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Research Article

EVALUATION OF ROAD TRAFFIC IMPACT ON THE AQUIFERS OF THE CROSSED AREAS. APPLICATION TO ANNABA PLAIN CROSSED BY (NR21, NR16 AND NR44). NORTHEASTERN ALGERIA

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ABSTRACT

In the Annaba plain, the contamination of groundwater and road runoff by heavy metals was studied through combining the geochemical and hydrochimical approaches. For different metals, the mineral sources of contamination, as well as the geochemical processes of mineral weathering were established. The understanding of the geochemical mechanisms involved and the realized assessment allowed determining the origins, the modes of transport (collective or individual, heavy or light) and control of metals in the plain. In this study, we examine the risks of road traffic on the quality of groundwater and road runoff in the Annaba plain crossed by three important communication nationals roads: RN 44, 21 and 16. The survey was carried out in June 2011, April 2012 and December 2013 and covers the transport of heavy metals from the road traffic in the roadsides environment. The concentration of heavy metals Pb^{2+}, Zn^{2+} , Cu^{2+} and Fe^{2+} in groundwater are respectively: 0.001 $mg.l^{-1}$, 0.13 $mg.l^{-1}$, 0.11 $mg.l^{-1}$ and 1.055 $mg.l^{-1}$, on average.

Keywords: Annaba plain, Emissions, heavy metals, pollution, road traffic.

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1. INTRODUCTION

1.1. Studies on water and soil pollution by road traffic

Heavy metals are considered as one of hazardous pollutants in natural environment due to their toxicity, persistence, risk to human, and long-term damage to the environment [1]. Although some heavy metals are essential for vital processes in many living organisms, including humans, yet these metals are generally toxic when their concentrations exceed certain thresholds [2].

Among the anthropogenic sources of heavy metals, we can report a mining activity, a metallurgical and steel activity, fertilizers and pesticides applied to farmlands, incinerators and waste incineration facilities, medical waste, city landfills, emissions of factories, wastewater and sludge. [3-6]. However, it seems that the main anthropogenic source of heavy metals for the environment is the one produced by the mining activity and related industries, and it was also identified as one of the first environmental impacts induced by humans [7]. A large part of pollution found in the cities is due to the road traffic, and its contribution is likely to further increase since more than 70% of the world population in 2050 will live in the cities [8].

The vehicles and traffic roads are a potential source of generalized contamination of groundwater and soils. Currently, in certain countries, the rapid economic development gives rise to a concomitant increase in pollution.

Different types of pollution can give rise to nuisance in a road environment: temporary, chronic and seasonal pollution [9]. Pollution of road origin, linked to engine exhaust emissions, to the wear of vehicles, roads and road equipments, constitutes a chronic pollution affecting immediately the vicinity environment through runoff and dry and wet atmospheric deposits (Fig.1). The impacted media are the superficial and/or underground hydrosystems, the atmosphere, the soils and vegetation that they bear [10].

The untreated atmospheric wastes (this amount tons year-1), mixed with aquifer system water through precipitation and aerosol deposit, contribute to the deterioration of soil and water quality. The behavior study of Zn, Pb, Fe and Cu in an unconfined aquifer system is axed on the identification of geochemical mechanisms associated with the origin of the concentration and nature of this system [11]. Sequential extraction schemes involving extractants of increasing power were thus applied to roadside soils [12], road dusts and pluvial sanitation sediments [13,14].

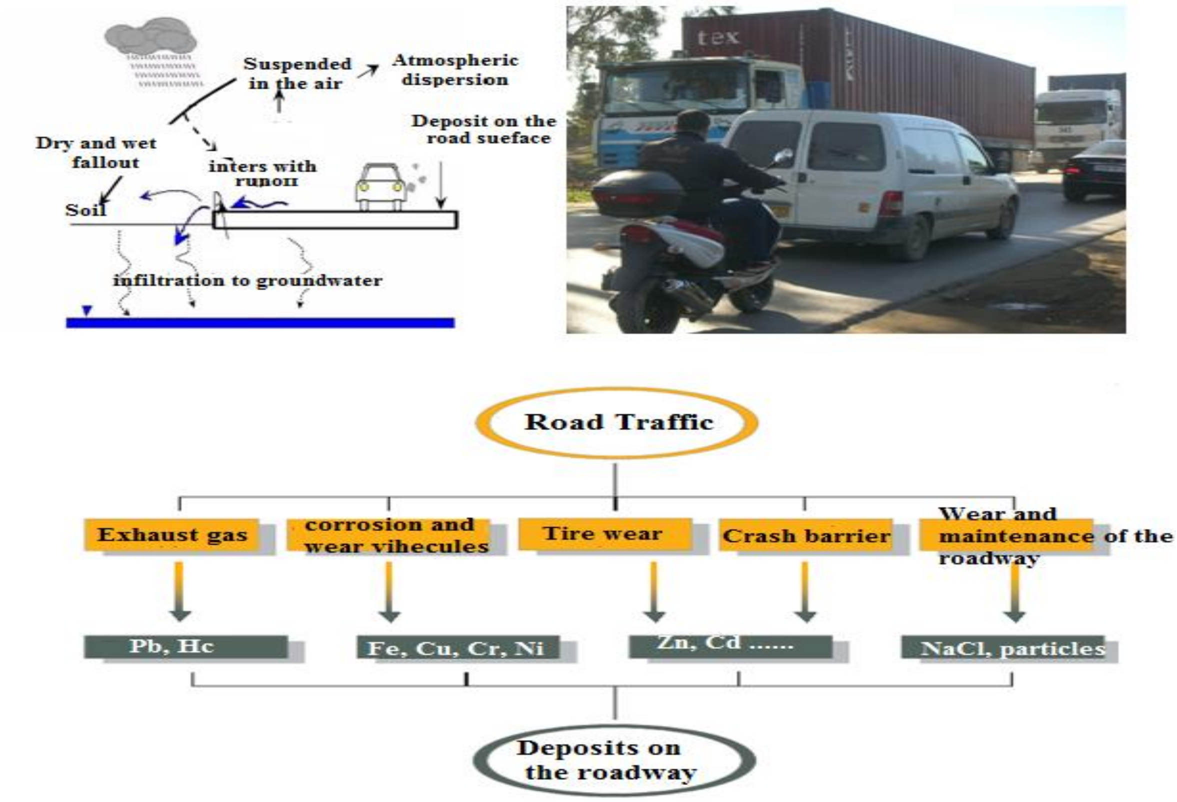

Fig.1. Very significant paths and sources of contamination of groundwater in a road domain

The study of heavy metals in road dust and their source identification has become necessary to reduce pollution effectively. Many researchers in various cities have well documented the presence of heavy metals in the road dust: Hong Kong [15], Birmingham and Coventry [16], Naples [17], Istanbul [18], Gela [19], and Samsun City [20].

A large part of pollution in the cities is due to road traffic, and its contribution is likely to further increase since 70% of the world population in 2050: [15-20] will live in cities pollution impact linked to the automobile traffic on the air and runoff quality. The present study aims to provide scientific information related to heavy metals pollution, such as Pb, Cu, Zn and Fe in road groundwater and road runoff samples of the Annaba plain.

2. MATERIELS AND METHODS

1.2 Location of the study area

The Annaba plain is located northeast of Algeria (Fig.2) and is subject to a Mediterranean climate defined by a rainy season ranging from October to May and a dry, hot summer. The mean annual rainfall, real evapotranspiration and the recharge are of 700, 500 and 80 mm respectively [21].

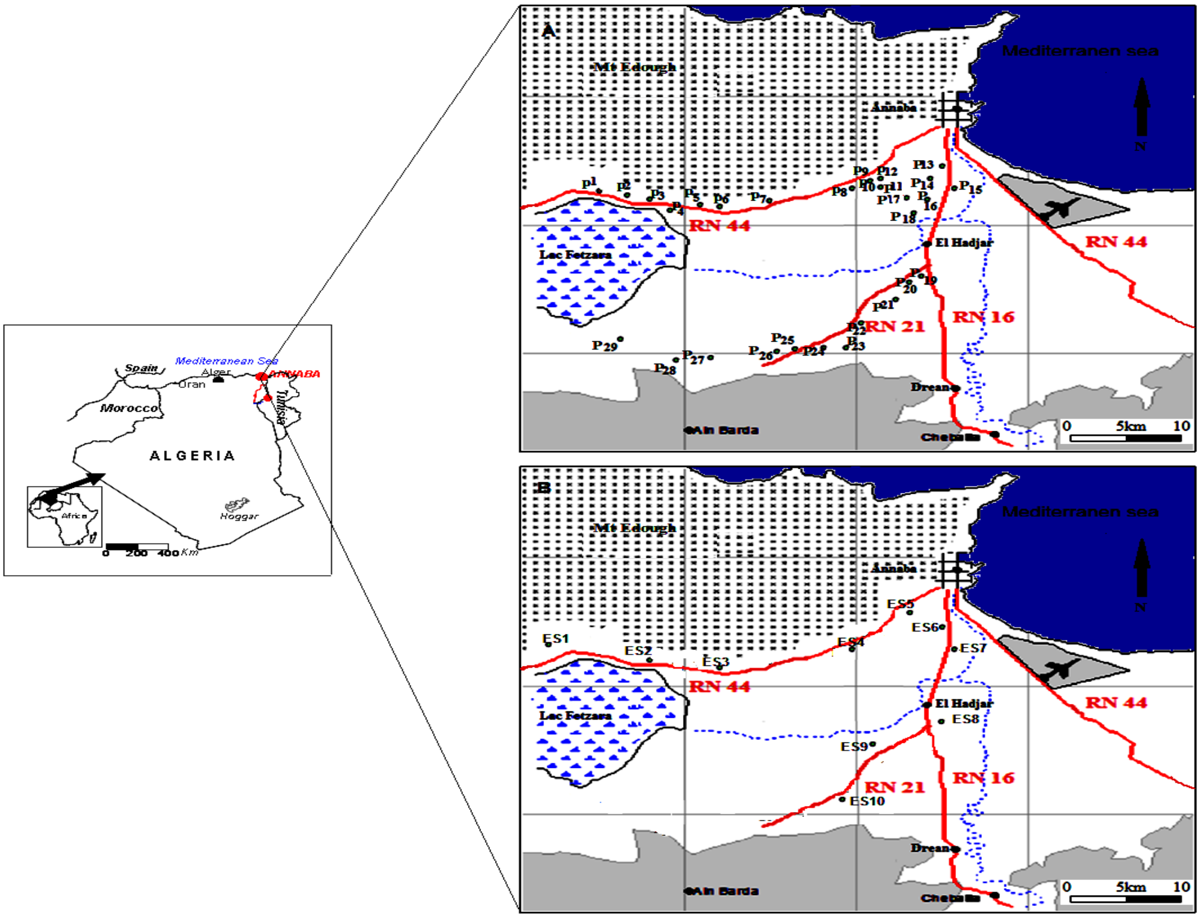

Fig.2. Geographical location of Annaba plain and the sampling points collection

The formations highlight two aquifers (Fig.3) linked principally by the Wadi Meboudja, as well as by the superficial aquifer of Annaba and by the alluvial aquifer of the high terraces. The second aquifer is fed by the first using the connection of the Meboudja wadi. This relationship may offer a source for salinity. Sandy clay materials between lenses of sand constitute the superficial aquifer of Annaba. These sand lenses are more frequent in close proximity to the Seybouse Wadi and on the periphery of the Numidian sandstones.

The water table fluctuates depending on the recharge/discharge rate, except at levels where it is confined under the clay in the north.

The Alluvial aquifer of high terraces in the southwest of Annaba extends alongside the Numidian sandstones. These gravely and stony alluvial deposits with a clay matrix have relatively important possibilities in the western part, near to the Fetzara Lake zone. More than 200 wells exploit this aquifer for irrigation and drinking water.

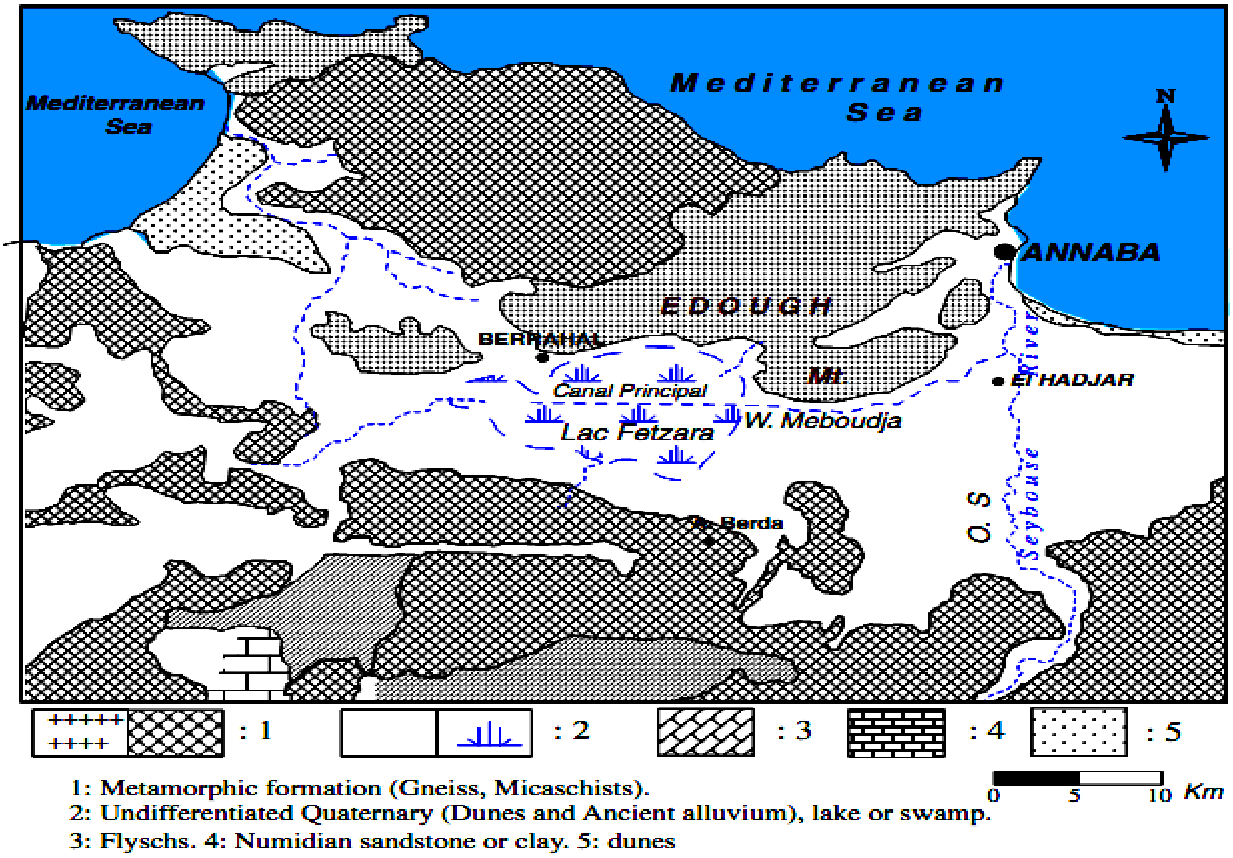

Fig.3. Geological map of the study area (Rouabhia et *al* 2010)

In this work, we present the findings regarding the variations of concentrations of trace metals in groundwater of the Annaba plain crossed by three nationals' roads (NR 44, NR16 and NR21). 39 samples were collected from quaternary aquifer.

A monitoring of chemistry was carried out for road runoff (June 2011, April 2012 and December 2013) and groundwater (June 2011, April 2012 and December 2013). The sampling points are well distributed and cover the whole plain (Fig.3). The hydrochimical properties of groundwater samples collected from the quaternary aquifer system are presented in Table 02. Cation and trace element analyses (Zn, Pb, Fe and Cu) were performed with ICP-MS in the chemical laboratory of Côte d'Opale Coast University, Dunkerque (France).

2.2 Annual statistics of the vehicle fleet of the study area

The Annaba city is considered as one of the most polluted cities of Algeria. On the one hand there is a steel plant and a very important vehicle fleet in relation to the travelled distances, and certain topographical and climatic characteristics create an atmosphere suitable to pollution on the other hand [22].

At the Annaba province scale, the vehicle fleet has more than 170 thousand vehicles [23] the tourist vehicles account for 68% of the total number of vehicles (Fig.4).

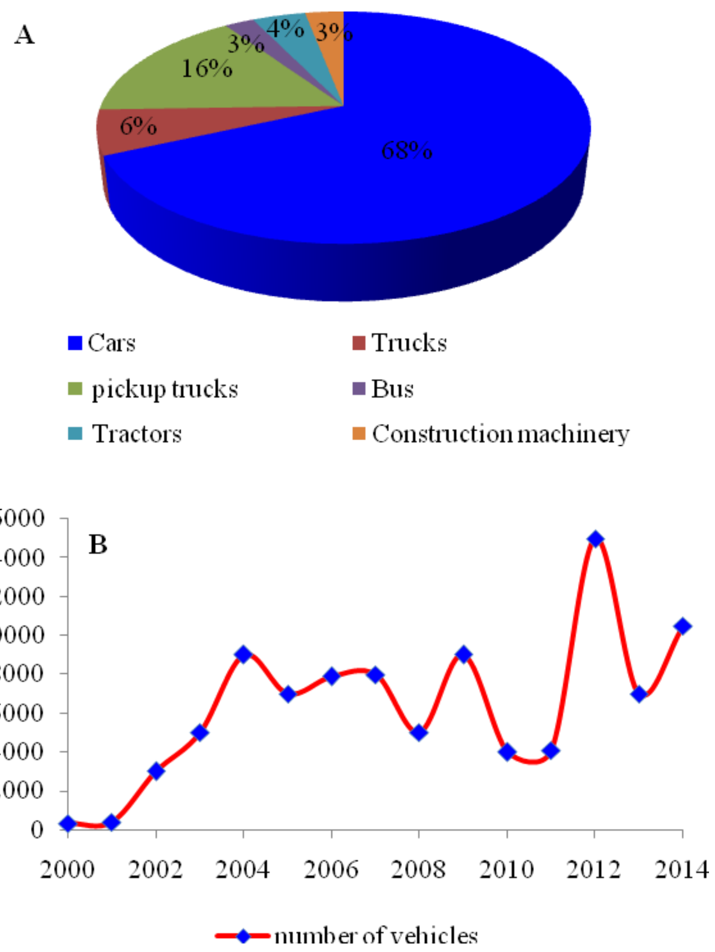

Fig.4. Statistics of the Annaba vehicle fleet: **A.** Number of vehicles by type. **B.** Annual evolution of the vehicles number (ONS, 2014)

2.3 Examination of road traffic pollution

It is the most significant point of our work. Recent industrial facilities caused a large increase in road traffic, notably of heavy goods vehicles for the transportation of different products. We wanted to make a census of the number of vehicles running on the sections of the national roads RN 44, 16 and 21 crossing the Annaba plain (Table 1) during one of our field visits.

Table 1. Intensity of the road traffic on the sections of the national roads RN 44 and RN16 (December 2013)

Type of vehicle	*Heavy goods vehicles*	*Light vehicles*	*Public transport*
December 13, 2013 from 09.00 to 09.15			
	Extrapolation (RN 44)		
15min	20	50	10
30min	40	100	20
Hour	80	200	40
Day	1920	4800	960
Month	59520	148800	29760
Year	700800	1752000	251850
	Extrapolation (RN 16)		
15min	17	35	6
30min	34	70	12
Hour	68	140	24
Day	1632	3360	576
Month	50592	104160	17856
Year	595680	1226400	210240

3. RESULTS AND DISCUSSION

3.1. Spatial evolution of heavy metals

The climate, the local geography, the population, the topography, the urbanization, the density of the road traffic are efficient factors for the distribution of trace metals in dust, which has harmful effects on human health [24].

The examination of the values obtained at the study area highlights the following observations:

The physicochemical characteristics and the concentrations of heavy metals of urban runoff (roads and roofs) vary according to the traffic intensity, to the road's characteristics (wear state, maintenance), to the road mode of use, to the environment and to the rain characteristics. The hydrochimical properties of road runoff and groundwater samples collected from Quaternary aquifer system are shown in Table 2, 3. The sites which samples were taken are showen in Figure.2

Table 2. Variation of heavy metals in road runoff. (10 samples)

Heavy metals	Fe ($mg.l^{-1}$)		Zn ($mg.l^{-1}$)		Cu ($mg.l^{-1}$)		Pb ($mg.l^{-1}$)	
Campaigns	Jun 2011	Apr 2012	Jun 2011	Apr 2012	Jun 2011	Apr 2012	Jun 2011	Apr 2012
Average	0.4	2.7	0.035	0.2	0.054	0.18		
Max	2.96	0.28	0.02	00	0.054	0.024	0.001	
Min	0.047	00	0.006	00	0.002	00		
Standard deviation	1.094	1.442	0.0041	00	0.00739	00	00	

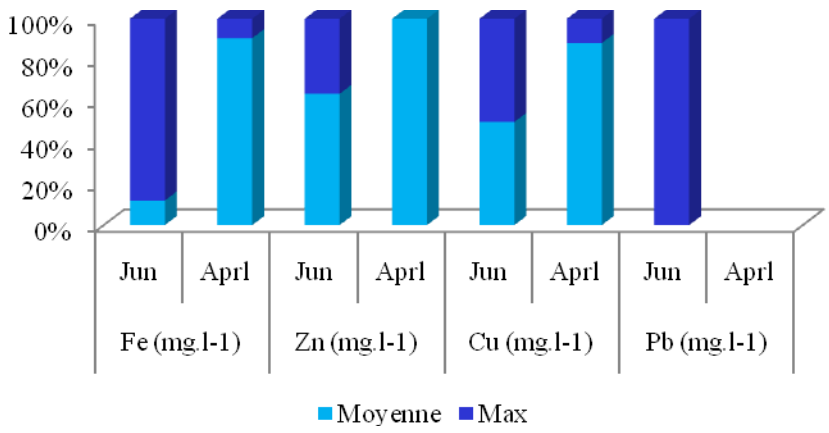

Fig.5. Temporal variability of heavy metals in road runoff (10 samples)

The findings concerning road runoff emphasized the low degree of contamination of water by copper, zinc and occasionally iron, the origin of which can be corrosion and wear of vehicles or geology of the soil after leaching, especially in winter period (Fig.5).

Table 3. Variation of heavy metals in groundwater (29 samples)

Heavy metals	Fe (mg.l^{-1})			Zn (mg.l^{-1})			Cu (mg.l^{-1})			Pb (mg.l^{1})
Campaigns	**Jun 2011**	**Apr 2012**	**Dec 2013**	**Jun 2011**	**Apr 2012**	**Dec 2013**	**Jun 2011**	**Apr 2012**	**Dec 2013**	**Jun.2011, Apr.2012, Dec.2013**
Average	0.4	2.7	0.065	0.035	0.2	0.15	0.0051	0.18	0.15	0.001
Max	4.96	5.5	0.34	0.23	0.6	0.42	0.1	0.70	0.54	0.018
Min	00	00	00	00	00	00	00	00	00	<0.001

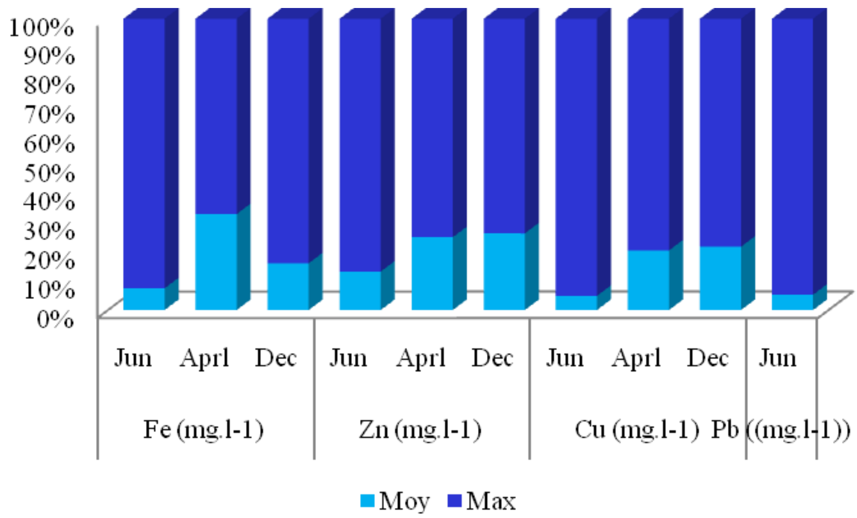

Fig.6. Temporal variability of heavy metals in groundwater

a) Lead variation

The average lead concentrations in the plain water are lower than 0.001 at the whole site except for some water points, where the concentrations increase (0.0088 mg.l^{-1}) but remain always lower than the standards WHO (0.01 mg.l^{-1}).

b) Copper variation

The average copper concentrations (Fig.6) are of the order of 0.0051 mg.l^{-1} (June 2011), 0.18 mg.l^{-1} (April 2012) and 0.15 mg.l^{-1} (December 2013), but remain always lower than the OMS standards (1 mg.l^{-1}).

c) Iron variation

The average iron concentrations (Fig.6) are of the order of 0.4 mg.l^{-1} (June 2011), 2.7 mg.l^{-1} (April 2012) and 0.065 mg.l^{-1} (December 2013); these concentrations exceed the potability standards (0.2 $mg.l^{-1}$). The highest concentration is recorded at the well (P10).

d) Zinc variation

The average zinc concentrations (Fig.6) in the groundwater of Annaba plain are still remaining below standards (2 $mg.l^{-1}$). As follows: 0.035 $mg.l^{-1}$ (June 2011), 0.2 $mg.l^{-1}$ (April 2012) and 0.15 mg. l^{-1} (December 2013)

3.2 Mapping of heavy metals variation in groundwater

a) Mapping of lead variation

At the whole plain, high concentrations of lead are observed in the center of the plain(but are still below standards OMS: 0.001$mg.l^{-1}$). The concentrations follow the flow direction of groundwater, which occurs from South to North. This state is due to the fixation of the element by the clay and may also be related to the industrial activities and geology (Fig.7).

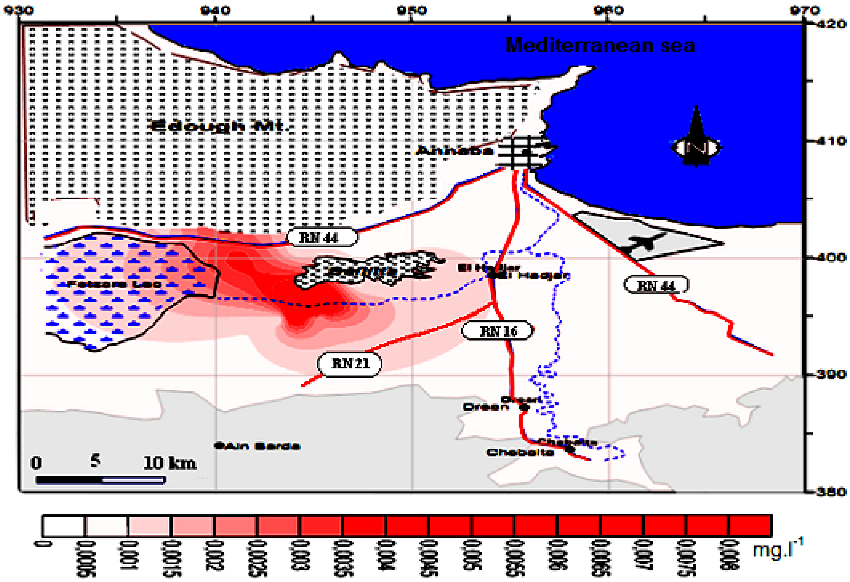

Fig.7. Map of lead distribution (June 2011)

a) Mapping of iron variation

The most significant contents of iron are localized north and in the center (Fig.8), probably due to not only road traffic, but also to metallurgical and steel activities, to chemical fertilizers applied to farmlands, to incinerators and waste incineration facilities, to medical waste, to city landfills and to wastewater and sludge.

b) Mapping of zinc variation

The examination of the map of the zinc distribution at the Annaba plain, indicates that this latter shows a behavior analogous to that of piezometry, i.e. that the concentrations follow the flow direction. It is clear that these concentrations are high in the center and low south and north as a result of the coincidence with the recharge areas, because in this locations, the Mio-Pliocene aquifer is near the surface, thus facilitating the transport of this element towards the saturated zone and then directly towards the phreatic aquifer (Fig.9).

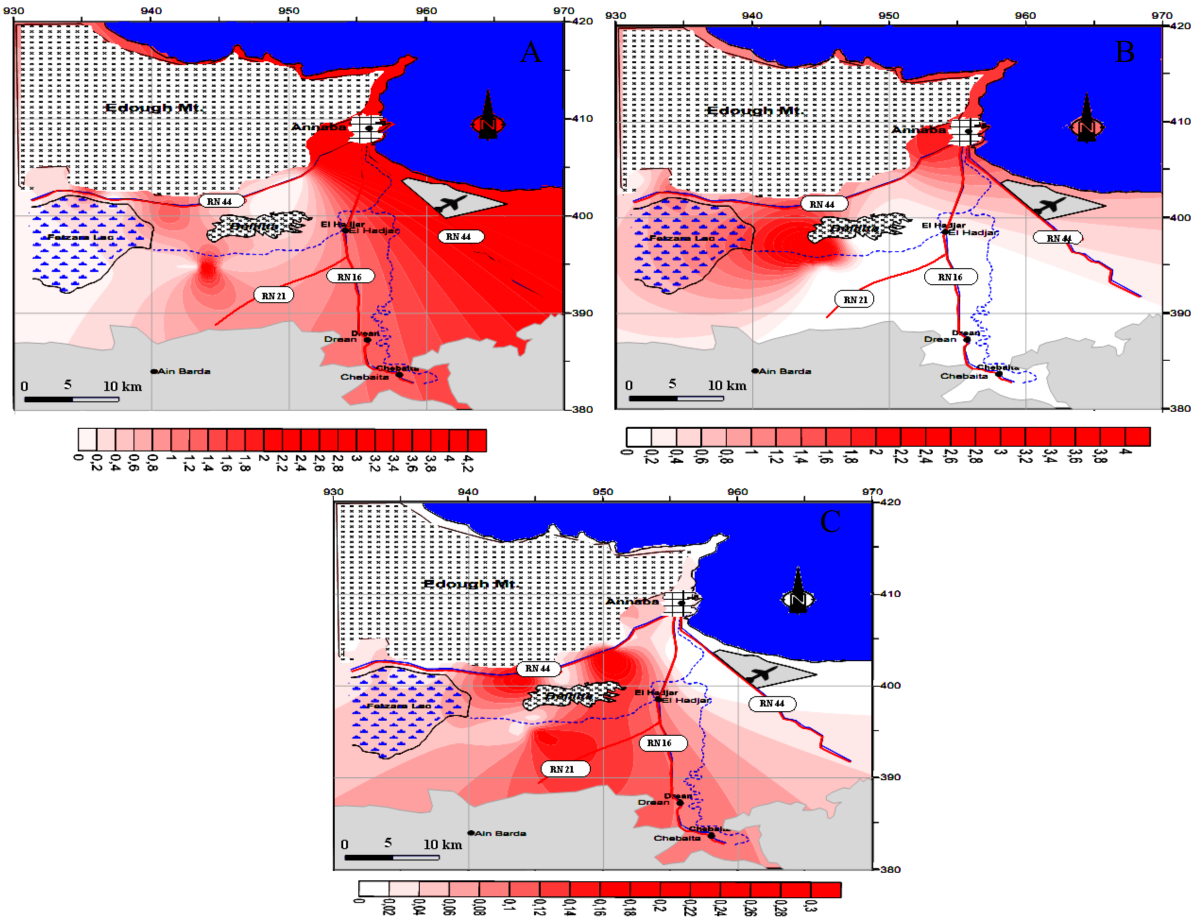

Fig.8. Map of iron distribution (a. June 2011, b. April 2012, c. December 2013)

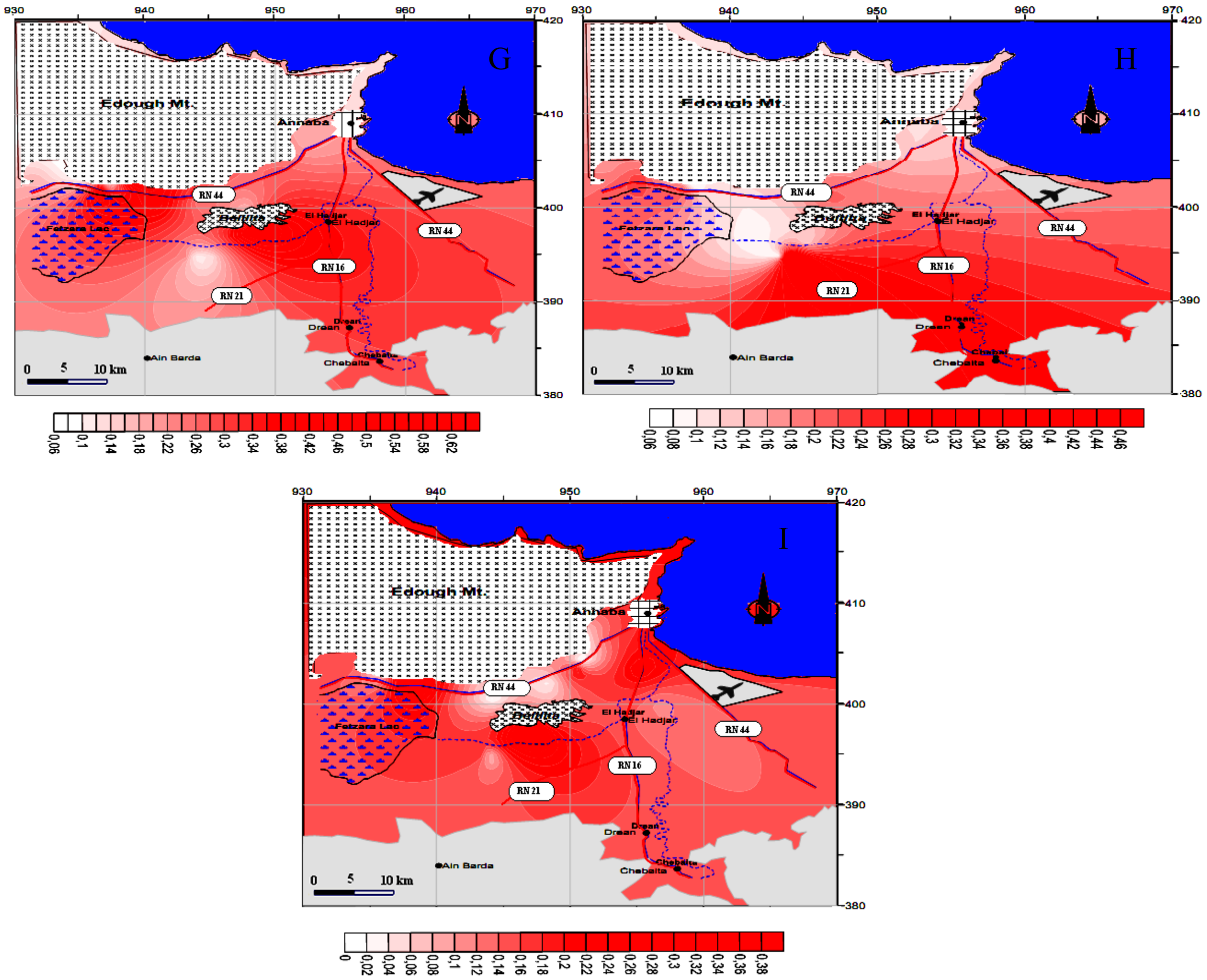

Fig.9. Map of zinc distribution ((**D.** June 2011, **E.** April 2012, **F.** December 2013)

c) Mapping of copper variation

Chemical modeling for natural waters shows that Cu remains in the 2+ ion state up to a pH of 6. For most neutral waters, Cu (CO3) -2 2 and CuCO3 are also important, the second is more important between pH 7 and 8. Copper also forms several complexes with organic ligants [25]. The standard set by WHO is 2 mg l^{-1} for drinking water and 1.5 mg l^{-1} for metal processing waste (Algerian standards), copper is in concentrations that do not exceed the norm in all points (Fig.10). The maximum average level is 0.70 mg.l^{-1}.

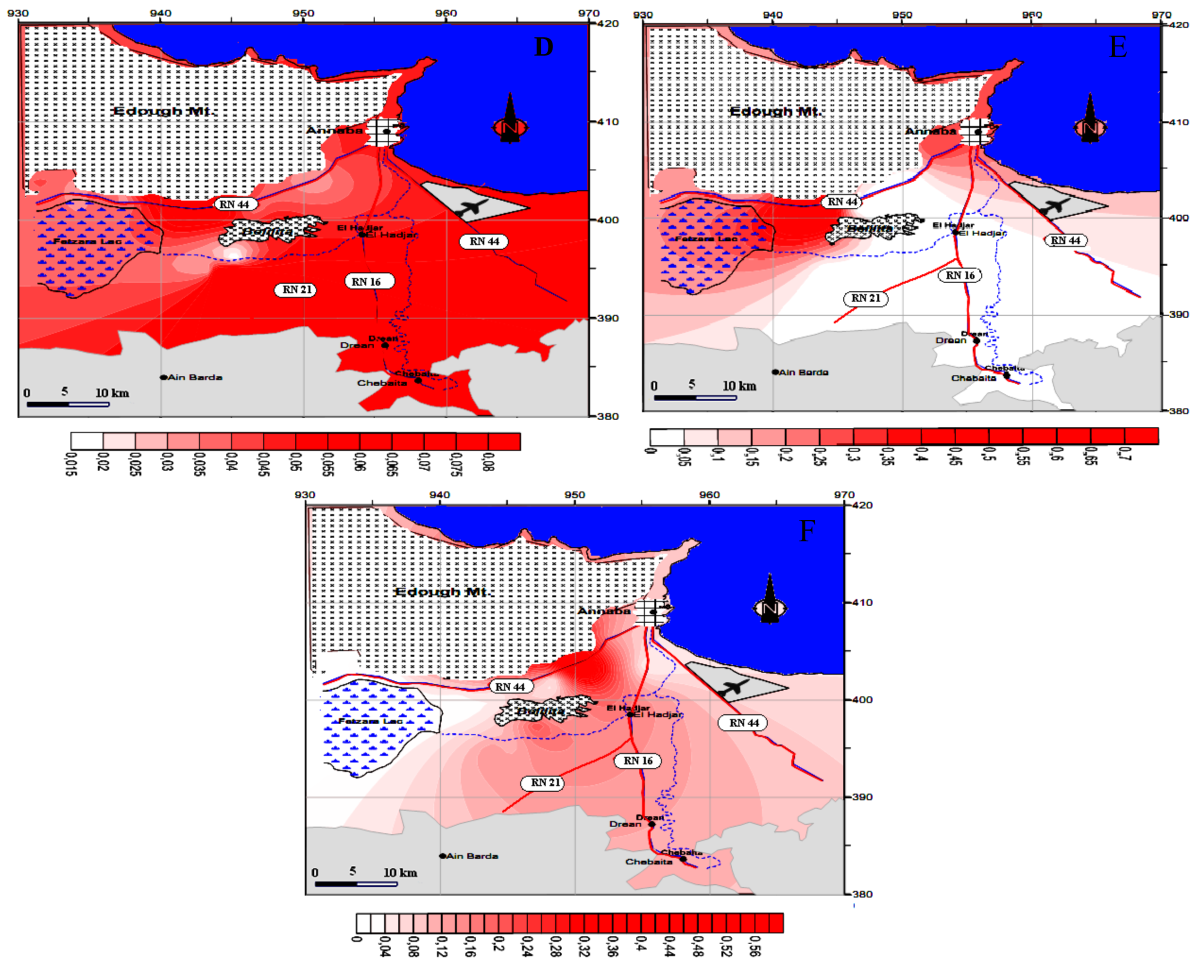

Fig.10. Map of copper distribution (**D.** June 2011, **E.** April 2012, **F.** December 2013)

3.3 Correlation of different heavy metals

A correlation was established to know the origin of trace metals: Fe, Cu, Zn and Pb (Fig.11) in groundwater of the Annaba plain lead to the following observations:

- The points aligned and parallel to the iron axis allow us to note that the origin of the two trace elements is the same, it is the road runoff.
- The majority of the points is aligned and parallel to the iron axis, thus confirming the origin of the two trace elements (iron and zinc) which is the road. The points which are aligned on a line parallel to the zinc axis indicate that the two elements come from the road.

- Six elements show a different aspect, which opposes the first ones (parallel to the lead axis), thereby indicating an origin other than the road, which can be lithology or anthropogenic activities.

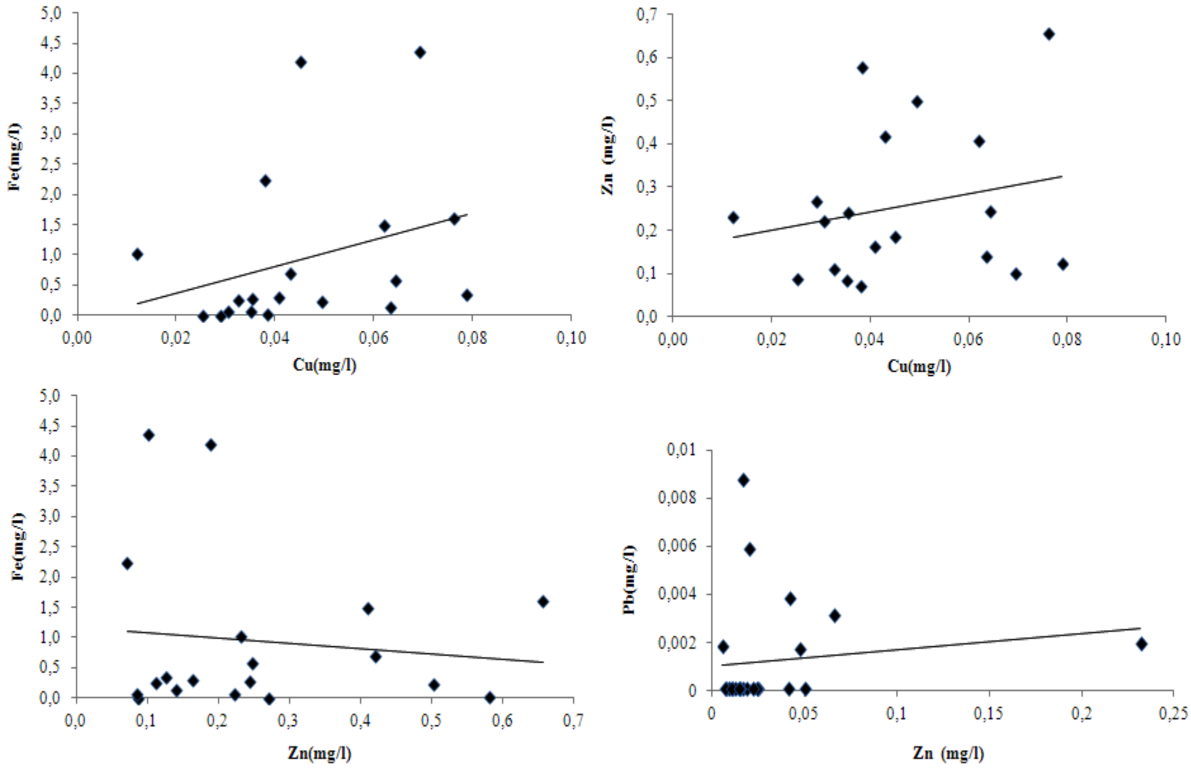

Fig.11. Correlation between Fe, Cu, Zn and Pb

3.4 Processing by principal component analysis (PCA)

3.4.1 Variables space

The circle of PCA is determined by the axes F1 and F2, which provide 70.53% of information. The observation according to the axis F1 (51.20%) shows a positive relation between the elements: Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-} . This is due to evaporates dissolution (continental origin) and saltwater intrusion (marine origin).

The axis F2 with 19.33 % of information highlights an opposition between highly mineralized water rich in Cl^-, Mg^{+2} and Na^+ HCO_3^-, SO_4^{2-} and water marginally mineralized and polluted by nitrates (Fig.12).

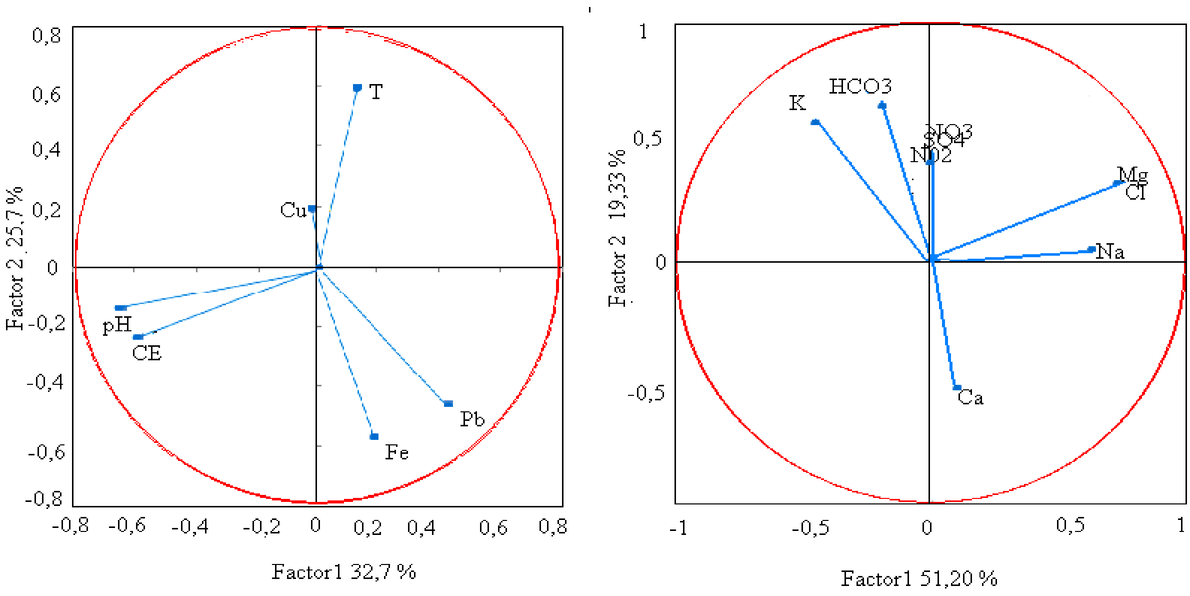

Fig.12. Projections of the groundwater sources from Annaba plain respect to the first two factors (PCA), and this in respect to the concentrations of all analyzed variables on locations

For heavy metals, processing provides an information percentage of the order of 58.4%. The axis F1 with 32.7 % of information highlights an opposition between Pb, Fe (positive part) and Cu, EC and pH (negative part). This can be explained by industrial pollution and also by the wadi-groundwater relationship, which allowed infiltrations of the wadi water into groundwater.

3.4.2 Projections of individuals

The projection of individuals shows the existence of four sets presenting distinct positions on the design (Fig.13). Four sets of individuals are observed:

- The set of water rich in chlorides representing the water points located downstream of the terrain;

-The set of water polluted by nitrates characterizing the water points generally located inside the irrigated portions, thus highlighting an exogenous origin of nitrates (anthropogenic origin caused by uncontrolled use of fertilizers);

-The set of water with low concentration of heavy metals and salt, located south of the study area;

-The set of water with an almost high content of heavy metals with respect to the set; these points are located in the center and north of the plain, thus highlighting the anthropogenic origin of pollution (industry and road traffic).

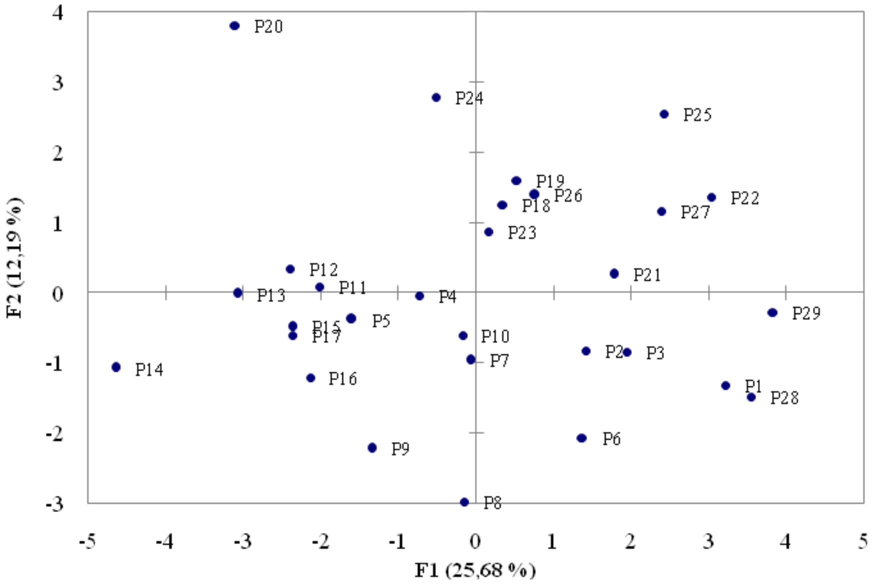

Fig.13. Graphical Representation of Individuals

4. CONCLUSION

The aim of this work is to assess the risk of groundwater pollution by heavy metals from road traffic in the Annaba plain crossed by RN 44, RN16 and RN21. The hydrochimical study of the plain groundwater shows the existence of multiple chemical pollutants with different concentrations. The superficial groundwater is affected by many pollution processes: leaching of geological formations, or industrial activities. The findings indicate that, for most wells, the concentration of trace metals linked to the road traffic remains lower than the permissible standards, except iron (Fe) 0.4 $mg.l^{-1}$ à 2.7 $mg.l^{-1}$ (standard WHO : 0.2 $mg.l^{-1}$).

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