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ABSTRACT

Zimar stream has become since the 1950's a sewage drain. The stream extends over 27 km from the west of Nablus City to Tulkarem City northwest of West Bank. There are lost opportunities for streams' water beneficial use, and nature conservation principals have been severely violated for the Zimar watershed, in addition to public health and biodiversity threats. This paper was prepared to predict the water quality of the Zimar's stream under current and proposed future conditions, and under different scenarios. Dissolved Oxygen was taken as the main quality parameter, and depending on steady state solutions of Streeter-Phelp's equation. QUAL2Kw model was used to predict the behavior of the stream. Water samples were collected, and field measurements were conducted for eight different critical locations along the stream, and during the wet and dry seasons of 2011–2012. Several scenarios were simulated, taking in consideration the influences of the under-construction wastewater treatment plant in the western area of Nablus city, proposing additional wastewater treatment plant at Anabta village, and proposing constructing of three artificial weirs. It was found that the stream has significant self-purification capacity as the dissolved oxygen concentration doubled from Nablus city to Anabta village; midway to Tulkarem. The Biological oxygen demand between those two points decreased to values up to 11% from the original value. This paper supports proposed solutions of the stream to improve its water quality, and enhance aesthetic views in the catchment.

Keywords- Dissolved Oxygen; Modeling; Reuse; Water Quality.

INTRODUCTION

Background

Water is a key economic development and humanitarian issue in Palestine. Palestinians presently have one of the lowest per capita water resource availability in the Middle East and North Africa (MENA) countries. In Palestine, water needs exceed the available water supply with steadily growing gap. Also, the continuing growth and development in the region in combination with ongoing climate change will continue to place increasing demands upon the water resource (PWA, 2013). So, the adoption of the integrated water resources management approach and the mobilization of all additional conventional and unconventional water resources are needed. Unconventional water resources in Palestine include treated wastewater, retained floodwater, and streams' water.

Study Area

The Zimar stream is running from the mountains of the West Bank to the coastal plains (Fig. 1). Zimar is one of the longest streams located to the west of Jordan River. The stream system is partly coupled to the large regional Mountain Aquifer as a source of water recharge (OPTIMA, 2007). Polluted stream-water leaches into the mountain aquifer and at the same time, there are springs originating from the aquifer that replenish the stream downstream. Pollutions in the stream are due to three main discharge sources: outfalls of untreated municipal wastewater, runoff from adjacent agricultural areas, and direct discharges from the industrial activities located along the stream.

This study covers the Palestinian part of the stream which spans over 27 km. A drainage area of 172 km2 is contributing the stream with runoff, and named as Zimar catchment (Fig. 1). The stream discharge varies between 13,000 m3/d and 22,000 m3/d. The altitude of the catchment varies from 50 to 600 m above mean sea level (Arabtech Jardaneh, 2008). There are two major governorates in the area: Nablus, and Tulkarem with total population in the catchment of more than 278,800 citizens (PCBS, 2007). The catchment is important for several industrial, agricultural, and recreational activities. 26 groundwater wells and springs are located in the catchment, which are the main source of all water uses.

Water Quality Modeling

Generating a model for the concentration of dissolved oxygen (DO) in this stream has become indispensable. DO is an important parameter that directly indicates the healthy conditions of rivers and streams (Masten and Davis, 2012). In the U.S. and other countries in the world, a DO level of 5 mg/L is a threshold limit, where below values indicates an impairment of rivers and streams (Chin, 2012).

Computer models are used extensively for water quality management of rivers and streams (Thomann and Mieller, 1987). However it is not widely spread to use computer based water quality models in Palestine.

The present paper describes the use of QUAL2Kw to create water quality model of Zimar stream. Creating mathematical model for the dissolved oxygen requires field data records for calibration. The more complex the model is the larger records are needed to validate the outputs, and vice versa, a fewer records needed for the simpler models. QUAL2Kw is one dimensional (1D), steady flow stream water quality model and thus its application is limited to steady state flow condition (Pelletier and Chapra, 2005).

Uncountable models were formulated worldwide to describe different cases such as streams, rivers, lakes, and oceans. Water quality models address the process of fate and transport of pollutants and the main essential parameters in the different water bodies (Ecosystems Research, 2013).

Several studies have been conducted in attempt to evaluate Zimar stream quality parameters. Studies have shown that the Zimar stream that passes through urban areas is extremely polluted with untreated municipal wastewater that affect the DO sag and cause DO depletion (Suleiman, 2010). The concentrations of the DO on several locations observed to be 0 mg/L during summer times (Hasan et al., 2010).

In 2004, a study was conducted on Zimar stream to estimate the costs and benefits derived from clean-up of the river so that

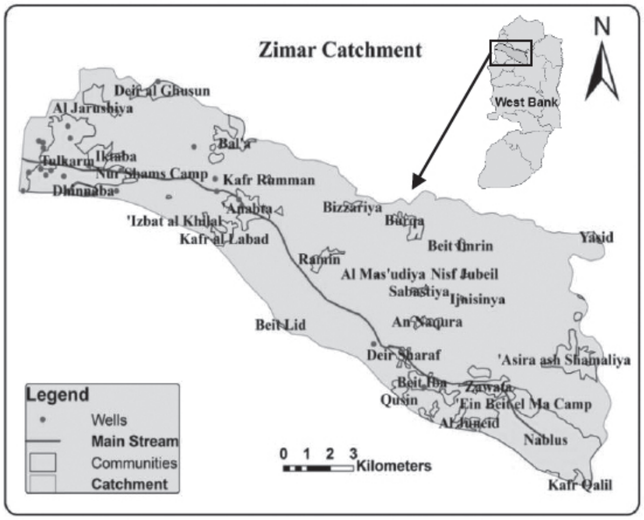


Figure 1. General map of Zimar catchment

For ten months of the year (January to September), and under the influence of drainage from the stone cutting workshops located upstream, the color of significant length of the stream is white. Olive wastes are usually spilled in Zimar stream in the period of (October-December) from more than 26 olive mills that are spread along the stream, and causing a dark black color for the stream's water (OPTIMA, 2004).

In 2011, the construction works were started for building the first wastewater treatment plant (WWTP) in the western area of Nablus, with total capacity of 14,000 m3/d (Municipality, 2013).

Thus, the main objectives of this study is to generate a water quality model based on the DO, as a key quality parameter in the Zimar stream, and under current and future conditions, in order to propose proper future restoration techniques for the stream.

MATERIAL AND METHODS

Data and Sampling Sites

The sampling sites (Fig. 2) for this study covered eight critical locations along the main stream, starting downstream: Tulkarem City, Nour Shams Camp, Aziza poultry slaughter house, Anabta Village In and Out, Deir Sharaf, Beit Eiba, and Nablus. Details of the sampling locations are summarized in (Fig. 3). Sampling locations were determined when major changes of the stream physical characteristics occurred such as slope or geometry, and when major flow contribution occurred from point sources. (Fig. 2) shows a layout of the samples with their distances from the upstream, and their elevations above mean sea level (AMSL).

The samples were taken during the period of (February 2011 – September 2012) in the dry and wet seasons. Water flow was determined at each sampling site by the velocity area method

(Michaud, J. 1991). Water quality measurements in this study included: temperature, pH, electrical conductivity (EC), DO, total suspended solids (TSS), ammonium (NH4), nitrates, 5 days biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Water samples were collected, transported and analyzed according to (APHA-AWWA-WPCF, 2005). Measurements of physical parameters such as flow, temperature, pH, EC and DO were performed at the sites. Temperature, pH, DO and EC were measured using portable sensors. The other parameters were analyzed in the laboratories of An-Najah University and Palestinian Water Authority.

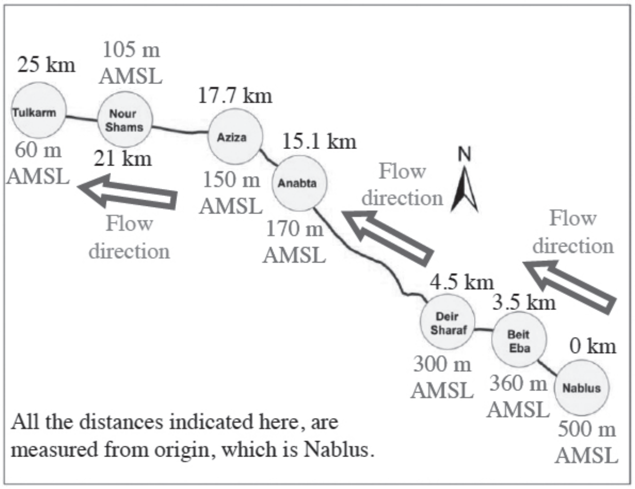


Figure 2. Samples locations layout

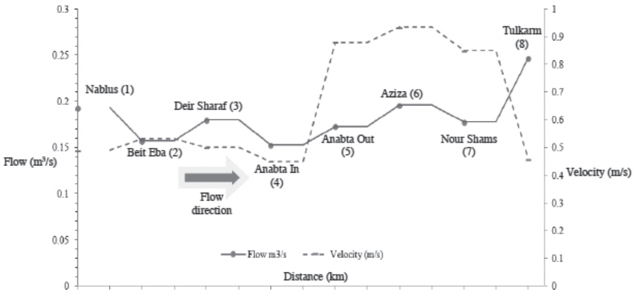


Figure 3. Flow and velocity measured along Zimar Stream

Modeling tool Zimar stream considered significantly long with respect to its cross section, with a total of 27 km of the mixing length over a maximum cross section up to 2 m. Therefore, the assumption of 1D process is valid. The modeling tool QUAL2Kw has a general mass balance equation for a constituent concentration (Fig. 4) in the water column (excluding hyporheic) of a reach i (the transport and loading terms are omitted from the mass balance equation for bottom algae modeling) as (Pelletier and Chapra, 2006):

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_i}{V_i}c_i - \frac{Q_{ab.i}}{V_i}c_i + \frac{E_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \qquad (1)$$

Where = flow at reach i (L/day), = abstraction flow at reach i (L/day), = volume of reach i (L), = the external loading of the constituent to reach i (mg/day), = sources and sinks of the constituent due to reactions and mass transfer mechanisms (mg/L/day), = bulk dispersion coefficient between reaches (L/day), , are bulk dispersion coefficients between reaches i−1 and i and i+1 (L/day), = concentration of water quality constituent in reach i (mg/L) and t = time (day). For auto-calibration, the model uses genetic algorithm (GA) to maximize the goodness of fit of the model results compared with measured data by adjusting a large number of parameters. The fitness is determined as the reciprocal of the weighted average of the normalized root mean squared error (RMSE) of the difference between the model predictions and the observed data for water quality constituents. GA maximizes the fitness function f(x) as:

$$f(x) = \left[\sum_{i=1}^{n} w_i\right]\left[\sum_{i=1}^{n} \frac{1}{w_i}\left[\frac{\left(\sum_{j=1}^{m} O_{ij}/m\right)}{\left[\sum \left(P_{ij} - O_{ij}\right)^2/m\right]^{1/2}}\right]\right] \qquad (2)$$

Where = observed values, = predicted values, m = number of pairs of predicted and observed values, = weighting factors, and n = number of different state variables included in the reciprocal of the weighted normalized RMSE. Detailed description of auto-calibration method can be found in (Pelletier and Chapra, 2006).

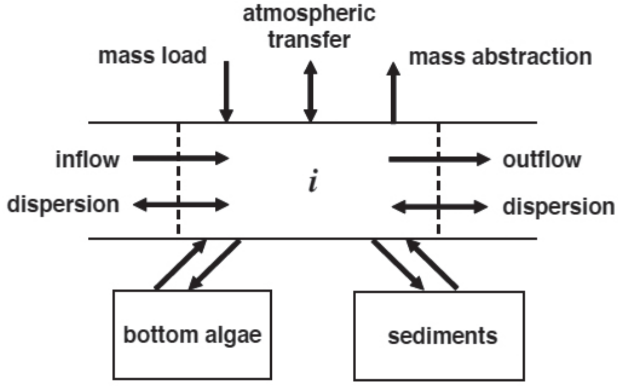


Figure 4. Mass balance in a reach segment i (Pelletier et al., 2006)

Model Simulation

The total selected 27 km length of the stream was segmented into 20 reaches with lengths equal to 1.35 km each. The measured data of winter and summer season were used to create the model. The calculation step was set at 11.25 min to assure more stability in the model. The solution of integration was done with Runge-Kutta's method since it is more accurate (Brent method for pH modeling). The hyporheic exchange simulation was chosen (No) to bypass calculation of mass transfer between the water column and the hyporheic pore water, and water quality kinetics in the hyporheic zone. The key parameters of Streeter Phelps equation (Reaeration, and Nitrification rates' coefficeints) were calculated according to the following equations:

$$K_r = Ku^a H^{-b} \qquad (3)$$

Where r K is the initial value of reaeration rate coefficient (d-1), K is a constant equal 2.148, u is the velocity (m/s), H is the depth (m),a is a constant equal 0.878, and b is a constant equal 1.48.

$$\frac{dD}{dt} = K_d L_o + K_N N - K_r D \qquad (4)$$

Where N K the nitrification rate (d-1), N is the ammonium concentration as nitrogen (mg/L), Kd is the deoxygenation rate coefficient (d-1), Lo is the ultimate BOD. D is the oxygen deficit (mg/L).

$$D = DO_{Sat.} - DO_{Meas.} \qquad (5)$$

Where DOSat. is the saturation dissolved oxygen level which is 9 mg/L at temperature of 20 oC, and DOMeas. is the measured dissolved oxygen (mg/L) for each location, and modified for altitude and temperature as 20 oC. Values of Kd and KN (Table 1) were determined by means of laboratory experiments according to Thomas graphical method (Cutrera et al., 1999). Kd values were averaged at 0.45 (d–1). Lo was calculated from measured BOD and Kd (Cutrera et al., 1999).

True reareation rate coefficients along the stream were determined by using the initial value in equation (3), and giving all other parameters of Streeter-Philips (Lo, N, Kd, KN, Do) model as known measured values, where Do is the deficit at the sampling point for the current situation as really measured or calculated for different segments of the stream (Fig. 2), and then calculating the DO values. Kr values were changed by trial and error to reach the actual value of DOMeas., providing the continuum principle of DO curve along the stream.

With initial estimates of some parameters and a manual calibration of others, the remaining parameters were then set within the auto-calibration algorithm using the fitness statistic by combining the normalized RMSE (Eq. 2). Each parameter was given a weighting factor to perform a good fitness and minimizing the error between measured and modeled parameter values. The weights for the parameters (Table 2) were determined by trial and error. To simulate water quality for future scenarios, the flow velocity and water depth are required, and so were calculated by using stream's bed geometry and Manning equation. It is hypothesized that each reach in the river is idealized as a trapezoidal channel. Under conditions of steady flow, the Manning equation can be used to express the relationship between flow and depth.

$$Q = \frac{S_\circ A}{np} \qquad (6)$$

Where Q is the stream's water flow; So is the bottom slope of a trapezoidal channel; n is the Manning roughness coefficient; P is the wetted perimeter.

Parameters	*DO*	*TN*	*TP*	*Temp.*	*CBOD*	*COD*	*pH*	*Others*
Weights	10	2	2	2	2	2	2	1

In order to test the ability of the calibrated model to predict water quality conditions under different conditions, the model was run using a complete different data set without changing the calibrated parameters. Then, the model was used to simulate water quality conditions during the critical period.

RESULTS AND DISCUSSION

The results for the water quality parameters for the (measurements on 16 February 2011) are shown in (Table 3). (Table 4) shows the (measurements on 24 September, 2012).

(Fig. 5) shows the measured DO values for the previous (2011) and current (2012) situation of Zimar stream, which in both situations, the western WWTP of Nablus is not functional. Curves are drawn to predict trend of DO levels along the stream.

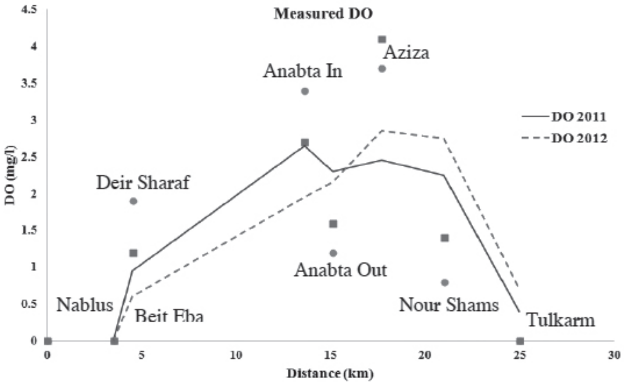


Figure 5. Measured DO values in (2011 and 2012) along Zimar Stream

Location	*Reaeration rate coefficient* $[K_d]$ (d^{-1})	*Nitrification rate coefficient* $[K_N]$ (d^{-1})	*Oxygen Deficit [D] (mg/L)*
Nablus	43.30	0.990	9
Beit Eba	102.42	0.990	9
Deir Sharaf	63.07	0.994	7.8
Anabta In	52.69	1.043	7.4
Anabta Out	47.02	0.594	6.3
Aziza	53.87	0.956	4.9
Nour Shams	65.66	0.938	7.6
Turkarm	36.26	1.024	9

Table 1. Streeter Phelps equation key parameters

Point	*Distance (km)*	*Flow* (m^3/s)	*Temp.* (c^0)	*pH*	*EC (µs/cm)*	*DO (mg/L)*	*TSS (mg/l)*	NH_4N *(mg/L)*	*BOD (mg/L)*	*COD (mg/l)*
1	0	0.214	18.3	9.3	1704	0	941	57.1	388	1333
2	3.5	0.167	17.2	8.3	1663	0	957	53.0	310	1301
3	4.5	0.201	16.1	8.8	1704	1.9	904	52.1	174	1127
4	13.6	0.160	17.1	8.9	1101	3.4	854	37.7	139	691
5	15.1	0.181	16.7	8.4	1208	1.2	744	43.3	150	803
6	17.7	0.210	17.2	7.9	889	3.7	510	39.2	113	710
7	21	0.181	18.1	8.2	940	0.8	648	44	171	812
8	25	0.251	17.9	8.8	1387	0	744	48.9	301	923

Table 3. Measurements on (16 February, 2011) along Zimar stream

Point	*Distance (km)*	*Flow* (m^3/s)	*Temp.* (c^0)	*pH*	*EC (µs/cm)*	*DO (mg/L)*	*TSS (mg/l)*	NH_4N *(mg/L)*	*BOD (mg/L)*	*COD (mg/l)*
1	0	0.193	20	9.1	1983	0	1231	63.7	409	1313
2	3.5	0.157	19.5	8.4	1863	0	1103	61.4	338	987
3	4.5	0.180	18.5	8.9	1859	1.2	1087	60.7	191	847
4	13.6	0.153	19.3	8.2	1346	2.7	804	43.9	111	519
5	15.1	0.173	18.4	8.8	1380	1.6	901	50.8	148	601
6	17.7	0.196	18.2	7.9	1130	4.1	684	37.4	104	417
7	21	0.178	19.9	8.3	1204	1.4	749	43.9	167	627
8	25	0.247	19.5	9.3	1694	0	981	57.4	288	894

Table 4. Measurements on (24 September, 2012) along Zimar stream

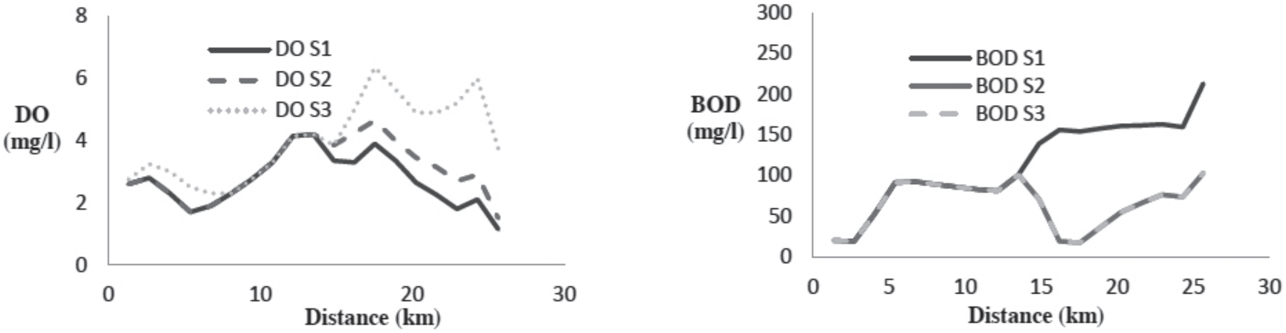


Figure 6. Modeling results of water quality parameters (DO and BOD) in Zimar stream for the current situation

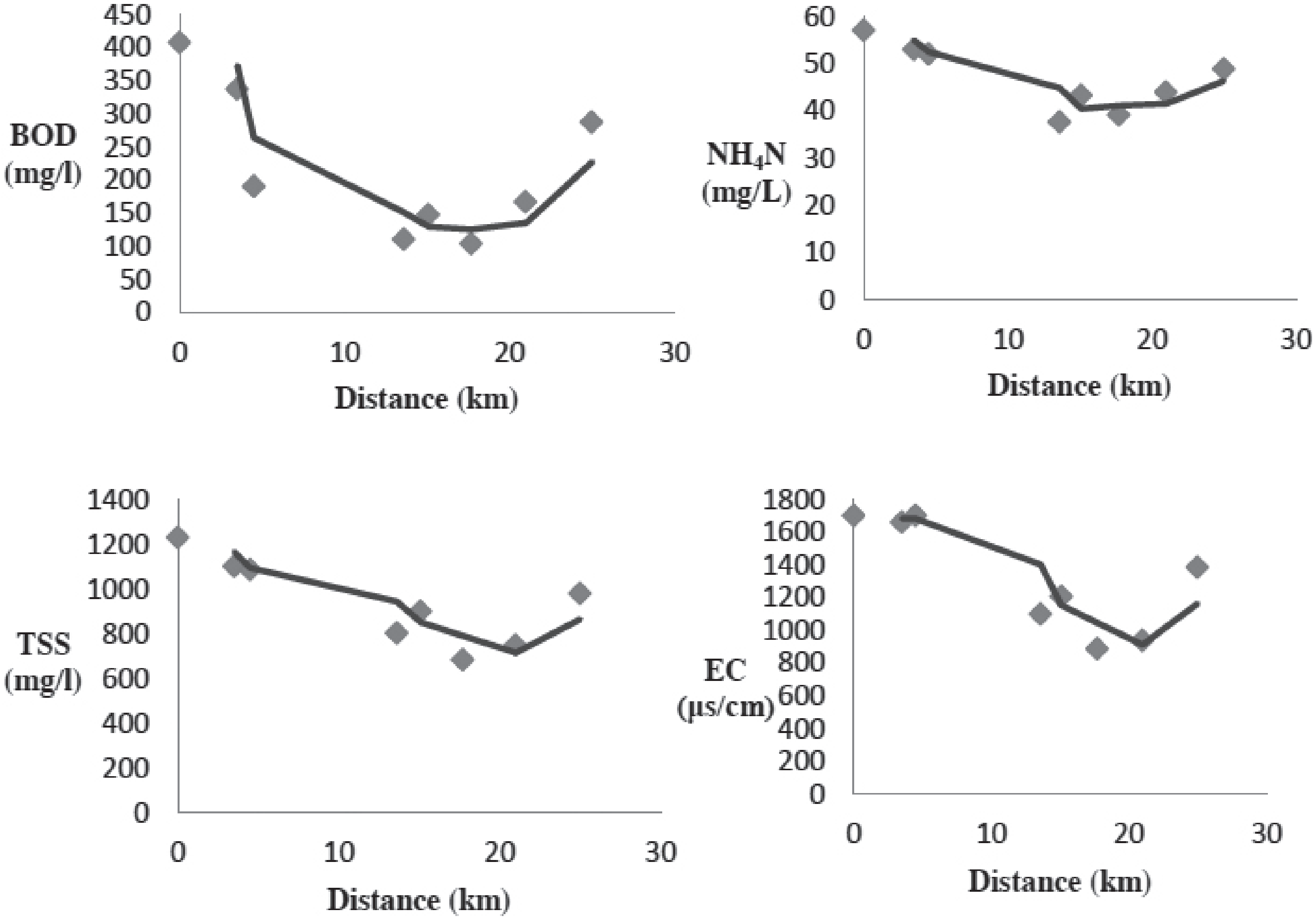


Figure 7. Calibration curves of the key water quality parameters in Zimar stream

The previous curves show that DO levels in the stream increase significantly when the stream passes through clean non urbanized areas which considered as sources for DO by reaereation. On the other hand the DO levels decreasing significantly when the stream passes through urbanized areas, which considered as sinks due to wastewater discharges. Increases in the DO level occurred at distances 4.5 km, 13.6 km, and 17.7 km. This is mainly due to the steepness of the stream across these locations that cause an increase in the velocity and so reaereation rates. The quality parameters did not meet any of the minimum Palestinian standards along the stream. However at location 6 (ahead of Aziza) DO increased up to 4 mg/L, and then decreased slightly due to discharge of wastewater from poultry slaughterhouse. Significant decrease in DO levels occurred at Nour Shams and continued through Tulkarem, and such behavior is attributed to discharges of wastewaters from agricultural activities, cars repair shops and light industries. Also the stream reaereation capacity is decreased due to the stream widening and reduced steepness of the stream (decrease in the water velocity).

Modeling and calibration

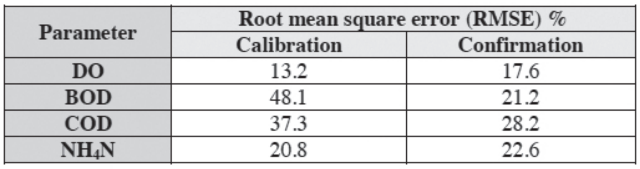
The modeling results (Fig. 6) showed a comparison between the current condition and three option-scenarios as future solutions for the stream. Scenario (S1) is after the operation of the western WWTP of Nablus which is already under construction. In this solution DO released form Nablus was assumed to be 2.5 mg/L and reached up to 4.7 mg/L just before Anabta village due to atmospheric reaeration. BOD levels acted exactly with the same pattern of DO with total self purification reached 11%.

Scenario (S2) is after construction and operation of additional WWTP at Anabta village (a foreseen future solution). In this solution DO released from Anabta WWTP also was assumed to be 2.5 mg/L, the model simulation was the same as in (S1) until it reached the new WWTP, from there DO reach up to 4.8 mg/L before it reaches the poultry factory (Aziza). Self purification lowered the BOD levels by 5.5% from the assumed value (20 mg/L) that will be released from Anabta WWTP.

Scenario (S3) was adding three artificial weirs along with the two suggested WWTPs in (S1 and S2). The locations of the weirs are (Nablus 1.35 km), (Anabta 16.35 km) (Nour Shams 17.7 km). Results showed that DO levels increased up to 6.7 mg/L and 6.2 mg/L. On the other hand, BOD levels did not noticeably change. From Fig. 6, it is clear that the BOD curves in (S2 and S3) are exactly the same. Flow over weirs generates high oxygenation by air mixing (Campolo et al., 2002). The DO produced in the stream was calculated by an empirical equation relating the DO deficit above and below the weir to the geometrical properties of the weir, weir type, quality of water and water temperature (Butts and Evans, 1983). 1 m high weirs were assumed.

In the confirmation (Table 5), RMSE (between assumed and modeled) for some of the stream quality parameters was calculated using equation (2). Fig. 7 shows the calibration curves for some of the parameters.

Despite of some mistakes and errors, the modeling results were somehow satisfying to reach reasonable management goals taking in consideration the lack a data in such developing country, and financial resources were extremely limited which prevented conducting some important tests and measures. However, greater accuracy could be achieved through devoting additional monitoring and measuring on longer and more successive field visits. Using more sophisticated models taking in consideration 2D or 3D could enhance the accuracy and reliability of the results.



Parameter	Root mean square error (RMSE) %	
	Calibration	Confirmation
DO	13.2	17.6
BOD	48.1	21.2
COD	37.3	28.2
NH_4N	20.8	22.6

Table 5. Root mean squared errors (RSME) for predicted vs. measured water quality parameters

CONCLUSION

The model was built to simulate different scenarios with different situations including wet and dry seasons. In all modeled cases, high sensitivity of DO values to reaeration and nitrification rates were detected. Low sensitivity of DO values was detected for pH, COD and TSS.

Special attention should be drawn to three critical locations along the stream (Beit Eba, Anabta, and Aziza). These three locations affected the stream quality parameters severely. As for Beit Eba. It affected the stream through the industrial activities (Stone cutting) which increased the suspended and dissolved solids. As for Anabta, the considerable flow of untreated wastewater produced by more than 8,000 citizens (PCBS, 2007) spilled directly in the stream lowered the DO level and increased the BOD. As for Aziza poultry factory, it is clear that the high organic wastewater produced from it, is polluting the stream which decreasing the DO and increased the BOD.

Measured quality parameters showed a proof on the considerable capacity of the stream self purification and natural restoration without any human interference. As for the future-modeled scenarios (installation of two WWTPs and weirs), DO increased to 6.7 mg/L which surpassed the critical value of 5 mg/L. Applying these solutions could produce high quality stream water that could be reused in some industries in the area such as stone cutting, and agricultural irrigation of more than 458 ha of irrigable lands in the catchment.

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REFERENCES

[1] PWA (2013). Assessment of Acquired Regional Experience on Wastewater Treatment , Reuse and Sludge Management. Palestinian Water Authority. Al-Bireh, Palestine.

[2] Optimisation for Sustainable Water Resources Management. The Alexander River – Wadi Zeimar Basin (OPTIMA). Israel–Palestine. 2007.

[3] Arabtech Jardaneh Engineers & Architects / Palestine (AJ), 2008. Regional Wastewater Disposal Tulkarem - Consultancy Services for Review of Feasibility Study (DRAFT).

[4] PCBS. (2007). Publications. Retrieved July 2013, from Palestinian Central Bureau of Statistics: http://www.pcbs.gov.ps/pcbs_2012/Publications.aspx

[5] Masten, S., Davis, M. Principles of Environmental Engineering and Science 3rd Edition. New York, USA. Irwin/McGraw-Hill. 2012

[6] Chin, D.: WATER-QUALITY ENGINEERING. 1st Eidition. New Jersey, USA. John Wiley & Sons, Inc., Hoboken. 2012

[7] Thomann, R. V., Mueller, J.A., 1987. Princibles of Surface Water Quality Modeling and Control. Harper-Collins, New York.

[8] Pelletier, G.J., Chapra, S.C., QUAL2Kw theory and documentation (version 5.1), A Modeling Framework for Simulating River and Stream Water Quality, retrieved 10 May 2005 from: http://www.ecy.wa.gov/programs/eap/ models/.

[9] Ecosystems Research, A. G. (2013, January 10). Water Quality Models. Retrieved July 02, 2013, from EPA United States

Environmental Protection Agency: http://www.epa.gov/athens/wwqtsc/html/water_quality_models.html

[10] Sulieman, S. Environmental Flow Regime for Wadi Zomar. Ramallah: Birzeit University. 2010. 105 P.

[11] Hasan, J., Abu Mohsen, N., Isleem, Y. Graduation Project. Water Quality of Wadi Al-Zeimar. Under the supervision of A.R. Hasan. Nablus: An Najah National University. 2010. 63 P.

[12] Optimisation for Sustainable Water Resources Management (OPTIMA). The Alexander River – Wadi Zeimar Basin Palestinian Israeli Case Study. Israel – Palestine. 2004.

[13] Municipality, N. (2013). Water and sanitation directorate projects. Retrieved July 2013, from Nablus Municipality Website: http://www.nablus.org/upload/water.pdf

[14] Michaud, J.P., 1991. A Citizens' Guide to Understanding and Monitoring Lakes and -Streams, retrieved 15 July 2013 from: https://fortress.wa.gov/ecy/publications/publications/94149.pdf

[15] APHA-AWWA-WPCF, 2005. Standard Methods for Examination of Water and Wastewater, 19th ed. American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, DC.

[16] Pelletier, G.J., Chapra, C.S., Tao, H., 2006. QUAL2Kw, A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environ. Model. Software 21, 419–4125.

[17] Cutrera, G., Liliana, M., Valle, C., and González, J., Short communication On the determination of the kinetic parameters for the BOD test. Water SA Vol. 25 No. 3, 1999/ 03770380-

[18] Campolo M., Andreussi P., Soldati A., 2002. Water quality control in the river Arno, technical note. Water Res. 36, 2673–2680.

[19] Butts, T.A., Evans, R.L., 1983. Effects of Channel Dams on Dissolved Oxygen Concentrations in Northeast Illinois Streams, Circular 132. State of Illinois, Department of Reg. and Educ., Illinois Water Survey, Urbana, IL.