Quality study of wastewater treated by Waste Water Treatment Plant (WWTP) in the city of Sana'a (Yemen) used for agriculture.

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Abstract
The wastewater treated by the PWTS Sanaa (Yemen), are discharged into Wadi Bani Houat to be used for irrigation of agricultural fields (cereals and "qat"). The quality of water discharged by the station is affected by neo-contamination part of untreated water diverted through bypass and also untreated effluent intake of a river that flows into the canal about 15 Km from the station. The various measurements show that the levels of contaminants studied, decrease at the exit of the station but undergo severe degradation after canal-branch river. Similarly, we noted illegal contributions at this place made of waste thrown into the canal by the surrounding population. The salinity is classified C4S2, C3S3, C4S3 and C4S4 in RICHARDS diagram, leading to poor quality water for irrigation. The ratio COD / BOD5 reaching a value of 2 after treatment and self purification of water, up to a value of 4, at a distance of 12 km along the canal before dropping to a value below 2 at the areas of retention dams located north of the study area, showing a self-purification capacity. NO_2^- (nitrite ions) appear downstream canal in the dams, highlighting the impact of agricultural activity on water quality. Minors cations and traces show different concentrations varying spatially and temporally along the canal during the dry and wet seasons. Overruns by FAO and Yemen standards were observed for some components such as phenol, organic micropolluant showing levels higher than standard along the canal in all seasons. The principal component analysis showed the correlation between the measured quantities and the vulnerability of sampling sites to different pollutants.

Keywords: *Irrigation, Wastewater, Pollutants, PWTS Sanaa (Yemen), Agriculture.*

1. Introduction

Yemen is among the countries of the Middle East experiencing water scarcity and suffering from regular droughts and water stress. (Mean Annual rainfall = 198 mm with 87% between June and September). The climate is semi-arid to arid with irregularities in precipitation and periods of intense and persistent droughts. The renewable water resources are estimated at 4.100 million m^3/year, of which about 2.575 million m^3/year for surface waters. It is estimated that the amount of water available per capita is only 125 m^3/capita/year, which represents a little more than a tenth of the critical level of water stress commonly estimated to 1000m^3/capita/year. This volume which was approximately 150 m^3/capita/year in 2014 [1], has decreased as a result of the very rapid and uncontrolled exploitation of the country's water resources. Indeed, the city of Sana'a, capital of Yemen, has experienced rapid urbanization and industrial development booming. This was accompanied by a very large demand of water for human consumption, for industry and for agriculture. Agriculture is considered as the main consumer of water with a total consumption rate of about 60% of total water resources [2]. The consequence of this socio-economic development is an increase in both wastewater flows discharged and high degree of pollution of surface water, groundwater and environment. The treatment station wastewater in the city of Sana'a is functional since 2000, designed for a capacity of about 50.000 m^3/d. In 2006, it had reached 43.000 m^3/d [3], now it cannot handle more 70% of the flow discharged through the sewerage system of the city of Sana'a, the remaining 30% are discharged directly into the river Bani Houat downstream from the treatment station by bypass, specially during the rainy season with increase of flow rate. The waste water partially treated by the station, then cross the Sana'a basin through a canal up to three dams located to the North East of the treatment plant: Al-Masham, Al-Mosyreka and Al - Samena [4]. On the 20 Km canal, water is used to irrigate adjacent fields located as far away as 5 km. In 2006, as much as 40% of the total area of the basin of the river Bani Houat is invested in agricultural activity [5]. About 95% of water used for irrigation is taken from the canal, the remaining 5% comes from confined aquifers locally (artesian wells) [4,6]. The canal has a width about 2.5 meters and a depth of 0.5 m. It runs through areas where the geology is complex with major faults, volcanic rocks and limestone outcrops [7].

According to the National Agency of Water Resource, the quality of the effluent leaving the PWTS, is usually below standards for discharges set by the Yemeni authorities [8-9]. The treated wastewater crosses areas intensively used by humans, therefore it is clearly important to study water quality used for irrigation in order to assess the potential risks that might result from the health of the surrounding population. In this context, this work highlights the hydrochemical study of these waters both spatially and temporally and makes a complete diagnostic on the various potential contaminants.

2. Method and materials

The study which has been carried out, took place over a period of one year from April 2013 to March 2014, with a sampling frequency every 3 months, corresponding to a total of 28 samples taken at 7 stations distributed from upstream to downstream. Two campaigns has taken place during the wet season and two during the dry season. Stations downstream from SO1 and SO2 are directly exposed to releases both cleared wastewater coming from the treatment station Sanaa and surplus of untreated raw sewage flowing into the river by the bypass. The stations BO1, BO2 and BO3 represent reservoirs (dams) and their water is used for agriculture and livestock watering. We followed several parameters during the dry and wet seasons: pH, T, electrical conductivity. Chemical oxygen demand: COD, biological oxygen demand after five days BOD5, the major, minor and trace cations, agricultural pollution, toxic organic pollution, etc ... The results presented correspond to the average values per season for each parameter measured at each station. The physicochemical parameters (electrical conductivity, pH) were measured in situ. The dissolved oxygen content was measured by the method of Winkler kind OXI 2000 Uklovibond. For suspended solids (SS), the filtration was performed on porous membrane of 0.45 micrometer and then drying at 105°C. The chemical oxygen demand (COD) was analyzed by oxydation in excess with potassium dichromate under acidic conditions at 150°C (Standard method). The BOD5 was evaluated by the method gauge, based on the principle of Warburg (AFNOR T90-103). Phosphates were dosed according to the 8178 method called active phosphorus adapted from Standard Methods for the Examination of Water and Wastewater (0 to 30.00 mg / L). For nitrogen compounds, the measurement was performed using a portable spectrophotometer DOTAL ogying- HACH DR / 4000. The dosage of the nitrate ions (NO_3^-) was made by the method 8507 based on chromotropic acid, Test 'N Tube (Source: Hach, 4000). The analytical method is the reduction of the nitrate to nitrite under acidic conditions. These form a yellow azo orange coloring. The measurement was performed using a portable spectrophotometer Dotalogying- HACH DR / 4000. For ammonium ions (NH_4^+), the dosing is based on the reaction of ammonium ions with chlorine under alkaline conditions to form monochloramine. Combined with thymol, this forms a blue indophenol dye. (Kit Spectroquant Merck .14752.0002). Several approaches have been adopted to assess the quality of the treated water of the canal and its use to irrigate fields of crops and livestock watering.

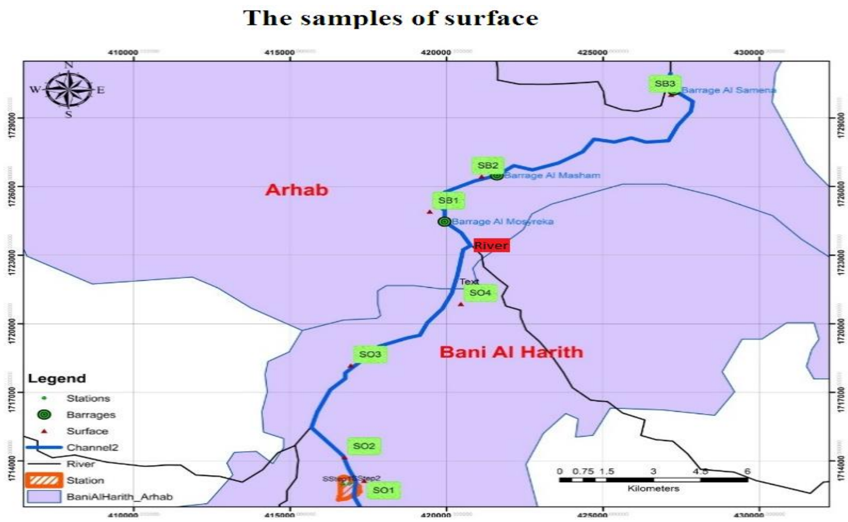

Figure1. Location Map of the various stations studied in the river Bani Houat.

3. Discussion and results

3.1. Determination of hydrochemical facies

The Piper diagram (Fig. 2) shows waters with a dominant chemical facies sodium bicarbonate for both rain and dry seasons.

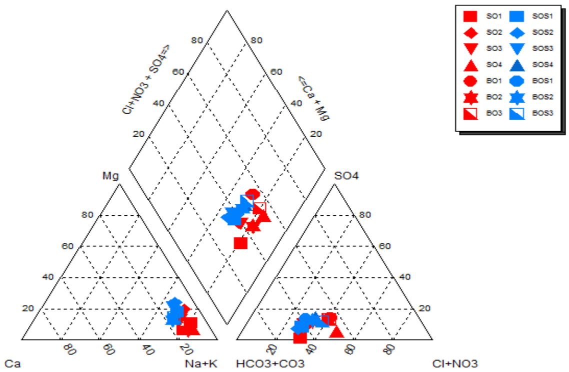

Figure 2. Piper Diagram : hydrochemical facies of the Wadi Bani Houat water.

We do not see significant fluctuations affecting the hydrochemical facies of the water (Fig. 3). Similarly, the dilution effect by rain does not modify the composition of water, despite the decrease of conductivity in rainy season (lower than 30 % measured during dry season in dams). A slight increase in the concentration of sodium during the rainy season is correlated with a decrease of hydrogen carbonate. The excess Na^+ ions during wet season not linked to Cl^- appear to be from rainfall and possibly from surface soil lixiviation over the watershed which accumulate salts by evaporating process of rain water during the dry season [10].

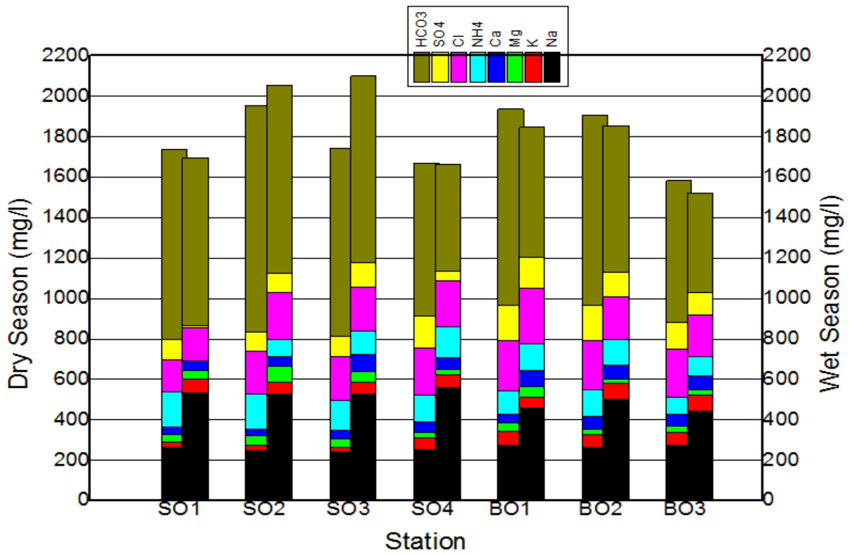

Figure 3. Concentration of major elements (mg / L) along the canal.

3.2. State Quality Sampling for an agricultural use

To evaluate the water quality of the river Beni Houat used to irrigate nearby fields, we used PIPER diagram for determining the hydrochemical facies firstly, and secondly the Wilcox diagram [11] and the diagram of "Riverside" Richards [12], to understand the risk of salinization and soil sodication. The water salinity is estimated by electrical conductivity, the RSC residual sodium carbonate, and sodium absorption index (SAI) or "polarizing power" SAI and Na% represents the percentage of sodium in mEq/L, relative to the sum of the major cations (Ca^{2+}, Mg^{2+}, K^+, Na^+). Eaton [13] showed that the Residual Sodium Carbonate

($RSC = \left[HCO_3^- + CO_3^{2-} \right] - \left[Ca^{2+} + Mg^{2+} \right]$, expressed as mEq / L) helps assess the risk of salinization and sodication for irrigated soils (RCS of irrigation water should have a value of 1). If RSC is negative, we add on the ionic balance sulfate ions ($RSC' = \left[HCO_3^- + CO_3^{2-} + SO_4^{2-} \right] - \left[Ca^{2+} + Mg^{2+} \right]$, determining water with risk sodication (RCS' > 0 - "neutral salt water chlorinated dominance"), for water without this risk (RSC < 0 - "neutral saline water sulfated dominance") [14]. In our case RSC is strongly positive (Fig. 4), showing a risk of high salinity in sodic dominance for irrigation water fron canal and contributes to the deterioration of the soil which is accentuated during the rainy season. Water samplings represented on Richards diagram (fig.5) are divided into the following classes:

• During the dry season, only the C4S2 class is represented, suggesting a poor quality, and highly mineralized irrigation water, which is suitable only for salt tolerant plants and soil well drained and washed.

• During the wet season , three classes, C3S3 , C4S3 and C4S4 are represented, which denote a poor quality water for irrigation and showing a high risk of salinity with an use under conditions of good drainage to prevent the deposition of salts in surface and in unsaturated zone and with salt tolerant crops [15]. Plants badly supporting the sodium saturated soils [16], the quality of water samples was also assessed using the WILCOX diagram, based on the relationship between electrical conductivity and % Na^+ ions. (Fig. 6). The different waters sampled show a poor quality for agricultural use in particular for the samples taken during the rainy season. Our results agree with another work by other authors [17] who concluded that the removal of salts by treatment at the PWTS was very limited. Mean concentrations very high remaining in the treated effluent.

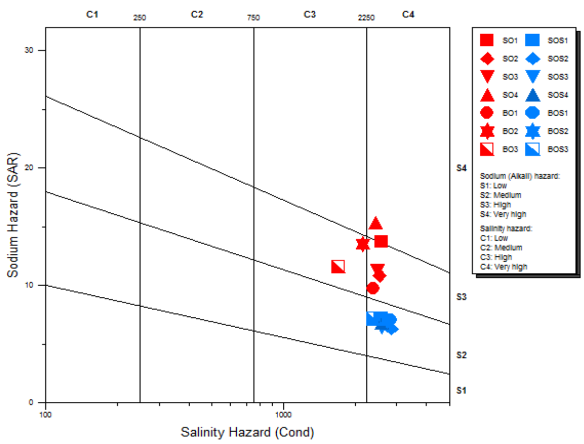

Figure 5. Canal's waters representation from RICHARDS diagram (Riverside).

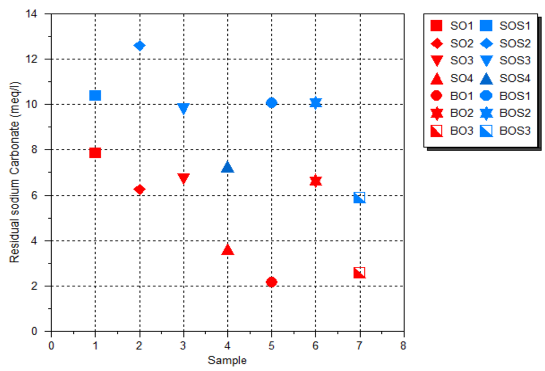

Figure 4. Residual sodium carbonate concentration (mEq/L) along the canal.

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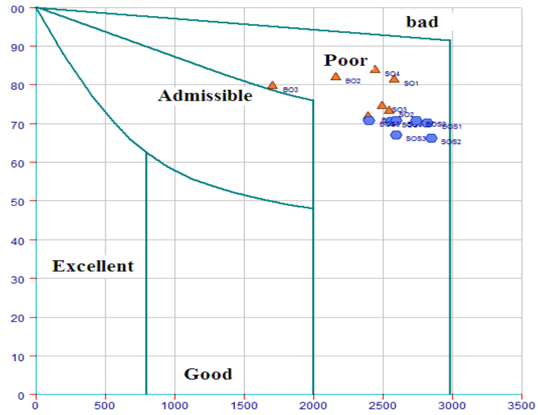

Figure 6. Canal's waters representation from the WILCOX diagram.

3.3. Water Pollution Level

Oxygen is essential to aquatic organisms; hypoxias can be fatal. To assess the state of hypoxia in the water of the river, we determined the concentration of dissolved oxygen (DO) in the water. Dissolved oxygen in water comes mainly from the atmosphere and photosynthesis of aquatic plants. For a concentration smaller than 1mg / L the survival of all species, even in the short term, is threatened. The ionic strength of the water also affects the amount of O_2 can be dissolved in water [18-19], it decreases with increase of water salinity. The low values of dissolved oxygen concentrations in the water induces a reduction of iron, manganese and phosphorus, and therefore a re-solubilization of these elements. It can also cause the reduction of nitrate to ammonium or ammonia. In summer, it is rather expected a deoxygenation of the water body (eutrophication, water reduction, anaerobic bacterial proliferation ...) can accelerate the release from sediments of elements such as phosphorus, ammonia nitrogen, iron and manganese, however, the results do not show significant variation between the two seasons (<0.2 mg / L) exept for the furthest point from PWTS in the north (0.45 mg / L in rainy season), which could be linked to weaker stagnation of water in rainy season in this dam. However the amount of oxygen dissolved in water, remain still very low in both seasons below favorable oxidation conditions. The organic materials in water also have an influence on the OD upon degradation; they consume oxygen dissolved in water. If they are too prolific, they can cause suffocation of aquatic organisms. The degree of water pollution may be expressed as biochemical oxygen demand over 5 days (BOD5) and the chemical oxygen demand (COD). FIG. 7 shows the contents of dissolved oxygen in water, the BOD5 and COD according to the sampling position relative to the PWTS. Output of the PWTS, the values of COD and BOD5 are clearly above the threshold required by the guidelines of the FAO and the Yemeni standard (fig. 7). The PWTS shows no specific or effective treatment in reducing carbonaceous substances in suspension. As soon as one moves away from the station, a net decrease of COD and BOD5 whether in wet or dry season is observed with values below the standard, possibly due to more deposit process to the bottom of the canal than the oxidation of organic matter, because of low dissolved oxygen measurements recorded along the canal. However, after SO4 is noted an increase of organic matter in water. This deterioration of water is more important in the dry season, linked to the contributions of the river entering the canal to more or less 15 Km from the PWTS. The water of this river which is untreated, is loaded with any kind of pollution, particularly illegal residues from local avian activity or other origins.

This high anthropogenic activity which consists of solid and liquid waste goes directly into the lake. The largest increase of the COD and BOD5, observed in dry season, could be due to the combination of two parameters, firstly the load carried by the river and untreated discharges, and secondly the water evaporation. We observed eutrophication in water pockets in the canal during the dry season which also limits the self-epuration process. The ratio COD / BOD5 (Fig. 8) gives a first estimate of the organic matter biodegradability for a given effluent. At the plant's inlet, effluents show a ratio COD/BOD5 between 1.66 and 2 [17], describing a readily biodegradable effluent [20]. Raw wastewaters flowing to the PWTS are higly contaminanted in inorganic pollution and in organic matter [17]. Out of the treatment station the ratio COD / BOD5 of the effluent remains below 2.5, nearly identically to ratio at the PWTS's inlet. Then, the ratio COD / BOD5 deteriorates along the first twelve kilometers of the canal to reach, at SO4, a value of "4", showing a weak biodegradability of the effluents. As the values of BOD and COD are low, there is the end of biodegradation process and depositing of the OM, the remaining carbonaceous materials are less readily biodegradable. With the input from the river after SO4, which increases in the content of MO, the process of biodegradation and deposit can continue, particularly in the dams, where stagnant water promotes a self-cleaning by the growth of microorganisms improving again the quality of the water with a COD / BOD5 value close to 2 [21-22-23-24]

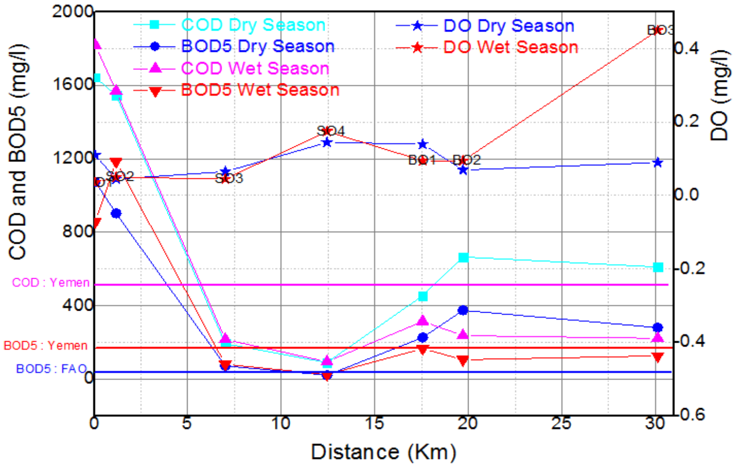

Figure 7. Monitoring the oxygenation state of the canal.'s waters.

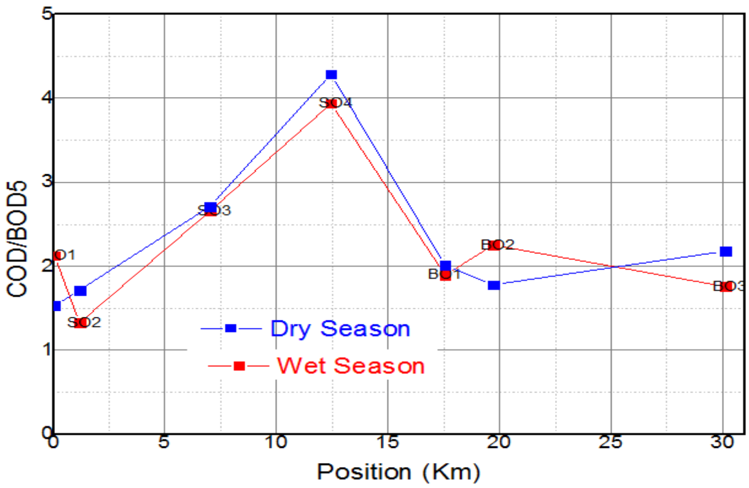

Figure 8. Evolution of COD/BOD5 ratio from PTWS to dams.

3.4. Agricultural pollution

Although the amount of nitrates and phosphates found in the different samples exceed the maximum value tolerated by the Yemeni standard (30 mg / L), the agricultural activity along the two banks of the canal does not seem to increase overall concentrations in water (fig. 9).

We note the presence of NO_2^- in rivers at level of the last dams. Nitrites appearing in densely populated areas or intensive agriculture, are often marker of water downgrading. They are issue during nitrogen compounds degradation by bacteria "Nitrosomas" in biological filtration [25].

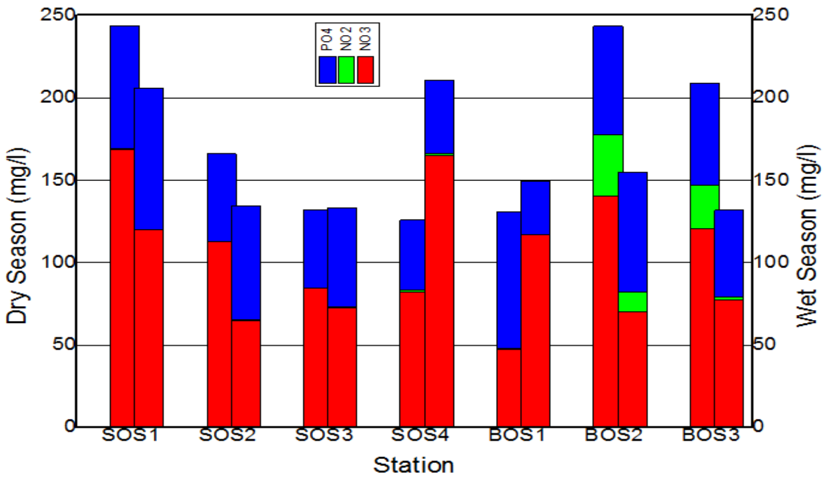

Figure 9. Concentration evolution of agricultural contamination along the canal.

3.5. Minor cations

The averaged results of minor cationic elements (trace) are shown in Table 1. In the same table, are given the maximum permissible values concerning waste water used for irrigation according to the FAO guidelines [26-27] and the Yemeni standard established in 2001. The different cations are of varying usefulness to plants growth. Mn and Fe are attractive for plants and does not pose any specific health problems. Pb, Sn, Cr Se and Al are useless for plants but do not present toxicity to humans. Cu, Mo and Zn are an interesting addition to the plants, but toxic to humans above a certain threshold. As, Ni and Cd are not a good source for plants and present a health problem at a low level value [28]. For some elements, values required by the standards for the use of water in agriculture are in excess. The behavior of these different traces varies according to station and the seasonality. Some elements exceed the standards throughout the year, others only during the dry season or the rainy period. The diversity of the observed phenomenon can be interpreted by the processes of leaching and sedimentation. During the rainy season, deposits on the roads of the city of Sanae are drained by the sewer system to the PWTS. In water solubles may have different speciation for a given ion. When the concentration of ionic species dissolved in water allows the saturation of the corresponding salts, they form solid compounds settling out or aggregating to suspended solids. Then the water waste flow entering the PWTS during the dry can present some unobserved elements or in very small quantities. For elements released in excess directly into the sewerage system, they are observed throughout the year with a dilution process typically found during the rainy season. The concentration of dissolved ions increases with evaporation of the water in relationship with the elevation of the temperature and humidity.

Table 1. Analysis of minor cationic elements along the canal.

	alcali metal	Alcali earth		transition metal										metal				Non metal	
	Li	Sr	Ba	V	Cr	Mn	Fe	Co	Ni	Cu	Mo	Cd	Zn	Al	Sn	Se	Pb	As	B
FAO*				100	100			50	500	200	10	10	2000			20	5000	100	
YEM**				100	100	200	5000	50	200	200	10	10	2000	5000		20	5000	100	2000
SO1	4.99	580.4	115.2	155.1	367.3	190.2	8977	59.66	214.5	77.63	368.8	48.88	643.1	9418	2244	94.9	437.8	407.7	219.1
SO2	4.28	510.4	101.6	142.7	410.1	114.5	2194	295.9	187.4	75.65	2054.	44.42	258.1	1568	6530	110.6	1209.	445.4	178.9
SO3	49.83	506.3	143.2	290.4	619.95	178.6	5272	241.9	346.7	97.02	855.4	216.1	1091	4879	419.0	182.8	892.0	416.9	175.9
SO4	7.17	515.2	79.47	30.17	640.1	167.2	1353	13.33	64.65	35.81	1839.	66.95	288.0	1800	5793.	128.9	1696	233.4	174.4
BO1	13.24	487.1	35.58	90.28	291.2	86.33	724.0	91.24	947.6	28.78	306.3	62.58	110.1	525.4	1344	200.7	1722	113.7	166.0
BO2	13.13	459.4	28.6	131.5	306.0	87.99	1119.	233.5	164.5	77.42	466.1	0	178.7	946.2	3819.	371.3	32.7	1044.	151.3
BO3	12.56	487.8	96.26	504.7	418.5	79.95	228.1	506.1	11.04	75.63	476.4	66.32	108.8	739.7	271.1	489.6	156.4	32.44	346.5
SOS1	48.66	473.7	153.5	67.22	64.9	289.6	7954	11.37	55.52	36.92	63.01	3.93	458.4	32227	2641	35.63	82.99	52.63	356.4
SOS2	52.22	397.5	236.5	5.92	75.55	338.4	8497	5.16	76.02	205.7	1370	3.2	775.6	10259	417.7	47.51	453.9	48.5	329.5
SOS3	48.96	361.1	177.3	7.01	56.31	201.2	3533	10.46	79.6	68.54	2396	2.38	605.4	3157	2803	47.4	84.53	45.77	325.0
SOS4	5.8	179.0	279.6	9.32	67.12	367.1	2562	2.46	64.63	36.89	5385	5.83	1574	9207	4165	913.5	332.7	327.0	131.0
BOS1	2.42	159.5	83.91	1.33	26.61	70.08	809.7	3.46	43.26	20.4	2083	2.14	128.8	61083	2117	12.85	15.81	15.81	21.76
BOS2	4.25	124.2	110.3	3.95	38.87	341.3	1155	4.14	36.31	16.23	1037	0.36	140.4	52516	2197	28.61	16.49	1.78	84.17
BOS3	4.16	137.6	106.2	73.97	43.07	67.29	1649	3.38	102.6	21.01	11.49	1.26	411.0	22576	1910	409.9	331.0	7.95	45.54

Yellow: limit values in water for irrigation use (Yemeni Standards (**)).
(*) Guidelines for the interpretation of the quality of irrigation water according to FAO.

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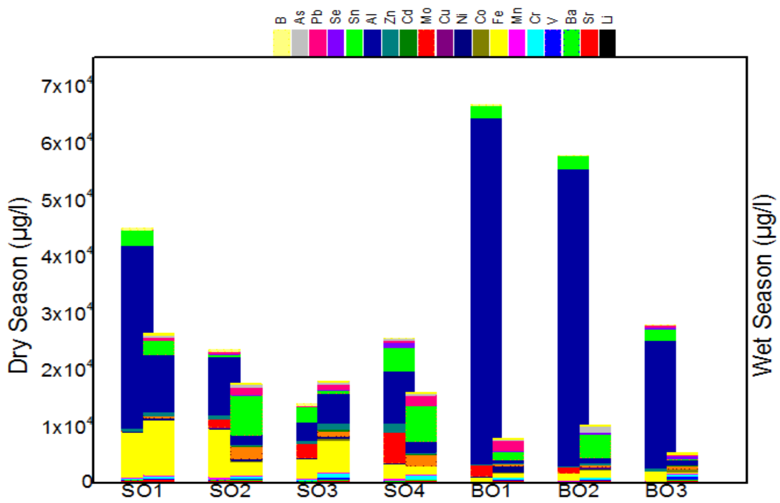

Figure 10. Distribution of minor cations along the canal.

Figure 10 shows the wide variation in mass of minor elements to the different sampling sites during the wet and dry phases. The concentration of minor elements vary from one season to another, it is lower during the rainy season by dilution effect. During the wet season, the amount of trace element is high in water leaving the treatment plant, then the concentration decrease with time and distance from the PWTS. During the dry period, the Al concentration drop out between PWTS and SO4. When the untreated river joins the canal, Al shows higher concentration, and increase in the three dams by a factor reaching 3.5. The Fe concentration is a little lower than Al at the outlet of the PWTS and decreases overall farther away during both dry or wet season.

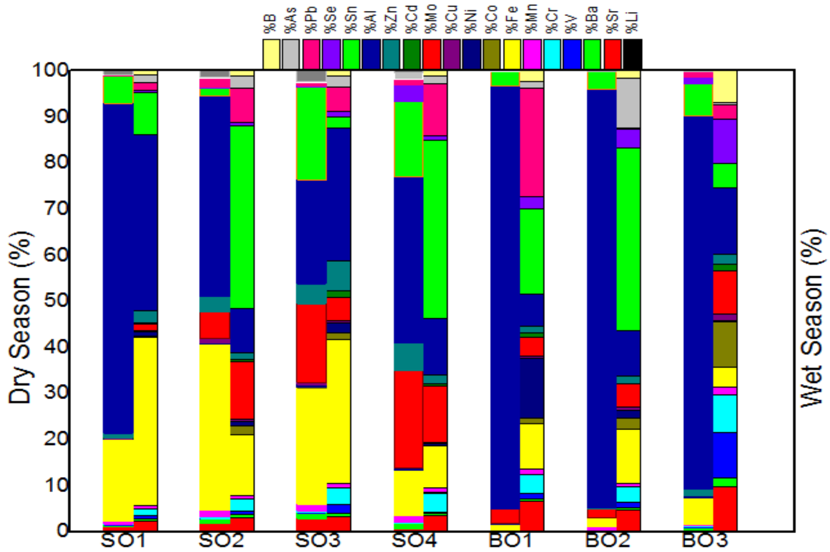

Figure 11. Values in % relative to the total concentration of minor elements; [Xi] / Sum ([Xi]) * 100).

The presence of Fe and Al in water leaving the PWTS can be interpreted by the use of polymers or inorganic salts with Fe and Al, used in the aggregation of colloids process for flocculate suspended matter On the contrary, the Al content increasing observed in the dams during the dry season can only be interpreted as a concentration process, due to the stagnation and the evaporation of water. Fe and Mn are primarily from urban waste generated by domestic wastewater discharged into the receiver without preliminary treatment and agricultural waste (animal manure and chemical fertilizers) [29]. The percentage of concentration for each component depending on the total concentration of minor elements analyzed is given in Figure 11. The abundance comparison of one element relative to the total concentration shows a high variability in water composition in both seasons and a change in the water quality during flowing in the canal until the last dam.

3.6. Suspended load in water

The suspended matter in the treated water is about 100 mg / L in the dams. It is higher at the outlet's plant (500 to 700 mg / L depending on the season) with a sharp drop between SO1 and SO2 (content from 300 to 350 mg / L), followed by a gradual decrease until the first dam. The influence of rain or dry season does not appear on the graph (Fig. 12). The values we found are consistent with those given by Raweh [30].

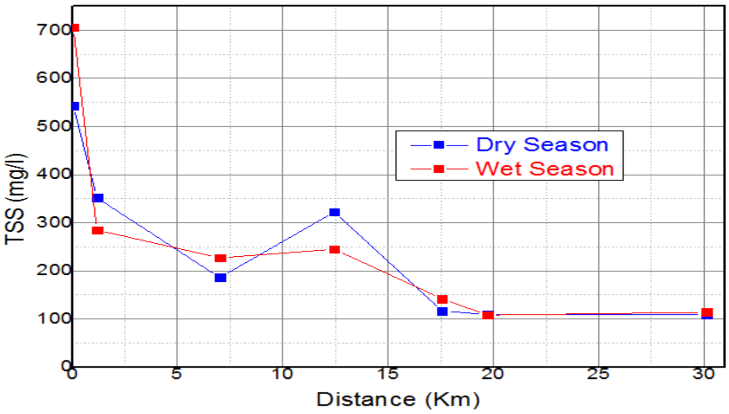

Figure 12. Evolution of the amount of suspended matter along the canal.

3.7. Solid residues in water

When water is evaporated at 105°C, the ions dissolved forming salts and suspended matter represent the solid residue to dryness (SRD). The obtained SRD must be correlated to the conductivity value of withdrawals and the mass sum of dissolved ions. Electrical conductivity is an important parameter in hydrology; its variation is linked, at constant temperature, to the changes in the water mineralization [31-32]. The variation of the different curves show essentially the same tendency (fig. 13). The correlation between the mass of the ions, the conductivity and SRD remains good, showing the discharged water does not contain too suspended matter (SM) would distort the relationship Conductivity / SRD (fig. 14). The electrical conductivity, higher during the dry season increases with the amount of the solid residue and the total mass of dissolved ions. The contribution of rain does not benefit the dissolution of minerals by soil erosion of watershed and transportation to the canal, only a dilution effect remains dominant.

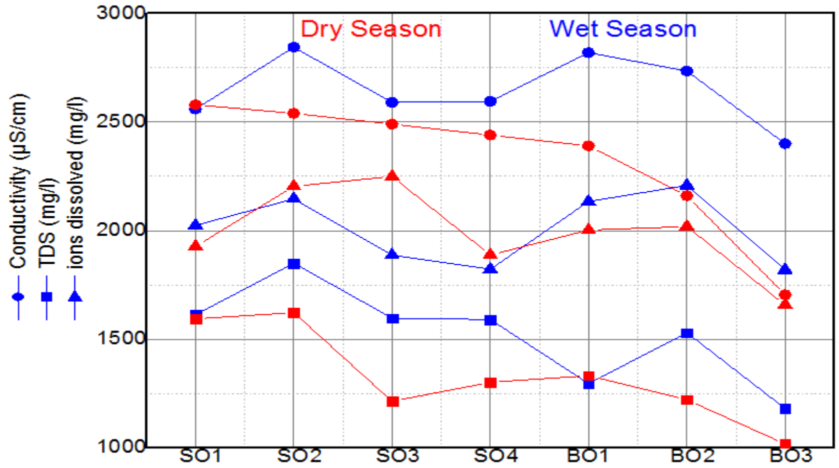

Figure 13. Evolution of electrical conductivity, TDS and residual mass after drying along the canal.

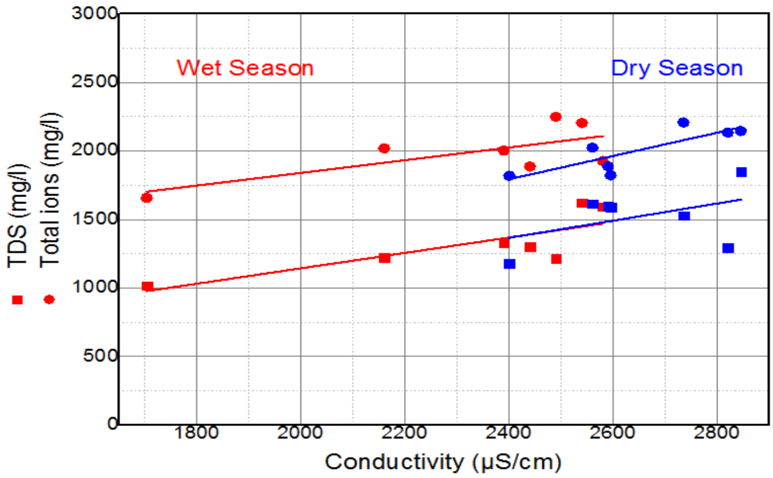

Figure 14. Correlation between TDS and electrical conductivity.

3.8. Pollution by toxic organic compounds

The water contamination by cyanuric ions does not exceed the usage limit along the watercourse and for the both seasons (Fig. 15). For against, the amount of phenol presents in the canal exceeds the limit required by the standard (Fig. 15). Phenol and derivatives are considered by the Environmental Protection Agency as major pollutants [33] but can be removed by physico -chemical techniques and biological treatments.

It is observed that the amount of phenol in particular at the SO4 station and in the last two dams is highert during the rainy season. Biodegradation is a major process to remove phenol in water [34]. Another process for surface waters is the sun, boosting the photo oxylation where phenol reacts with hydroxyl and peroxyl radicals and singlet oxygen [35]. So it seems during the dry season, especially on stagnant surface water, degradation of phenol is faster.

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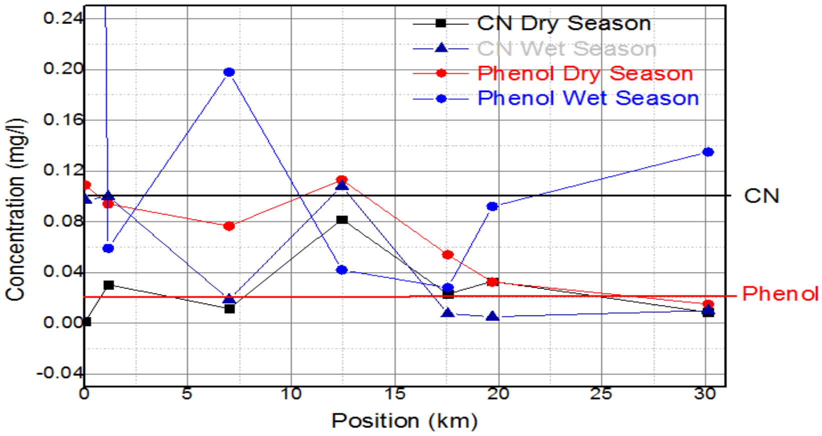

Figure 15. Evolution of organic pollution along the canal.

3.9. Principal Component Analysis (PCA)

PCA is typically used to reduce the number of dimensions in a data matrix, and to study the correlation between data. To simplify interpretation, for the wet season data, we keep three factors accounting for a total variance of 84% and for the dry season two factors, representing 72% of the total variance (Table 2, 3). For the wet season, the first factor (44.63% of the total variance) corresponds to NO_3^-, COD, BOD5 and CN$^-$, associated to pollution process, the second factor (21.30% of the total variance), corresponds to NH_4^+ and NO_2^- related to nitrogen pollution and the third factor representing 17.83% corresponds to DO and PO_4^{2-}, linked to phosphate pollution. For the dry season, the first factor (48.45% of the total variance), corresponds to NH_4^+, PO_4^{2-}, COD, BOD5 and CN$^-$, associated to global pollution and the second factor (23.70% of the total variance) corresponds to NO_3^- and NO_2^-, related to nitrogen pollution (nitrate and nitrite). The principal components analysis of the factorial plane F1-F2 shows a different behavior of parameters for both rain and dry seasons. The graphical representation in space of statistical units of factorial F1-F2 (fig. 16) highlights two main groupings. Throughout the year the correlation between the biogeochemical contaminants measured is very low, except between BOD5 and COD, showing a very good correlation (0.995 and 0.953). During the dry phase, sampling points at SOS1 and SOS2, adjacent to the treatment station, show vulnerability to pollutants (COD, BOD5, NH_4^+), by against the BOS2 and BOS3 dams are more sensitive to agricultural pollution (PO_4^{2-}, NO_2^-).During the wet season, the water outlet of the PWTS, SO1 and SO2, is sensitive to organic pollution (COD, BOD5). Agricultural pollution DO, NH_4^+, NO_3^-, is present in SO4 until BO3 dam. From BO2 dam appears NO_2^- ion in relation with reduction conditions more favorable.

Table 2. Eigen values and percentages of variabilities in the main axes for the wet season.

	F1	F2	F3
Eigen values	3.5708	1.7042	1.4267
Variability in%.	44.6352	21.3031	17.8339
Accumulated in%	44.6352	65.9383	83.7722

Table 3. Eigen values and percentages of variabilities in the principal axes for the dry season.

	F1	F2
Eigen values	3.8760	1.8961
Variability in%.	48.4499	23.7009
Accumulated in%	48.4499	72.1508

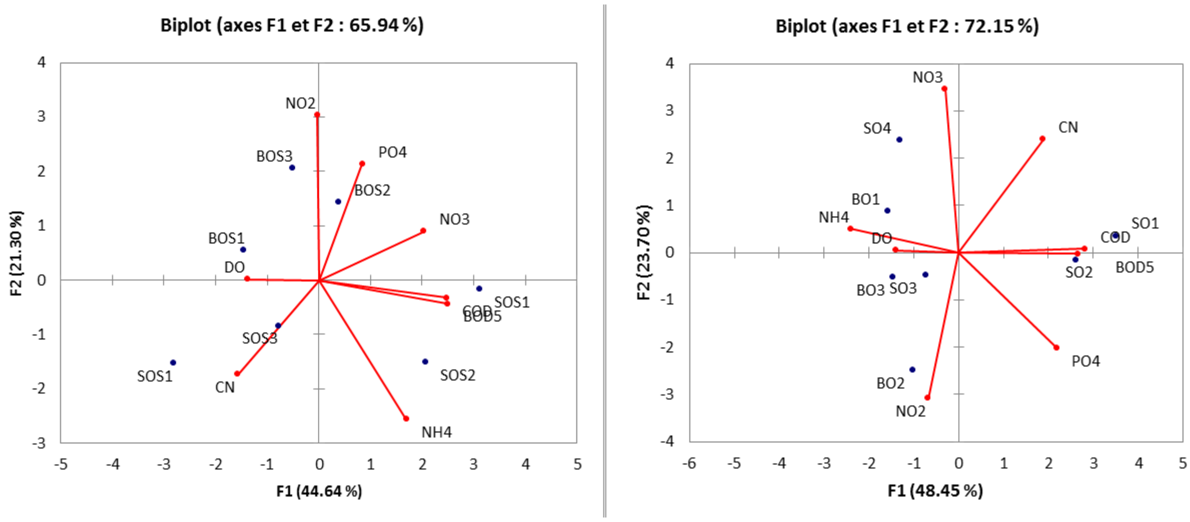

Figure 16. Principal components analysis of the factorial F1 - F2 (right and left wet season dry season).

4. Conclusion

- The canal of the river Bani Houat receiving water treated by the sewage station wastewater south of the Yemeni capital is used to irrigate about 95% of the surrounding farmlands. The nature of agriculture applied in this area is diverse, cereal and culture of "qat" representing one third of agricultural production and consumes a large amount of water. The "qat" Catha edulis, is a shrub of the family Celastraceae cultivated for its stimulant leaves.
- The quality of water used for irrigation has several effects on both agricultural product, soil conservation and quality of the deep water. We studied in this work the physico-chemical quality of the waste water treated in PWST from its outlet of plant to storage in dams built at a distance of 20 Km from the station.
- No change on quality of the water transported by the canal was observed for the both studied seasons, rain and dry. Similarly, the water chemistry is not altered by the canal watershed.
- We showed the water salinity is high and may cause degradation of irrigated soils over the medium to long term and thus increase their desertification.
- For the organic material, the treatment station reduces it highly, despite the entry into PWTS waters heavily loaded, from the city of Sana'a. However the use of the bypass releasing raw waste water near SO2 and the presence of a untreated river flowing into the canal at a distance of 15 Km from the station, limit treatment efforts. Similarly, it would strengthen controls and raise awareness on the danger of throwing waste into the canal.

- For minor elements, a remarkable diversity was observed on changing concentrations of the elements studied during their transport in the canal, but analysis of raw waste water could give more information on the variation of element concentration between the input and the output of the PWTS.
- For agricultural contaminants, we have highlighted the presence at the level of retention dams, nitrite ions, which appear in densely populated areas or intensive agriculture, which is often an important parameter of water downgrade.
- The correlation between physical parameters (conductivity, TDS, SRD) has been tested and showed the stagnation of water in the dams reduced the amount of ions dissolved in water by forming solid compounds settling to the bottom of the canal. Dilution during wet phase is the main process, no dissolution of salts coming from soil watershed were observed
- The organic micropollutants analysed show an excess of phenol and some cyanuric trace ions.
- The results were confirmed using principal component analysis, which showed the different sources of contamination (urban wastewater or agricultural contaminants) and how it can affect the canal water and the water dams depending on local conditions. .

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