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Physico-chemical characterization of rainwater of the area of Algiers : Valorization

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Abstract

This article presents the numerical modeling of dynamic and thermal behavior of turbulent forced convection in a horizontal channel within a provided of baffles represented by the obstacles for the cooling of the hot walls. The governing equations, based on the k-ε model have been used to describe the turbulence phenomena and solved by the finite volume method. The velocity and the pressure terms of momentum equations are solved by the SIMPLE algorithm. For the turbulence's modeling, we opted for the standard model $k-\varepsilon$,in which we study the increase of heat exchange between walls and the heat transfer fluid depending on the spacing between the baffles on the lower wall of the channel. The mean velocity profiles and temperature fields as well as the Nusselt number distribution are presented for several cases.

1. Introduction

The existence of all kinds of life is linked to the presence of water. The inadequacy of the latter is one of the most crucial problems faced by humans, so it is essential to limit the release of pollution into the natural environment.

Rainwater has long been regarded as pure water with no harmful effects on the environment. Only the fight against the risks of flooding was taken into account, in which the field of rainwater only covered a purely quantitative view. Over the past decade, it has been clear that urban discharges in rainy weather are the number one problem in water pollution [1, 2]. Indeed, rainwater from leaching and runoff mobilizes the pollution accumulated in dry weather [3, 4].

In addition, rainwater is likely to disrupt the balance of receiving environments and causes health problems such as contamination of surface and groundwater [5, 6]. Some remediation is carried out by soils, rivers and other water systems, but the capacity of this self-purification is largely exceeded [7].

Treatment techniques with helophytic plants are receiving increasing attention. Interesting helophytes in the field of phyto-purification are quite numerous, among which the reed which is the subject of this study. The purifying potential of aquatic plants, particularly the reed, was identified by Seidel in 1946 to treat industrial effluents containing chemicals such as heavy metals [8].

2. Materials and methods

2.1. Physical and chemical parameters of pollution

The samples are recovered in plastic tanks initially rinsed with distilled water and then placed in jerry cans which are first rinsed with distilled water and then with the water to be analyzed. The analyzes were carried out at the Laboratory of Electrochemistry, Corrosion, Metallurgy and Mineral Chemistry of the Faculty of Chemistry (USTHB) and at the water laboratory of ANRH of Algiers.

The pH measurements were carried out using a BASIC CRISON pH meter; that of turbidity with a turbidity-meter of TERRAIN 2000 NTU, that of the COD with a COD meter of brand: Spectroquant TR 320 MERCK, and that of the ions: NH_4^+, NO_3^-, NO_2^- and PO_4^{3-} with a visible spectrophotometer of mark JASCO V-630. These physical and chemical parameters of rainwater were analyzed according to the standardized protocols AFNOR and ISO [9].

The methods used for analysis are: the Nessler, Zambelli, sodium salicylate, ascorbic acid for the NH_4^+ , NO_2^- NO_3^- and PO_4^{3-} ions respectively.

2.2. Plant material

The reed, for its resistance to the conditions encountered: long submerged period of filter, dry periods, high organic matter content and rapid growth of the roots and rhizomes, is most often used in this type of treatment.
The treatment is carried out on an experimental pilot consisting of two containers filled with successive layers of gravel and sand. Both bins are planted with young reed stems. The system is supplied exclusively by rainwater through a system of drip irrigation piping that is placed on the sand layer. The water is filtered through the coarse substrate composed of sand and gravel which, just as the roots of plants serve as support for microorganisms.

3. Results and discussion

3.1. Analysis

Analysis of pollution parameters (Turbidity, COD, TSS and NH_4^+, NO_3^-, NO_2^- and PO_4^{3-}) showed that some of them exceeded acceptable potable standards. The results of analysis of physical and chemical parameters of rainwater compared to standards of potability are reported in Table 1.

Tableau 1: Caractéristiques des eaux de pluie

Parameters	Min	Max	average	Standard deviation	Variance	Algerian standards
pH	6.42	7.08	6.72	0.264	0.093	6.5-9
Conductivity (µS/cm)	50.9	187.8	128.15	53.069	3755.137	1000
Turbidity (NTU)	33.5	187.8	73.575	41 .005	2241.889	0.5
TSS (mg/L)	11	30	17	7.649	78	25
NH_4^+ (mg /L)	0.169	0.375	0.278	0.073	0.007	0.1
NO_3^- (mg/L)	5.765	10.328	7.467	1.830	4.467	50
NO_2^- (mg/L)	0.19	2.645	1.606	0.945	1.192	0.05
PO_4^{3-} (mg/L)	0.041	0.222	0.122	0.065	0.006	0.4
SO_4^{2-} (mg/L)	7.864	19.025	14.356	4.11	22.521	250
Cl^- (mg/L)	2.13	3.55	2.751	0.634	0.536	250
Na^+ (mg/L)	1.38	2.3	1.783	0.411	0.225	150
Ca^{2+} (mg/L)	9	15	12.250	2.165	6.25	200

Dust mobilized by rainwater during its fall is the representative pollutant of suspended matter. During rainfall, rainwater flows through the atmosphere (from cultivated areas) and richerly carries pesticides (gaseous pesticides) [11, 12] and into suspended matter and organic nitrogen. NH_4^+ ion then occurs by ammonification of the latter. TSS containing bacteria that are responsible for nitrification [13] of ammonium ion to produce nitrite ions[14].
Turbidity is due to the presence of finely divided suspended matter: clays, silica grains and organic matter transported by rainwater. Dust mobilized by rainwater during its fall is the representative pollutant of suspended matter [15].
Chemical reactions due to solar radiation between oxides of nitrogen emitted during combustion (boilers, motors, etc.), volatile organic compounds and carbon monoxide are responsible for the formation of nitrates [16]. Rainwater may be contaminated during its passage into the atmosphere by TSS containing bacteria which are responsible for the nitrification of ammonium ions to produce nitrite ions.

3.2. Chemical classification

In order to determine the chemical facies of rainwater, we placed concentrations in major elements as of this water on the Piper diagram (figure 1). It is composed of two triangles representing the distribution of anions and those of cations, respectively, and of a rhombus representing the synthetic distribution of the major ions. In this rhombus, the high pole corresponds to 100 % of sulfates and chlorides and 100 % of calcium and magnesium, the low pole accounting for 100 % of carbonate and bicarbonate and 100% of sodium and potassium. Thus, in this diagram, a calcium bicarbonate water would be located at the left pole of the rhombus whereas a sodium chloride water would be located at the right pole (According to figure 1, the points representative of rainwater on the Piper diagram gather in only one group of dots. This provision of points shows that the chemical facies dominating is calcium sulfate.

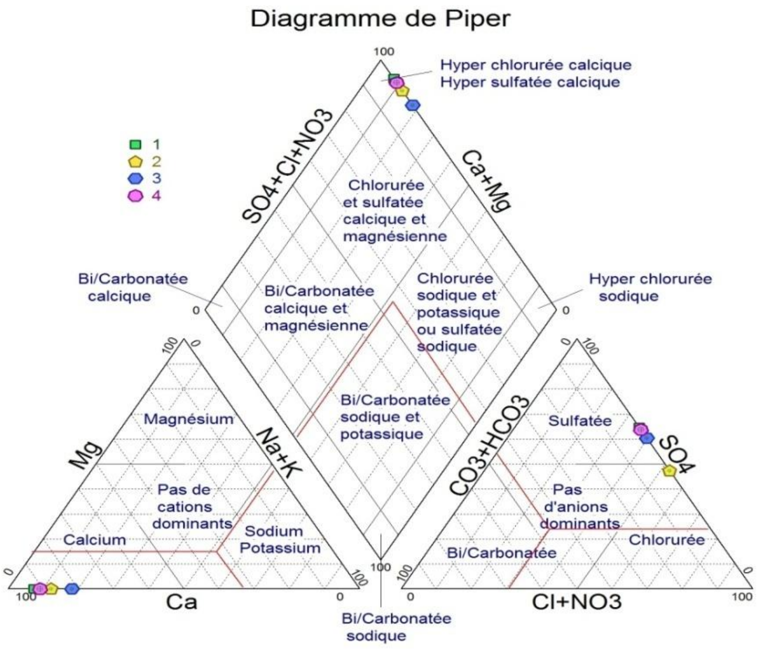

Figure 1: Piper diagram of rainwater

To highlight variability of the chemical composition of rainwater, we represented the various chemical elements on Shöeller Berkaloff diagram. It is about a chart on semi-logarithmic scale on which the composition in major elements is deferred. A water of composition given will be represented by a broken line. Representation of rainwater on Shöeller Berkaloff diagram (figure 2) makes it possible to highlight a low chemical heterogeneity of rainwater.

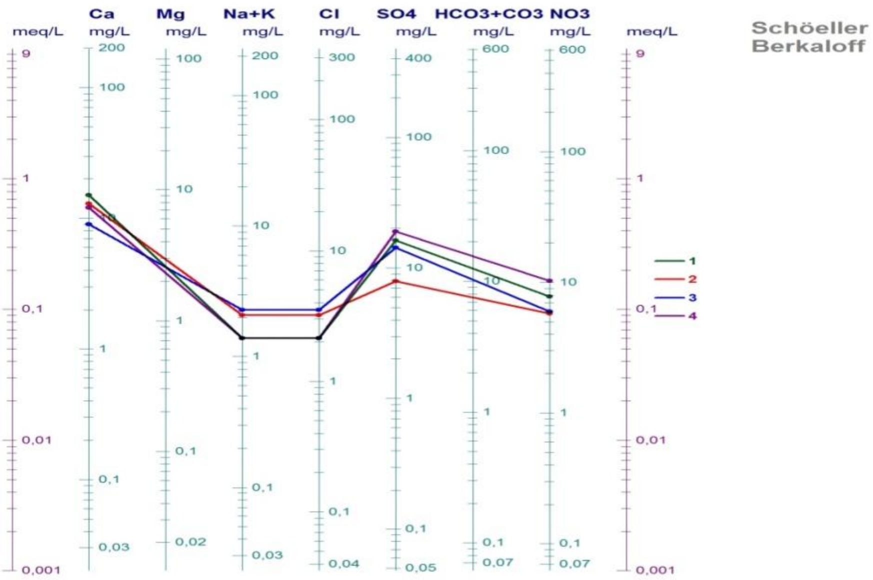

Figure 2: Shöeller Berkaloff diagram

Combination of electric conductivity of rainwater and sodium absorption report (SAR) makes it possible to classify this water according to the Riverside diagram of classification of irrigation water (figure 3).The graphic representation of 4 sites shows that rainwater has a low alkalizing power and does not present any risk of salinisation.

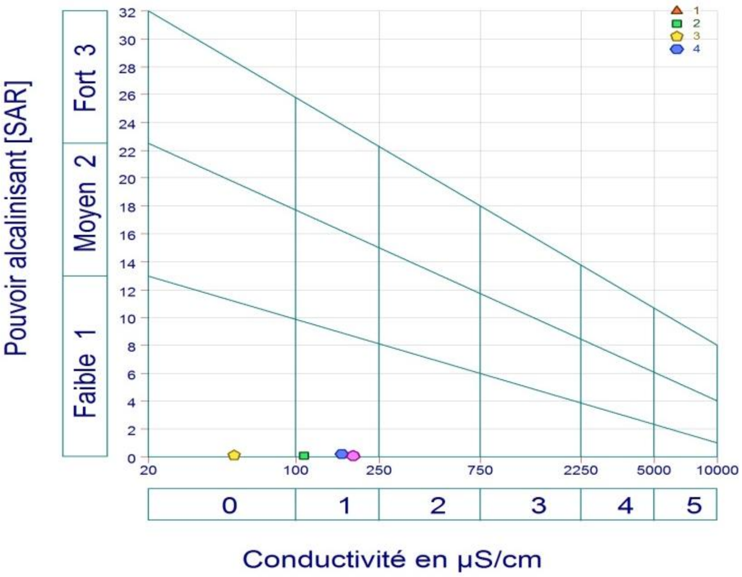

Figure 3: Riverside diagram

Stabler diagram is very useful for the study of carbonate equilibria. It allows to represent the calcite residual alkalinity and the generalized residual alkalinity. Anions and cations are listed separately in descending order. This study allowed us to distinguish a chemical calcium sulfate facies for the 4 sites (Figure 4).

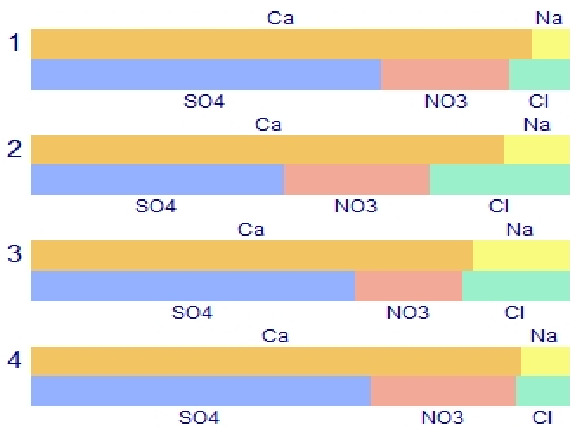

Figure 4: Stabler Diagram

3.3. Analysis correlation

Several significant correlations (table 2) could be identified and made it possible to show the good correlation of pH and conductivity group. These significant bonds can be allotted to common origins as of these elements.
pH is strongly correlated with ions: SO_4^{2-} (0.76), NO_3^- (0.69), PO_4^{3-} (0.92) and Ca^{2+}(0.60), when NH_4^+ ion is strongly correlated With Na^+(0.67) ions and TSS (0.63), while NO_2^- is strongly correlated with CE (0.95), turbidity (0.86), and SO_4^{2-} (0.67) ions. Conductivity is strongly correlated with ions: SO_4^{2-} (0.85), NO_3^- (0.62) and NO_2^- (0.95) as well as turbidity (0.70). SO_4^{2-} ions have good correlation with ions: NO_2^- (0.75) and PO_4^{3-} (0.66).

3.4. Treatment by planted filters

The main purification mechanisms are based on the combination of several processes in an aerobic condition, which take place successively on two stages of purification.

Tableau 2: Correlation matrix of rainwater

	pH	TSS	CE	Tur	SO_4^{2-}	NO_3^-	NH_4^+	NO_2^-	PO_4^{3-}	Ca^{2+}	Na^+
pH	1										
TSS	-0.55	1									
CE	0.31	-0.93	1								
Tur	-0.25	-0.64	0.70	1							
SO_4^{2-}	0.76	-0.92	0.85	0.31	1						
NO_3^-	0.69	-0.58	0.62	-0.12	0.84	1					
NH_4^+	-0.93	0.63	-0.32	0.005	-0.71	-0.43	1				
NO_2^-	0.21	-0.93	0.95	0.86	0.75	0.38	-0.34	1			
PO_4^{3-}	0.92	-0.58	0.26	-0.05	0.66	0.39	-1.00	0.28	1		
Ca^{2+}	0.60	0.33	-0.54	-0.90	-0.02	0.24	-0.43	-0.65	0.47	1	
Na^+	-0.90	0.35	-0.22	0.49	-0.67	-0.85	0.67	-0.01	-0.66	-0.70	1

Under aerobic conditions and high pH, the NH_4^+ ion undergoes nitrification by the nitrifying bacteria Nitrosomonas and Nitrobacter. The nitrification process translates the biological oxidation of ammonium (NH_4^+) into nitrates (NO_3^-) by adapted microorganisms [17]. This process is carried out in two steps where the nitrite ions are formed as intermediate ions [14].

$$\mathbf{55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7NO_2 + 54NO_2^- + 57H_2O + 104H_2CO_3} \quad \textit{(Nitrosomonas)}$$

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \rightarrow 400NO_3^- + C_5H_7O_2N + 3H_2O \quad \textit{(Nitrobacter)}$$

Nitric nitrogen can be used to oxidize organic matter if all the oxygen is absent or already consumed, it is denitrification. This explains the decrease in NH_4^+ ions during treatment. The lower nitrate concentration at the outlet of the system can be explained in part by the use of this nutrient for both plant growth and bacterial processes of denitrification in anoxic conditions [18]. The litter of the plants produced may favor this denitrification [19]. Denitrification can produce mainly N_2 [20].
According to Paul Lessard, denitrification is given by the following equation:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10\ OH^-$$

Aerobic autotrophic nitration, corresponding to the oxidation of ammonium ions to nitrite ion; The nitrite ions then oxidized to nitrate ions by Nitrobacter microorganisms [12], so the decrease in nitrite ions is due to the oxidation of nitrite ions to nitrate ions according to the following equation [21]:

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

In order to study the effectiveness of our pilot we calculated the elimination efficiencies (Table 3) of each parameter during the treatment period.

Tableau 3:Elimination efficiency

Parameters	Efficiency (%)
Turbidity	79.26
TSS	77.31
NH_4^+	67.48
NO_3^-	60.84
NO_2^-	62.82
PO_4^{3-}	62.92
Cl^-	5.92
Na^+	22.73
Ca^{2+}	38.12

During this treatment the monitoring of the evolution of the different parameters of pollution showed an improvement of the abatement of organic load and nutrients. This improvement is much more important for nutrients.

Conclusion

The results show that rainwater is poorly mineralized, low in organic matter, but also has high concentrations of ammonia nitrogen as well as nitrite ions.

Analysis of pollution parameters showed that some of them exceeded the permissible potable standards, hence the need for treatment.

The hydrochemical approach (piper diagram) classifies water in a chemical calcium sulphate facies and the Riverside diagram shows that rainwater has an excellent quality for irrigation of green spaces.

The installation of aquatic plants in a fully mineral substrate irrigated by rainwater allows to obtain their purification around the rhizomes of the plants where live microorganisms. The substrate allows the retention of some of the pollutants by sieving and the plants contribute to the purification of the waters by the removal of the nutrients contained in the waters and by the supply of oxygen to the level of the rhizomes where the micro - organisms.

In view of the different results obtained this treatment technique can be considered for the improvement of the quality of the rainwater recovered after runoff on roofing and used for sanitary uses in the countries where this resource can be of great importance.

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