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Evaluation of water quality in open channels flowing through Beni-Mellal City (Morocco)

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Abstract

The water quality of the open channels (Foughal, OumDhar and Tamagnounte) flowing into Beni-Mellal city were assessed in a bid to determine impacts of anthropogenic activities. Physicochemical and bacteriological parameters comprising temperature, pH, alkalinity, electrical conductivity, oxidizability, total hardness, ammonia, nitrite, nitrate, total coliforms, fecal coliforms and geochemical analyses were determined for the channels water before reaching the irrigation areas. While biological parameters demonstrated substantial variability, other parameters showed relatively little spatial variations. The spatial variations in water quality may be attributed to the effects of the urban wastewater discharge in the channels and to surface urban and agricultural runoff. Compared with drinking water quality standards of Moroccan and WHO, the results indicated that the channels water was suitable for drinking purpose with prior treatment. Various determinants such as electrical conductivity, residual sodium carbonate, total dissolved solids and hardness revealed that all water samples were suitable for irrigation.

Key words:*Urban channels, physicochemical parameters, wastewater, water quality*

INTRODUCTION

Surface water pollution has become a very big issue in the world today, mostly in the developing countries. It is caused by both natural processes and anthropogenic activities. Natural processes impacting water quality include changes in precipitation inputs, erosion, and weathering of crustal materials, whereas anthropogenic effects include urban, industrial and agricultural activities, and increasing exploitation of water resources [AGBAIRE, OBI 2009; BAGHVAND *et al.* 2010; BAYRAM *et al.* 2012; JARVIE *et al.* 1998; NAJAFPOUR *et al.* 2008; SIMEONOV *et al.* 2003; YU *et al.* 2001]. These activities often result in the degradation of water quality, and impair their use for drinking and irrigation purposes. Most of watercourses flowing through residential areas are vulnerable to pollution because they are often the end point of urban runoff and untreated wastewater effluents [AITKENHEAD-PETERSON *et al.* 2011; ALMEIDA *et al.* 2007; AYENI *et al.* 2011; BRAVO-INCLAN *et al.* 2008; KOUKAL *et al.* 2004; MAANI-MESSAI *et al.* 2010; PHIRI *et al.* 2005; SUTHAR *et al.* 2009]. Moreover, watercourses that receive wastewater also become sinks for some hazardous substances or products that contain harmful elements which are not degradable in the environment and may cause deleterious effects to the health [ASHRAJ 2005; GULEC *et al.* 2011; TAVARES, CARVALHO 1992]. Therefore, constant control of river water quality is becoming a necessity in order to record any alteration in its quality and to safeguard public health. Traditionally, water quality refers to some physicochemical and microbiological characteristics of water, usually in respect to its suitability for a particular purpose. These characteristics are recognized as indicators of quality-related problems, since they are useful to understand the water quality and pollution status of the studied systems.

In Morocco, surface water which represents two thirds of the water potential forms an important source of water supply for drinking and industrial purposes. It is estimated that about 69% of domestic and industrial water requirement is met from surface water. Surface water also plays a major role in agriculture and industry. However, with rapid increase in population size and growth of industrialization in most regions of Morocco, the quality of surface water is being increasingly threatened by disposal of urban and industrial wastes and agricultural chemicals. This resulted in recent years in an increase in public concern and awareness about degradation of urban riverine systems [AZZAOUI *et al.* 2002; BARAKAT *et al.* 2012; BELLUCCI *et al.* 2003; DERWICH *et al.* 2011; EL BAGHDADI *et al.* 2012; EL HASSEN *et al.* 2011; IAVAZZO *et al.* 2012; KOUKAL *et al.* 2004; NAOURA, BENAABIDATE 2011; OUFLINE *et al.* 2012]. Tadla-Azilal region is one of the Moroccan regions that is blessed by abundant water resources. It's predominantly an agricultural zone with dense agricultural activities. Beni-Mellal city belonging to this region is known for its natural water springs such as AineAsserdoune and Tamaghnounte. Water from these sources utilized as a water resource for domestic and agricultural uses, flows through the open channels which pass through the Beni-Mellal city to reach the agricultural fields downstream. However, the quality of water from these channels is threatened every day by the population pressure and wastes disposal. Apart from the few studies that have been conducted on spring's water, no studies have yet been done to assess chemistry and microbial activity of water in channels. Therefore, the aim of this study is to determine microbiological and chemical quality of water in these urban channels. The data collected were compared with Moroccan and WHO standards to determine the suitability of this water for drinking and irrigation purposes.

MATERIALS AND METHODS

Study area: Beni-Mellal is the largest city and the capital of the Tadla-Azilal region. It is located at the central part of Morocco (Fig. 1) and covers an area of about 74 km^2 with population of 163 248 as per 2004 census records. It lies between the High--Atlas Mountain and the vast Tadla plain, and is characterized by a semi-arid climate with averaged annual temperature of 26°C and annual rainfall of 400 mm. The geology of the region is presented by the Mesozoic limestone with travertine and Cenozoic phosphate. The Beni-Mellal Atlas is the karstic mountain which is made up mainly of fractured dolomite limestone (Liassic) with its spectacular karstic type shapes. It is drained by significant water resources including two important water springs, i.e. AineAsserdoune and Tamegnounte originating in the Atlas Mountains, upstream from Beni-Mellal city. Water from all springs is used for agricultural irrigation purposes. However, part of Aine-Asserdoune-spring's water is used for urban water supply to Beni-Mellal city. Water from these spring feeds following open channels: Foughal and OumDhar channels originate from AinAsserdoune spring and Tamagnounte channel from Tamegnounte spring. These open channels flow through the Beni-Mellal city before reaching downstream Farmlands. Significant pollution loadings including industrial and domestic waste and sewage and some runoff of rainwater on soils and pavements are discharged into these channels. No detailed study has been carried out on the assessment of pollution load into these channels yet. Therefore, the water quality of all open channels was assessed in a bid to evaluate the effects of human activities on water quality. Physicochemical and microbial parameters were determined for these channels before reaching the irrigation areas.

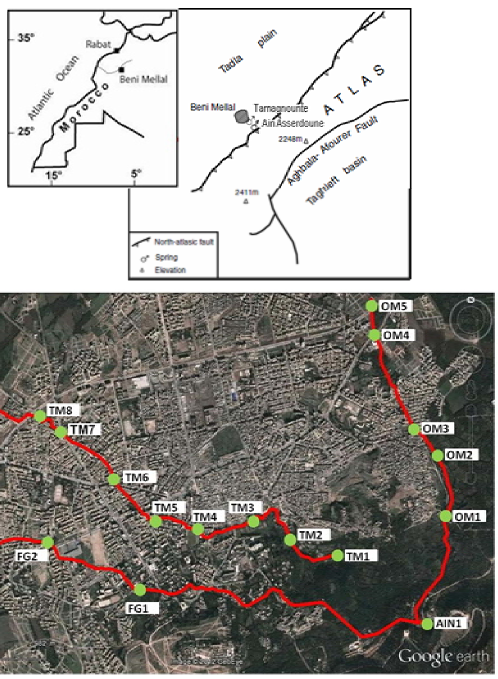

Fig. 1. Location of Beni-Mellal City (top); location of studied open channels and different sampling stations (down); source: own study

Water sampling and analysis: To characterize water quality and its spatial variability along the studied channel network, locations for 16 sampling stations were carefully selected. The first sampling stations were located at the outlets of springs. Samples were collected during May 2011 from each open channel with polyethylene bottles and preserved in ice boxes. The bottles were rinsed with effluent water before collection. In order to preserve the metals, 2 ml concentrated HNO_3 were added to the water samples.

The physico-chemical analysis was performed following standard methods [APHA 1998]. Measurements of pH, conductivity *EC* and temperature *T* were carried out at site, using thermo scientific portable multiparameter meter. Turbidity (NTU) was determined by turbidimeter. Alkalinity (TAC), total hardness (TH), oxidizability, Ca and Mg were analyzed by volumetric methods; and nitrite (NO_2), nitrates (NO_3), ammonium (NH_4) were estimated by aspectrophotometric technique.

Total coliforms (T. Col.) were determined by a multiple tube fermentation technique (MPN). The collected water samples were inoculated into three sets of tubes each containing lactose broth and 10, 1, and 0.1 ml each of water samples. All tubes were incubated at 37°C for 48 h before they were observed for acid and gas production. The production of acid and gas indicates the presence of coliforms and therefore a positive test. Fecal coliforms were determined by multiple tube fermentation technique using *E. coli* broth at an incubation temperature of 47°C for 24 h.

In order to analyze the metal content, water samples were digested with 5 ml of di-acid mixture (HNO_3). Analyses were performed using a mass spectrometer at the National Office of Drinking Water (ONEP) laboratory.

RESULTS AND DISCUSSION

Characteristics of water. The physicochemical and bacteriological parameters of water from all studied channels are summarized in Table 1 and Fig. 2. To determine the drinking quality of surface water samples, the results were compared with the standards of Moroccan [SGG 2002] and of the World Health Organization [WHO 2008] (Tab. 1).

The temperature of the water show a gradual increase across each channel due to the fact that ambient temperature increased as sampling progressed. However, the observed temperature did not exceed 18.8°C and was well within the safe limit for drinking (Moroccan standards).

The pH value ranged from 6.88 to 8.12, which was within the recommended range for drinking water

Table 1. The results of bacteriological and physicochemical analysis of water supplied from all channels

Sample	*T*	pH	*EC*	Turbidity	*TDS* Vrai	TAC	Oxidizability	TH	Ca	Mg	NO_2	NO_3	NH_4	T. Col.	*E. coli*
	°C		$nS·cm^{-1}$	NTU					$mg·l^{-1}$	$CFU·(100\ cm^3)^{-1}$					
Tamagnounte channel															
TM1	17.5	6.879	590.0	19.80	289.10	366.00	0.487	293.0	117.2	7.000	0.0068	7.5	0.03	9	9
TM2	17.2	7.020	615.5	20.10	301.60	369.05	0.500	295.5	117.1	7.600	0.0070	7.5	0.03	–	–
TM3	17.6	7.085	613.0	21.80	300.37	366.00	0.550	298.0	116.8	7.190	0.0087	7.9	0.03	752	20
TM4	18.0	7.285	607.0	25.70	297.43	366.00	0.560	298.0	115.9	7.800	0.0117	8.3	0.04	–	–
TM5	18.3	7.430	616.5	28.15	302.09	362.95	0.576	306.0	116.4	9.120	0.0169	8.5	0.04	1020	90
TM6	18.2	7.535	612.0	28.20	299.88	369.05	0.630	305.0	115.6	9.070	0.0170	9.0	0.04	1085	112
TM7	18.3	7.645	610.5	30.55	299.15	353.80	0.720	300.0	113.5	11.130	0.0175	9.6	0.05	1110	141
TM8	18.8	7.715	615.0	32.10	301.35	359.90	0.784	302.0	113.2	11.552	0.0225	10.5	0.06	1100	150
OumDhar channel															
AIN	16.8	7.040	503.0	65.90	246.47	323.30	0.412	277.0	105.6	7.904	0.0025	5.0	0.04	4	4
MDI	16.8	7.550	482.0	85.60	236.18	292.80	0.589	276.0	105.3	6.010	0.0095	5.0	0.04	–	–
MD2	17.1	7.900	505.0	58.80	247.45	320.25	0.676	265.0	105.2	5.401	0.0090	5.4	0.04	210	210
MD3	17.1	7.970	502.0	58.60	245.98	320.25	0.845	265.5	97.2	3.410	0.0435	5.7	0.05	2100	600
MD4	17.0	8.010	515.0	65.20	252.35	329.40	0.890	267.0	98.4	3.740	2.5000	6.5	0.06	4230	1170
MD5	16.9	8.000	511.0	62.30	250.39	335.50	0.907	268.0	105.2	3.040	2.6000	8.0	0.04	4600	1500
Foughal channel															
AIN	16.8	7.040	503.0	65.90	246.47	323.30	0.412	277.0	105.6	7.904	0.0025	5.0	0.04	4	4
FG1	17.9	7.720	501.0	105.00	245.49	298.90	0.980	268.5	98.8	5.680	0.0630	5.7	0.07	9300	1540
FG2	18.0	8.120	483.0	52.10	236.67	305.00	1.278	250.0	96.8	4.864	0.3267	6.0	0.08	11000	2100
Min	16.8	6.879	482.0	19.80	236.18	292.80	0.412	250.0	96.8	3.040	0.0025	5.0	0.03	4	4
Max	18.8	8.120	616.5	105.00	302.08	369.05	1.278	306.0	117.2	11.552	2.6000	10.5	0.08	11000	2100
Mean	17.55	7.530	552.03	48.58	270.49	338.91	0.690	283.03	108.46	6.970	0.3300	7.12	0.05	2608.86	546.43
Morrocan Standards	20.0	6.5–8.5	2700	5.00	–	–	5.0	300	100	50.0	0.5	50	0.5	0	0
WHO Standards	–	7.0–8.5	600	5.00	500	–	–	500	100	50.0	3.0	50	–	–	–

Source: own study.

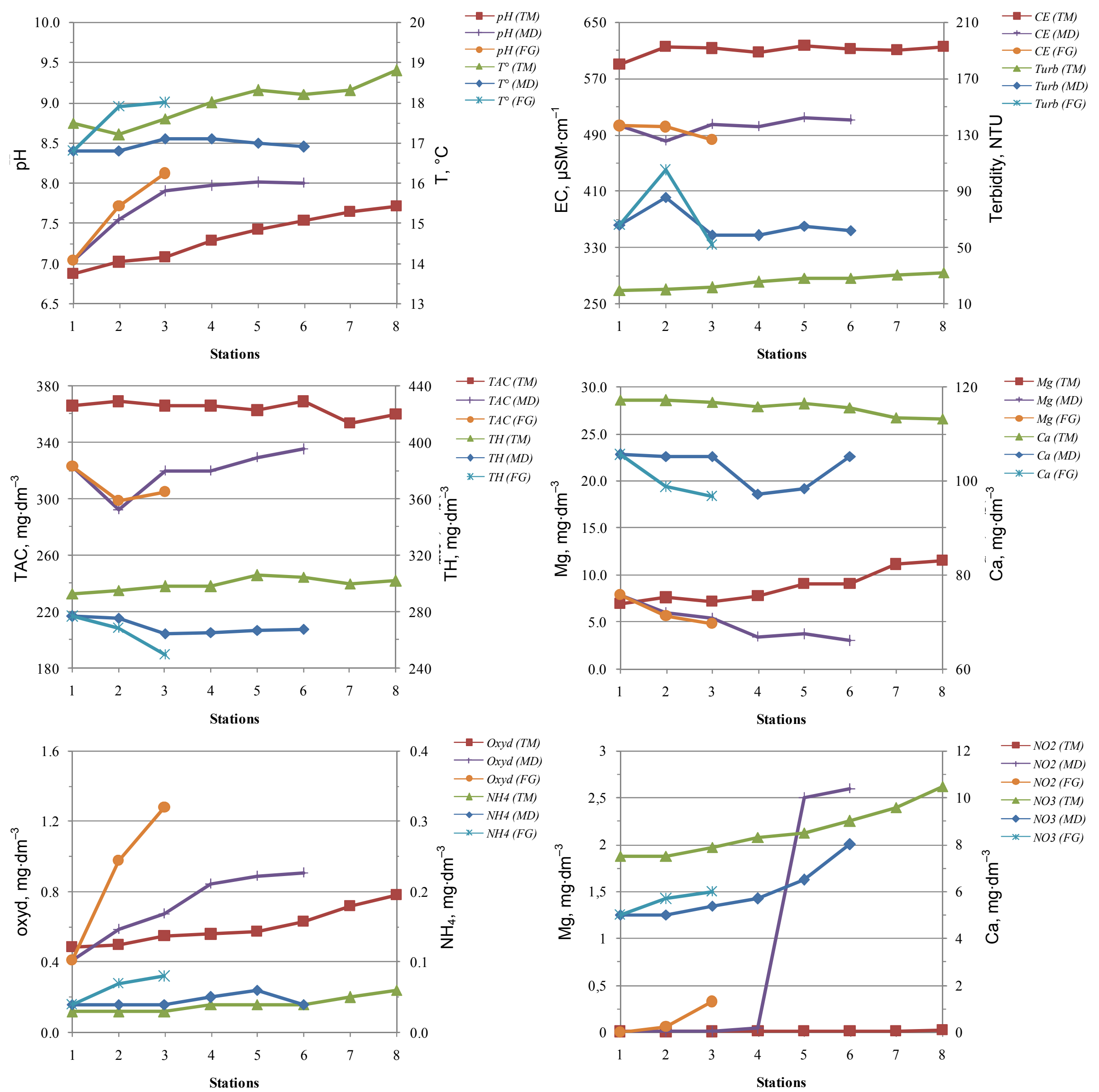

Fig. 2. Distribution of physicochemical parameters at Tamagnounte (TM), OumDhar (MD) and Foughal (FG) channels; source: own study

referring to Moroccan and to the WHO limits. The pH values not exceeding 8.3 suggested that the alkaline nature of the water was particularly due to bicarbonate and not due to carbonate alkalinity. Significant difference in the observed pH was noted between channels. Spatial variations in pH were also observed in all studied channels. Downstream water samples showed higher pH values as compared with upstream water sample, which might be due the influence of wastewater loads on the channels.

Conductivity qualitatively reflects the status of inorganic pollution and is a measure of total dissolved solids and ionized species in the waters. *EC* of Foughal and OumDhar channels ranges between 482 and 515 $\mu S \cdot cm^{-1}$, whereas its counterpart from Tamaghnounte channel ranges between 590 and 616.5 $\mu S \cdot cm^{-1}$. Compared to the permissible limits of the WHO (600 $\mu S \cdot cm^{-1}$), samples from Foughal and OumDhar channels showed a low value of *EC* while those from Tamaghnounte channel showed high *EC* values. In general, water EC of the downstream channels is higher compared with the upstream one. This might be due to mixing of salts through agricultural runoff and to the wastewater discharges on these urban channels. In natural waters, dissolved solids consists mainly of inorganic salts including carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates of calcium, magnesium, sodium, potassium, and iron, as well as a small amount of organic matter and dissolved gases. The total dissolved solids (*TDS*) values in the studied channels varies from 236 to 302 $mg \cdot dm^{-3}$, with low *TDS* content at OumDhar and Foughal channels comparatively to this recorded at Tamagnounnte channel. All *TDS* values lie well within the desirable limit of 1000 $mg \cdot dm^{-3}$[SGG 2002; WHO 2008].

As per Moroccan and WHO standards, turbidity should be less than 5 NTU and is observed to be in the range of 19.80–105.00 NTU. The turbidity could be attributed to high sediment levels entering water bodies during rain storms and groundwater flow. Also, the high turbidity values observed in downstream samples from all channels indicate that urban activities contribute to chiefly to turbidity through storm-water pollution from paved surfaces such as roads, bridges, parking lots, and domestic wastes.

The content of Ca and Mg in all channels water ranges between 96.80–117.20 and 7.00–11.55 mg·dm^{-3} for the first and the second, respectively. Ca content generally exceeds Mg content in accordance with their relative abundance in rocks. Mg concentration is found to be lower than Ca concentration in all the channels. Ca and Mg concentrations in Tamagnounte channel are higher as compared with OumDhar and Foughal channels. This difference might be due to the residence time of water in reservoirs karst. Ca and Mg concentrations in OumDhar and Foughal channels are tendency to decreased levels from station 1 might be due to a significant rate of precipitation. Decreased concentration of Ca in the downstream in Tamagnounte channel might be due to this precipitation. However, increased concentration of Mg in this channel in downstream direction might be due to various anthropogenic activities. Maximum permissible limit of Ca and Mg in drinking water is 100and 50mg·dm^{-3}as suggested by WHO. All studied samples from all channels did not exceed the maximum permissible limits of Ca and Mg prescribed for drinking water.

The hardness (TH) of a water body is regulated largely by the levels of Ca and Mg salts. Other metals if present such as Fe, Mn, and Al may also contribute to hardness. TH of water from Tamagnounte, OumDhar and Foughal channels are found in the range 293–309, 246–277 and 250–277 mg·dm^{-3}, respectively. In general, the TH values are high in spring water samples than downstream samples. However, they not cross the desirable limit for drinking water of 300 mg·dm^{-3} [SGG 2002; WHO 2008]. The decrease of TH is quite proportional to Ca and Mg contents in all channels.

The alkalinity of water is defined as the ionic concentration, which can neutralize the hydrogen ions. The presence of carbonates, bicarbonates, and hydroxides are the main cause of alkalinity in natural waters. The alkalinity value in all studied channels was found in the range of 353.80–369.05 mg·dm^{-3}, which is lower than the permissible limit of the WHO, i.e., 500 mg·dm^{-3}. Spring water shows lower alkalinity values as compared with downstream water. This might be explained by the reaction of carbonate with Ca and Mg ions to form insoluble minerals leaving bicarbonate.

NO_2 always indicates the input of organic load into the water system. Domestic wastewater loads are accounted as the main source of organic matter for the aquatic system. NO_2 concentration varies in the ranges 0.006–0.023, 0.003–2.500, and 0.003–0.327 mg·dm^{-3} for Tamgnounte, OumDhar and Foughale channels, respectively. Enhancement of NO_2 concentration from the upstream stations was due to organic waste discharges from non-point sources. NO_3 content in drinking water is considered important for its adverse health effects. A limit of 45 mg·dm^{-3}has been prescribed by WHO for drinking water supplies. NO_3 concentration varied from 0.1 to 16 mg·dm^{-3}, 0.1 to 14 mg·dm^{-3} and 0.1 to 14 mg·dm^{-3} in Tamgnounte, OumDhar and Foughale channels, respectively. All samples are within the desirable limit for drinking water supplies. NH_4 concentration shows the same trend mentioned in the case of NO_2. NH_4 concentration is the range 0.03–0.06, 0.04–0.06, and 0.04–0.08 mg·dm^{-3} for Tamgnounte, OumDhar and Foughale channels, respectively. The increase in NH_4 concentration from the upstream station was attributed to local wastewater input.

The oxidizabilitywhich measures the concentration of organic matter displays spatial variation in all studied channels, in clear agreement with the variation of NO_2 and NH_4 contents in the water. Itvary from 0.29 to 6.27 mg·dm^{-3}, 0.29 to 6.27 mg·dm^{-3}, and 0.29 to 6.27 mg·dm^{-3}, for Tamagnounte, OumDhar and Foughal channels, respectively. Increase in oxidizabilityfrom upstream to downstream direction denotes the effect of contamination with organic waste. The high levels of oxidizability not exceed the permissible limit for drinking water [SGG 2002; WHO 2008].

Coliform bacteria are common indicators of overall water quality because their presence in high concentrations often coincides with more dangerous bacteria. The presence of coliforms in water is an indicator of contamination by human or from animal excrement, and indicates a potential public health problem. Significant levels of total coliform and *E. coli* are found in all channels, but the highest levels are obtained in Foughal. Total coliform ranges from 9 to 1100 CFU·(100 cm^3)$^{-1}$, 4 to 4600 CFU·(100 cm^3)$^{-1}$, and 4 to 11 000 CFU·(100 cm^3)$^{-1}$ for samples from Tamagnounte, OumDhar and Foughal channels, respectively. *E. coli* levels range 9–150 CFU·(100 cm^3)$^{-1}$, 4–1500 CFU·(100 cm^3)$^{-1}$ and 4–2100 CFU·(100 cm^3)$^{-1}$ in Tamagnounte, OumDhar and Foughal channels, respectively. The upstream stations have consistently lower bacterial levels than the downstream stations. This fact may be attributed to the runoff flows, town flows, and human activities in the catchment of channels.

The contamination of surface water by heavy metals gained a lot of interest during recent years due to their toxicity and their nonbiodegradibility. The major sources of heavy metals in groundwater include weathering of rock minerals, discharge of sewage and runoff water. The water used for drinking and irrigation purposes should not contain excessive amount of toxic elements that may be hazardous to health. Some heavy metals are essential for human health, but can be harmful in large quantities. The concentration and the distribution of various heavy metals are presented in Table 2. Mn, Pb, Cd and Cr were detected in the range of 23.0–154.0, 0.6–5.0, 0.0–0.8, and 2.5–10.0 $\mu g \cdot dm^{-3}$, respectively. All analyzed samples fall within the Moroccan and WHO desirable limits. Heavy metals show a little variability in concentration both along each channel and between channels. Heavy metal concentrations, with the exception of Mn, show low variation (less than 8 $\mu g \cdot dm^{-3}$) between stations from the same channel. The concentrations of heavy metals increase from upstream station to downstream station in all channels, except for Mn, Cr and Cd in Tamagnounte channel.

Table 2. Metal concentrations in water of studied channels

Sample	Mn	Pb	Cd	Cr
	$\mu g \cdot dm^{-3}$			
Tamagnounte channel				
TM1	66.0	0.6	0.2	5.9
TM2	–	–	–	–
TM3	39.6	1.3	0.1	3.7
TM4	37.8	1.8	0.1	3.6
TM5	30.7	1.7	0.1	3.0
TM6	32.2	2.0	0.1	3.1
TM7	29.7	2.1	0.1	2.8
TM8	23.0	3.2	0.0	2.5
OumDhar channel				
AIN	57.0	1.9	0.2	2.9
MDI	–	–	–	–
MD2	85.0	2.2	0.3	4.0
MD3	115.0	4.5	0.5	6.4
MD4	118.0	3.9	0.5	10.0
MD5	154.0	5.0	0.8	7.5
Foughal channel				
AIN	57.0	1.9	0.2	2.9
FGI	62.0	2.0	0.2	3.3
FG2	67.0	2.0	0.2	3.6
Min	23.0	0.6	0.0	2.5
Max	154.0	5.0	0.8	10.0
Mean	64.9	2.4	0.2	4.3
Morrocan Standards	500	10	3	50
WHO Standards	400	10	3	50

Source: own study.

The water quality determines the suitability of water for a particular purpose.

Drinking water quality. The water quality determines the suitability of water for a particular purpose (i.e., drinking, agriculture). In this study, the analytical results were compared with the universal and local standards to assess the drinking water quality (Tab. 1, 2). The average concentration of all physicochemical parameters and dissolved heavy metals lied within the permissible limits of the WHO and the Moroccan standards, and indicated that the surface water in the studied channels is chemically potable and suitable for domestic purposes but with prior treatment to remove impurities and ensure water disinfection.

As per classification of water source used for drinking purposes [SGG 2002] (Tab. 3), water quality data (Tab. 1, 2) showed that the quality of all channels fall in "Class A1" i.e. drinking water source requiring a simple physical treatment followed by disinfection including filtration and chlorination. However, microbiological results show that water quality has deteriorated and falls in "Category A2 to A3" i.e. can be used for drinking purpose after normal physical and chemical treatment and disinfection including prechlorination, coagulation, flocculation, sedimentation, filtration and final chlorination.

Table 3. Classification of water used for drinking purposes [SGG 2002]

Characteristics	Categories					
	A1		A2		A3	
	G	I	G	I	G	I
T, °C	20	30	20	30	20	30
pH	6.5–8.5	–	6.5–9.2	–	6.5–9.2	–
EC, $\mu S \cdot cm^{-1}$	1300	2700	1300	2700	1 300	2700
Oxidizability, $mg \cdot dm^{-3}$	2	–	5	–	10	–
NO_3, $mg \cdot dm^{-3}$	–	5	–	50	–	50
NH_4, $mg \cdot dm^{-3}$	0.05	0.5	1	1.5	2	4
T. Col., $(100\ cm^3)^{-1}$	50	–	5000	–	5000	–
Mn, $\mu g \cdot dm^{-3}$	–	100	100	100	1000	–
Pb, $\mu g \cdot dm^{-3}$	–	50	–	50	–	50
Cd, $\mu g \cdot dm^{-3}$	1	5	1	s	–	5
Cr, $\mu g \cdot dm^{-3}$	–	50	–	50	–	50

Explanations: A1 –drinking water source requiring a simple physical treatment and disinfection; A2 – drinking water source requiring normal physical and chemical processing and disinfection; A3 – drinking water source requiring physical and pushed chemical treatment and a refining and disinfection; G – guideline values; I – imperative values.
Source: SGG [2002].

Irrigation water quality: As for irrigation suitability, the water quality used is essential for the crop yield, the maintenance of soil productivity, and the protection of the environment. Therefore, the channels water samples are classified on the basis of *EC*, *TDS*, hardness and the residual sodium carbonate (RSC).

Salinity hazard (EC). *EC* is a good measurement of salinity hazard, and plays a vital role in assessing the suitability of water for irrigation. The high salt content in irrigation water produces the undesirable effects of changing soil properties and reducing soil permeability [KELLEY 1946]. Water classes proposed by USSL [RICHARDS 1954] are widely used for judging the suitability of channels water for irrigation purpose. They have categorized irrigation water quality into four classes on the basis of *EC* as given below.

According to USSL classification (Tab. 4), the surface water in the study channels is ranging from

Table 4. Classification of irrigation water based on *EC* value

Class	Salinity hazard	*EC* µS·cm^{-1}	Suitability criteria
C1	low	<250	suitable for most crops and soils
C2	medium	250–750	suitable for soil of moderate drainage
C3	high	750–2.250	unsuitable for soils of restricted drainage
C4	very high	>2.250	unsuitable for average condition

Source: RICHARDS [1954].

482–616.5 µS·cm^{-1}, which is suitable for irrigation to soil of moderate drainage.

Total dissolved solid. A significant increase in water salinity increases soil salinity and leads to salinization problem. Based on the classification of water according to *TDS* values [WILCOX 1955] (Tab. 5), all studied water samples fall in best water category for irrigation purpose.

Table 5. Classification of irrigation water based on *TDS* value

TDS, mg·dm^{-3}	Status
200–500	best quality water
1000–2000	water involving hazard
3000–7000	used for irrigation only with leaching and perfect drainage

Source: WILCOX [1955].

Residual sodium carbonate. The excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability of groundwater for irrigation. This is termed as residual sodium carbonate (*RSC*) [EATON 1950; RICHARDS 1954]. The *RSC* is calculated using the formula given below:

$$RSC = (HCO_3 + CO_3) - (Ca+Mg)$$

Where the concentrations are reported in meq·dm^{-3}. Based on the *RSC* values, three classes were reported: the water is considered safe if $RSC <$ 1.25 meq·dm^{-3}, the water is of marginal quality if RSC lies between 1.25–2.5 meq·dm^{-3}, and the water is unsuitable for irrigation If $RSC >$ 2.5 meq·dm^{-3}.

According to Richards's classification, all the water samples analyzed have *RSC* values less than 1.25 suggesting that the water can be used for irrigation. An observed negative *RSC* indicated that Na buildup is unlikely since sufficient Ca and Mg are in excess of what can be precipitated as carbonates.

Hardness of the water. Hardness is the sum of Ca and Mg concentrations expressed in terms of mg·dm^{-3} $CaCO_3$. The degree of hardness in water is commonly based on the classification listed in Table 6 [SAWYER, MCCARTY 1967].

Table 6. Classification of water hardness

Hardness mg·dm^{-3} of $CaCO_3$	Water classification
0–75	soft
75–150	moderaly hard
150–300	hard
>300	very hard

Source: SAWYER, MC CARTY [1967].

All water samples analyzed had hardness value ranging from 99–125 mg·dm^{-3}. These Hardness values fall in the moderately hard category.

CONCLUSION

In this study, surface water samples collected from all channels flowing through the Beni-Mellal city were analyzed. The results presented here demonstrate that the physicochemical values fell below within the permissible values according to Moroccan and WHO standards. However, all channels show some pollution downstream that can be attributed to waste and wastewater discharge into channels as well as surface runoff water. Microbiological analyses suggest the necessity to disinfect water from these channels before any domestic use. Our study further reveals that the water from these channels is suitable for irrigation purpose.

While the extent of the pollution at the studied channels may not appear severe, the pollution downstream stresses the need of urgent measures to protect the quality for their water for the benefit of the community and the environment. This will certainly pass by increasing local public awareness on waste management.

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Ocena jakości wody w otwartych kanałach płynących przez miasto Beni-Mellal (Maroko)

STRESZCZENIE

Słowa kluczowe:*jakość wody,kanały miejskie, parametry fizyczno-chemiczne, ścieki*

Oceniono wpływ działalności człowieka na jakość wody w otwartych kanałach (Foughal, OumDhar i Tamagnounte), dostarczających wodę do miasta Beni-Mellal. Zmierzono takie parametry fizyczne, chemiczne i bakteriologiczne, jak: temperatura, pH, alkaliczność, przewodnictwo elektrolityczne, utlenialność, twardość całkowitą, jony amonowe, azotyny, azotany, całkowitą liczbę bakterii coli, bakterie pochodzenia kałowego oraz przeprowadzono analizy geochemiczne w wodzie kanałów przed jej wprowadzeniem do systemów nawadniających. Podczas gdy parametry biologiczne wykazywały znaczną zmienność, pozostałe parametry cechowała stosunkowo niewielka zmienność przestrzenna. Na zmienność jakości wody w przestrzeni mogąwpływać ścieki miejskiespuszczane do kanałów oraz powierzchniowy spływ z terenów miejskich i obszarów rolniczych. Uzyskane wyniki porównane do norm jakości wody pitnej obowiązujących w Maroku i norm WHO pokazują, że woda w kanałach nadaje się do spożycia po wstępnym uzdatnieniu. Różne wskaźniki, takie jak przewodnictwo elektrolityczne, stężenie węglanu sodu, ilość całkowitej zawiesiny i twardość dowodzą, że analizowane wody nadają się do nawodnień.