HYDROLOGY AND SURFACE WATER QUALITY OF THE INAOUENE RIVER WATERSHED, MOROCCO

J. Naoura[1], L. Benaabidate[2] and A. Dridri[3]

[1] USMBA, FST Fez, Morocco, E-mail: najamal20@yahoo.fr
[2] USMBA, FST Fez, Morocco, E-mail: Benaabidate@yahoo.fr
[3] USMBA, FSDM Fez, Morocco, E-mail: abdallahdridri@yahoo.fr

ABSTRACT

The evolution of the annual mean flow reflects the spatiotemporal irregularities, while taking account the annual variations of flows in the two main gauging stations in the Inaouene watershed; Bab Marzouka and Elkouchate. The spatial irregularities are in direct relation with the position upstream of the station of Bab Marzouka and downhill of Elkouchate, on the other hand the temporal irregularities put in relief a succession of humid and dry periods. Indeed, the low flow, strongly influenced by withdrawals and discharges, has revealed a drying up marked mainly in summer. Indeed, zero flow was recorded several times.

Although the level of the industrial activities is comparatively less important in the Inaouène watershed, the use of the main watercourse of this watershed as outlet of wastewaters originating essentially from city of Taza and the crossed towns constitutes a big threat of the physicochemical and bacteriological qualit of its waters. Thus, a systematic study of the current position of the pollution of this river, in comparison with the different anthropic activities, becomes a necessity, owing to usage of these waters as the principal source of irrigation.

Keywords: Inaouene watershed, Hydrological regime, flows, wastewaters, contaminations, physicochemical parameters, heavy metals.

1. INTRODUCTION

The watershed of Inaouene River is located in Northern Morocco (Fig.1) covers an area of approximately 5184 km^2, between parallels 33.84 N ; 34.58 N and meridians 3.78 W ; 4.91W. This watershed is characterized by a wide topographic and geologic complexity, due mainly to its geographic position between the Middle Atlas outcrops and the Rif domain.

The study area is subjected to a semi arid. Indeed, this basin receives an annual rainfall of about 634.27 mm which has been obtained during the cycle 1971-2005. Despite this mean value, precipitations remain irregular and not well distributed, but they generate an important flow in the water body.

During its flow, the watercourse of the Inaouène River constitutes the receptacle of all liquid wastes issued from the urban areas (Fig.1) (City of Taza, Bab Marzouka, Oued Amlil, Bouhlou…). The risk of pollution and the state of contamination of surface waters of Inaoene is evaluated by studying the physicochemical characteristics of these waters.

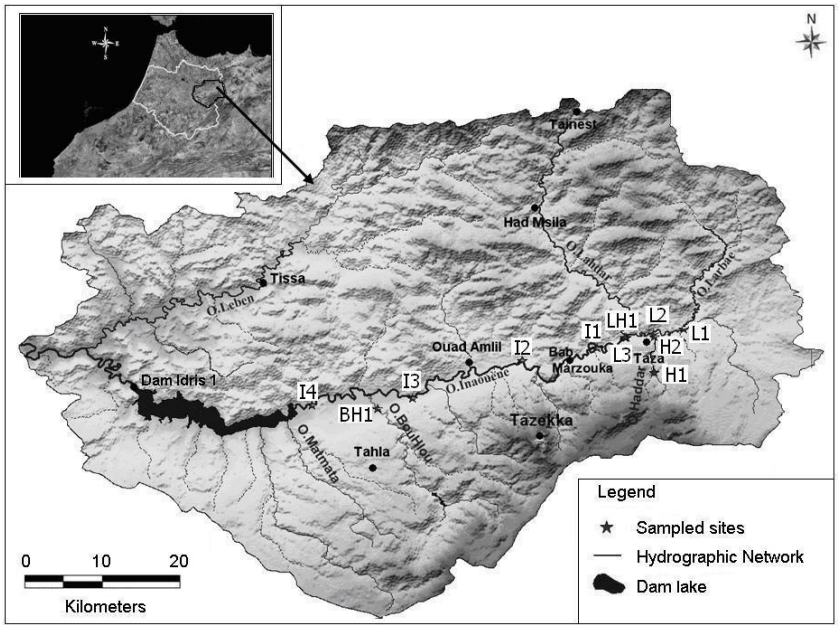

Fig.1 Situation map of Inaouene watershed

2. MATERIALS AND METHODS

The hydrologic study of Inaouene River is therefore based on the data of the two gauging stations located on its main course Bab Marzouka and Elkouchate. The data of the two stations were furnished by the Sebou Watershed Agency (ABHS). The predetermination of the maximum flow of swelling is of a notorious importance in the domain of the hydrology, just as well for the characterization of the hydrologic systems, that for ends of evaluation of the disastrous risks.

The data relative to the water quality of Inaouene River were collected from the samples main tributaries, following the degree of contamination linked to public disposals and the spillage of wastewaters without any pre-treatment. The conductivity was measured in situ with a conductivimeter type Orion. Nutrients, DCO and DBO_5 were realized at the laboratory of biotechnology of the Faculty of the Sciences Dhar El Mahraz (Fez) respectively by a DCO-meter, a DBO-meter type Oxitop and the Spectrophotometer. Those elements are relative to two campaigns April and October 2010.

The dosage of Trace elements, (Cd, Co, Cu, Fe, Ni, Pb, Cr, Ti and Zn), was carried out using the Emission Spectrometry Coupled to Induced Plasma at the laboratory of CNRST (National Centre of Scientific and Technical Research) of Rabat. The analyses of trace elements are relative to two campaigns; September 2009 and April 2010.

3. RESULTS AND DISCUSSIONS

2.1 Hydrologic Characterization

Despite that flow data do not represent gaps of measures; their reliability was checked by the Man Whitney's test of consistency and the Wald Wolfowitz's test of stationarity (Naoura [1]). The hydrologic study of the Inaouene watershed will be therefore based on the data of the two gauging stations situated on its principal course. This study was carried out only on the annual main flows.

2.1.1 Spatial and temporal variations of the annual flows

The evolution of the annual mean flows reflects the spatiotemporal, while taking account of the inter-annual variations of flows in the two stations (Fig.2 and 3). The spatial irregularities are in direct relation with the upstream position of the station of Bab Marzouka and downstream of Elkouchate, on the other hand the temporal irregularities put in relief a succession of humid and dry.

Annual mean value in, the station of Bab Marzouka is of 7.74 (m^3/s) but at Elkouchate, it is more important 10.99 (m^3/S). The other characteristic of flows in the two stations are as follow (Tab.1):

Table 1 Flow characteristics at Bab Marzouka and Elkouchate stations

Stations	Surface (Km^2)	Mean annual flow (m^3/s)	Specific flow ($l/s/Km^2$)	Mean annual volume (Mm^3)
Bab Marzouka	1497	7,74	5,17	244,09
Elkouchate	2678	10,99	4,10	346,58

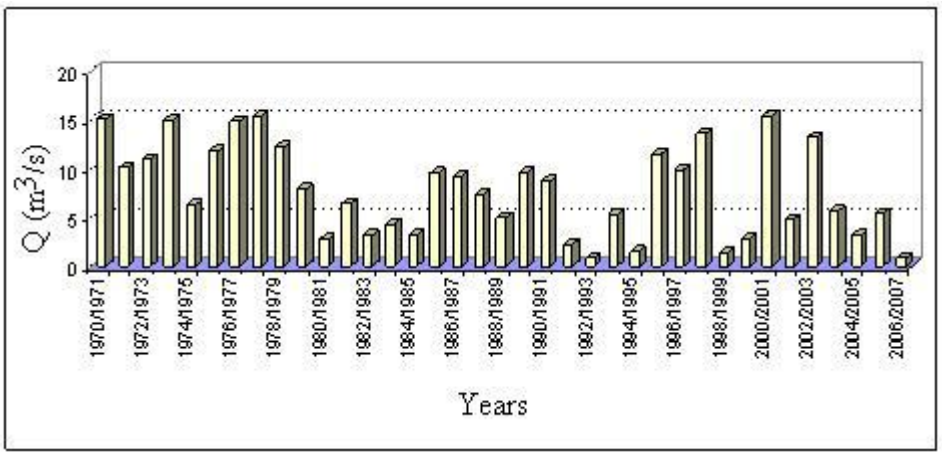

Fig. 2 Inter annual variations of flows at the Bab Marzouka station (1971-2007)

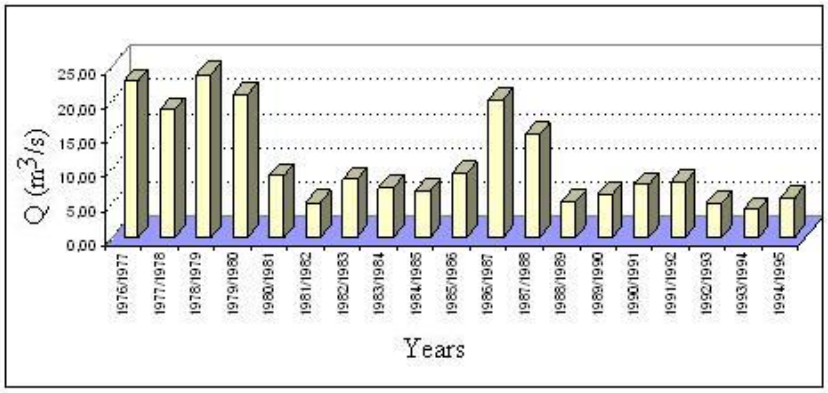

Fig. 3 Inter annual variations of flows at the Elkouchate station (1976-1994)

To make obvious the hydroclimatic fluctuations that affected the Inaouene watershed, the methodology of the standard deviation (Ec) of the annual mean flows (Qma) to the inter annual mean flows (Qmi) seems adequate, since this method was used with success by several authors; Probst and Tardy [2], Etchanchu [3] , Haida [4], Sibari [5]. This method allows distinguishing the humid periods or excess periods (Ec> 0) from dry periods or deficit periods (Ec <0) (Tab.2), the used formula is:

$$Ec = \frac{(Qma - Qmi)}{Qmi} \times 100$$

Q_{ma} : annual mean flows,

Q_{mi} **:** inter annual mean flows

The obtained results, (Fig. 4 and 5), reveal an alternation of excess periods and deficit periods at each station. According to Haida [4], the alternation of these periods is explained by the climatic fluctuations that allow refilling the hydrologic reservoirs in humid periods on the other hand they will be drained in periods dry.

However, this alternation of humid periods and periods dry is not conforming in the two stations. Indeed, deficit period are more important than excess periods. These results allow deducting the temporal and spatial irregularity of both stations.

Table 2 Hydrologic Deficit and excess in both stations (1981-2002)

Stations	Period of deficit	Period of excess	Comparative value to the medium
Bab Marzouka	18	17	2
Elkouchate	13	6	0

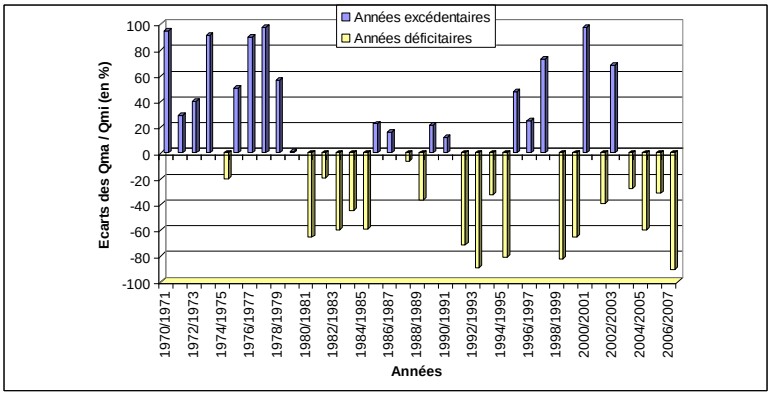

Fig. 4 Variations of inter annual mean flows standard deviation at Bab Marzouka

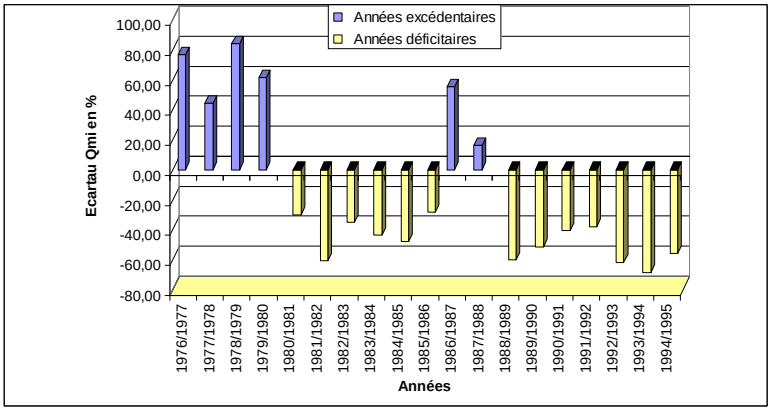

Fig. 5 Variations of inter annual mean flows standard deviation at El Kouchate

2.2 Qualitative Characterization

The determination of the physicochemical characteristic of waters constitutes an essential means for assessing the risks of pollution. The studied elements parameters are the COD, BOD_5, nutrients and the trace elements. These elements could have a natural origin (Zhang and Huang [6]) as well as anthropic due to the industrial activities.

2.2.1 The COD

According to the obtained results, the chemical oxygen demand is very weak in upstream of the study zone, testifying of a weak concentration in mineral or organic matters dissolved or in suspension in air. The evolution of the COD is progressively increasing at the site L3 (Fig.6), which shows a provision of the oxidable matters by the domestic and industrial effluents of Taza urban zone, but it decreases at the site LH1 which is not exposed to a strong anthropic pollution.

The maximum of the COD was recorded at the site I1, reflecting thus a strong concentration of the compounds necessitating oxygen for their oxidation, in particular the wastes of oil mills concentrated in this zone. A brutal fall of the DCO marks the site I2, which should be due to a dilution of the oxidable compounds by tributaries characterized by a weak concentration in these matters

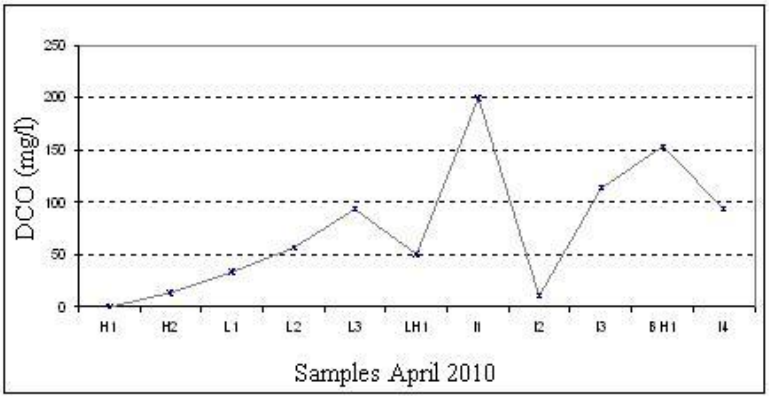

Fig.6 DCO variations (April 2010)

The COD increases again at the site I3; this shows the impact of the domestic and industrial effluents of the Oued Amlil urban zone. This increasing becomes important at the site BH1 reflecting a strong load in oxidable matters of Bouhlou stream waters. Just in upstream of the the Idris1st dam, the DCO decreases again by the effect of the dilution.

2.2.2 The BOD_5

The BOD_5 present an evolution than the COD (Fig. 7). The values of BOD_5 is close of zero in the sites (H1, L1, LH1, BH1), which suggests that these waters are not polluted; however, in the sites (L2, L3, I1, I2, I3 and I4) the values of the BOD_5 increases lightly with a peak at the site L2 after the enrichment in organic matter by the domestic and industrial effluents of Taza urban zone, afterward the value of the BOD_5 decreases at the site L3 and I1 under the effect of dilution by the Haddar and Lahdar streams.

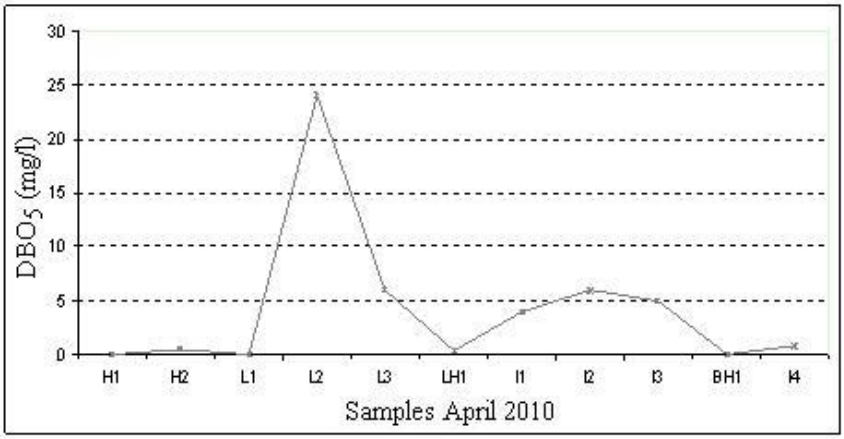

Fig. 7 BOD_5 variations (April 2010)

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2.2.3 The Nutrients

The Ammonium

The obtained results during the campaign of October reflect weak content in ammonium (<0,06) (Fig. 9) compared to international norms (0.5mg/l).

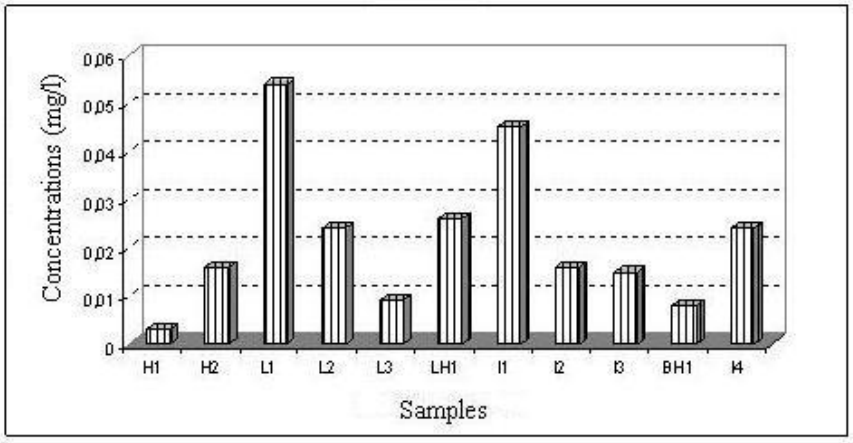

Fig. 9 Spatial variation of Ammonium (October 2010)

These results show that in upstream of Taza urban zone, the ammonium content is weak on the Haddar stream tributary (H1). However, the high concentration is observed at the site L1 situated on the Larbae stream tributary. Downstream, the content of ammonium increases at H2 but it decreases at L2 and L 3. Average concentrations are recorded at Lahdar stream tributary (LH1). These concentrations increase at the site I1, which represents the first sampled site after the confluence of these tributaries to form Inaouène River. These weak concentrations in ammonium could be explained by a weak ammonization or a high nitrozation.

The Nitrites

The normal contents in the non polluted waters vary between 0,03 and 3mg/l, with a r general tendency inferior to 3 mg/l (Chapman and Kimstash [7]). The nitrites contents of Inaouene waters are usually very weak in all samples, with exception of sites H2 and LH1 (Fig.10) where high concentrations have been recorded, surpassing widely the international norms during the campaign of April. For the site H2, the impact of pollution by the domestic effluents of Taza urban zone could be the cause. Furthermore, the agricultural pollution by the fertilizers must not be excluded.

Despite its position far of all the effects of pollution by effluents, the site LH1 contains the highest content in nitrite and this could be explained by an agricultural pollution and a high activity of nitrozation or a reduction of the nitrates.

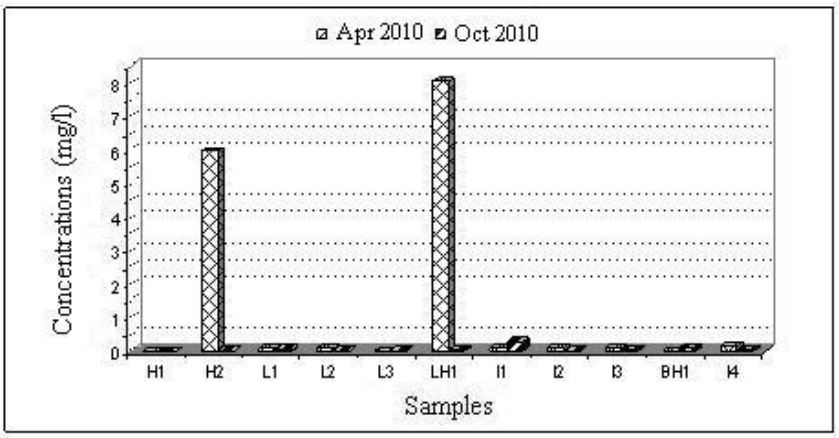

Fig. 10 Spatial variations of nitrites

The Nitrates

The obtained results, during the two campaigns, show spatial variations (Fig.11). The wintry period is characterized by high concentration in some sites, testifying thus of the impacts of a pollution by urban (H2, L2, I3) and agricultural (L1, LH1, I2) effluents, the nitrification process is excessive under the effect of water oxygenation.

The highest concentration in nitrates is recorded at the site L1, this could be explained, on one hand by its position to the neighborhood of a small garbage zone relative to the new industrial zone at the North of Taza, on the other hand the L1 is located at the confluence of Larbae and Boulajrafe streams, that probably have rich concentrations in nitrates.

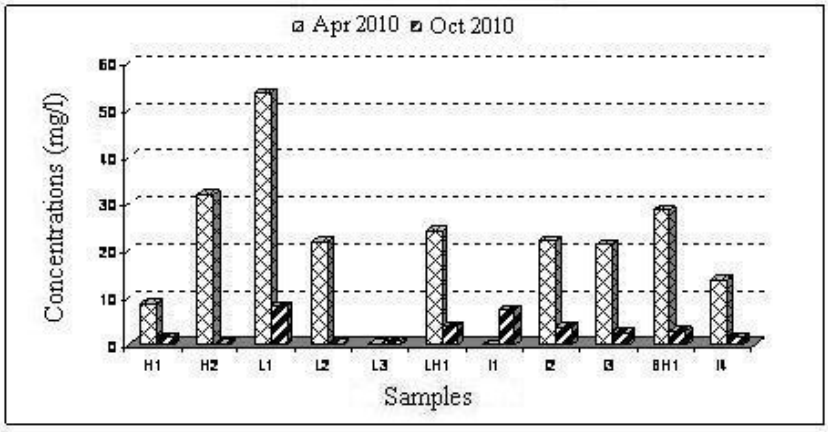

Fig. 11 Spatial variations of nitrates

The summer period is characterized by very low contents in nitrates; this could be explained by weak provisions of the agricultural effluents and the acceleration of process of denitrification by a lack of oxygenation of waters that results in a transformation of nitrates in nitrites then in nitrogen gaseous.

The Sulfates

The concentrations in sulfates in the Inaouene tributaries are important, with a peak that surpasses1000mg/l at the site LH1 situated on Lahdar stream (Fig.12). This high concentration could be explained by an alteration of the evaporitic rock minerals characterizing the Rif domain drained by Lahdar stream, to which are added sulfates coming from the use of fertilizers in farming. The same sources can be attributed for the site L1 situated on Larbae stream situated under the same geological context. A decrease of the sulfates content is recorded at L2, that normally must increase under the effect of the effluents of Taza urban, this decrease could be explained by the activity of the bacteria that use the sulfates to produce the sulfurates of hydrogenates (H_2S). Moreover, the site L3 shows high concentrations indicating an alteration of the evaporitic rocks minerals the minerals and a bacterial activity that induces a decomposition of the organic matters rich in sulfates in aerobic environment.

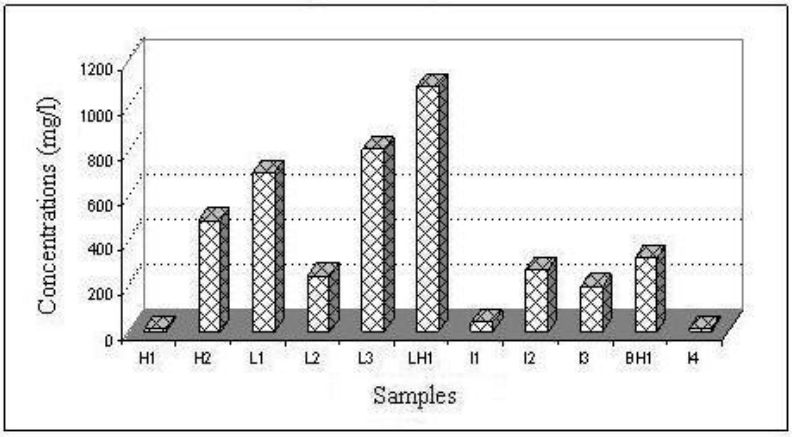

Fig. 12 Spatial variations of sulfates (April 2010)

The Phosphates

In the wintry period, obtained results show in general very low contents, with exception to sites (L3, I1) (Fig.13) that are sign pollution by the excess of fertilizers used in the fields on the shores of Inaouène River. This excess results from an important vegetables agricultural activity during this period. Average contents are noticed at H1 and BH1, these two sites are also seat of an agricultural activity.

The impact of pollution by the domestic and industrial effluents of the Taza urban zone, in terms of phosphates, is not clear, since low concentrations in phosphates have been recorded in the sites (H2, L2) that are exposed directly to the rejection of wastewaters and the solid wastes.

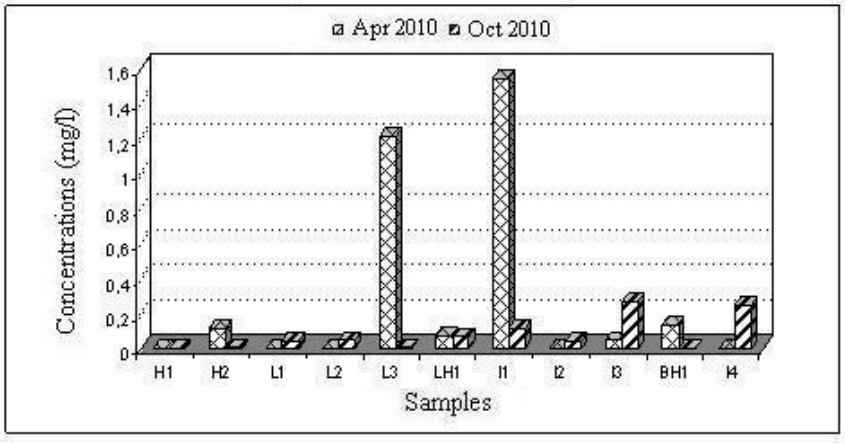

Fig. 13 Spatial variations of phosphates

The summer period is characterized also by weak contents in phosphates, with exception to the sites (I3, I4), where mean contents have been recorded.

2.2.4 The trace elements

The results of the trace elements analyses in Inaouene waters and its principal tributaries show two series according to the detection thresholds; a Series of the trace elements of which the concentrations are above the limits of detection. This series is composed of Fe, Ni, Mn and Ti. The second series including trace elements of which the concentrations are below the limits of detection and composed of Cr, Cu, Pb, Zn, Cd and Co. The study will be therefore limited to the elements of the first series.

The Iron

The iron contents of the campaign 2010 are very weak at all the sampled sites. Concerning the campaign 2009, concentrations values are above the Moroccan norms (0.2mg/l) in the sites (H2, L1, LH1) (Fig.14). The highest concentration is detected at the site L1, and this could be explained by a natural source for this element.

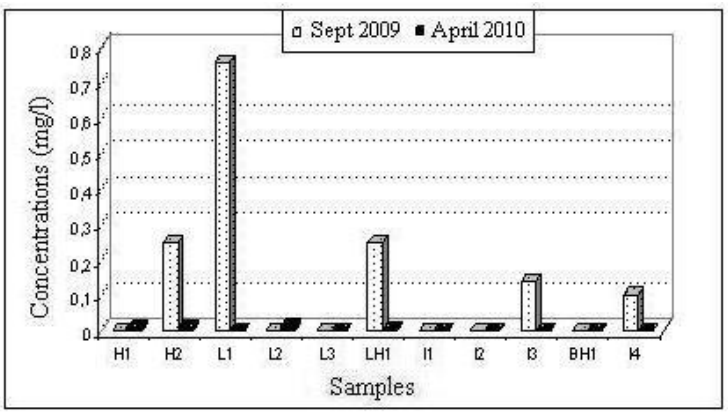

Fig. 14 Spatial variations of Iron

These low concentrations in iron in the Inaouene waters could be explained by the Fact that, iron generally is located in surface waters in the form of a salt containing the Fe^{3+} when the pH is superior to 7; which is the case or the studied waters (Naoura [1]). Most of these salts are insoluble and are precipitated or adsorbed on different surfaces. Consequently, the iron concentration in well ventilated waters rarely is raised.

The Nickel

The analysis results recorded during the campaign 2009 show concentrations under the limit of detection. Those of 2010, despite that they are above the detection limit, the nickel contents are very weak in the majority of the sampled sites (Fig.15), the highest detected concentration at the site L1 is about 0,014 mg/l. As iron, the nickel is located in the does most cases under the particular form when the pH is above 8, what explains these weak concentrations of nickel Coughtrey and Thorne [8]).

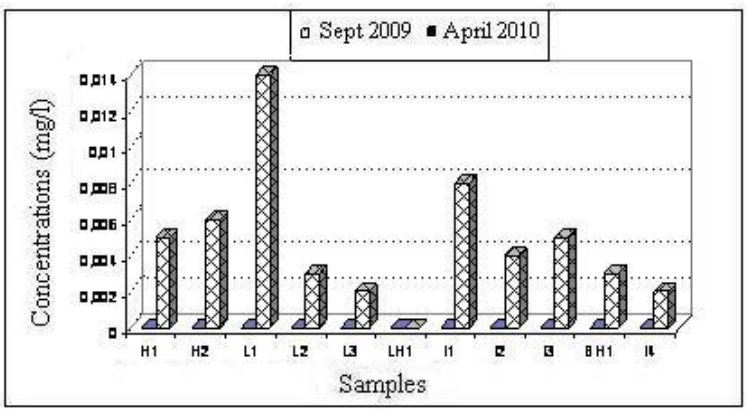

Fig.15 Spatial variations of Nickel

The Titan

In the Inaouene waters, the recorded concentrations of Titan during the campaign 2009 are very low. The highest concentration characterizes the site L1 (0.07mg/l), followed by the site LH1 (Fig.16). The origin of this high values is probably natural, since the two sites are not exposed to a net pollution.

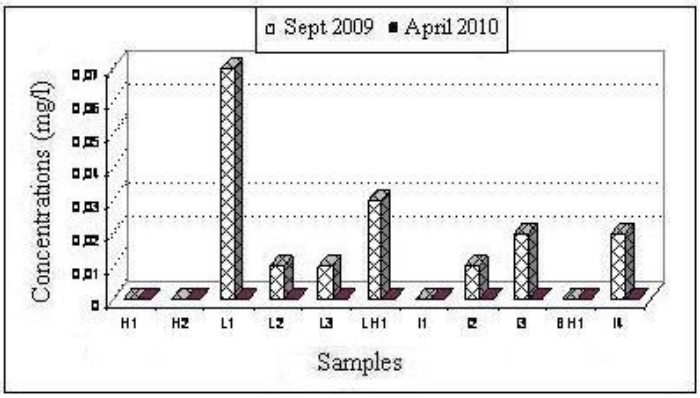

Fig. 16 Spatial variations of Titan

The Manganese

The manganese could be of an agricultural origin since it enters into the composition of certain phytosanitary products as it can have as industrial origin as wastes of batteries and dyes (Weast [9]). During the campaign 2010, recorded concentrations are above the detection limit but are in accordance with the norm at the site H2. These concentrations should be issued from the industrial wastes, since these sites are exposed directly to this kind of pollution (Naoura [1]).

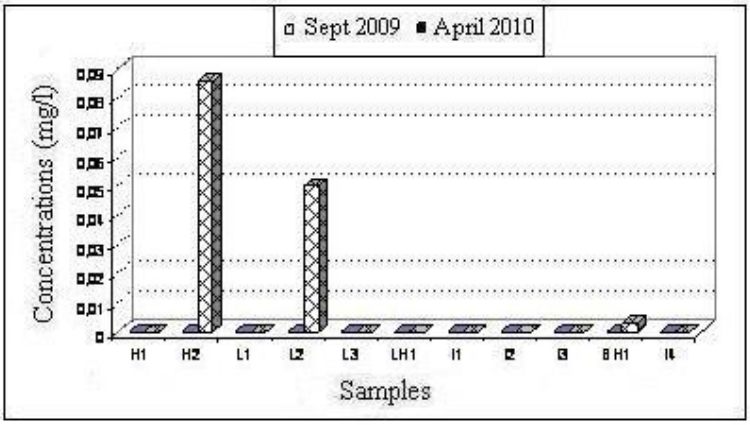

Fig. 17 Spatial variations of Manganese

3. CONCLUSIONS

Situated in a semi arid zone, the Inaouène watersheds is subject of problems of water scarcity, due to the annual and inter annual climatic variability. The obtained results reveal an alternation of excess periods and of deficit periods at the both study stations. This alternation of humid periods and dry periods dry is not conforming in the two stations with an importance of dry periods.

Beside the hard climatic situation of this watershed, its main course acts as collector of all wastewaters issued from the city of Taza and the small towns of the watershed. This situation reflects the degradation of the surface water quality in the watershed. This pollution has been put in evidence by the relatively high

concentrations of some nutrients, COD, BOD_5 and mainly the high contents of some heavy metals such as Fe, Ni and Mn.

Such results argue the imbalance of the Inaouene River hydrological system and its quality due to the natural factors and or socio-economic activities. Consequently, the safety of the water becomes a problem, requiring a focused discussion on the challenges of managing water resources in this watershed.

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