nummulitic reefal Limestone	Jenin	Jenin 4	Jenin	Te-j	Te-j4	'Avedat Group	Aquifer	90 - 670
		Nummulitic bedded Limestone		Jenin 3			Te-j3			
		Nummulitic Limestone,Chalk		Jenin 2			Te-j2			
		Chalk ,Nummulitic Limestone		Jenin 1			Te-j1			
	Paleocene	Marl,Chalk	Khan Al-Ahmar		Nablus	Ks-n	Ks-ka	Mt.Scopus Group	Aquitard (Local Aquifer)	40 - 150
Cretaceous / Upper / Senonian	Maastrichtian Danian	Chalk ,Marl								
	Campanian	Main Chert ,Phosphate	Wadi Al-Qilt				Ks-aq		Aquiclude	10 - 120
	Coniancian Santonian	Chalk and Chert	Abu Dis				Ks-ad			0 - 450
	Turonian	White Limestone ,stilolithes	Jerusalem	Upper	Ramallah (West Bank)	Kc-j	Kc-ju	Bina	Upper Aquifer	40 - 190
		Limestone and Dolomite		Middle			Kc-jm			
		Yellow thin bedded Limestone		Lower			Kc-jl			
	Cenomanian	Dolomite,soft	Bethlehem	Upper		Kc-b	Kc-bu	Weradim		50 - 210
		Chalky Limestone,Chalk		Lower			Kc-bl	Kefar Sha'ul		
		Karstic Dolomite	Hebron			Kc-h		Amminadav		65 - 160
		Yellow marl	Yatta	Upper		Kc-y	Kc-y2	Moza	"Aquitard"	50 - 125
		Lime & Dolostone,Chalk,(Clay)		Lower			Kc-y1	Beit Meir		
Cretaceous / Lower	Albian	Reefal Limestone	Upper Beit Kahil	UBK2		Ka-ubk	Ka-ubk2	Kesalon	Lower Aquifer	10 - 20
		Dolomite Limestone, interbedded with Marl		UBK1			Ka-ubk1	Soreq		60 - 130
		Dolomite	Lower Beit Kahil	UBK2		Ka-lbk	Ka-lbk2	Giv'at Ye'arim		40 - 90
		Karstic Limestone		UBK1			Ka-lbk1	Kefira		100 - 160
		Marl ,marly nodular Limestone	Qatana		Kobar	Ka-q		Qatana	Aquitard	42
		Marly Limestone and Limestone	Ein Qinya			Ka-eq		Ein Qinya	Local Aquifer	55
	Aptian	Shale	Tammun			Ka-t		Tammun	Aquiclude	300+
		Shale and Limestone	Ein Al-Assad			Ka-ea				20+
		Marly Limestone,sandy	Nabi Sa'id		Kurnub	Ka-ns		Hatira	Aquifer	20+
	Neocomian	Sandstone	Ramali			Kn-r				70+
		Volcanics	Tayasir			Kn-t				35
Jurassic	Oxfordian	Marl interbedded with chalky limestone	Maleh	Upper Maleh	-	Jo-m	Jo-um	'Arad Group	Aquitard	100 - 200
		Dolomitic limestone, jointed and karstic		Lower Maleh	-		Jo-lm		Aquifer	50 - 100

Figure 2.9: Hydrological Map of the Western Aquifers Basin (SUSMAQ, 2001)

Table 2.1: Lithology and hydrostratigraphy of the Western Aquifer Basin

	Age	Group		Formation	Lithology	Hydrostratigraphy
Tertiary	Eocene	*Avedat*	Jenin	Jenin	Chalk and Limestone	**Aquifer or aquitard by region**
	Paleocene	*Mt.Scopus*	Abu Dies	Abu Dies	Chalk and Chert	**Aquiclude**
Cretaceous	Senonian					
	Turonian	*Judea*	West Bank	Jerusalem	Limestone and Dolomite, karstic	Upper Aquifer
	Upper Cenomanian			Bethlehem	Dolomite, chalky	
	Lower Cenomanian			Hebron	Dolomite, karstic	
				Yatta	Marl at top, Clay at bottom, Limestone, Dolomite and Chalk in between	**Aquitard at top and/or bottom; sometimes aquifer in the middle**
	Upper Albian			Upper Beit Kahil	Dolomite interbedded with thin Marl; reefal Limestone at top	Lower Aquifer
				Lower Beit Kahil	Limestone and Dolomite, karstic	
	Lower Albian	*Kurnub*	Kobar	Qatana	Marl and nodular Limestone	**Aquiclude**
				Ein Qinya	Limestone and marly Limestone	**Aquitard - Aquifer**
	Aptian			Tammun	Shale and marl	**Aquiclude**
	Neocomian - Aptian			Ein Al-Assad Nabi Sa'id	Shale and Marl with Limestone intercalations	
			Kurnub	Ramali	Sandstone and sandy Limestone	Deep Aquifer

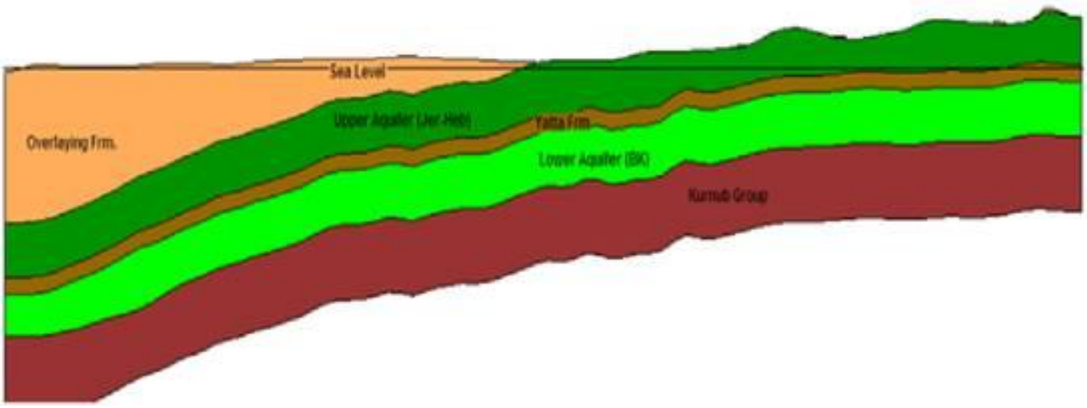


Figure 2.10: A hydrological cross section for study area (Abu Sa'da, 2001)

Chapter Three

Material and Methods

3.1 Background

The evaluations of the surface flow wastewater quality and infiltrated for Wadi Al Zomar were investigated. The physical, chemical and biological parameters were analyzed. Two sampling campaigns were carried out, during dry period and wet period to assess the variation in wastewater quality and pollution fluxed (loads) in base flow and in flood events. Soil and sediments samples were extracted from the bed of the wadi.

3.2 Selection of stations

The study area was visited several times to identify the locations of the wastewater sampling stations along the wadi. After review of the geological and topographical maps, the wadi is flowing above four types of geological formations as described previously. These formations are Jerusalem-Hebron, Abu Dis and Lisan and Nari formation. Four locations were identified to be the sampling stations, one station (St. 1) in Abu Dis formation, and two in Jerusalem-Hebron formation (St.2 and St.3) and one in Lisan-Nari formation (St.4). So the locations were identified depending on top soil type and wadi slope which covered the relatively steep and relatively flat section of the wadi and distance between stations, the St.2, St.3 and St.4 were identified in gently sloping section and St.1 in steeply sloping section. Figure 3.1 shows wadi Al Zomar and the samplings stations.

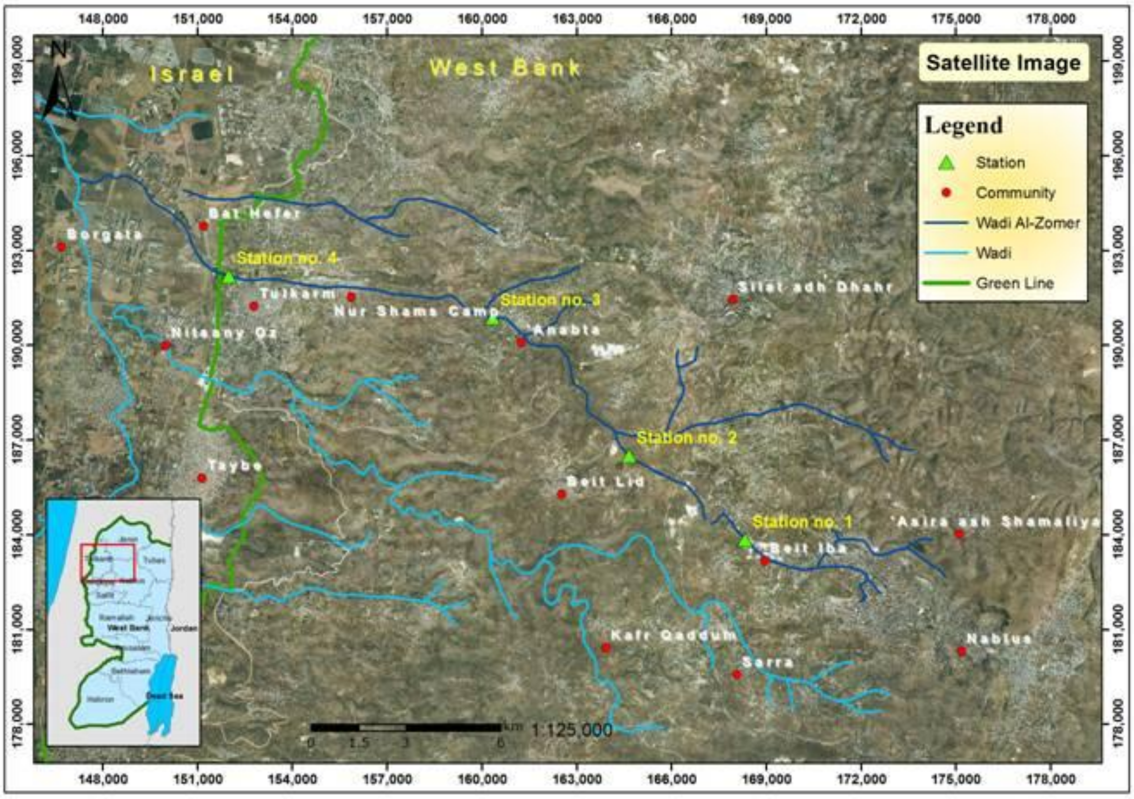


Figure 3.1: Arial photo for Wadi Al Zomer and wastewater sampling stations

Station No. 1: This location receives high quantity of sewage from Nablus City and Beit Iba Village as domestic sewage and industrial sewage from nearby factories especially stone cutting factories. The top soil in this station is Brown rendzinas and pale rendzinas. On the other hand, the slope of wadi is high and range from 2.0-2.5 %.

Station No. 2: This station is located near West Nablus Wastewater Treatment Plant. The reason for selecting this location is to evaluate the quality and quantity of wastewater in the wadi after 6 Km of flowing without any additional input sources of wastewater. The top soil in this station is Brown rendzinas and pale rendzinas.

Station No. 3: The additional source of domestic (from some houses) and agricultural sewage comes from Anabta village; in addition, the slope of the wastewater stream become more gently 0.9 -1.2 %. The top soil in this station is Brown rendzinas and pale rendzinas.

Station No. 4: This station was chosen to evaluate the stream quality and quantity before crossing green line at its final destination inside the West Bank, the top soil in this station is alluvial (gravel and silt material). Additional quantity of sewage from the houses nearby to the dispose directly in this section of the wadi was notice and also agriculture pollutant from adjacent farms.

Table 3.1: Locations of sampling stations, with elevations and coordinates along wadi Zomar

Station No.	Location	Distance from Nablus west outlet (Km)	Elevation (m) (above sea level)	Coordinate	
				N	E
1	Beit Iba	4.2	330	183180	168937
2	WW plant (Beit Lead)	7.9	233	186211	164826
3	Anabta	18.0	140	190911	159953
4	Green line	26.7	56	192250	152250

3.3 Wastewater Flow Measurements

The flow measurement was performed using current flow meter device (SIGMA 900 MAX Portable Sampler and Hach Sigma SD900 Portable Sampler). The basic principle of this method is that the flow in a channel (cubic meter/second) is equal to the average velocity (meter/second) times the cross sectional area (square meter) of the channel.

In most streams, where flows change slowly with time in comparison to flows in highway- and urban runoff-drainage systems, point velocities are measured in multiple vertical sections along a cross section of the stream channel by using of a velocity meter or current meter (Buchanan and Somers, 1969; Rantz, 1982a; Rantz, 1982b). The velocity in each vertical section is measured at a depth that theoretically, and field verified, represents the mean velocity in that section. If depth of the flow is sufficient, velocity is measured at two or more depths, the average representing mean velocity. Mean velocities are multiplied by the cross sectional area they represent, and are then summed to obtain the total flow, or discharge, at that stream cross section. Many velocity/area measurements are taken along the stream cross section to reduce the influences of irregularities in the stream channel and non-uniform distribution of velocities at the stream cross section on the total flow measurement (Peter *et al*, 1999).

The calculation mechanism of the flow quantity was based on two dimensions which are:

1. The position of wadi path and its dimensions.
2. The Flow Meter equipment that used to measure the speed of the flow of the wastewater during a specified period with specific dimensions.

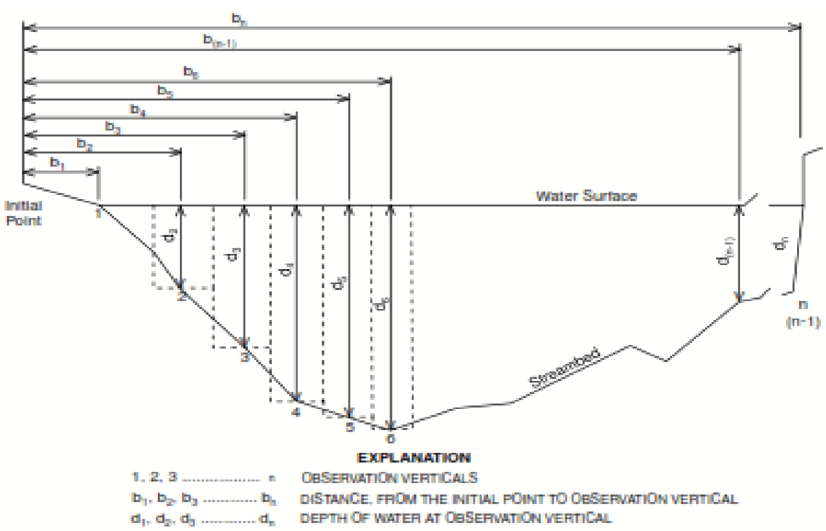


Figure 3.2: flow meter measurement procedures

The total flow was calculated using following equations:

$$n = P/t$$

Where n: number of propeller rotation per second, P: number of propeller rotation in the test, and t: 30 second, then determine the velocity (V m/s) from calibration tables of the SEBA mini current meter M1 device (German).

The discharge (Q m^3/s) was calculated using the following equation:

$$Q = V \times A$$

Where A: cross section area (The wadi section dimensions will measure while testing then the area will calculate using AutoCAD program).

Seven flow measurement events were performed (one in February, two in March, one in June and three in September 2012). These measurements were performed at the same days of collecting wastewater samples during the wet and dry sampling campaigns.

Table 3.2: The communities discharge in Al Zomar wadi, population and estimates of wastewater generated (Tal *et al*., 2007)

Name	Projected Population (2007)	Generated Wastewater (m^3/d)
Nablus Western Outlet	80000	5300
Deir Sharaf	2809	165
Beit Iba	3497	300
Tulkarem Camp	13738	1191
Nur Shams Camp	8028	696
Anabta	7990	437
Shewaiki	7878	469

3.4 Infiltrated Wastewater

3.4.1 Station setup

At the identifiable sampling and flow measurement stations along the wadi, infiltrated wastewater collection setups were installed. A backhoe (JCB) machine was used for digging holes below wadi bed that top soil is removed. Then a plastic tube was places at each station below the wadi bed. These tubes were open from both sides as shown in Figure 3.3. The top of the barrels were closed by tight covers and buried by a layer of soil with a thickness of 0.5 m. The natural soil levels at the bottom of the tubes have been drilled manually in concave shape to allow collecting of infiltrated wastewater samples.

Figure 3.3: Barrel installed in the hole adjacent to wadi Al Zomar

3.4.2 Infiltrated wastewater sampling

Sampling of infiltrated wastewater was performed during February to March 2012 for winter (wet) samples. Three sampling events were performed during wet period one day after rainfall event on 22/2/2012, 9 and 19/3/2012. Three samples were also taken during dry period on 11, 16 & 29/9/2012**.**

Chemical analysis at each station was performed for flowing wastewater and infiltrated wastewater. At each station, representative mixed samples were taken. The composite sample is compounded of wastewater which was collected every ten minutes (1L) for 3 hours. Chemical and biological analyses were carried out for these samples, the samples were filled in plastic bottles and placed in an ice box at (4°C) and delivered to the laboratory within 4 hours. Samples were immediately pre-treated (filtration) and stored in a refrigerator (-20°C) until analysis within two days.

The following physical parameters were measure in the field: water temperature, pH value, conductivity, total dissolved solid, dissolved oxygen and turbidity using Type YK-2005WA meter (Lutron electronics co.) and turbidity meter.

3.5 Surface flowing wastewater sampling and analysis

The wadi was sampled during two seasons in order to evaluate variations of wastewater quality under different flow conditions and to evaluate the degree of dilution in winter season as a result of rain runoff. Sampling was performed from February 2012 to March 2012 for winter (wet) samples; three sampling events were performed during wet period after one day of rainfall event on 22/2/2012, 9 and 19/3/2012. Another three sampling were performed during dry period on 11, 16 and 29/9/2012**.**

Chemical analysis at each station was performed for surface flowing wastewater and for infiltrated wastewater. At each station, representative mixed samples were taken.

Surface and infiltrated samples were collected every ten minutes over 3 hours to form a final composite sample of around 1 liter each. Chemical and biological analyses were carried out for these samples. The samples were filled in plastic bottles and placed in an ice box and transported to the laboratory within 4 hours. Samples were immediately pre-treated (filtration) and stored in a refrigerator (4°C) until analysis within two days according to APHA (1995).

The chemical analyses were conducted in Birzeit University Testing Laboratories. The methods used for the analysis are presented in the Table 3.4.

Physical measurements in the field: water temperature, pH value, conductivity, total dissolved solid, dissolved oxygen and turbidity were measured using Type YK-2005WA meter (Lutron electronics co.) and turbidity meter. The devices used in field measurement presented in the Table 3.3.

Table 3.3: Methods used and water quality parameters measured in the field

Parameter	Device Model	manufacture	Location of testing
Field Measurement			
pH value	Type YK-2005WA	Lutron electronics Enterprise co.	Field
Electrical conductivity			Field
Total dissolved solid			Field
Dissolved Oxygen			Field
Temperature			Field
Turbidity			Field

Table 3.4: Methods used and wastewater quality parameters measured in the laboratory

Parameter	Instrument used for analysis	Method of analysis	References

COD & BOD_5	Hach COD reactor DO meter- Oxi-197	5210-B 5220-D	APHA,19th ed.
Nitrate NO_3	UV 300/UV-visible spectrophotometer/UNICAM	4500-NO3	APHA,19th ed.
Ammonia NH_4	visible spectrophotometer/UNICAM		APHA,19th ed.
Phosphate PO_4	visible spectrophotometer/UNICAM		APHA,19th ed.
Fecal Coliforms (FC)		9221-E	APHA,19th ed.
Total Suspended Solids (TSS)			APHA,19th ed.
Volatile Solid VS			APHA,19th ed.
Heavy Metals	ICP OPTIMA 3000 Perkin Elemer		APHA,19th ed.

3.6 Field Infiltration Test

3.6.1 Introduction

The determination of infiltration downward entry of water into a soil (or sediment) is receiving increasing attention in hydrologic studies because of the need for more quantitative data on all phases of the hydrologic cycle. A measure of infiltration, the infiltration rate, is usually determined in the field or measuring water entry from cylinders (infiltrometer rings).

It is concluded that specific values of the infiltration rate for a particular type of sediment are probably nonexistent and that measured rates are primarily for comparative use.

3.6.2 Double Ring Infiltration

The infiltration rates for wadi bed were conducted using the Double ring infiltration method.

Four infiltration tests were performed on 1/5/2013 adjacent to stations locations by using the double ring method. A detailed description of the double-ring infiltrometer test method is provided in ASTM standard D3385-94. This test method is particularly applicable to relatively uniform fine-grained soils, with an absence of very plastic (fat) clays and gravel-size particles and with moderate to low resistance to ring penetration. The measurement is taken in the inner cylinder; the outer cylinder is used only as a tool to ensure that water from the inner cylinder will flow downwards and not laterally.

The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water, and maintaining the liquid at constant level. The volume of water added to the inner ring, to maintain the water level constant is the measure of the volume of water that infiltrates the soil. The volume infiltrated during timed intervals is converted to an incremental infiltration velocity, usually cm/hour and plotted versus elapsed time. The maximum steady-state or average incremental infiltration velocity, depending on the purpose/application of the test is equivalent to the infiltration rate.

Figure 3.4: Infiltration test using double ring method

3.7 Analysis of Field Data

The volume of water used during each measured time interval is converted into an incremental infiltration velocity for both the inner ring and annular space using the following equations:

For the inner ring, calculate as follows:

$$V_{IR}=\Delta V_{IR}/ (A_{IR}.\Delta t)$$

Where:

V_{IR} = inner ring incremental infiltration velocity (cm/hr)

ΔV_{IR} = volume of water used during time interval to maintain constant head in the inner ring (ml);

A_{IR} = internal area of inner ring (cm^2), and

Δt = time interval (hour)

3.8 Soil sampling and analysis

3.8.1 Soil sampling for physical analysis

The drilling was carried out on 10/10/2011 using a mobile rig (B-31) by applying rotary drilling and auto percussion method in selected stations; four boreholes were drilled along the wadi up to a depth between 2.5-3.5 m. The locations and the depths of the boreholes are shown in Table 3.5.

Table 3.5: Location and the depth of drilled boreholes

	Distance from Nablus outlet (Km)	coordinate	Elevation (asl)	Soil depth (m)*
Station No.1	4.2	168937 E 183180 N	335	3.0
Station No.2	9.6	164826 E 186211 N	247	2.3
Station No.3	18.0	159953 E 190911 N	133	2.5
Station No.4	27.6	152054 E 192250 N	56	3.5

Figure 3.5: Borehole drilling closed to Wadi Al Zomar using mobile rig machine

After carrying out the visual description on the obtained samples, a laboratory tests program was issued in the Geotechnical and Material Testing Center. This program contained the required tests on selected samples in order to determine the physical properties of the wadi bed materials. The used standards and specifications of the American Society for Testing and Materials (ASTM) are presented in Table 3.6.

Table 3.6: Soil properties tests and specifications

	Soil Properties	**Specification**
Physical Prosperities	Classification USCS method	ASTM D 2487-93
	Particle size analysis	ASTM D 422-90
	Hydrometer Test	Soil mechanics lab. Manual-Das
	Atterberg limits	ASTM D 4318-95
	Moisture content	ASTM D 2216-92
	Wet density	Block samples & sampling tubes
	Specific gravity	ASTM D 854-92

- **Soil classification**

The most common engineering classification system for soils is the Unified Soil Classification System (USCS). The USCS has three major classification groups: (1) coarse-grained soils (e.g. sands and gravels); (2) fine-grained soils (e.g. silts and clays); and (3) highly organic soils (referred to as "peat"). The USCS further subdivides the three major soil classes for clarification.

The classification based on sieve analysis results and Liquid limits and Plastic Limits value, which the soil classification determine by using USCS chart.

- **Atterberg limits**

The Atterberg limits are a basic measure of the nature of a fine – grained soil, depending on the water content of the soil; it may appear in four states: solid, semi-solid, plastic and liquid. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays.

The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic states of consistency. The moisture content at this boundary is arbitrarily defined as the water content at which two halves of a soil cake will flow together, for a distance of ½ in. (12.7 mm) along the bottom of a groove of standard dimensions separating the two halves, when the cup of a standard liquid limit apparatus is dropped 25 times from a height of 0.3937 in. (10 mm) at the rate of two drops/second.

The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a thread ⅛ inch (3 mm) in diameter using a ground glass plate or other acceptable surface.

The plasticity index of a soil is the numerical difference between its liquid limit and its plastic limit, and is a dimensionless number. Both the liquid and plastic limits are moisture contents.

- **Hydrometer test**

A hydrometer analysis is the process by which fine-grained soils, silts and clays, are graded. Hydrometer analysis is performed if the grain sizes are too small for sieve analysis. The basis for this test is Stoke's Law for falling spheres in a viscous fluid in which the terminal velocity of fall depends on the grain diameter and the densities of the grain in suspension and of the fluid. The grain diameter thus can be calculated from knowledge of the distance and time of fall. The hydrometer also determines the specific gravity (or density) of the suspension, and this enables the percentage of particles of a certain equivalent particle diameter to be calculated.

3.8.2 Sediment samples for chemical analysis

Bed material sediment samples were collected in March, 2013 for the assessment of the environment quality of the sediment in Wadi Al Zomar. The sediments were collected manually using a plastic Petri dish and stored in thermally isolated cases with ice until they reached the lab. The sediment samples were collected from station locations. At each station, two sediment samples were collected 10 m apart to take into account the variability at each site. Each sample included a cluster of three sampling points with a two to three meter distance between them to account for spatial representation of sediment composition. The sediments were collected from the upper layer only (3-5 cm) below top surface.

The analysis of total solids, volatile solids and heavy metals were carried out at the Birzeit University Testing Laboratories. The analyses were carried out according to SIMe method for total and volatile solids and using ICP method for heavy metals.

3.9 Water Balance

The total quantity of wastewater that percolated into groundwater from wadi bed, were calculated based on the following equation:

$$S = Q1 - Q2 - EP - ETP$$

Where S: Infiltration quantity (m^3/d)

Q1, Q2: Water discharge at station 1 and 2, respectively (m^3/d)

EP: Evaporation (mm/d)

EPT: Evapotranspiration

3.10 Infiltration quantity calculation based on infiltrated rate

For the estimation of losses or gains in the wadi, a water balance approach was used. Several assumptions were made accordingly: since there are additions of water along the stream those changes the water balance. Water loss is caused by three main processes: infiltration into the ground, evaporation and evapotranspiration.

Evapotranspiration can be a major source of water depletion from riparian channels in arid and semiarid climates, yet it is very difficult to estimate over large areas (Goodrich *et al.*, 2000; Dahm *et al*., 2002). The rate of evapotranspiration depends on many factors including plant species, stage of growth, leaf area, and plant density (Makenzie and Craig, 2000) and can vary seasonally with surface water availability and depth to groundwater (Snyder and Williams, 2000). Transpiration from groundwater and unsaturated soil layers by riparian vegetation may depend on the interaction between site conditions and species assemblage (Snyder and Williams, 2000). Hence, the complexity and difficulty in evaluating evapotranspiration involves large uncertainties and imprecision (Goodrich *et al*., 2000).

The quantity of infiltration can be calculated by using infiltration rate that results from double ring infiltration tests were performed adjacent to stations, the infiltration rate multiply by area of wadi section, the wet perimeter of the wadi are measured and the average value will be considered in area calculations

$$Q = R_{inf.} * A$$

Q: Quantity of infiltration (m^3/d)

R_{inf}: Rate of infiltration (m/day) (from Double ring infiltration test)

A: Cross section area (m^2)

3.11 Fluxes loads estimation

Chemical mass balance was used to evaluate pollution fluxes lost or added to the system, by calculating the difference in fluxes between sites.

To determine the pollutants fluxes during dry and wet season, data from flow measurements and grab sampling in dry and wet seasons were used in the following formula:

$$FB = \sum Qt * Ct$$

Where FB - Integration pollutant flux in base flow (kg/day), Qt - Water discharge (m^3/sec)

Ct - Pollutant concentration in the water sample (mg/l)

Chapter Four

Results and Discussion

4.1 Soil Properties of Wadi Bed

The soil samples were performed along wadi Al Zomar, these samples were taken from wadi bed to determine the properties for soil of wadi bed. Composite samples were taken from each measuring station and laboratory tests were issued, these tests contained the required tests in order to determine the physical prosperities of soil beds The tests that were performed in GMT laboratory are Particles size analysis, Atterberg limits and Hydrometer test and moisture content. The results of testing are show in Tables 4.1 and 4.2.

Table 4.1: Soil samples location and soil description

Station No.	Distance from Nablus outlet (Km)	coordinate	Elevation (asl)	Soil depth (m)*	Soil Description
1	4.2	168937 E 183180 N	335	3.0	0.0-3.0m Wadi Material
2	9.6	164826 E 186211 N	247	2.3	0.0-1.3m Stiff dark brownish clay loamy material 1.3-2.3m Wadi material
3	18.0	159953 E 190911 N	133	2.5	0.0-1.0m Fine fill material (sediment) 1.0-2.0m brownish clayey loamy material 2.0-2.5m cobbles of limestone with clayey material
4	27.6	152054 E 192250 N	56	3.5	0.0-3.0m Wadi material – Cobbles of flint and limestone with light reddish sandy loam material

Table 4.2: Soil classification according USCS method and moisture content, particles size and Atterberg limits for soil samples extracted from wadi bed from stations along Wadi Al Zomar

Station No.	Distance (Km)	Moisture content (%)	Particles size				Atterberg Limits			Soil classification according USCS method
			Gravel %	Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plastic Index	
1	4.2	15	4	36	29	27	41	30	11	Clay loam
2	9.6	14	4	25	30	41	42	19	23	Clay
3	18.0	26	27	12	41	20	37	25	12	Loam
4	27.6	17	37	44	9	10	38	21	17	Sandy loam

4.2 Wadi Bed Infiltration Characteristics

The field infiltration tests were performed on 1/5/2013 adjacent to the all four measuring stations by using double ring method. One test was conducted for each station. The results of infiltration rate are shown in Table 4.3.

Station no.1 has the highest infiltration rate (0.102 cm/min) and St.3 with lowest value (0.023 cm/min). These results indicated that the infiltration of wastewater from wadi bed in the section between St.01 and St.02 is more than the infiltration from the remaining sections from St.2 to St.04.

Table 4.3: Field infiltration rates of wadi Al Zomar bed

Station No.	Infiltration rate cm/min	Hydraulic Conductivity
1	0.102	$1.43*10^{-4}$
2	0.098	$1.40*10^{-5}$
3	0.023	$2.20*10^{-6}$
4	0.053	$4.80*10^{-6}$

4.3 Wastewater Flow Measurements in Wadi Al Zomar

There are many wastewater sources that discharge sewage into the streams. The main source is western part of Nablus City, Beit Iba, Deir sharaf, part of Anabta, and Shweika village.

These sources of sewage are the main water sources that feed the wadi during dry periods. Figure 4.1 shows the average flow rate at the four monitoring and sampling stations along the wadi in dry season and in wet season.

The diurnal flow variation was considered in the calculations of flow quantity. The variation in diurnal flow was calculated by using the flow data recorded by Anabta station on August 30. 2006 (Source: PWA, Summer Period Data). The variation percent between our measurement and average diurnal variation is 27 %. The average flow in wet and dry seasons is shown in Figure 4.2.

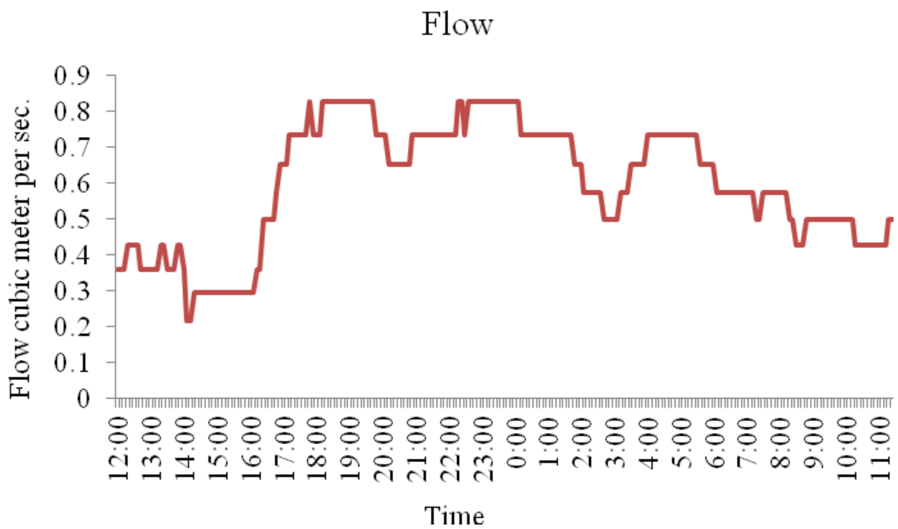


Figure 4.1: The variation in diurnal flow was calculated by using the flow data from Anabta station August 30. 2006 (Source PWA, 2006)

4.4 Wastewater quality for Wadi Al Zomar

According to the samples collected from the stations the wastewater characteristics (surface flow and infiltrated) from Wadi Al Zomer in term of physical and chemical parameters are tabulated in Table 4.4 and 4.5. Figure 4.2 show the flow quantity in wet and dry season in monitoring stations

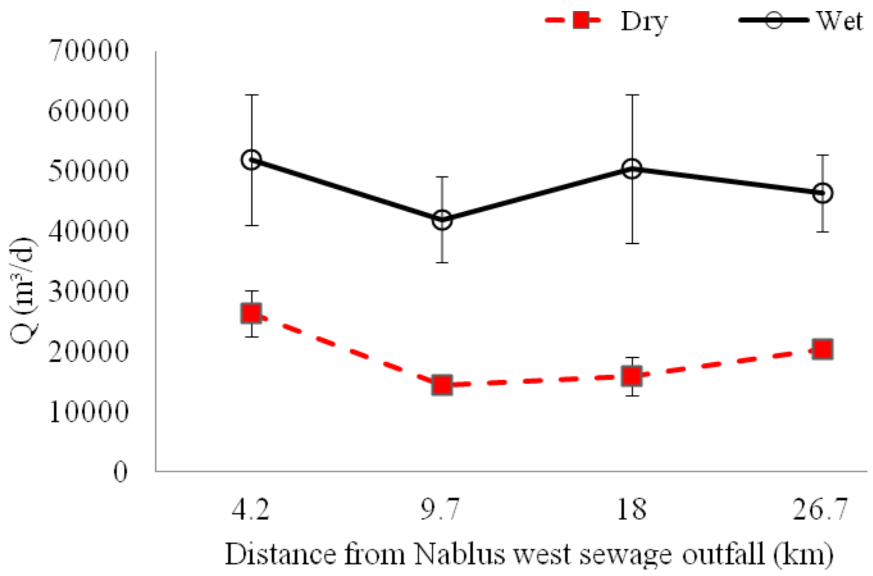


Figure 4.2: Average flow discharge in wet and dry seasons of wadi Zomar/Palestine

4.4.1 Physical Parameters

Result of wastewater quality parameter analyses (DO, TSS, TDS, pH, EC, Temp. and Turbidity) for four selected sampling station from the study catchment area are shown in Tables 4.4 and 4.5.

Table 4.4: Average values of physical parameters of surface and infiltrated wastewater samples in wadi Zomar during dry season

Station No.	St.1	St.2	St.3	St.4
Location Name	Nablus	Ramine	Anabta	Tulkarem

Distance from Nablus outfall (Km)	4.2		9.6		18.0		26.7	
	Surface	infiltrated	Surface	infiltrated	surface	Infiltrated	surface	Infiltrated
Temp.	27.9 (1.62)	27(0.81)	27.6(1.30)	N.I	27.3(1.23)	N.I	27.60(1.04)	28.0(1.79)
pH	7.47 (0.24)	7.34(0.30)	7.71(0.23)	N.I	7.54(0.21)	6.79(0.19)	7.90(0.30)	7.70(0.21)
TSS	2735(776)	2012(365)	1035(203)	N.I	1743(715)	2956(589)	1577(574)	8687(207)
VSS	1049(470)	830(246)	474(308)	N.I	570(201)	1544(815)	542(14)	407(268)
VSS/TSS	0.37(0.09)	0.37(0.09)	0.41(0.20)	N.I	0.43(0.16)	0.45(0.03)	0.35(0.09)	0.29(0.16)
EC	2.943(1.03)	2.497(0.12)	1.633(0.43)	N.I	1.69(0.42)	2.30(0.05)	2.02(0.63)	2.072(0.11)
TDS	1615(488)	1663(91)	1244(279)	N.I	1121(28)	1638(116)	1351(436)	1374(68)
Turbidity	877(448)	110(87)	860(76)	N.I	747(39)	720(359)	1067(86)	615(454)
DO	0.40(0.12)	1.70(0.57)	2.50(0.14)	N.I	0.30(0.10)	1.30(0.57)	0.50(0.20)	2.50(0.31)

The numbers of samples are 5 for all parameters except TSS are 3 samples;
The numbers of samples are 3
N.I: No water was infiltrated;
Unit for Temperature (°C) - TSS, VSS, TDS and DO (mg/l) – EC (µs/m) – Turbidity (NTU);
Standard deviations are presented between brackets.

Table 4.5: Average values of physical parameters of surface and infiltrated wastewater samples in wadi Zomar during wet season

Station	St.1		St.2		St.3		St.4	
Location	**Nablus**		**Ramine**		**Anabta**		**Tulkarem**	
Distance from Nablus west outfall (Km)	**4.2**		**9.6**		**18.0**		**26.7**	
	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated
Temp.	15.4(1.61)	18.1(1.76)	17.7(4.08)	N.I	16.0(3.58)	16.8(4.29)	16.5(4.24)	15.5(1.41)
PH	7.87(0.06)	6.98(0.22)	7.89(0.22)	N.I	7.8(4.2)	6.83(0.1)	8.23(0.22)	7.41(0.29)
TSS	1464(698)	400(100)	673(444)	N.I	716(230)	745(73)	823(227)	663(222)
VSS	N.M	N.M	N.M	N.I	N.M	N.M	N.M	N.M
VSS/TSS	N.M	N.M	N.M	N.I	N.M	N.M	N.M	N.M
EC	1.92 (0.74)	0.71 (0.35)	1.47 (0.38)	N.I	1.21(0.49)	1. 45(0.51)	1.18(0.62)	1.04(0.23)
TDS	1055(499)	410(250)	734(603)	N.I	809(320)	782(337)	778(375)	699(297)
Turbidity	327(117)	69(4)	314(334)	N.I	160(116)	78(29)	122(71)	39(21)
DO	3.76(1.53)	3.0(1.65)	5.68(3.21)	N.I	6.02(2.40)	1.7(2.70	5.12(3.55)	3.0(2.82)

The numbers of samples are 3
N.I: No water was infiltrated;
Unit for Temperature (°C) - TSS, VSS, TDS and DO (mg/l) – EC (µs/m) – Turbidity (NTU);
Standard deviations are presented between brackets

4.4.2 Chemicals Parameters

Result of wastewater quality parameter analyses (BOD, COD, NH^+_4 –N, NO_3^- –N, PO_4 and Fecal coliforms) for four selected sampling station from the study catchment area are shown in Tables 4.6 and 4.7.

Table 4.6: Average values of chemical parameters of surface and infiltrated wastewater samples in wadi Zomar during dry season

Station No.	**St.1**		**St.2**		**St.3**		**St.4**	
Location Name	**Nablus**		**Ramine**		**Anabta**		**Tulkarem**	
Distance from Nablus west	**4.2**		**9.6**		**18.0**		**26.7**	
	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated
BOD	186(62)	73(51)	160(51)	N.I	149(53)	67(5)	217(83)	149(44)
COD	514(21)	304(62)	263.0(22)	N.I	329(54)	213(86)	350(22)	173(53)
COD/BOD	2.8	4.1	1.6	N.I	2.2	3.1	1.6	1.2
NH^+_4 –N	76.1(18)	55(4)	63.8(18)	N.I	50.3(2)	68.0(3)	74.1(11)	67.3(15)
NO_3^- –N	BDL	33.3(36)	0.70(1.2)	N.I	BDL	19.65(18)	BDL	14.3(13)
PO_4	4.14(1.06)	4.24±0.40	3.29(1.25)	N.I	2.49(0.36)	3.50(0.57)	3.64(1.46)	1.60(0.44)
FC	1.32E+06	5.66E+03	7.36E+05	N.I	2.08E+05	2.65E+04	6.72E+05	2.13E+04
Zn	0.42(0.45)	0.11(0.02)	0.09(0.01)	N.I	0.10(0.04)	0.05 (0.04)	0.08(0.04)	0.07 (0.05)
Fe	1.24(1.45)	0.65(0.51)	0.13(0.04)	N.I	0.28 (0.30)	0.12 (0.06)	0.11(.04)	0.05 (0.07)
Mn	0.12(0.04)	0.43(0.20)	0.24 (0.32)	N.I	0.05 (0.03)	0.45(0.19)	0.04 (0.01)	0.29 (0.17)

The numbers of samples are 3
N.I: No water was infiltrated;
Unit for COD, BOD, NH^+_4 – NO_3^- –N and Heavy metals (mg/l)– FC (cfu/100ml);
Standard deviations are presented between brackets

Table 4.7: Average values of chemical parameters of surface and infiltrated wastewater samples in wadi Zomar during wet season

Station No.	**St.1**		**St.2**		**St.3**		**St.4**	
Location Name	**Nablus**		**Ramine**		**Anabta**		**Tulkarem**	
Distance from Nablus west outfall (Km)	**4.2**		**9.6**		**18.0**		**26.7**	
	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated	Surface	Infiltrated
BOD	288(43)	33(1)	192(22)	N.I	88(58)	61(42)	110(67)	20(1)
COD	509(69)	80.2(8)	439(145)	N.I	241.7(29)	181(25)	246(35)	157(42)
COD/BOD	1.8	2.4	2.9	N.I	2.7	2.0	2.2	7.9
NH^+_4–N	50(20)	9(2.5)	27(13.9)	N.I	27(10.9)	24(15.5)	33(9.8)	16(6.6)
NO_3^- –N	1.04(1.8)	0.81(1.4)	5.57(7.9)	N.I	4.37(6.2)	2.62(4.5)	2.61(4.5)	4.4(4.4)
PO_4	3.43 (0.8)	1.70(0.3)	3.23(1.9)	N.I	1.63(0.4)	4.93(0.4)	1.77(0.5)	2.60(1.8)
FC	2.212E+06	9.533E+03	3.483E+06	N.I	8.217E+05	1.750E+05	3.367E+05	7.167E+03
Zn	0.1(0.09)	0.08(0.05)	0.13(0.08)	N.I	0.08(0.07)	0.10(0.05)	0.06(0.02)	0.06(0.02)

Fe	0.23 (0.13)	0.08(0.040)	0.02(0.1)	N.I	0.021(0.09)	0.34(0.36)	0.18(0.17)	0.11 (0.07)
Mn	0.07(0.022)	0.13(0.040)	0.09 (0.03)	N.I	0.10(0.06)	0.31(0.09)	0.05(0.04)	0.23(0.05)

The numbers of samples are 3
N.I: No water was infiltrated;
Unit for COD, BOD, NH^{+}_{4} – NO_3^- –N and Heavy metals (mg/l) – FC (cfu/100ml);
Standard deviations are presented between brackets

4.5 Self Purification in Wadi Al Zomar Stream

The flow in Al Zomar Stream is primary of raw sewage discharge from western part of Nablus City. There is additional point sewage sources mainly from Anabta Village and from communities surrounded the stream in Tulkarem City. These additional resources led to the fluctuation in the quality of wastewater, making it difficult to assess the process of self-purification of the stream.

The self purification process naturally occurs in the flow water. This process depends on factors that effect on degree of purifying of water such as dilution, temperature, sunlight, flow velocity and rate of oxidation.

For evaluation of self purification processes that take place in Wadi Al Zomar, the average concentration for each tested parameter will be discussed in the following paragraphs.

pH Values

The dry season results show variation in average pH value along the wadi. At stations 1 and 3 the pH values 7.47 and 7.54, respectively. While at stations 2 and 4 the results show higher pH values 7.71 and 7.9, respectively.

In the wet season the results are approximately similar with no significant variation of pH values that were in the range of (7.71-7.85). The variation percentage between the highest value and the lowest value in dry and wet seasons were 5.7% and 1.8%, respectively.

Figure 4.3 shows the highest value in ST.4 in both dry and wet season, the result indicates to introduce to waste from factory of cutting stone.

Dissolved Oxygen

The DO concentrations in dry season were in the range of 0.3-2.5 mg/l, and in wet season in the range of 3.6-6.0 mg/l. The oxygen profile in the wet season differs from that in the dry season, showing a peak at ST.2 and declined at further stations. The results showed a decrease in dissolved oxygen when the effluent contained a higher organic load, that might be as a result of oxygen consuming processes, bacteria carbon oxidation and nitrification (Suliman, 2010). On the other hand, the DO varied with temperature and altitude, cold water hold more oxygen than warm water (Bartram and Rees, 2000; Schuze *et al.*, 2001).

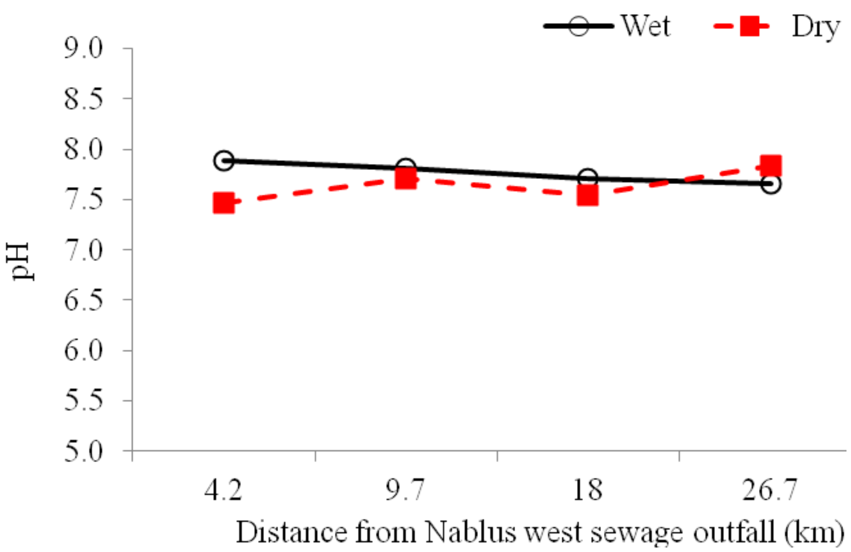


Figure 4.3: pH value for dry samples and wet samples for wadi Zomar-Palestine

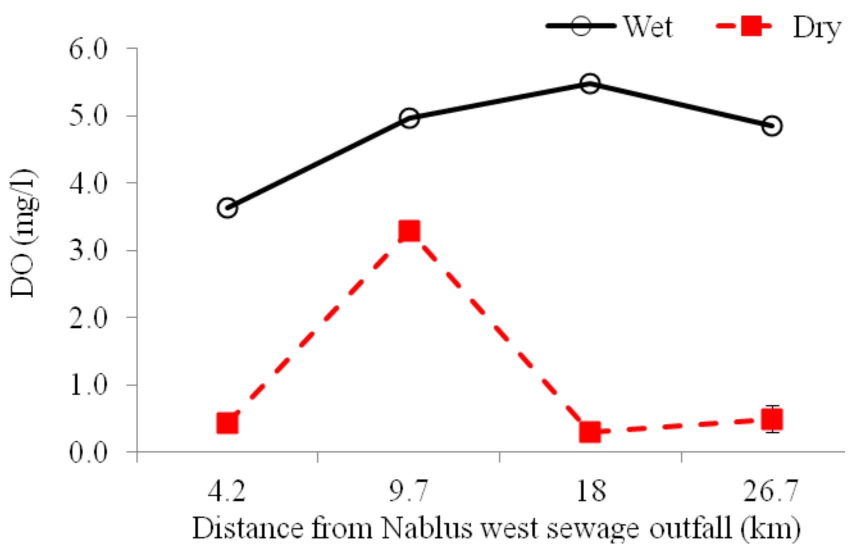


Figure 4.4: Dissolved Oxygen concentrations for dry and wet samples for wadi Zomar-Palestine

COD and BOD

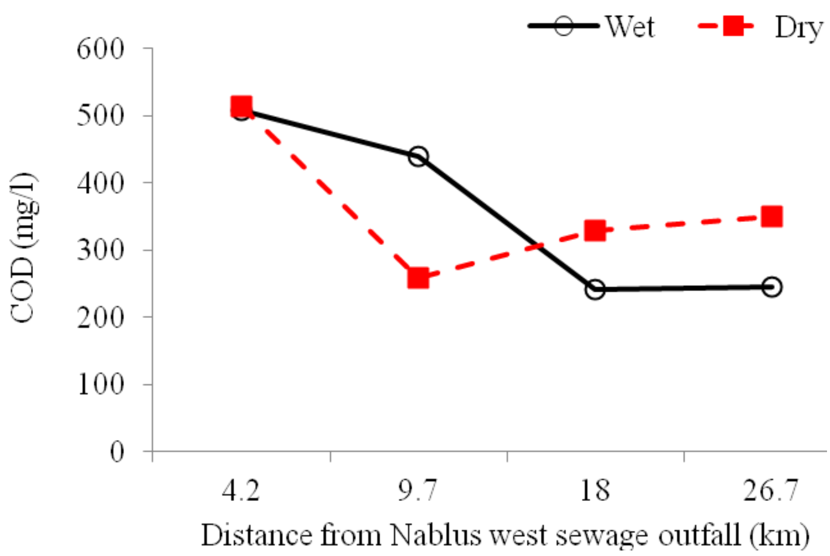
The average COD concentration at ST.1 (upstream) in dry season was 513 mg/l decreased as the water reach ST.2 by 50% (260 mg/l), then a slightly increases were occurred in ST.3 and ST.4 (last station) 329 mg/l and 350 mg/l, respectively. These increases in most likely due to direct sewage discharge from some houses surrounding the wadi from Anabta village (ST.3) and Tulkarem city (ST.4). The percentage decrease of COD was 50% from ST.1 to ST.2 but this reduction decreased through ST.3 and ST.4 to be 36% between ST.1 to ST.4 due to slightly increase in COD concentrations in last stations.

In wet season the results showed continuous reduction in COD concentrations while moving downstream, the average concentration at ST.1 was 509 mg/l and at ST.4 was 240 mg/l, the percentage decrease of COD in wet season were 53%.

For BOD concentrations the results showed that in dry season the concentration at ST.1 was 186 mg/l decreased up to ST.3 by 14% and then increase again in downstream ST.4 (217 mg/l). In wet season the BOD concentration was 288 mg/l decreased in ST.2 to value 192 mg/l and then decrease by 48% (88 mg/l) at ST.3 but the BOD concentration return to increase at downstream to value of 110 mg/l.

The self-purification process of the stream was observed. This purification results from biodegradation of pollutant while moving downstream. BOD and COD values showed a reduction in organic matter concentrations.

The results showed a dilution effect of pollutants concentration in wet season samples in comparison with dry season samples. The degree of reduction or dilution in the values range 20-50% in BOD and COD values, respectively.



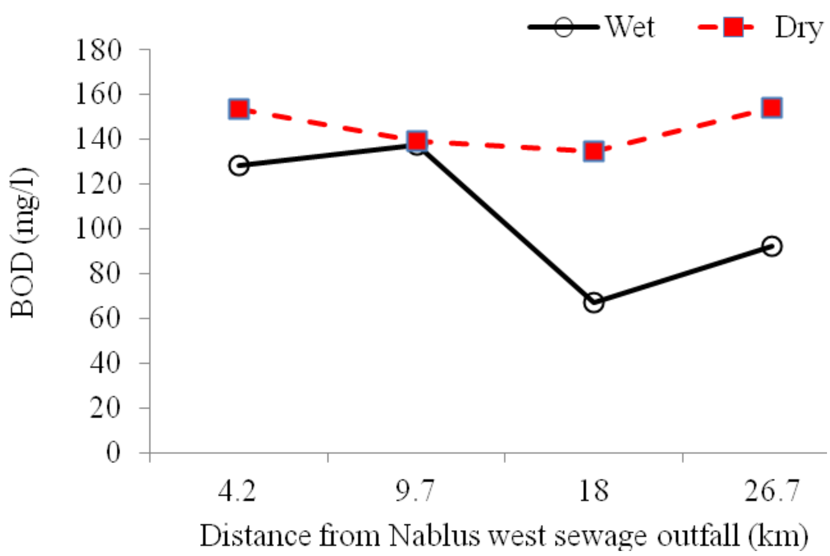


Figure 4.5: COD and BOD concentrations along wadi Al Zomar in dry and wet samples

Ammonia (NH_4-N)

The range of NH_4-N in the stream was 50.3-76.1 mg/l in dry season and 27.0-50.0 mg/l in wet season, where the highest values were during both seasons at ST.1 and the lowest values were at ST.03. That indicates the dilution effects and the rate of dilution was (29-53) %.

In dry season the average ammonia concentration at ST.1 was 74 mg/l and decreased downstream to 50 mg/l at ST.3 and then increase to 74 mg /l at ST.4 due to additional wastewater input from houses surrounding the wadi in Tulkarem City. The rate of self purification of NH_4-N in stream from ST.1 to ST.3 (18 Km) was 34 %.

In wet season the NH_4 reduction was 37 % from upstream to downstream in spite of slight increase from ST.3 to ST.4. The reduction from ST.1 to ST.3 was 48%. The dilutions effect in wet season varies from 34% at ST.1 to 63% at ST.2.

The dilution effects and self purification process are clear notice in NH_4-N, through the decreasing values at the measuring stations along the stream. These decreases in ammonia concentrations from upstream toward downstream are due to ammonia oxidation.

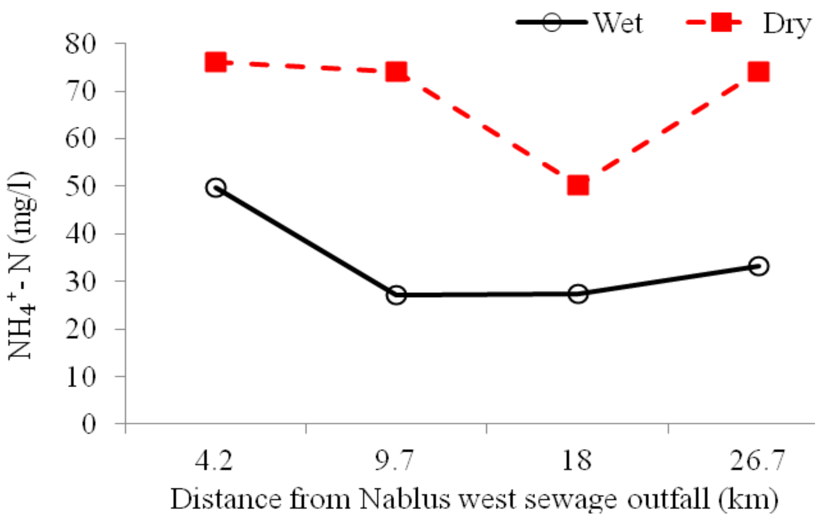


Figure 4.6: NH_4-N concentrations in surface wet and dry samples for wadi Zomar-Palestine

Nitrate (NO_3 -N)

The results of NO_3 -N showed limited in nitrification process in dry season, as the nitrate was detected just at ST.2 (9.7 Km). Which means that with the increase of dissolved oxygen, the process partially began as in case of ST.2 with NO_3-N concentration is 0.16 mg/l, in same time no nitrate detected in the remain stations. This case might be as a result of oxygen depletion (0.3-0.5 mg/l). On the other hand, there is a negative correlation with TSS value measured during the two seasons. The results suggest that high sediment concentration also delay the nitrification process.

In wet season the NO_3 -N detected at all stations along the wadi, which indicated nitrification process especially with the increased DO concentration in comparison with dry season. The nitrates were in the range 0.23-1.26 mg/l. The other sources of nitrate might be from runoff water in wet season that carry the nitrate from adjacent agricultural land.

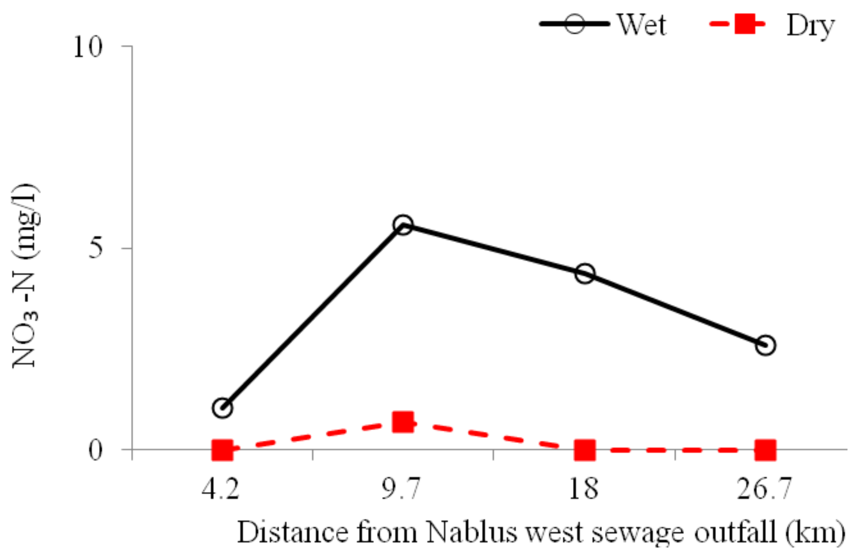


Figure 4.7: NO_3-N concentrations in surface wet and dry samples for wadi Zomar-Palestine

Orthophosphate (PO_4)

The PO_4 results showed self purification in the stream (Figure 4.7). In both seasons the highest concentration was found at upstream ST.1 with values in the range of 4.1-3.4 mg/l that gradually decreased with flow toward downstream, reaching at (ST.4) 3.6-1.8 mg/l. The decreasing percentage was in the range of (39-52) %. On the other hand, there was a positive correlation between PO_4 and flow velocity in both seasons, which means when the velocity of flow increase the phosphate concentration increase. This increase that indicate that the clay content in the sediment play a vital role in absorbing and temporary storage and release of the phosphorous in the stream (Haggards, 2004). The dilution effect was clear noticed, the rate of dilution was in the range of (17-51) %.

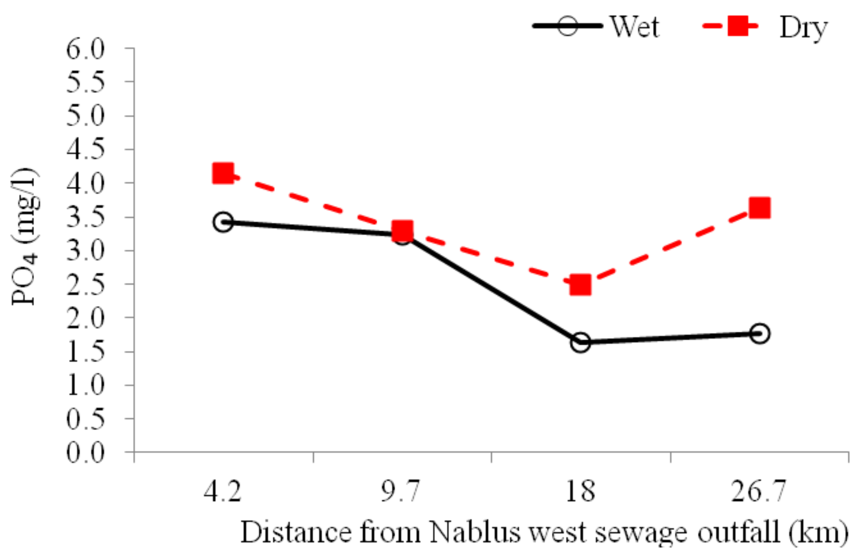


Figure 4.8: Ortho Phosphate concentrations in surface samples for both wet and dry samples for wadi Zomar-Palestine

Fecal Coliforms

The average concentration of Fecal coliforms at ST.1 (4.2 km) was ($1.317*10^6$ cfu/100ml) in dry season. The concentration of fecal coliforms decreased between ST. 1 and ST.3 through ST.2 by approximately 84%, then the concentration increased with flow direction at ST.4 by approximately 2 fold from ST.3 to ST.4 due to the introduced new sources of pollutants from Tulkarem City.

In wet season, the FC was increased in comparison with dry season at all stations except ST.4. The concentrations of FC were $(2.212, 3.483, 0.822 \& 0.337)*10^6$ cfu/100ml at ST.1, ST.2, ST.3 and ST.4 respectively. In wet season the fecal coliforms increased between ST.1 and ST.2 by 57 % and deceased between ST.2 and ST.4 by 90%. The increase at ST.2 might be due to possible contamination from non point sources. The results showed that the self purification in wadi was clear between upstream and downstream.

Sedimentation plays an important role in the decrease of FC in the mainly straight, wide, silt and slowly flowed and this complying with Heidenwag *et al*, (2001) conclusion. On the other hand, the fecal coliforms showed a positive correlation with velocity flow which indicate high load of fecal coliforms in discharge wastewater and the increase of stream velocity may be attributed to carry settled fecal coliforms from sediments. There was an inverse correlation between high fecal coliforms concentrations and increased discharge.

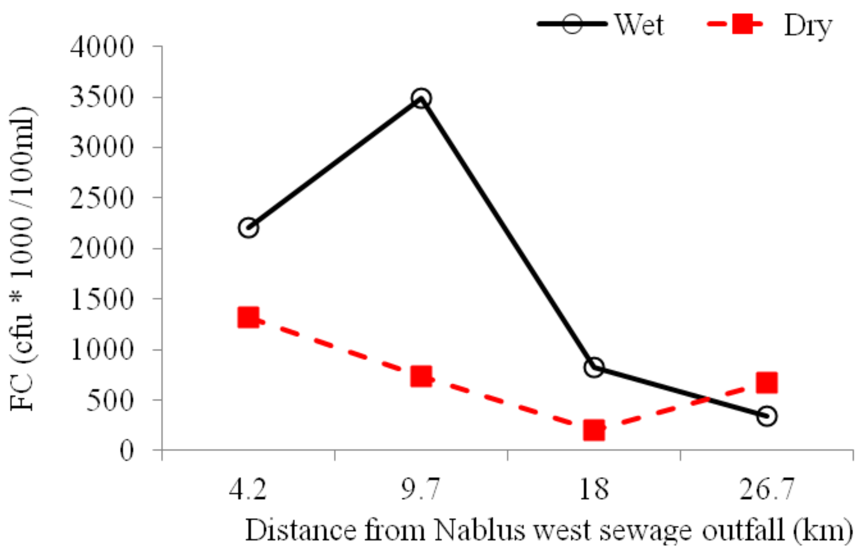


Figure 4.9: Fecal coliform in wet and dry season for wadi Zomar-Palestine

In summary, self purification had been clearly shown along the wadi. The degree of purification varied between dry and wet season due to temperatures variation and dilution effects. The results of this study have shown that there are considerable differences in degree of purification between a parameter and others.

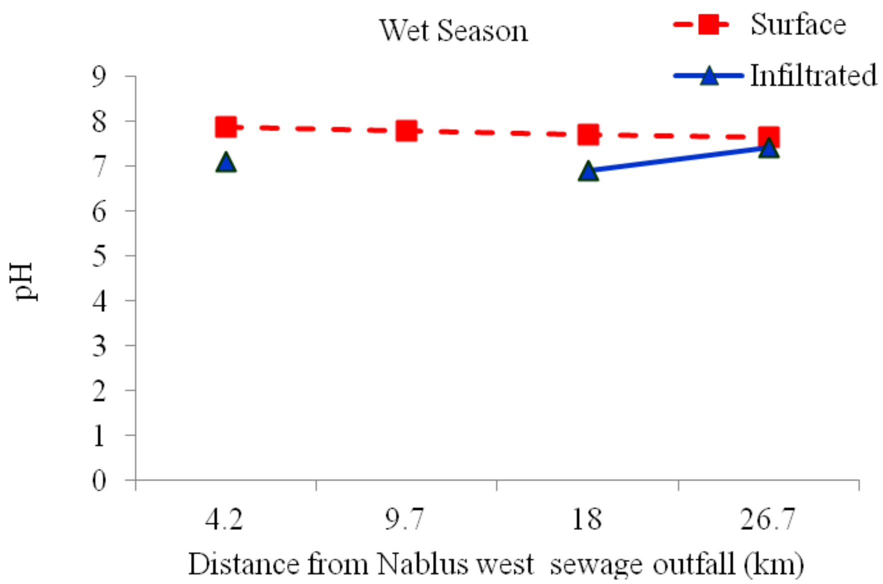
The ability of the wadi to absorb pollution that originates from sewage outfalls is affected by many factors including flow rate, time, temperature, presence of micro organisms and plants, pH and the dissolved oxygen content of the water. The natural self-purification process consists of various complex phenomena involving the interactions of numerous physical, chemical and biological factors (Vagnetti *et al*., 2003). Each watercourse has its individual self-purification capacity (Clarence, 1970).

The nature of the contaminants also plays an important role in the river's recovery capacity.

4.6 Quality of Infiltrated Wastewater through Wadi Beds

4.6.1 pH Values

The pH values of infiltrated water were reduced from values range of (7.47-7.90) to values range of (6.79-7.70) in dry season and reduced from values of (7.71-7.85) to range values of (6.92-7.41) in the wet season. The percentage of decrease varied from 3% to 10%. The pH decreases in most likely due to soil microbial activity that produces CO_2 and organic acids. On the other hand, the pH decreases connect with increase in nitrate concentration that indicates the nitrification process in subsurface zone.



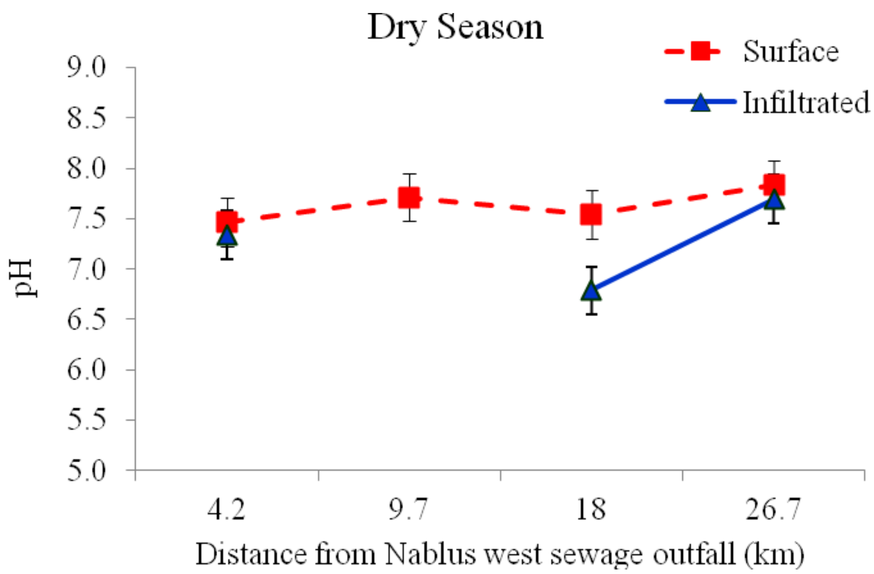


Figure 4.10: pH value in surface and infiltrated samples in wet and dry seasons for wadi Zomar-Palestine

4.6.2 Dissolved Oxygen

The concentrations of dissolved oxygen (DO) measured in infiltrated samples in dry season were low, in the range of (1.3-2.5) mg/l. These low concentrations may be due to nitrification process, the value of NO_3-N in the range of (14-33) mg/l in dry season and (0.8-5.57) mg/l in wet season. In wet season the concentration of DO range (3.2-4.8) mg/l. The concentrations of DO were decreased in infiltrated samples in wet season; In contrast there is an increase in the DO concentration in comparison of dry season.

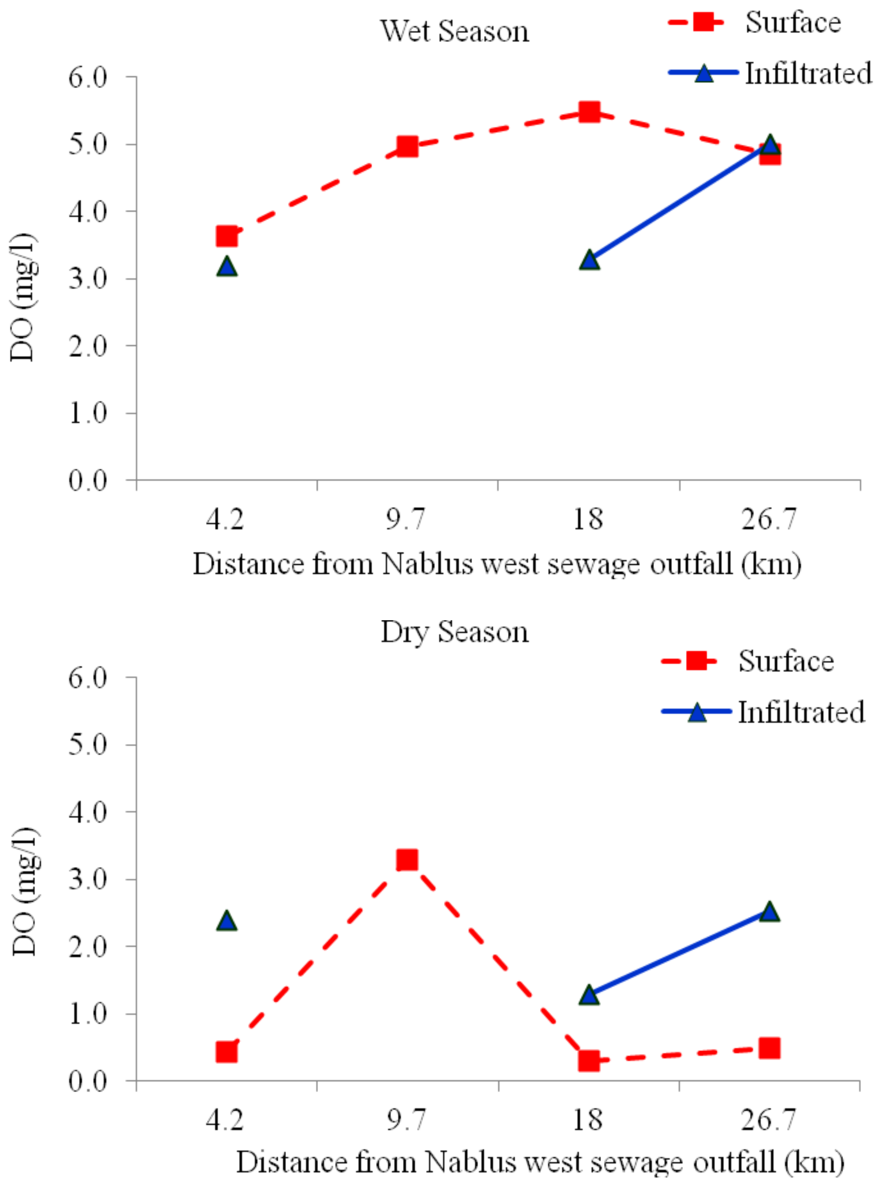


Figure 4.11: Dissolved oxygen concentration in infiltrated and surface samples dry and wet season for wadi Zomar-Palestine

4.6.3 COD and BOD

The reduction in BOD and COD values in infiltrated samples were clearly observed. The percentage of decrease ranged from 24 to 80% for both parameters, which indicate to biodegradation in the wadi.

Table 4.8: Reduction rate of BOD and COD in infiltrated samples in wet and dry seasons

	ST.1 (4.2 Km)		**ST.2 (10 Km)**		**ST.3 (18 Km)**		**ST.4 (27.8 Km)**	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	wet
COD mg/l	41%	84%	N.A	N.A	35%	25%	19%	36%
BOD mg/l	61%	89%	N.A	N.A	55%	31%	31%	82%

The results presented in Table 4.8 show a little variation in the amount of removal with quality variation in the wastewater infiltrated and this complies with the results of Foster *et al.* (1994).

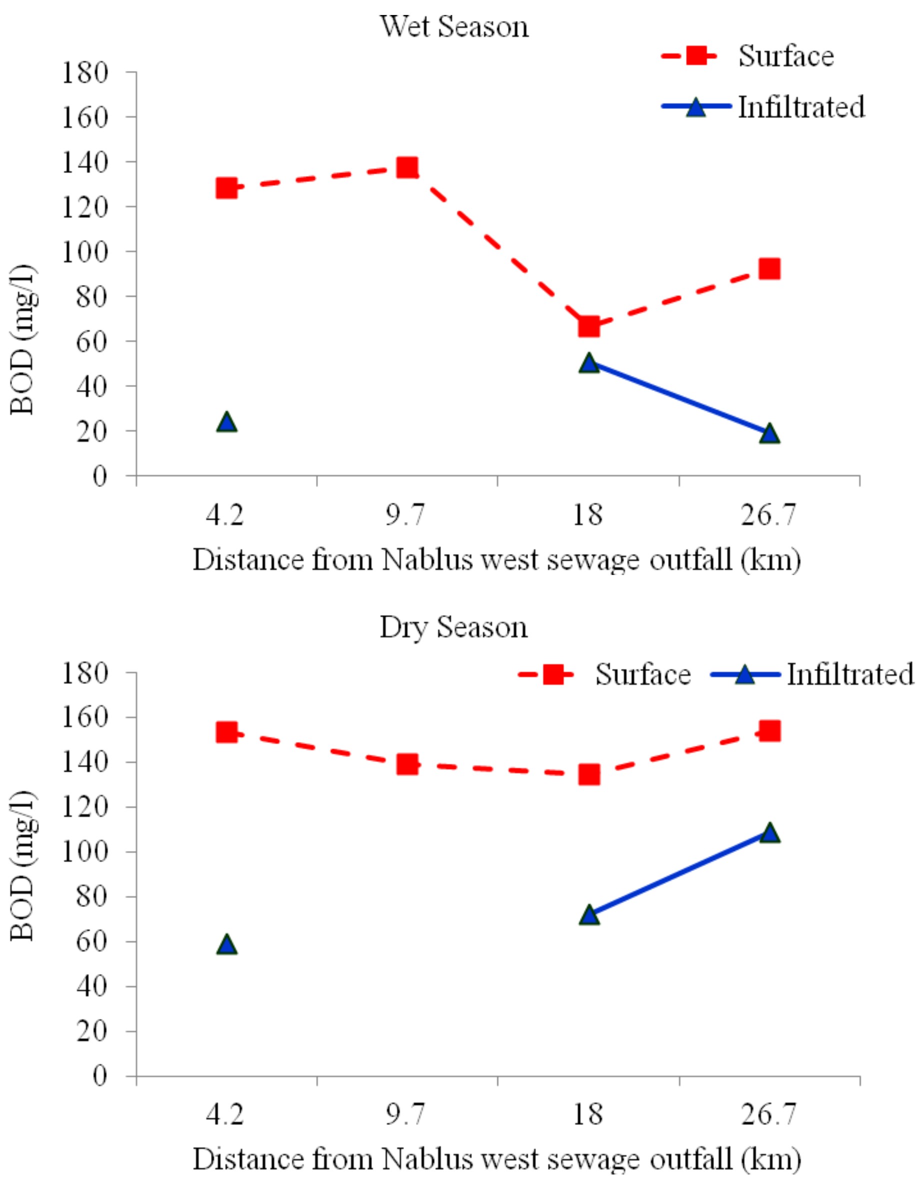


Figure 4.12: BOD concentrations in wet and dry season of surface and infiltrated wastewater for wadi Zomar-Palestine

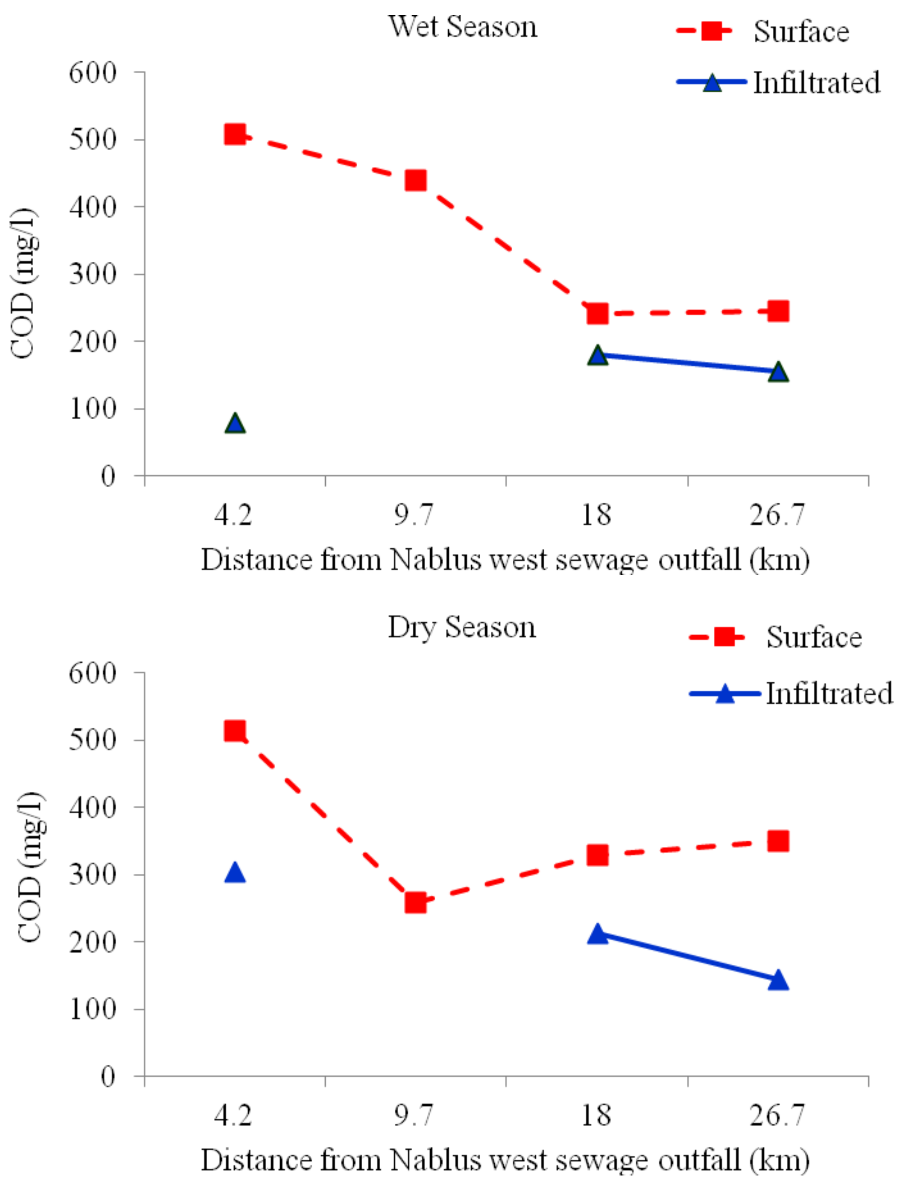


Figure 4.13: COD Concentration in wet and dry season at infiltrated and surface samples for wadi Zomar-Palestine

4.6.4 Ammonia

The results show that the concentration of NH_4 in infiltrated wastewater range (9.3-23.6 mg/l in wet season and 55-68 mg/l in dry season). The percentages of reduction were (14-81%) in wet season and (4-28%) in dry season. The low percentage of ammonium reduction is attributed to depletion of dissolved oxygen (1.3-5.0) mg/l. In other hand, the results show the dilution effect in the surface and subsurface.

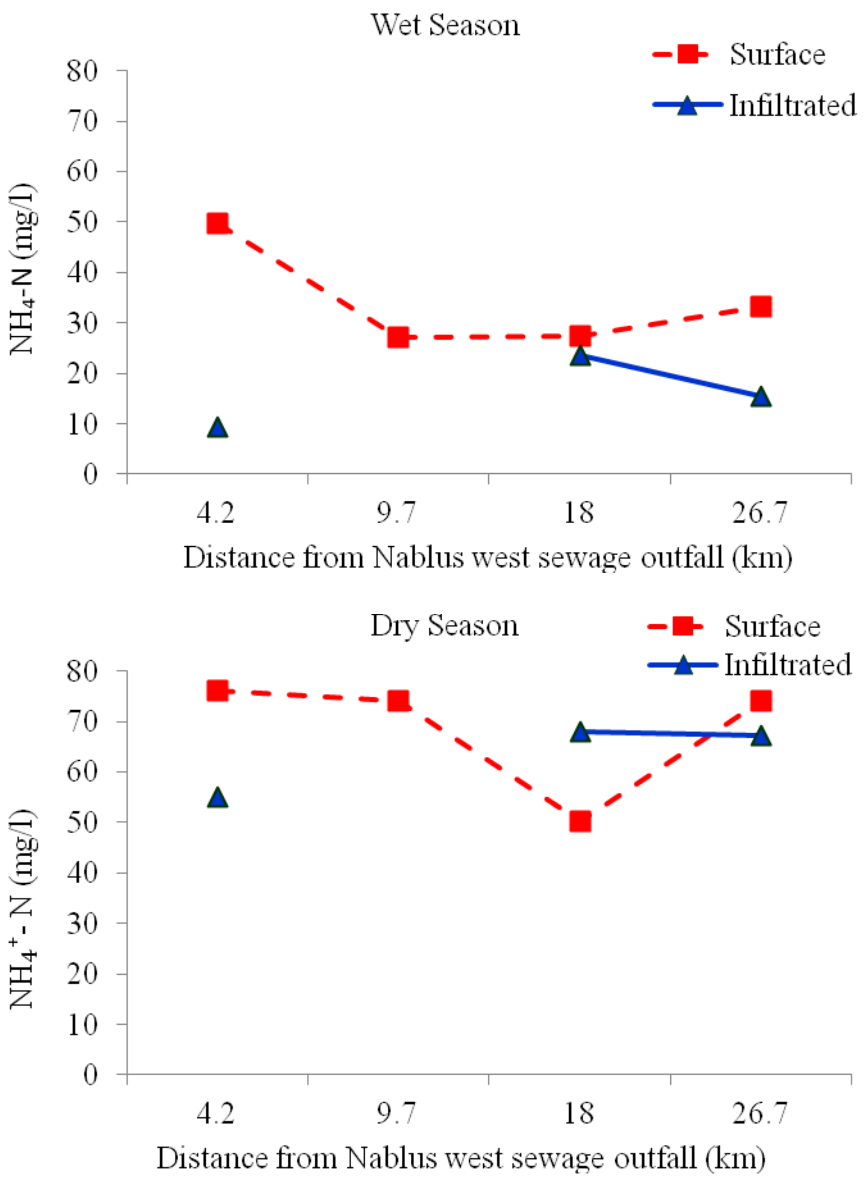


Figure 4.14: Ammonia (NH_4-N) Concentration in infiltrated and surface wastewater dry and wet season for wadi Zomar-Palestine

4.6.5 Nitrate

The nitrification process was clearly noticed in infiltrated wastewater at all stations. The concentrations of nitrate were in the range of 21-33 mg/l in dry season and 0.8-4.4

mg/l in wet season. The big variation in these results between wet and dry seasons is due to low temperatures in wet season.

In the wadi, the nitrogen in the surface wastewater is exclusively represented by the NH^{+}_{4} species. Ammonium persists the surface wastewater in the wadi, which indicates the absence of oxidation (the oxygen contents are very low and variable between 0.3 and 2.0 mg/l). During infiltration through wadi bed the ammonium transformed into nitrates. This transformation is favored by the oxygen increase in soil (2.5 mg/l), according to Debeiche *et al*, (2003) study, due to the oxygen-rich infiltration waters, which encourage a nitrification of the ammonium. This transformation requires aerobically conditions.

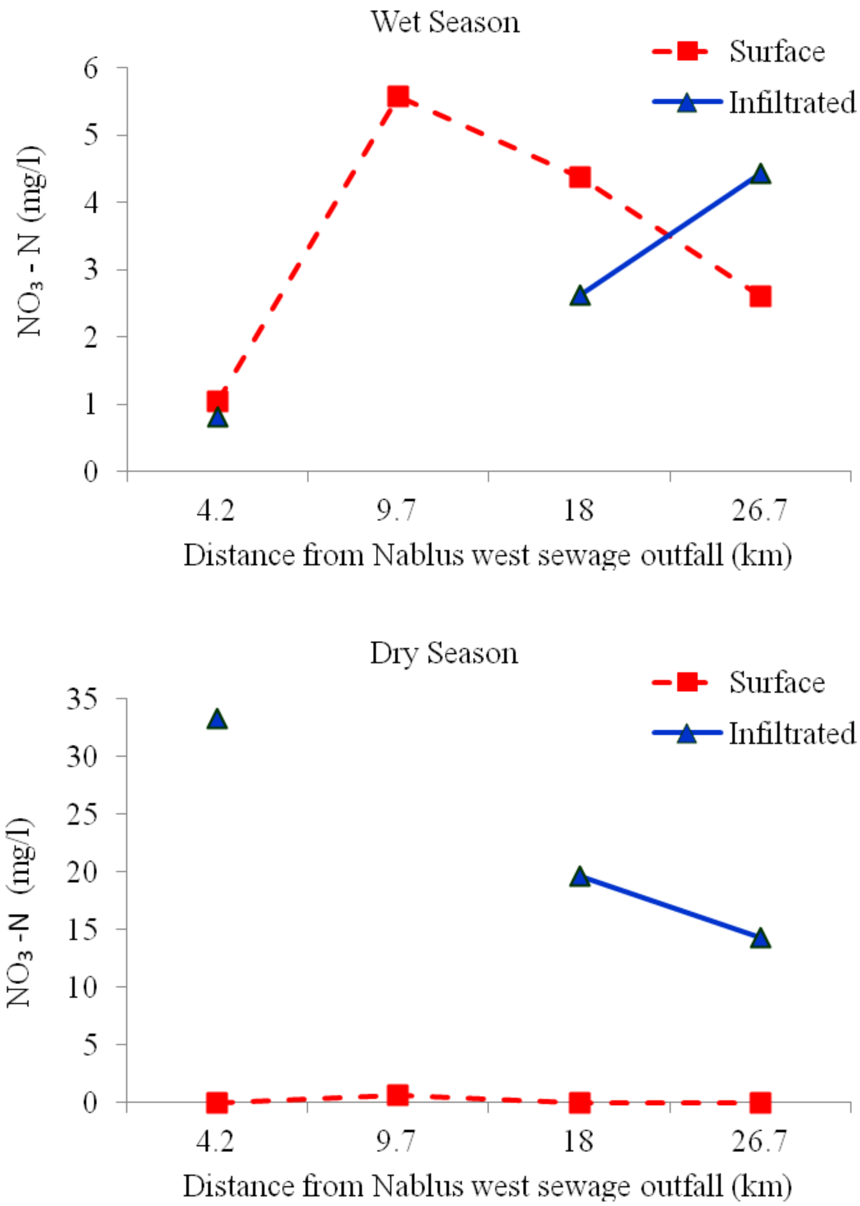


Figure 4.15: Nitrate NO_3 -N Concentration n infiltrated and surface samples, dry samples wet samples for wadi Zomar-Palestine

4.6.6 Orthophosphate (PO_4)

The concentration of PO_4 in infiltrated wastewater was in the range of (1.7-4.9 mg/l) in both seasons along the wadi. The results show increase in PO_4 concentration in infiltrated wastewater at most stations except ST.4 in dry season and at ST.1 in wet season.

The low concentration of oxygen might explain the increase in PO_4 through desorption processes along with the removal of nitrate which may produce redox condition facilitating the release of PO_4. On the other hand, Whelan and Barrow (1984) and Gerrits (2000) have noted that soil have a finite capacity for the sorption of phosphate. Once this capacity is exceeded the phosphate discharged into the soil dispersal area will not be retained but will gradually move into the groundwater.

Phosphate removal presumably occurs by adsorption on clay and silt lenses and by chemical precipitation, both in the unsaturated zone and in aquifers. There is also some phosphorus uptake by bacteria.

The parameters (temperature, dissolved oxygen, redox potential and pH), which influence the phosphates mobility and the different adsorption processes of phosphates (Debieche, 2003).

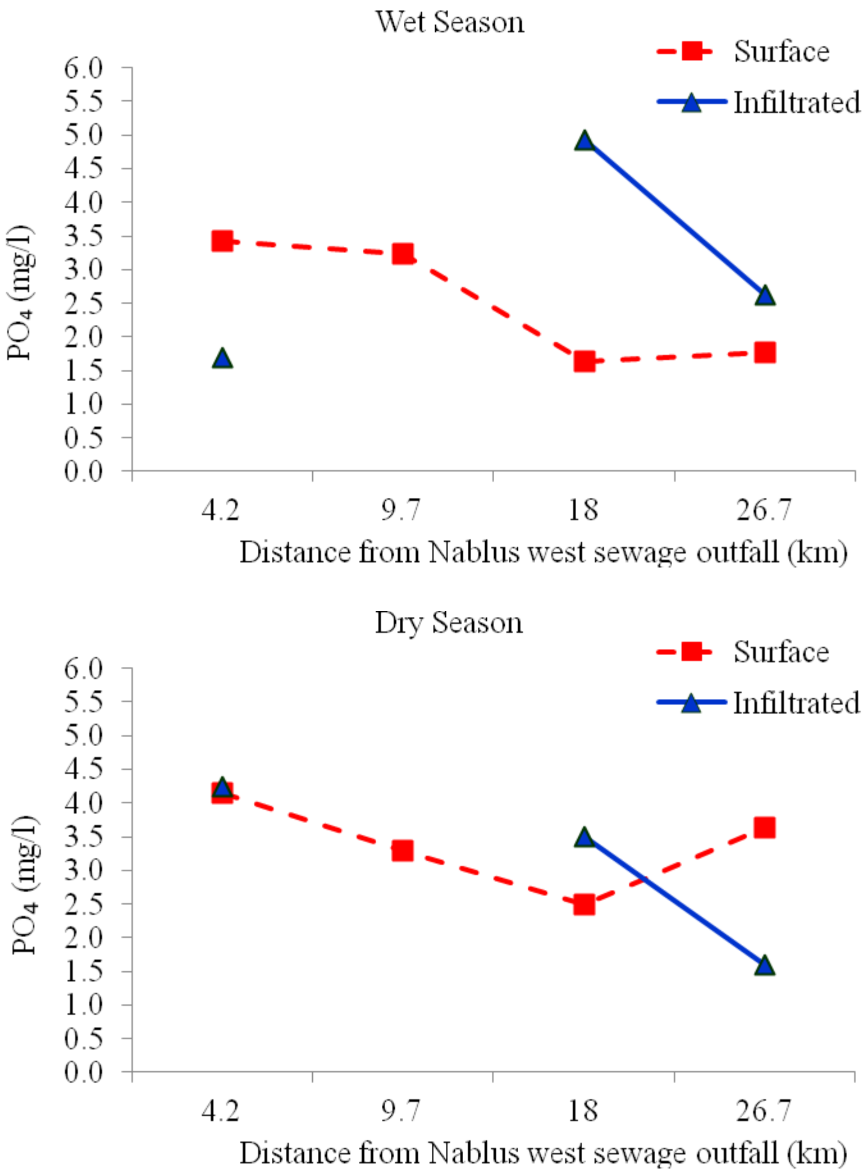


Figure 4.16: Average surfaces and infiltrated Ortho-phosphate (PO_4) Concentration in wet seasons in wadi Zomar-Palestine

If phosphate is not retained in the vadose zone, but it is transported into groundwater zone, it has the potential to be persistent and to be mobile enough to constitute a threat to down gradient surface water environment. This evidence also shows that when a wastewater is decommissioned and oxidized, PO_4 plume is present, down gradient phosphorous loading is not diminished for many years thereafter (Robertson and Harman, 1999).

4.6.7 Total Dissolved Solid

The salinity of the stream water is reflected by Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Cl^- concentration values which all showed similar trends. In this study, electrical conductivity (EC) and (TDS) serves as a representative of solute concentration in the stream (Figure 4.18). The higher conductivity and TDS levels were observed in the upper part of the stream, and then decreased towards the downstream up to ST.3, and then at ST.4 the relative increase due to entry of sewage into the Wadi from Tulkarem City.

4.6.8 Total Suspended Solid

The TSS in infiltrated wastewater was in the range of (1378-2289) mg/l in dry season and (400-663) mg/l in wet season. The percentage of reduction was in the range of (13-73) %, except ST.3 that infiltrated wastewater was increased from 4% in dry season to 31% in wet season.

4.6.9 Turbidity

The results of turbidity in infiltrated wastewater range (39-78) NTU in wet season and (110-720) NTU in dry season. The reduction percentage was from 41% to 88% during both seasons. Reduction in turbidity indicates the effectiveness of the subsurface soil filtering processes.

4.6.10 Fecal Coliform

The infiltrated wastewater results show excellent removal of fecal coliform ranging from (96.8 - 99.6) % at ST. 1 and ST.4, and range between (78-87) % at ST.3, which is due to physical straining or filtration (Hagedorn, 1984). Most of the fecal bacteria die or are immobilized at the top of the soil. Virus removal is primarily due to adsorption by silt and clay particles; most viruses are adsorbed in the top 5 cm of the soil (Bouwer and Chaney, 1974).

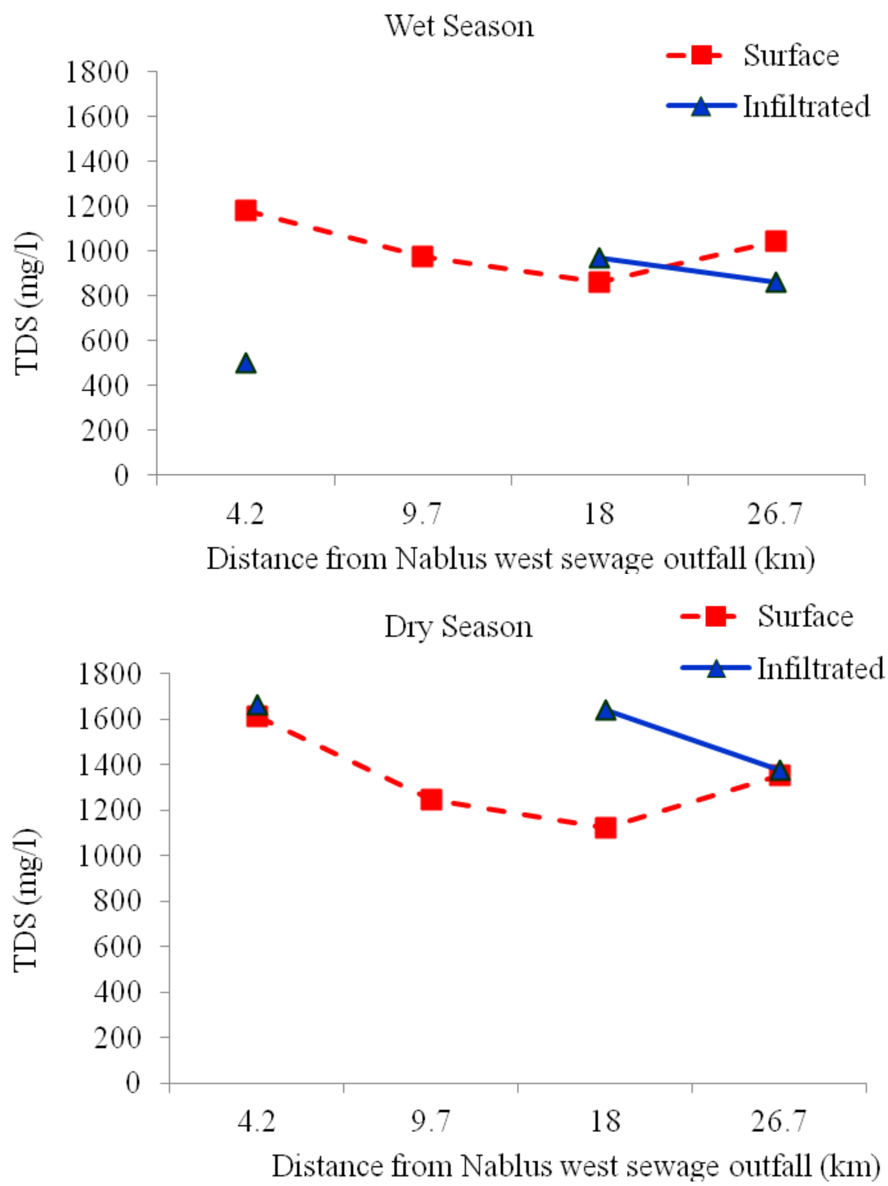


Figure 4.17: Total dissolved solids in infiltrated and surface wastewater during wet and dry seasons for wadi Zomar-Palestine

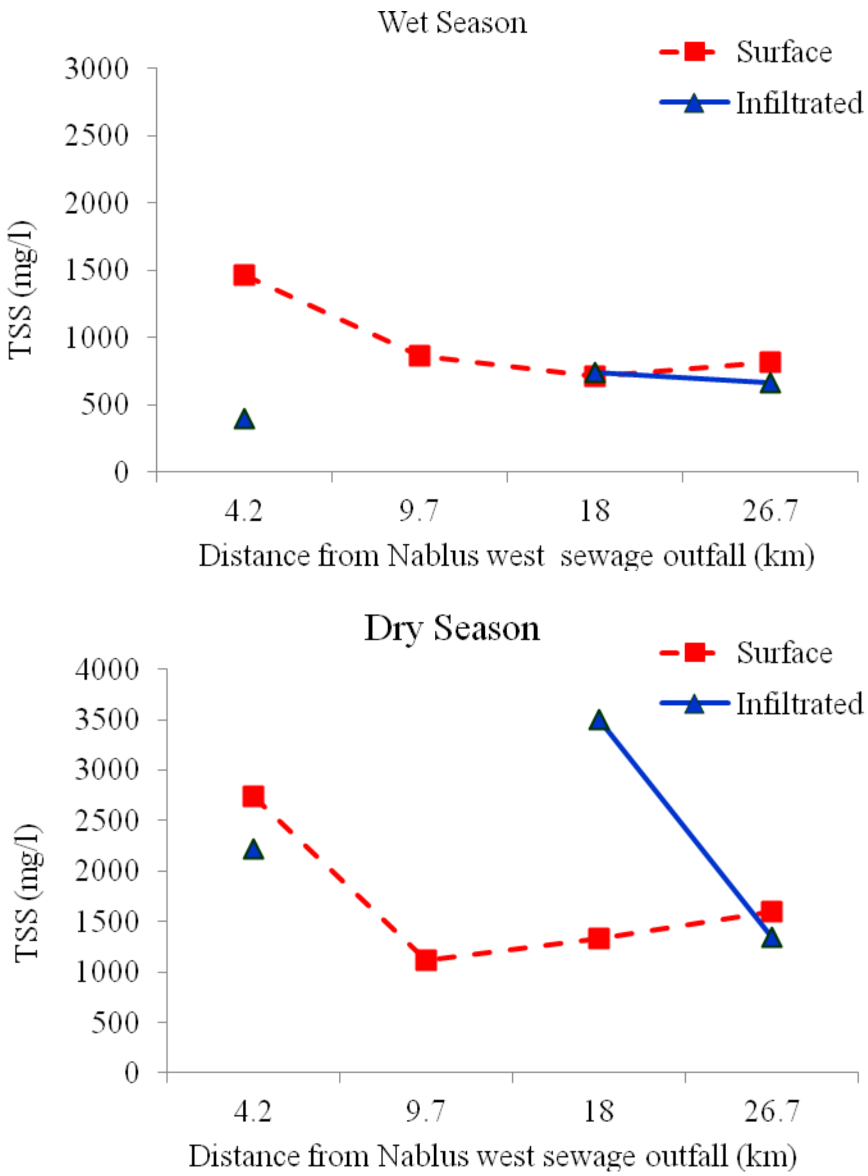


Figure 4.18: Total suspended solid concentration in surface and infiltrated wastewater during wet and dry seasons in wadi Zomar-Palestine

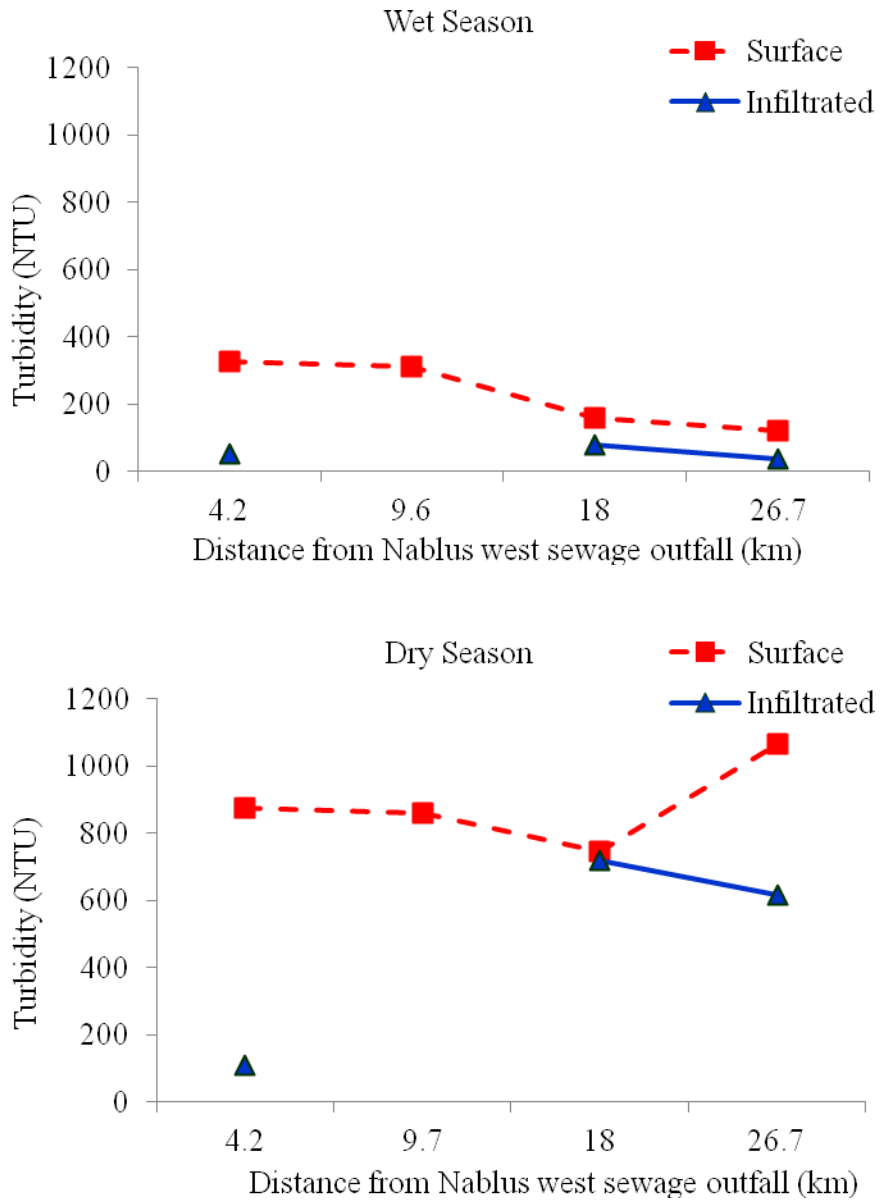


Figure 4.19: Turbidity in surface and infiltrated wastewater during dry and wet seasons in wadi Zomar-Palestine

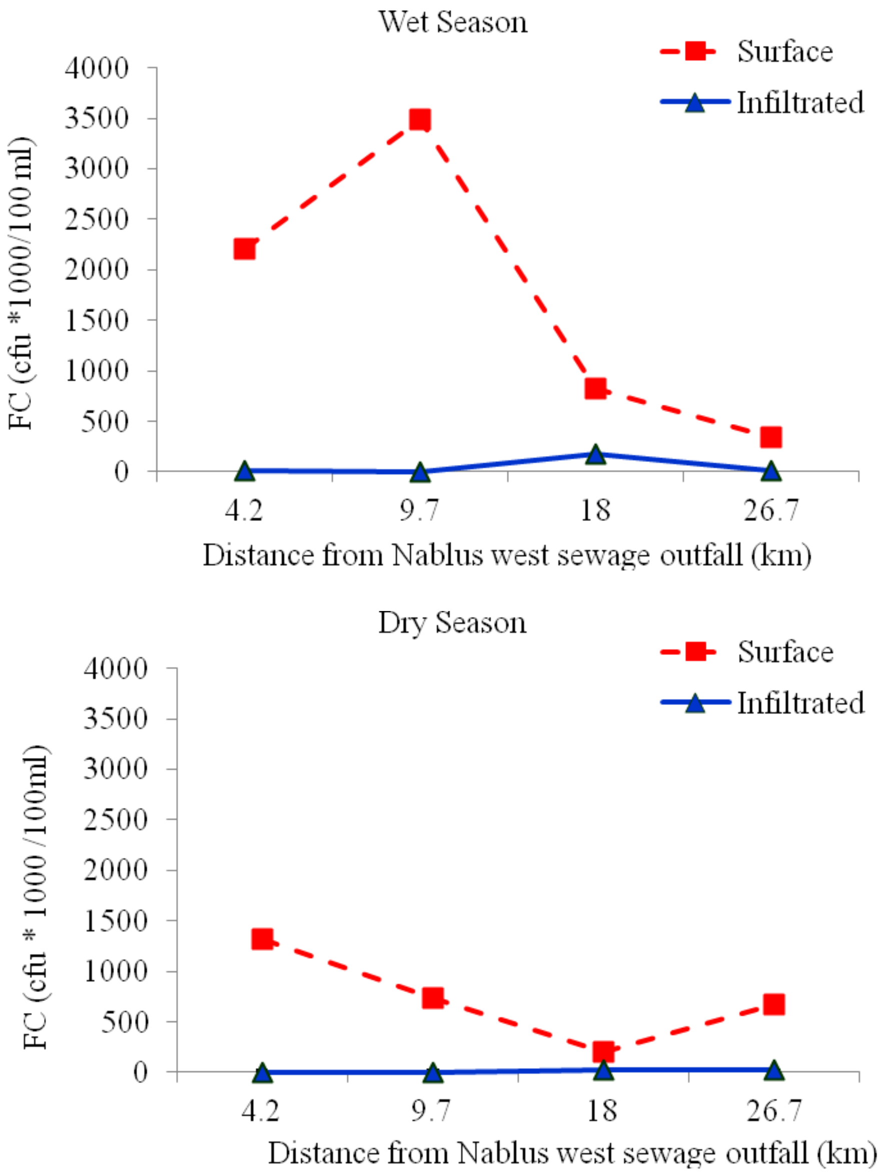


Figure 4.20: Fecal Coliforms in surface and infiltrated wastewater during dry and wet seasons in wadi Zomar-Palestine

4.6.11 Heavy Metals

The surface and infiltrated samples were analysis for heavy metals; seven heavy metals were analysis (Zn, Fe, Mn, Cu, Cr, Ni and Pb). Three heavy metals above detection level were encountered in surface and infiltrated samples Zinc (Zn), Iron (Fe) and Manganese (Mn).

The results of heavy metals infiltrated wastewater showed the reduction in Zn and Fe concentrations in the range of (2 -73) %. These reductions are attributed to fixation processes while wastewater infiltrate through soil bed layers as Lesage (2006) reported. According to Hoeks (1977), the reduction of the Fe concentration, may therefore be ascribed to adsorption and precipitation of the free Fe ion in the form of FeS and perhaps $FeCO_3$. Zn-ions were effectively removed from the infiltrated soil bed as reported by Hoeks, (1977).

At ST.3 during wet season, the concentration of Fe^+ was increased in infiltrated soil due to acid soils, where heavy metals are likely to be more mobile. In fact, acidity conditions often enhance the solubility of heavy metals in soils. The average pH value for infiltrated wastewater at ST.3 was 6.92.

For Mn the opposite occurred, high increase in Mn concentrations in infiltrated wastewater from 1-fold to 6-folds of the Mn concentrations in surface wastewater that indicate to export of dissolved Mn and particulate Fe was probably related to redox condition in the soil layers, this complies with Lesage (2006) and Egiarte *et al*. (2007) results.

Heavy metals may be very mobile in soil if they are present in the leachate as organic metal complexes. The anaerobic fermentation of organic acids is very effective, so the presence of complexes and the consequently high mobility of the heavy metals only temporary. As soon as the metal ions are again released as free ions they become involved in adsorption and chemical precipitation reactions. The mobility then is drastically reduced because most heavy metals are strongly adsorbed in the usually low concentration present.

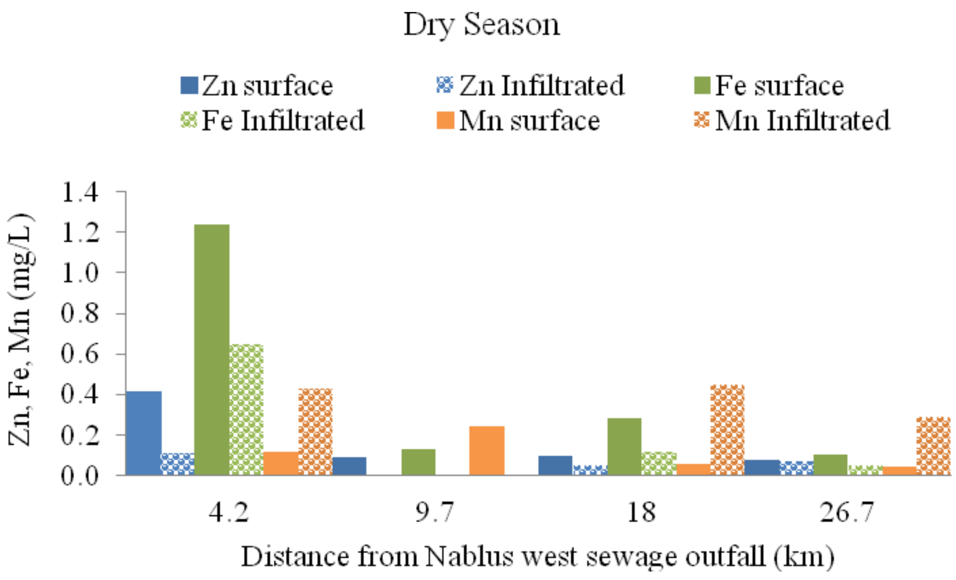


Figure 4.21: Heavy metals concentration in surface and infiltrated wastewater through top soil of wadi bed during dry season in Wadi Al Zomar/Palestine

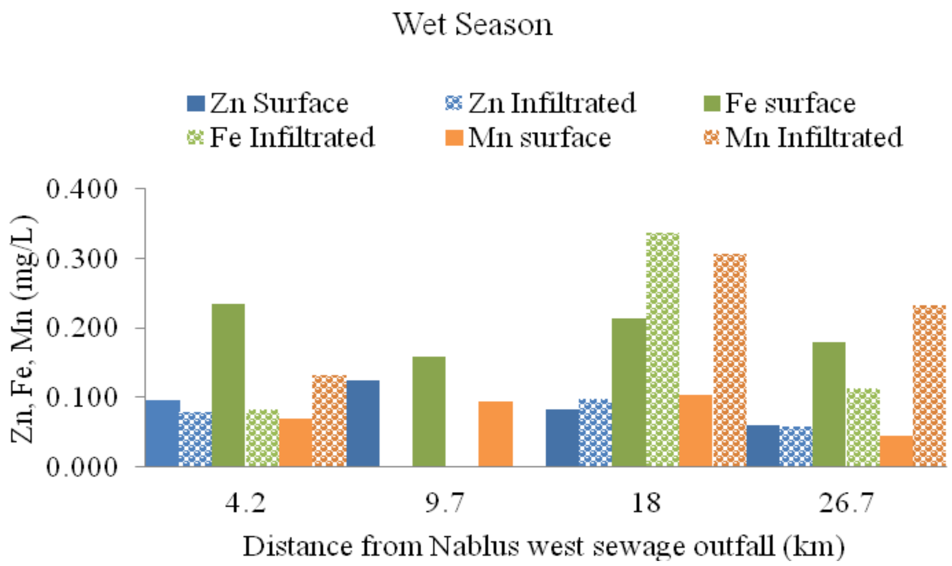


Figure 4.22: Heavy metals concentration in surface and infiltrated wastewater through top soil of wadi bed during wet season in Wadi Al Zomar/Palestine

4.7 Water mass balance for Wadi Al Zomar

4.7.1 Background

For the estimation of losses or gains in the wadi, a water balance approach was used. Several assumptions were made accordingly: since there are additions of water along the stream those changes the water balance. Water loss is caused by three main processes: infiltration into the ground, evaporation and evapotranspiration.

At Wadi Al Zomar, there is little if any vegetation cover, consisting of weeds or low shrubs. Moreover the vegetation on the channel bank is uprooted during the cleaning process and opens the stream by the municipalities on an annual basis.

4.7.2 Wadi section selection for wastewater balance

The water balance calculation takes into account only section located between Beit Iba (ST.1) and Western WWTP (ST.2), which has less vegetations cover, and hence less evapotranspiration. In streams, which tend to lack vegetation, evaporation plays a greater role than transpiration (Cataldo *et al.*, 2004). Since this study did not attempt to evaluate evapotranspiration, measurements were not made; yet, it cannot be ignored.

The evaporation rate value used in calculating stream loss is based on an average for the entire basin, but in fact the rate varies between seasons. Direct evaporation from the stream appears to be approximately 7.0 mm/day in the summer months, 2.5 mm/day in the winter months and 6.0 mm/day in the spring months (Palestinian Meteorological Department, 2012).

From ST.1 down to ST.2, loss estimations show that about 44% of the water is lost in dry season and 17% in wet season, by considering an average width of the wadi of 2.0 m, only 1% of the loss in both seasons can be explained by evaporation. This implies that 43% and 16% of the water is lost via infiltration/percolation in dry and wet seasons respectively, during dry season 11800 m^3/day and 10000 m^3/day during wet season. Such high losses over a very short distance (5.5 km) indicate a very high infiltration rate of 2,300 m^3/km-day, or 8% per km per day in average. This high rate is similar to that calculated by Dor *et al*. (1976) in Nahal Soreq Wadi in Jerusalem Area. However, their estimation was about (13.0% of flow per Km per day) and also similar to Dunkerley (1999) in a small (sub-bank-full) flow event in an Australian desert lying on gravel bed channel. However, his estimation referred to sub-bank-full flow (13.2% per km) and for bank-full and shallow over-bank it was lower (5 – 6.9% per km) along the same channel. Indeed, most studies on ephemeral streams focus on transmission losses during flow events, and therefore are not strictly comparable to transmission losses during base flow. Therefore, in the Al Zomar case, the rate of infiltration during base flow is likely at equilibrium, which is very high (the same as during a flow event).

Table 4.9 shows the estimated quantity of wastewater infiltrated into groundwater based on infiltration rates calculations.

Table 4.9: Infiltration quantity through three sections along wadi Al Zomar calculated based on infiltration rates

Section From - To	Section length (m)	Average section width (m)	Infiltration rate cm/min	Infiltration quantity m^3/d
ST.1 - ST.2	5500	1.75	0.10	13860
ST.2 - ST.3	8400	1.6	0.05	9677
ST.3 - ST.4	9600	2.0	0.02	5530

The infiltration quantity calculation show that the quantity of wastewater infiltrated through section (1) between St.1 and St.2 is about 14000 m^3/d. This value is close to the previous results from water balance calculations. The infiltrated quantities in the other sections were less than section (1), due to soil bed types which have low infiltration rates.

In summary, the stream lies on West Bank formation limestone and dolomites, which is characterized by jointing and massive karst phenomena such as caves, which have very high hydraulic conductivity (Gvirtzman, 2002). High transmission losses in this area may cause severe groundwater pollution, by directly delivering sewage of very low quality into the West Bank aquifer (without any pre-treatment) which is the most important source of drinking water in this area.

4.8 Addition source of wastewater along wadi Al Zomar

Additions of wastewater to the surface flow were found at ST.4 and partially at ST.3 of the wadi. The sources of the wastewater can be attributed to discharge of sewer pipe from some parts of Tulkarem City in case of ST.4 and from Anabta village in case of ST.3. Further, the some residents living along the wadi bank do not have connections to the sewer system, so they typically dispose their sewage waste into wadi.

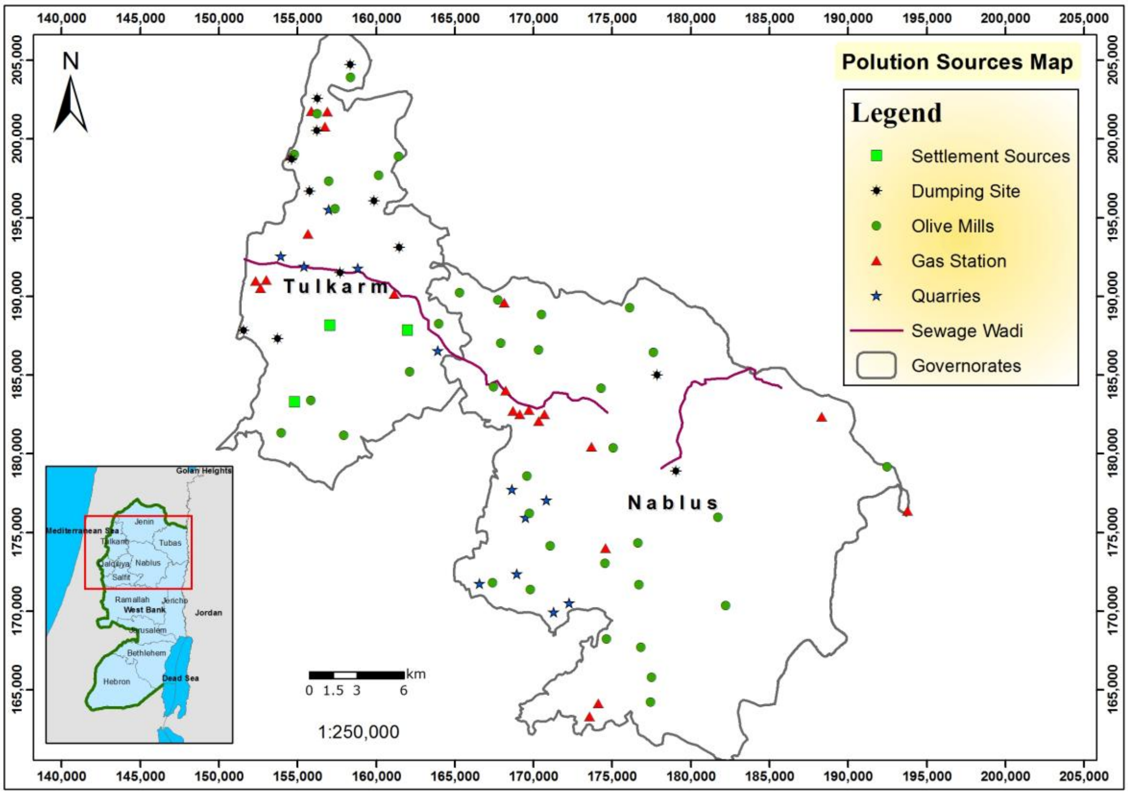


Figure 4.23: The distribution of pollution source in Wadi Al Zomar/Palestine (HWE)

4.9 Fluxes Loads in Dry and Wet Seasons

Table 4.10 provides the flow measurements conducted in both seasons, and quantity estimations of the infiltrated wastewater. Table 4.11 provides an estimation of pollutants loads, calculated with average values of pollutants measured in the stations in dry and wet seasons at several occasions. Pollutants loads were calculated assuming the average discharge estimates (Table 4.9) so that the full capacity of pollutants loads during dry and wet seasons could be estimated.

Measurements of flow taken from the ST.1 –ST.2 section of the stream in dry and wet seasons indicate that infiltration along the section can reach between 17% in wet season and 45% in dry season of the wastewater discharged (12000 m^3 in dry and wet seasons) percolates into groundwater before it reaches the green line. (Table 4.10) represented transmission losses in the channel during the flow and infiltration/percolation quantity.

Table 4.10: Measured wastewater discharge in dry and wet seasons and estimated quantity of infiltrated wastewater in wadi Al Zomar

Section From - To	Average Discharge Dry Season (m^3/d)	Average Discharge Wet Season (m^3/d)	Infiltrated quantity (m^3/d)		Infiltration quantity (m^3/d)
			Dry	Wet	
ST.1- ST.2	26,336 -14,476	51,967 - 41,985	11,860[1]	9,982[1]	13890[2]
ST.2- ST.3	14,476 -15,819	41,985 - 50,450	Non		9,677[2]
ST.3- ST.4	15,819 - 20,455	50,450 - 46,340	Non		5,530[2]

1 Based on mass balance calculations
2 Based on infiltration rate calculations (Double Ring test)

Average load: The mean concentration of nutrients measured in all collected samples was multiplied by the total water discharge.

Accordingly, flux calculations were undertaken for BOD, COD, NH_4, NO_3, PO_4, NO_3, TDS, TSS and heavy metals (Table 4.11).

4.9.1 Fluxes load in Wadi Al Zomar

As can be seen in Table 4.11, overall nutrient loads in wet season are much higher than those loads in dry period (base flow), at least by one-fold. By way of contrast, nutrient concentrations are much higher in dry period (base flow) than in the wet period. This can be attributed to a dilution effect contributed by the rainfall.

In conclusion, the most plausible explanation for the high nutrient loads is that non-point source pollution sources from agriculture activity the major contribution to the calculated pollution loads. In fact, the results are in line with these shown by Roach and Grimm (2001) and Tal *et al*. (2007).

4.9.2 Self purification along the wadi

The results from fluxes loads calculations in wet and dry seasons at the four stations show a clear self purification processes through the flowing along the wadi.

In dry season, the degree of reduction in COD, BOD, NH_4 and PO_4 loads from upstream at ST.1 to ST.3 range from (57 – 69) %. These pollutants relatively increased at downstream ST.4 due to the introduced sewage from Tulkarem City, as shown in Table 4.12.

The average TSS load in upstream is about 78000 kg/day, and decreased by time flowing down to reached 24240 kg/day at ST.3, then slightly increased to 39000kg/day at the downstream ST.4. The degree of reduction was 50 % from ST.1 to St.4.

For Heavy metals the loads reduction were high from upstream to downstream ST-1 to ST.4 range from 70 % for Mn, 93 % for Fe and 84 % for Zn.

In wet season, the reduction in fluxes load were less than in dry season, the reduction percent from upstream to downstream range from (40-70) % for in COD, BOD, NH_4 and PO_4 loads. The TSS load reduction was similar to that during dry period.

The degree of reduction of heavy metals in wet season were less than in dry season, range from (31-44) % Table 4.11.

Table 4.11: Pollutants fluxes load in wet and dry season and load difference between wet and dry seasons at the Al Zomar (surface samples)

	Station	ST.1	ST.2	ST.3	ST.4
	Season	**Flow (m_3/d)**			
	Dry	26,336	14,476	15,819	20,455
	Wet	55,961	41,985	50,450	46,340
	Difference	112%	190%	219%	127%
		Load (kg/d)			
COD	Dry	13537	3749	5204	7159
	Wet	26439	20223	12192	11400
	Difference	95%	439%	134%	59%
BOD	Dry	4029	2012	2136	3150
	Wet	11433	5794	3380	4263
	Difference	184%	188%	58%	35%
TN	Dry	2006	933.7	791	1514
	Wet	2583	1139	1443	1612
	Difference	28%	22%	82%	6%
PO_4	Dry	109	48	40	74
	Wet	178	136	81	83
	Difference	64%	183%	103%	12%
TSS	Dry	72029	14983	27604	32258
	Wet	76080	36149	36122	38138
	Difference	(-)5%	141%	31%	18%
TDS	Dry	51276	18008	17812	27635
	Wet	61373	41019	43488	48333
	Difference	20%	128%	144%	75%
Zn	Dry	11.0	1.3	1.5	1.6
	Wet	5.0	5.3	4.1	2.8
	Difference	(-)55%	308%	173%	75%
Fe	Dry	33.0	1.8	4.5	2.1
	Wet	12.1	6.7	10.7	8.3
	Difference	(-)63%	272%	138%	295%
Mn	Dry	3.1	3.5	0.9	0.8
	Wet	3.6	3.9	5.2	2.1
	Difference	16%	11%	478%	50%

Table 4.12: Degree of removal in fluxes loads in wet and dry seasons from ST.1-ST.4

	COD	BOD	NH_4-N	Ortho PO_4^{-3}	TSS	TDS	Zn	Fe	Mn
% of self purification Wet	56	63	39	52	50	21	44	31	42

% of self purification Dry	47	22	24	31	55	46	84	94	70

4.9.3 Fluxes loads for infiltrated wastewater

The flux load calculations were undertaken for TN, TP, COD, BOD and heavy metals Table 4.13. The flux load calculations were performed at St.1 and St.2 only and generalized to the whole wadi. This is because along this section of the wadi (St.1 to St.2) (1) there is no pollution input from human activities, (2) vegetation cover is minimal so evapotranspiration could be neglected.

Table 4.13: Pollutants fluxes load in section (1) during dry and wet season at wadi Al Zomar

Dry Season	N	P	BOD	COD	Zn	Fe	Mn
Load in (kg/d)	2004	109	4898	13511	10.9	32.5	3.1
Load out (kg/d)	933.7	48	3155.8	544.3	1.3	1.8	3.5
load penetrated (kg/d)	623	37	1423	3653	0.93	4.64	3.25
Load removal (kg/d)	**447.3**	**24**	**319.2**	**9313.7**	**8.67**	**26.06**	**-3.65**
Load out (%)	47%	44%	64%	4%	12%	6%	113%
Load penetrated (%)	31%	34%	29%	27%	9%	14%	105%
Load removed (%)	22%	22%	7%	69%	80%	80%	-118%

Wet Season	N	P	BOD	COD	Zn	Fe	Mn
Load in (kg/d)	2583	178	12368	26440	4.99	12.11	3.64
Load out (kg/d)	1139	136	8061.1	18431	5.25	6.68	3.95
load penetrated (kg/d)	174	37	379	1390.5	0.78	0.73	2.24
Load removal (kg/d)	**1270**	**5**	**3927.9**	**6618.5**	**-1.04**	**4.7**	**-2.55**
Load out (%)	44%	76%	65%	70%	105%	55%	109%
Load penetrated (%)	7%	21%	3%	5%	16%	6%	62%
Load removed (%)	49%	3%	32%	25%	-21%	39%	-70%

The amount of fluxes infiltrated into underground as shown in Table 4.13 indicate high reduction in pollutants fluxes in term of all parameters, Quantification of these fluxes serve the purpose to evaluate the effect of these mass quantities on groundwater.

The fluxes loads calculation for N and P showed that 31% (623) Kg/d and 34% (37) kg/d respectively, of the total amount of Nitrogen and Phosphorus penetrated through soil bed.

The Heavy metals (Zn, Fe and Mn) fluxes loads penetrated into subsurface were (0.93, 26.0 and 3.25) kg/day in the dry season and (0.78, 0.73 and 2.24) kg/day in the wet season, respectively.

Based on the data available in PWA data base, the water quality of the wells, located in Tulkarem area adjacent to wadi Al Zomar was reviewed. These results revealed high concentrations for some measured parameters such as Nitrate and Phosphate.

The Nitrate concentrations in these wells in the range of 23 to 68 mg/l NO_3-N and for phosphate PO_4 the concentrations range from 0.1 to 7.2 mg/l.

The results of pollution investigation for domestic and agricultural wells in Tulkarem area indicate that there are high levels of nitrate concentrations exceeding the WHO maximum recommended of 50 mg/l for drinking purposes.

In summary, over time the large amount of sewage infiltration into the groundwater reservoir could affect the fragile water resources. However, the water that infiltrates into the soil in this area has reached groundwater wells or influences them as indicated by in the quality of water wells. There are high nitrate and phosphate concentrations in the wells adjacent to Wadi Al Zomar. This might be the case because groundwater levels are shallow in this area and the Western Aquifer is quite large, flowing relatively quickly, with considerable dilution.

4.10 Speculation of groundwater contamination after pollution sources removal

Water movement in the unsaturated zone can be complex and it is to pollutants attenuate difficult to predict. In many instances, the degree of contaminants attenuation will be largely dependent on pollutant pathways and residence times.

Natural flow rates in the unsaturated zone at almost all formations do not generally exceed 0.2 m/d (Foster *et al.*, 1994), and less when averaged over longer periods. Flow rates in fissured formation may be more than an order of magnitude higher. The presence of fractures, fissures and other macro pores is thus a key factor in reducing the potential for contaminant attenuation.

For Wadi Al Zomar situation, sewage discharges in the wadi will be terminated as wastewater treatment plants will be constructed, and the treated wastewater effluents will be transported in pipelines. As a result of 50 years of wastewater disposal in the wadi area, the contaminants plume had been produced in unsaturated zone and may be to aquifer. In general the unsaturated zones have the ability to self remediate or natural attenuation. The self remediate depends on many factors, including the type and the amount of contamination and the biological, chemical and physical processes that affect the speciation, transport, and fate of the contaminants (Repert *et al.*, 2006).

Contaminant monitoring is vital for characterizing the effectiveness of natural attenuation.

The Cape Cod, Massachusetts contaminant plume taken as case study to estimate the effect of contaminant plume produced as a result of 50 years of wastewater disposal in wadi Al Zomar area.

The study on Cape Cod was conduct by (Smith et al., 2013). The Cape Cod site was contaminated by disposal of secondarily treated municipal wastewater from a military reservation onto surface infiltrated beds for 60 years. As a result, a groundwater contaminant plume developed that is presently more than 8 Km long. The study was conducted as part of a long- term investigation to document the natural attenuation of a wastewater-derived contaminant plume in groundwater after removal of the wastewater source. The purpose of the study was to quantify and compare carbon and nitrogen pools sorbed on the aquifer sediments to the oxygen consumption capacity.

The results of Cape Cod study showed that the initial changes in the Cape Cod contaminant plume soon after disposal of wastewater was stopped consisted of flushing and downgradient transport of soluble, more mobile constituents such as chloride, nitrate, and some components of the dissolved organic carbon (DOC) pool (Repert *et al*., 2006). However, the persistence of anoxic conditions in the core of the contaminant plume, as well as the spatial distributions of dissolved organic carbon (DOC) and dissolved inorganic nitrogen (DIN), suggest that constituents sorbed to aquifer solids within the contaminant plume path will provide a long-term, continuous source of aqueous-phase contaminants and thereby maintain the persistence of the plume for the foreseeable future.

The field data showed that a relatively steep gradient of decreasing oxygen concentration in the direction of groundwater flow exists beneath the former infiltration beds and the oxygen gradient is advancing in the direction of flow at a rate that is considerably slower than the rate of water movement.

In summary, desorption and degradation of sorbed organic compounds continue to control the geochemistry and redox status of a treated-wastewater contaminant plume more than 15 years after the source of contamination was removed. Oxygen entrainment into the contaminated zone is slow, even though the quantifiable organic carbon content of the aquifer solids is also relatively low. The oxygen gradient is moving in a relatively narrow spatial configuration in the direction of flow at about 10% of the rate of groundwater velocity, but the rate of advance and shape of the front could change as other conditions change. However, the impact of the disposal practice will be evident in the groundwater chemistry for several decades after the wastewater source has been removed.

4.11 Sediment quality

The sediments samples were collected from station locations in order to assess the sediments quality. The analysis of total solids, volatile solid and heavy metals (Zn, Cu, Ni, Fe, Mn, Pb and Cr) were performed on sediment samples at St.01 and St.02 Table 4.14.

To assess the degree of contamination, the typical trace element content Table 4.15 in the soil according to Adriano (2001).

Table 4.14: Sediment soil samples results for wadi Al Zomar

Element	ST.01 (Nablus)	ST.02 (Ramine)
Total Solids (g/Kg)	916.11	863.18
Volatile Solids (g/Kg)	77.96	64.9
Zn (mg/Kg)	162.0	97.0
Cu (mg/Kg)	47.0	39.0
Ni (mg/Kg)	33.0	57.0
Fe (mg/Kg)	6843.0	13941.0
Mn (mg/Kg)	199.0	456.0
Pb (mg/Kg)	52.0	38.0

Cr (mg/Kg)	27.0	71.0

Table 4.15: Typical trace element contents in soils in mg/kg. Data are given for the range that can be observed frequently; according to Adriano (2001), Kabata-Penias (2000)

Element	Soil –mg/kg
Chromium	10-50
Cobalt	1.0 - 10
Copper	10-40
Iron	10000 – 50000
Lead	10 – 30
Manganese	300 - 1000
Nickel	10-50
Zinc	20 - 200

The content of Cr, Pb, Ni, Cu and Zn measured in sediment taken from ST.2 were higher than typical content of trace element in the soil, which mean after the source of pollution is eliminated the possibility of these metals to mobile through vadose zone and reach the groundwater is high.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

- The discharge of sewage from the outfall of sewage network of the western part of Nablus City into Wadi Al Zomar of about 25,000-33,000 m^3/day is the main point source of pollution into the system.
- Self purification had been clearly shown along the wadi. The degree of purification varied between dry and wet seasons due to temperature variation and dilution.
- The degree of purification in dry season for COD, BOD, NH_4, PO_4 and Fecal coliforms were (50%, 12%, 34%, 50% and 84%), respectively and in wet season the percentage of reduction were (53%, 48%, 48%, 50% and 90%), respectively.
- The concentrations of pollutants in respect to dilution effect showed that the concentrations in the dry season higher than in the wet season, the percentage of the reduction as a dilution affect for COD and BOD were 50%, 20 %, respectively. The reduction for NH_4 in the range of (34-63)% and (17-51)% for PO_4 but the concentration of the Fecal coliforms were increased in the wet season in respect of the dry season by 2-4 folds of magnitude.
- The nitrate results show restricted nitrification processes in dry season due to oxygen depletion, and changes in COD/BOD ratios indicate the existence of easy biodegradation processes in dry season. But the high ratios in wet season (3.4-5.4) indicate low degradation process may be due to the low temperature.
- Infiltration rates have been shown to be very high in the upper part between ST.1 to ST.2 range from 16% to 43% of the wastewater infiltrates into the subsurface.

The surface water flow into wadis and the subsequent bed leakage, which will depend on flow rate, bed lithology and the underlying aquifer characteristics.

- The infiltrated wastewater results in dry season showed reduction in the measured pollutants COD (35-51) %, BOD (31-61) %, NH4-N (9-28) %, fecal coliforms (87-100) %.
- The nitrate NO_3 concentrations in infiltrated wastewater at ST.1, ST.3 and ST.4 were (33, 20 and 14) mg/l respectively. In same time the dissolved oxygen increased by 3-folds to 4- folds of DO concentrations of surface wastewater.
- Phosphate (PO_4) concentration increased in ST.1 and ST.3 and decreased in ST.4 in dry season, but in wet season the phosphate increase at ST.3 and ST.4 (48-200) % and increased in ST.1.
- The heavy metals in infiltrated wastewater decreased in case of Zn and Fe in the range of (48-73) % at all stations in the dry and wet seasons, but for Mn the opposite occurred, the Mn concentration increase from 1-fold to 6-folds of the Mn concentrations in the surface wastewater.
- In wet season the infiltrated wastewater showed reduction in the measured pollutants COD (25-41) %, BOD (24-89) %, NH4-N (14-81) %, fecal coliforms (79-100) % and NO3 (22-40) % at ST.1 and ST.3 and decreased at ST.4 (70)%.
- The results from fluxes load calculations in wet and dry season at the four stations are show clearly self purification processes occurring through the flowing along the wadi. In the dry season, the reduction in COD, BOD, NH_4, PO_4 and TSS loads from ST.1 to ST.3 range from (57-69) %. In wet season, the reductions were less than in dry season. The reduction percent from ST.1 to ST.3 range from (40-70) %. These pollutants relatively increased at downstream (ST.4).

- For Heavy metals (Zn, Fe and Mn) high reduction in fluxes loads in dry season were Zn (84) %, Fe (93) % and Mn (93) % but in wet season the reduction less than in dry season range from (31-44) %.
- High quantities of N (623) Kg/d and P (37) Kg/d were penetrated through section (1), which represented about 32% of total loads enter to the wadi.
- The heavy metals (Cr, Pb, Ni, Cu and Zn) content in the sediments especially at ST.2 of the wadi were in the level higher than typical content of trace elements

5.2 Recommendations

- ➢ Self purification capacity along the wadi not enough to reduced the pollutants quantity.
- ➢ The infiltration capacity after pass 1.0m still high while lead to hazard to groundwater especially in the sensitive area as in the wadi Al Zomar case.
- ➢ Soil sediment is high pollution after the source of wastewater will be stopped,
- ➢ Long term monitoring of groundwater and polluted soil and sediments in the wadi area and a remediation process should be develop to mitigate the aquifers from pollutants leach.

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