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THE WATERS OF THE CESSE WATERSHED (SOUTH-EAST FRANCE) CARTOGRAPHIC AND GEO-ENVIRONMENTAL APPROACHES

LES EAUX DU BASSIN VERSANT DE LA CESSE (SUD EST DE LA FRANCE) APPROCHES CARTOGRAPHIQUE ET GEO-ENVIRONMENTALE

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ABSTRACT

The degradation of water quality and the competitive exploitation of this resource are accelerating, especially in the Mediterranean region. Climate change accentuates the phenomenon of water scarcity which is itself catalyzed by a marked degradation of resources.

In order to produce an image of the runoff water quality of the Cesse watershed, located in the South-East of France, a method is proposed that combines a geo-environmental and cartographic study. Results and the mapping of the physico-chemical analyzes of the waters of the Cesse showed that the transfer of chemical facies occurs from upstream to downstream. High concentrations are often found at the outlets of rivers and tributaries. Interpretation of obtained results revealed the origin of the strong mineralization. The geology and hydrology of the study area explain the spatial variations.

The experiment errors are negligible. The mapping by interpolation fills some gaps in the values obtained. The technique adopted reflects a better representation of certain processes, in particular Upstream / Downstream communication in the same watershed. That is, the concentrations of chemical elements in the samples change in relation to the morphology and hydrology of the watershed. This could improve the existing database in particular for the hydrological conditions of the small watersheds of the Mediterranean.

Keywords: The Cesse Watershed, cartography, chemical facies, evolution.

RESUME

La dégradation de la qualité de l'eau et les exploitations compétitives de cette ressource s'accélèrent, spécialement en région méditerranéenne. Le changement climatique accentue le phénomène de la rareté en eau qui est lui-même catalysé par une nette dégradation des ressources.

Dans le but de produire une image de la qualité de l'eau de ruissellement du bassin versant de la Cesse, situé en Sud-Est de la France, une méthode est proposée qui combine une étude géo- environnementale et cartographique. Les résultats et la cartographie des analyses physico-chimiques des eaux de la Cesse ont montré que le transfert des facies chimiques se fait de l'amont à l'aval. Les fortes concentrations se trouvent souvent à l'exutoire des cours d'eau et des affluents. L'interprétation des résultats obtenus a permis de dévoiler l'origine des fortes minéralisations. La géologie et l'hydrologie de la zone d'étude expliquent les variations spatiales. Les erreurs de l'expérimentation sont négligeables. La cartographie par interpolation comble certains écarts des valeurs obtenues. La technique adoptée reflète une meilleure représentation de certains processus notamment la communication Amont/Aval dans un même bassin versant. C'est-à-dire les concentrations en éléments chimiques des échantillons changent en rapport avec la morphologie et l'hydrologie du bassin versant. Ceci pourrait améliorer la base de données existante notamment pour les conditions hydrologiques des petits bassins versants de la Méditerranée.

Mots clés : Bassin versant de la Cesse, cartographie, facies chimique, évolution.

INTRODUCTION

In all climatic domains, the spatiotemporal study of the physicochemical parameters of water is necessary to understand the nature and functioning of upstream and downstream of watershed. This idea has been expressed by several authors. According to Vaudour (1988), Beffy (1992), Merzoug (2009) and Mouissi (2016), the study of the distribution of water flows loaded with chemical elements as well as their relationship with downstream systems is essential. Similarly, Vaudour (1984) proves that in semi-arid geosystems, the variation of the physico-chemical parameters of water depends closely on the environment because the physical (hydrogeological, morphological, bioclimatic) and anthropogenic conditions are determining. These investigations were supported by other research such as that of Lavabre (1995); Sehober-Eimer (1996); Martin (1999); Gremillon (2000); Fourcade et al. (2001); Nicod et al. (2001). The concentrations of the chemical elements in an ecosystem increase as a result of several factors. We can cite geological and anthropogenic factors. According to Nou et al. (2013), geological structure and water-rock interactions determine chemical composition of surface and groundwater. It is pollution that causes changes in the concentration of chemical elements in water, not the other way around (Magara, 2003).

In the Mediterranean basin, pollution by trace elements has intensified in recent decades (Copat et al., 2012). This pollution affects the quality of water and sediments (Palanques and al., 2008; Rahaingomanana, 1999). Researchers have focused on contamination through the study of chemical facies in Mediterranean basins (Radakovitch et al., 2008; Roussiez et al., 2011 and 2012; Reoyo-Prats et al., 2017; Larue, 2001 and 2004; Montoroi, 2004; Hoffmann et al., 1995). Analysis of water samples from the Cesse watershed and compared with other results such as geological ones, (Nou et al., 2013) or anthropogenic ones (Nicod, 1978; Mérot, 1988; Prost,1992 and Lahmar, 2010), are essential. Also, this study makes it possible to prove the upstream / downstream communication of chemical elements in the Cesse basin. The mapping by interpolation of the chemical elements of runoff water and the use of topographic data (maps of slopes, exposure and the hydrographic network) allow the further clarifying the communication in chemical elements between the upstream and downstream of the basin of the Cesse.

SITE PRESENTATION: GEOGRAPHICAL AND GEOLOGICAL SETTING

Site presentation

The study covers the watershed of the Cesse which covers 269 km². The Cesse is the last tributary of the Aude before reaching the Mediterranean (Figure 1). The maximum altitude is 1013 m. The main course measures 50.8 km and the total stream is 353.3 km, which gives a drainage density of 1.31 km / km² (Esposito et al., 2010). From upstream to Agel, the Cesse crosses a veritable karst plateau following a line of more than 23 km beyond which other formations appear. The karstic domain, with an area exceeding 160 km², is made up of carbonate formations of the Lower and Middle Cretaceous of Urgonian facies (Marmonier, 2013). These carbonate formations contain an important groundwater resource and play a decisive role in supporting the low flow of the Cesse in dry periods. The karstic supply basin extends widely in the north-eastern part of the Cesse basin. The karst plateau does not have a surface drainage network, rainwater not taken up by vegetation infiltrates and circulates underground to emerge in the form of sources (Re-Bahuaud et al., 2014).

Figure 1: Localization of the Cesse basin.

The climate of the study area is typically Mediterranean and it is characterized by low rainfall, relatively mild average temperature and frequent and strong winds. Precipitation occurs mainly in autumn during the months of September, October and November and represents about 40% of the annual rainfall. This varies little on the territory, except on the northwestern where we can already note the influence of the “Montagne noire”. Thus, during the period 1951 to 1984, the average annual rainfall is distributed as follows: 613 mm in Pouzols-Minervois, 628 mm in Argeliers (Béziers), 643 mm in Laure-Minervois, 687 mm in Aigues-Vives and finally 1295 mm at Lespinassière substation. Actually, this precipitation is very irregular in time, which clearly characterizes the Mediterranean climate. Figure 2 shows the recent variation in precipitation in the Cesse watershed. It decreases from the North to the South.

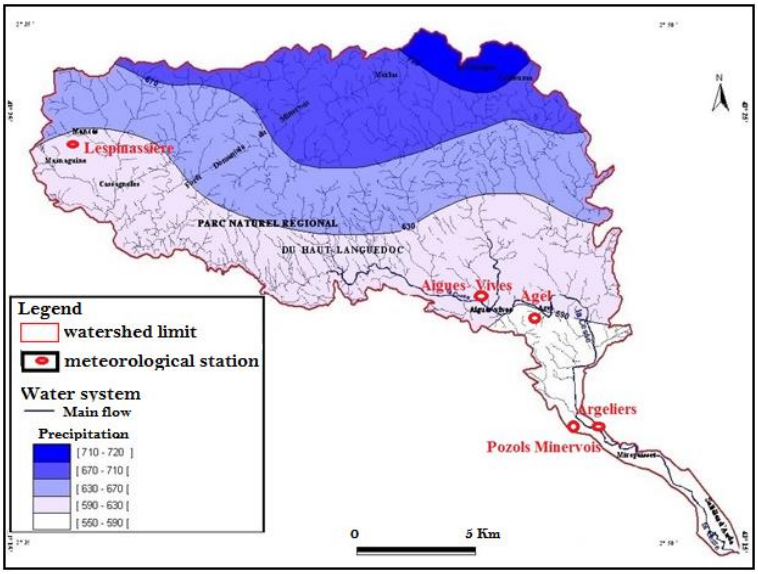

Figure 2: Precipitation in the Cesse basin according to French weather data (2007).

Geology and nature of the soil in the study area

The Cesse basin is made up of different geological formations (Figure 3). The litho-stratigraphy of the Cesse watershed begins with the primary basement of the southern slope of the Montagne Noire with lands ranging from Cambrian to Devonian, mainly made up of dolomitic limestone and shale (Bertolini, 1980; Berger, 1990; Larue, 2008). Then, on these lands of the primary era, come in discordance of the Cenozoic lands made up of marine limestones with Alveolines (Ilerdien) on which the molasses of Carcassonne made up of limestones from Ventenac (lower Cuisien) were deposited, from the sandstone-marl formation of Assignan (Superior Cuisien), Agel limestones (Lutétien) and Aigne sandstones (Bartonien) (Genna and Capdeville, 2007). These lands were affected by the Hercynian tectonics for the primary lands and by the Pyrenean tectonics for the tertiary lands which are structured in a series of anticlines and synclines with a northeast/ southwest axis (Nou and al., 2013). Clay-sandstone formations (Lower Cretaceous) occupy the center and south-west of the basin. In the north, conglomerates with sandstone to sandstone-limestone elements and unconsolidated sands develop (continental Pliocene), a more or less detrital silt series from the Lower Miocene, clays and marl-limestone formations (Lower Jurassic). Massive limestones (Eocene) occupy the northeast of the basin (Nou and al., 2013). According to Ceze (1951), Conord and al. (1966), Bouteyre (1967), Joseph and al. (1967), Yvroux (2001) and Marchal (2004), the alluvial terraces and the alluvial plain of the Cesse are essentially formed of little rolled pebbles wrapped in an often compact and highly variegated clay-sandy matrix. The pebbles, which come mainly from the “Montagne Noire”, are often very weathered and have varied lithologies: dark blue, gray or calcite-veined limestone, coarse sandstone, white sandstone, quartz sandstone and psammitic sandstone, dark quartzite, green quartzite and chlorite quartzite, quartz, fine textured green schist, gray dolomite, dolerite and nummulite limestone.

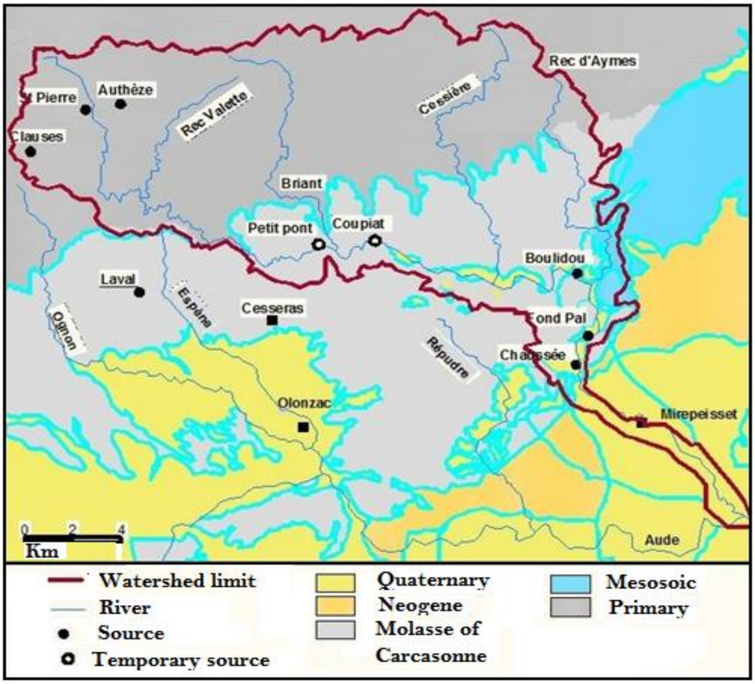

Figure 3: Simplified geological map of the Cesse watershed and its surroundings (Nou et al., 2013)

A heavily developed watershed

The hydraulic arrangements in the Cesse basin are diverse. We can cite the 'Canal du Midi', the junction canal then the open basins and masonry works, the canals and the dikes. There are also other forms of development such as strips of grassed topsoil, gabion mattress type protections and dike coverings with a grooved concrete track (Plastre et al. 2019). In Figure 4, we tried to locate some types of arrangements used for the control of the waters of the Cesse and tributaries. All of these developments contribute to reducing the kinetic speed of the course in the Cesse and its tributaries. The nature of the development changes from upstream to downstream (Lahmar 2010).

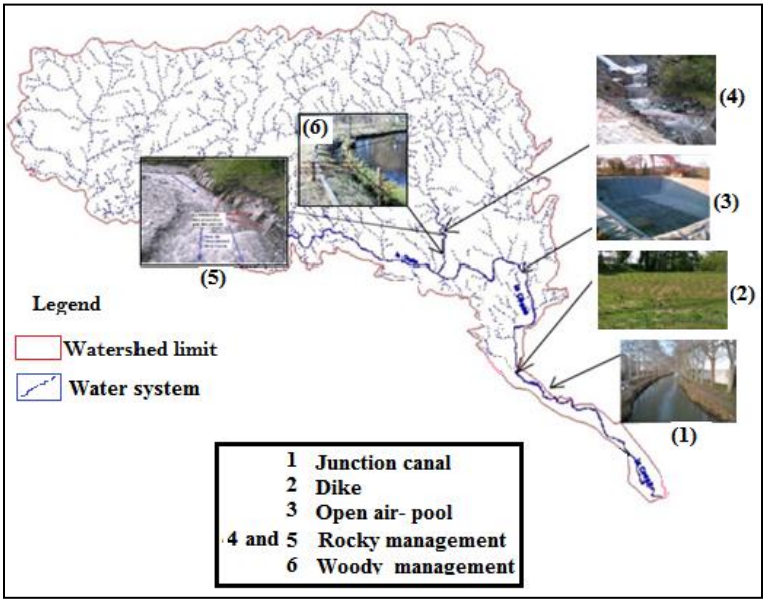

Figure 4: Example of developments in the Cesse basin (Lahmar, 2010)

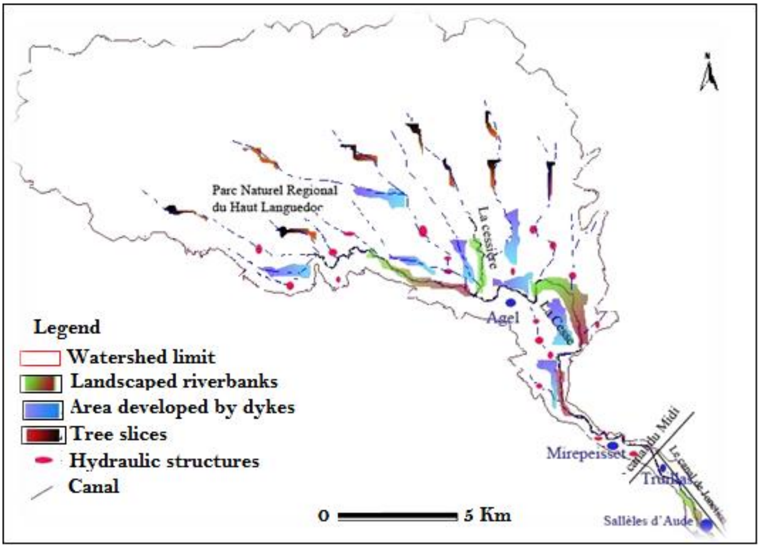

Figure 5: Simplified map of the hydraulic installations of the Cesse (Lahmar, 2010)

In the upstream part of the Cesse basin, the facilities are not very dense. We can detect some old techniques such as dry stones, ditches and more recent ones such as open basins and canals. On the other hand, the downstream part includes more facilities and the techniques are diverse at the level of Salèlles-d'Aude, Agel and Mirepeisset. The mapping of developed areas (Figure 5) locates the five development methods adopted: dikes, cisterns, canals, open basins and tree sections, and underlines the importance of hydraulic installations in the downstream part of the basin.

METHODOLOGY

The methodology adopted during this study is based on the analysis of water samples, mapping and then crossing with geological and topographical data as well as on observations made in the field (Figure 6).

First of all, the use of topographic maps by a Geographic Information System (GIS) made it possible to obtain maps of the hydrographic network, slopes, exposure and grid maps then using the same tool (GIS) we were able to draw up, by the method of interpolation, the maps of the chemical facies distributions of the Cesse basin. For this, mapping, image processing and GIS software (ArcView3.2, Adobe Illustrator CC and Segma Plot) were used. All the maps obtained make it possible to understand the natural environment of the Cesse and its upstream / downstream functioning in chemical elements.

Principal component analysis (PCA) widely used to interpret hydrochemical data from hydrosystems (El Morhit et al., 2008; Makhoukh et al., 2011; Lamrani et al., 2011; Belghiti et al., 2013) as well as the Ascending Hierarchical Classification (CHA) were carried out using the Xl stat software.

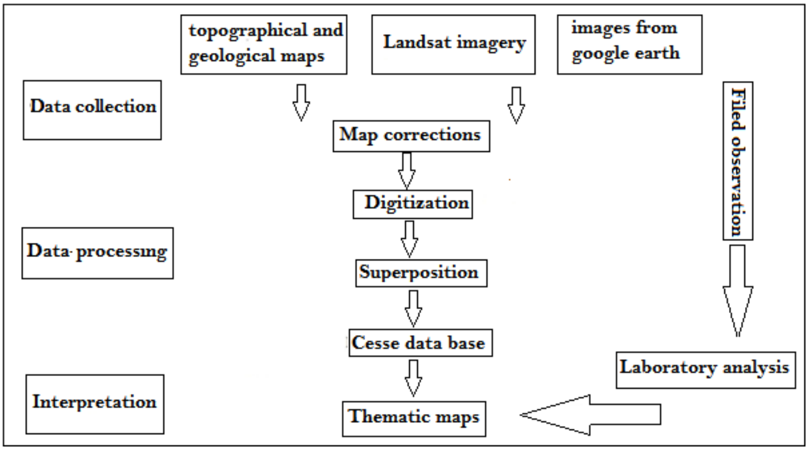

Figure 6: Synthetic diagram of the methodology adopted

Sampling

The study aims to determine the hydro-chemical characteristics of the waters of the Cesse. It also makes it possible to define the chemical facies, the mechanisms and the origins of the mineralization, then to determine its spatial distribution. In this context, a collection was carried out during which 30 water samples were taken. These were carried out on the 21^{th} of April 2015. Automatic samplers have been installed downstream of each sampling station. They are of the Segma type (belonging to the chemical analysis laboratory of BRGM France). The material is 100% inert for this kind of chemical analysis. For each sample, two liters of water were taken to allow a sufficient quantity of water for analyzes.

Water sampling sites and the distribution of sampling points are located in Figure 7. Four (4) samples were taken per day for each of the stations at different times: 8 am, 10 am, 2 pm and 5 pm. Samples were taken at Coulouma, Cassagnoles, Aigues-Vives, Agel, Mirepeissetet de Sallèles d'Aude, located in the upstream of the confluence of the Aude and Cesse rivers.

The station of Aigues-Vives, put into service on 09 December 1960, is at an altitude of 51 m in relation to the sea. It updates the data every 15 minutes and recorded 0,524 m^3/s on the day of collection. The station allows the measurement of the waters of a 240 km^2 basin.

The Station d'Agel (Y1605060) is located at an altitude of 91 m, presents the outlet of a basin of 186 km^2. It has a flow rate of 0,498 m^3/s on the day of sampling. The Mirepeisset station (Y1605050) recorded 0,679 m^3/s on the day of sampling and the upstream basin was 270 km^2. For the other sampling stations, the flows on the day of sampling were 0,201 m^3/s in Cassagnoles, 0,195 m^3/s in Coulouma and 0,712 m^3/s in Sallèle d'Aude.

Samples were taken on the same day. We started the water intake at 8 am. The catches are spread over 8 hours: either a sample every 2 hours (Table 1). The taken samples were kept in polyethylene bottles previously rinsed with distilled water for analyzes. At the time of sampling the following physico-chemical parameters are measured: temperature, pH, dissolved oxygen content, electrical conductivity and redox potential (Eh). The choice of the different sampling points must meet several criteria. These points must be representative and based on the following parameters:

- Diffuse underground inputs that may come from pebble banks should be avoided (Marmonier, 2013).
- We tried to represent all the geographical areas of the Cesse basin. The interpolation method adopted for mapping is based on a good presentation of the territory. Furthermore, any lack of representation causes gaps in the mapping.
- To account for the rank of the tributary, a field survey was carried out, during which the most representative tributaries of the basin were chosen. The choice was not made randomly but according to the experimental protocol.
- The sampling was done in dynamic waters. We avoided areas of water accumulation where there is no circulation. Settling waters promote certain

chemical reactions (exchange and oxidation reduction) between the water and the rock on which it rests (Nou, 2013).

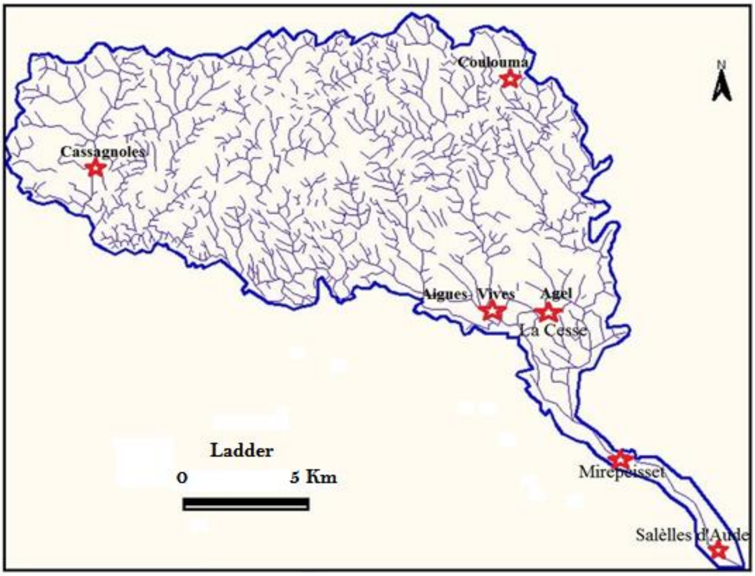

Figure 7: Sampling Location

Table 1: **Programming of automatic collection**

Collection	Dated	Collection time	Collection interval	Comments and clarification
1		8H	T= 0	T= 0
2		10H	120 min	T0 + 2h
3		12H	240 min	T0 + 4h
4		14H	360 min	T0 + 6h
5		16H	480 min	T0 + 8h

Parameters studied

The temperature was obtained using a Y.S.I thermometer. The pH of the samples was measured using an Orion Research pH meter after calibration of the electrode. The redox measurement is done using an electrode coupled to the pH meter and verified using a standard solution. Conductivity measurements were done in situ using a conductivity meter.

The measurements of the major elements are analyzed at the Faculty of Science of Avignon (France) and then verified. Table 1 summarizes the analytical method used to measure Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, Na^+, NO_3^-, Cl^-, and K^+ (Table 2).

Table 2: Methods adopted for dissolved element analyses

Chemical element	Analytical Method	LQ (mg/l)	analytical Precision
HCO_3^-	potentiometric method	4.99	4.99%
Ca^{2+}, Mg^{2+}, Na^+, K^+	ICP analysis- emission spectrometry	0.51	5%
Cl^-, NO_3^-, SO_4^{2-}	Ion Chromatography (DIONEX)	0.505	5%

RESULTS

Temperature and hydrogen potential pH

The water temperature of the Cesse basin is shown in Figure 8. It is between 23°C and 25°C (Table 3). In the map, we tried to represent by interpolation method the temperature map of the various sampling stations in the Cesse basin. The color screens obtained show at least three zones. The extreme northeast and the extreme northwest are the sunny spots in the basin: their temperatures are the highest.

Table 3: Temperature (°C), pH, conductivity (µS /cm) and mineral elements concentration (mg/l) of the Cesse water

Stations	T	pH	Cond	Ca^{++}	Mg^{++}	Na+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	Mg^{++}/Ca^{++}
Coulouma	24	7.5	366	17	58	3.1	1.2	275	12	14	3.41
Cassagnoles	25	7.9	312	29.5	50	2.1	0.8	8	10	10	1.69
Aigues-Vives	24.5	7.5	369	38	57	3.2	1.1	301	10	14	1.50
Agel	25	7.8	322	29	49	2.9	0.8	262	9	12	1.69
Missepeisset	23	7.9	345	30.5	49	2.5	1	264	9	10	1.61
Sallèles d'Aude	23	7.7	379	39	63	3.9	1,3	354	14	16	1.62

The examination of the two maps (Figure 8 and Figure 9) showed that the temperature of the water is strongly correlated with the exposure. In fact, high temperature values are recorded in the East and Ouest exposure however the lowest ones are observed in extreme north and extreme south.

The pH of the surface water of the Cesse is between 7,5 and 7,9 (Table 3) with an average of 7,7. This value reveals the importance of limestones in the basin. There is a significant increase in the pH of the Cesse at the entrance to the confluence zone of the Cessière with the Cesse. Thus, the pH decreases in the upstream of the confluence with the Aude at the level of Aude Salleles (sample taken not far from the junction canal), characterized by a lower pH (7, 7). The pH of the waters of the Cesse is medium.

Table 3 shows all of the results obtained. For each element, the concentrations are expressed in milliequivalents per liter (meq/l = concentration in mg/l divided by the molecular weight of the element itself divided by its valence).

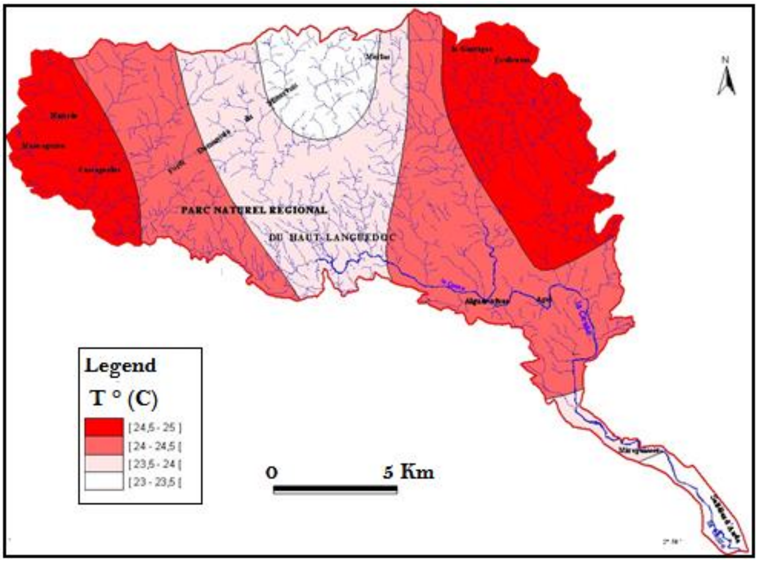

Figure 8: Water Temperature of different sample points in the Cesse

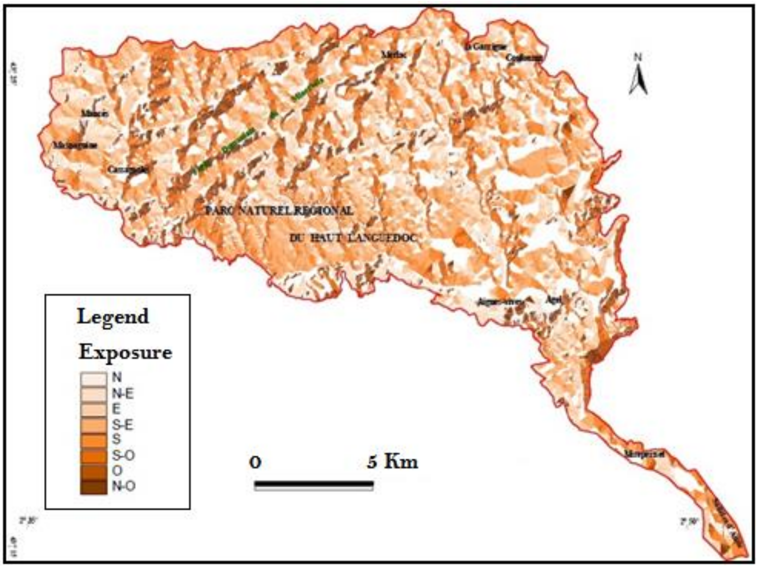

Figure 9: Map of exposures in the Cesse basin (Lahmar, 2010)

Table 4 reflects the results obtained in the 6 sampling stations. The different chemical elements tested are presented horizontally (in columns) while the values found according to the hours are drawn up in lines (vertically). The table illustrates the each chemical facies average of found in all the stations.

Table 4: Mineral elements Concentration Ca^{2+}, Mg $^{2+}$, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-} (meq /l)

			Concentrations of major element						
	Stations	Hour	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}
	Coulouma	8h	28,5	27,6	1,9	0,4	4,9	8,3	8,5
		10h	29,5	33,8	1,9	0,7	7,2	9,5	9
		12h	30	49,3	2,1	0,8	8,5	9,2	10,1
		14h	29,5	66,8	2,2	1	8,9	11,2	1,4
		16h	30	72,5	2,4	1,1	10,5	11,8	12
Mean			**29,5**	**50**	**2,1**	**0,8**	**8**	**10**	**8,2**
	Cassagnoles	8h	27,1	32,6	2,6	0,2	88,3	7,8	9,5
		10h	28,2	50,1	2,8	0,5	198,4	8,4	10,4
		12h	28	51,3	2,9	1	238,7	9,2	11,6
		14h	30,5	54,2	3	1,1	382,1	9,5	13,7
		16h	31,2	56,8	3,2	1,2	402,5	10,1	14,8
Mean			**29,27**	**49,55**	**2,46**	**0,80**	**123,45**	**9,55**	**9,93**
	Aigues- Vives	8h	17	57,3	2,8	1	79,7	9,9	11,3
		10h	16,5	54,1	2,7	1,1	199,4	10,1	12,6
		12h	17,5	57,2	2,8	1,2	265,6	12,4	14,1
		14h	18	58,6	3,5	1,3	421,2	13,5	15,7
		16h	16,00	62,80	3,70	1,40	409,10	14,10	16,30
Mean			**25,66**	**52,03**	**2,65**	**0,92**	**168,03**	**10,27**	**11,13**
	Agel	8h	35,6	47,1	2,8	0,6	97,5	9	10,1
		10h	37,1	56,8	3	1	197,1	9,1	13,8
		12h	37,4	59,8	3,2	1,2	301,3	9,6	14,7
		14h	39,9	60,5	3,4	1,3	419,9	11	15,6
		16h	40,1	61,8	3,6	1,4	489,2	11,3	15,8
Mean			**28,35**	**53,16**	**2,77**	**0,96**	**196,93**	**10,21**	**11,75**
	Mirepeisset	8h	28	46,4	2,2	0,7	107,2	7,9	7,8
		10h	28,5	47,2	2,4	0,8	186,4	8,3	8,7
		12h	29,8	48,9	2,5	1	246,2	8,9	9,9
		14h	32	50,1	2,6	1,2	367,9	9,2	11,4
		16h	34,2	52,4	2,8	1,3	412,3	10,7	12,2
Mean			**28,72**	**52,44**	**2,72**	**0,96**	**208,50**	**10,00**	**11,45**
	Sallèles d'Aude	8h	37	54,2	3,5	0,8	126,2	10,1	11,8
		10h	38	58,5	3,8	1	300,6	11,7	18,4
		12h	39	65,4	4	1,2	348,1	12,6	17,8
		14h	40	67,1	4	1,4	476,8	17,5	18,2
		16h	41	69,8	4,2	1,6	518,3	18,1	18,8
Mean			**30,19**	**53,95**	**2,89**	**1,00**	**229,28**	**10,57**	**12,24**

To facilitate the representation of the maps by interpolation made under the Arc Gis software, we used means values. Data simplification can only be beneficial in obtaining interpolations and good representativeness of study area regions.

The average temperature is 24, 08 °C. It varies between 23 °C in Mirepeisset and Sallèle d´Aude and 25 °C in Agel and Cassagnoles (Table 3). The average pH is rather basic with a value of 7,72. The average conductivity of the waters of the Cesse is 348, 83 mS.cm^{-1}. The average sodium ion concentration is 2, 95 mg/l. Reading table 4 allows us to say that apart from the values of the calcium ion (Ca) and bicarbonate (HCO_3) respectively in the Coulouma and Cassagnoles station, the values of the other stations are rather close to the average and don't represent a significant difference.

Electrical conductivity

Electrical conductivity is generally related to the concentration of dissolved ions, thus reflecting the overall fluctuations in the chemical charge of water. Conductivity is a measure of the ability of water to conduct the electricity. It is undoubtedly affected by the presence of dissolved minerals such as chlorides, nitrates, sulphates, and phosphates (for the anions) or sodium, magnesium, calcium, and aluminum (for the cations). The conductivity in streams and rivers is particularly affected by the geology of the region through which the water flows, but also by anthropogenic discharges. It is closely related to the lithological nature, the speed, the direction of flow of the basin and the residence time of water in the watercourse. The Cesse basin is characterized by a conductivity that varies between 312 µS/cm and 379 µS/cm (table 3). The waters sampled in the southwest end of the watershed show the highest values of conductivity. Low values were recorded at the northeast end of the basin (Figure 10).

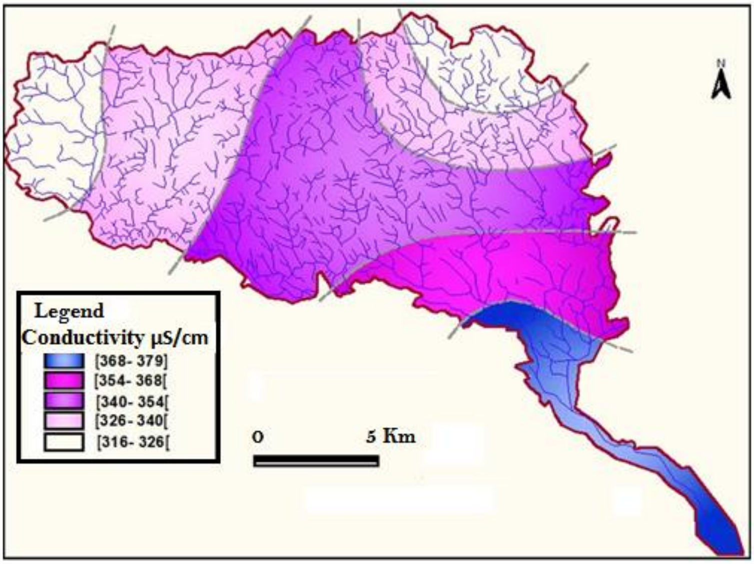

Figure 10: Distribution of conductivity in the Cesse basin

Chemical characteristics of the waters of the Cesse basin

To determine the chemical facies of the waters of the Cesse, the composition in major elements was reported on the Piper diagram (Figure 11). The diagram corresponds to a diamond representation based on the percentages expressed in meq / l. The process consists of plotting the percentage of each element on two equilateral triangles, one for the anions and one for the cations (Freeze and Cherry, 1979). The projection of representative points on the diamond allows us to determine the chemical facies of the water.

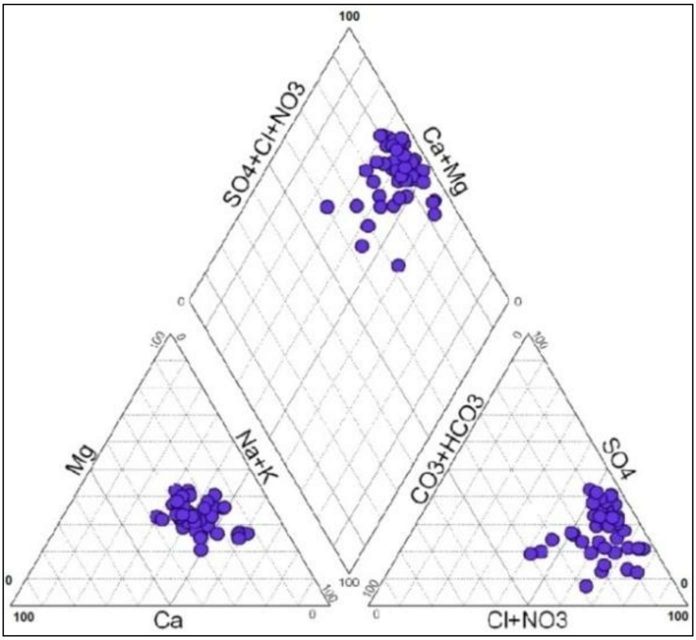

Figure 11: Piper diagram of the waters of the Cesse basin.

On the triangle of anions, the majority of points are concentrated mainly at the level of the chlorinated pole. The sulphate and bicarbonate levels are low. The facies are then chlorinated. On the cation triangle, water samples show mixed-sodium facies with low magnesium concentrations (Meybeck 1984; Nicod 1990). Therefore, the waters of the Cesse show a mainly chlorinated-sodium-calcium facies. In order to facilitate the reading of the graphs, the watershed of the Cesse is divided into 3 distinct parts, the upstream, the median zone and the alluvial plain or the downstream. The diagram shows that the Cesse waters are predominantly Mg-Ca-HCO_3. They are of the calcium and magnesian bicarbonate type.

Application of PCA using the physicochemical parameters of water

The analysis of the results shows that most of the information is explained by the first two factor axes. In the factorial plane F1xF2, the eigen values of the two components F1 and F2 and their contribution to the total inertia are shown in table 5. The two axes taken into account to describe the correlations between the variables related to spatial structures, alone hold 74.22% of the total information with 74.86% respectively for axis 1 and 14.20% for axis 2 (Figure 12). Axis 1 is expressed towards its positive pole by the content of sodium, magnesium and chlorine, which have good correlations between them (Figure 12 and Table 5). While axis 2 is defined by calcium ions towards its positive pole. Table 5 shows that the higher the correlation, the more related the variable is to the component. Conversely, the closer r^2 is to "zero" the less the variable is linked to this component.

In the correlation circle (Figure 12), the 1st component (F1), contributing with 74,86% inertia, is defined by the following chemical elements Ca^{++} (0,346%), Mg^{++} (17,858%), Na^{+} (17,71%), K^{+} (18,33%), HCO^{-}_{3} (16,85%), SO_4^{--} (10,82) and Cl^{-} (18,06%). The 2nd component (F2) contributes with 14, 20% inertia. It is essentially defined by the Ca $^{++}$ element (97,93%) while the other elements do not exceed 2% (Table 5).

Table 5: Contribution of chemical elements in the inertia of the waters of the Cesse

	F1	F2	F3	F4	F5
Ca++	0.3461	97.9348	1.1823	0.2943	0.0851
Mg++	17.8585	1.0604	6.0689	10.9813	45.5108
Na+	17.7137	0.0074	9.1532	13.2204	1.4154
K^+	18.3369	0.2889	0.8644	47.9046	16.7510
HCO_3^-	16.8579	0.0693	16.2684	0.7447	21.3001
SO_4^{--}	10.8215	0.4836	59.6009	21.4530	7.3513
Cl^-	18.0655	0.1557	6.8620	5.4017	7.5863

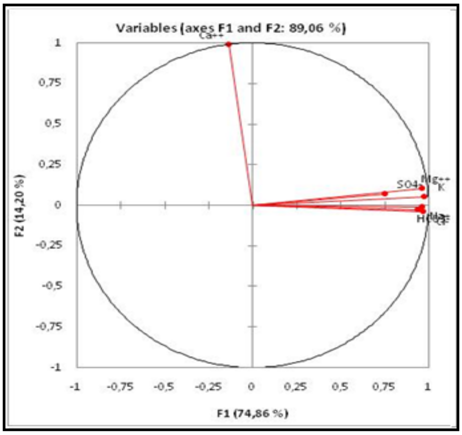

Figure 12: PCA of the mineral element concentration waters of the Cesse

Distribution of mineralization in the waters of the Cesse

The determination of the origin of the mineralization of the waters of the Cesse is based on the one hand on establishing the relationships between the main major elements (Cl^-, SO_4^{2-}, Na^+ and Ca^{2+}), and on the other hand on the relationships between these elements and the total mineralization. The development of maps of the spatial distribution of major elements also makes it possible to highlight the origin of the mineralization. The dry residue (Rs) expresses the saline load of the water. Its correlation with the different chemical elements helps to trace the origin of the mineralization.

Indeed the correlation coefficient is very close to 1 (R^2 = 0.9). It follows that these two elements strongly contribute to the acquisition of the saline load of the waters of the Cesse basin. This is probably dissolution of halite (Nacl) which exhibits high solubility at a temperature of 20 ° C (Chaboureau, 2012). This hypothesis is rather validated in the present work on the Cesse basin whose temperature exceeds 20 ° C and the substrate is rich in limestone (map 3 and the geological data of the Cesse basin). The calcium sulphate/ dry residue diagrams show good correlation coefficients (R^2 = 0.8). This indicates that these two elements play an important role in acquiring the saline load of the waters of the Cesse basin.

According to Nou et al (2013), water from the groundwater shows a low correlation coefficient between bicarbonates and the dry residue (Rs) (R^2 = 0, 1). This poor correlation indicates that bicarbonates (HCO_3) are hardly involved in the mechanism of mineralization in the waters of the Cesse.

Na^+ concentration

Going from upstream to downstream, the waters of the Cesse are increasingly enriched in chloride and sodium (Figure 13). In addition, a good correlation is observed between these two ions with a correlation coefficient close to 1. These two arguments argue for the presence of a common source of these two ions. This source is probably the dissolution of the halite (NaCl) during the transit of the waters, through the unsaturated zone and during their stay in the lower levels of the Cesse. The mechanism of dissolution of halite is also confirmed by the index of saturation of the waters of the Cesse vis-à-vis this mineral. Indeed, this index is less than 1 for all the samples; this indicates a stage of under-saturation of the water vis-à-vis the halite. The chloride-sodium facies of the waters of this basin justify the dissolution of halite.

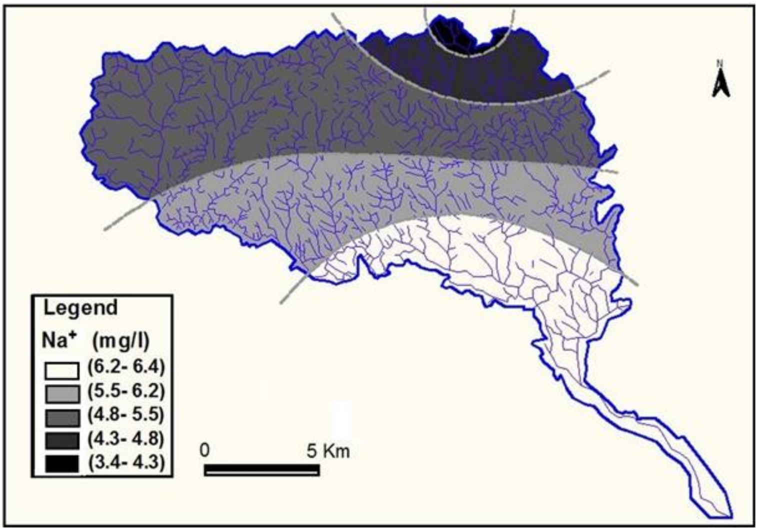

Figure 13: Sodium distribution in the Cesse basin.

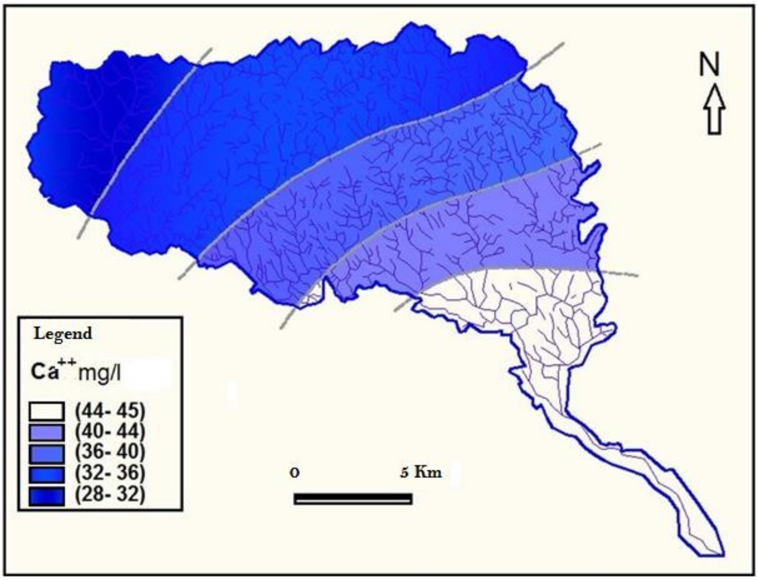

Figure 14: The distribution of calcium in the Cesse basin.

Ca^{2+} concentration

Figure 14 shows that the watershed contains four zones according to the Ca^{2+} concentration. Going from upstream to downstream the average values gradually increases from 28 to 45 mg/l. We could deduce that there is an asymmetric axis between upstream and downstream as two classes at the top and two others at the bottom separated by an intermediate zone.

DISCUSSION

The relevance of the cartographic and geo-environmental approach to analyzes of the waters of the Cesse has just been demonstrated through the 30 samples analyzed. The variation in dissolved element concentrations in the Cesse basin and their spatio-temporal variability can be explained by natural and anthropogenic factors. Our data showed that the mineral element concentration increase from the north to south of the Cesse watershed. This increase is due to various factors such as: natural and anthropic ones.

Natural factors

Geological factors

On the upstream part of the Cesse basin, the water flows over the terrain of the 'Montagne Noire' or is infiltrated into the Cambrian karst systems which develop along the fracturing. This part of the basin can then be considered as the main feeding area of the Cesse. When in contact with Alveolin limestone from the Ilderdian, surface water is lost in the subsoil or is transferred to it (Nou et al., 2013). However, they contribute to the supply of the upstream part of the Cesse.

Dissolution by the infiltration water of the Urgonian-facies reef limestones is the cause of significant conductivity and high concentrations of calcium ions in the downstream part of the Cesse before reaching the confluence zone with the Aude. According to Chapuis (2017), "the large underground inputs strongly modify the water chemistry of the upstream river downstream of the karst sector. They cause a dilution of sulfate, potassium and sodium ions, as well as enrichment in hydrogen carbonate and calcium ions". In the same context, Nou et al. (2013) prove that the upstream part of the Cesse can then be considered as the main feeding area of the basin. In contact with Alveolin limestone from the Ilderdian, the surface water gets lost in the subsoil or is transferred to it. They help to supply the upstream part of the Pouzols aquifer. The phenomenon of karstification is realized when the Cesse crosses the Pouzols synclinal (Nou et al., 2013). The phenomenon of mineralization thus increases from upstream to downstream, as we have shown in this present work.

This hypothesis also applied to the Wadi Maarouf basin (central Tunisia). The latter is dominated in its upstream part by the reliefs of Jbel Serdj and Bargou (Turki, 1975). The chemical facies of the Maarouf wadi, analyzed and mapped, concentrate from upstream to downstream forming a veritable chemical tree (Lahmar, 2010). Downstream of 'Wadi Maarouf' and in the confluence zone with 'Wadi Kseub', the concentrations of chemical elements buffer with very high values (Lahmar, 2016). Similar studies have also been carried out in other Mediterranean basins such as the 'Wadi Tinja' basin in northern Tunisia and the 'Wadi Joumine' basin in northern Tunisia (Boukari et al., 2019). These studies reveal that the chemical facies are more concentrated in the downstream part and this independently of the profiles of the course and its tributaries (Ben Garali et al., 2008). We also cite the study carried out on the Real Collobrier basin in which it was concluded that the transfer of chemical elements accelerates from upstream to downstream (Grésillon et al., 1997). The same results were also proved in an expert study of the Gardon d'Anduze basin (Planques et al., 2006).

It can be seen that the chemical concentrations are increasing from upstream to downstream. This concentration results from several phenomena such as karstification (Fabre, 1978 and Nicod, 1990), redox, marine intrusion and/ or discharges into domestic and industrial rivers. The hydraulic arrangements in the watershed don't block the normal circulation of chemical elements from upstream to downstream. The exception is noted at the 'Canal du midi', for which it was noted that the concentration of certain chemical elements is greater in the upstream of the canal. However, the hydraulic arrangements have facilitated the appearance of this chemical connection in the watershed of the Cesse. They are real hydraulic communication between upstream and downstream in the same watershed.

Climatic factors

Spring floods and precipitation participate in the transit and accumulation of chemical elements in the sediment volumes at the outlet of rivers. Recent studies, which are based on dating techniques (gamma spectrum), have been able to reveal the rate of accumulation at the level of the confluence zone between the Aude and the Cesse (Bonté et al., 2001). These dating and sedimentological studies have made it possible to find, in addition to chemical facies (major elements), traces of radioactive elements in the sedimentary archives. Results obtained support the idea that the transit of chemical and radiological materials takes place from upstream to downstream and following the trajectory of rivers. Other results have been identified in rivers such as Ouvèze (Vaucluse) and Gardon d'Anduze (Bonté and al., 2001). In addition, accumulations at outlets or/ and dams (such as bridges, upstreams of canals and dikes) are often in the form of low alluvial terraces (Ballais and al., 2011). These terraces have a drop of 3 to 4 meters and are often very fertile and suitable for agro-pastoral activities. Sedimentological and mineralogical analyzes of the sand cores from these terraces show their richness in chemical facies, the outcome of which is the reliefs that surmount them (Lahmar, 2010).

However, the river system suggests a stability of the climate variable to maintain a fluid movement of chemical elements between the upstream and downstream of the basin. Climate change and in particular precipitation have been the subject of several studies for several decades. Studies of the Cesse don't recommend changes in precipitation or flow (Norrant and Douguedroit, 2003). Other studies on other basins, close to and belonging to the Mediterranean basin, would be useful to enrich our investigations and test the reliability and validity of this method.

Hydrological and morphological factors

Remaining in the river system and its hydraulic development, we notice that the high concentrations are proportional to the intensity of the developments on the ground. We could deduce that the developments block the normal circulation of chemical elements in the course of the Cesse. This process, characterized by an Upstream/ Downstream variation, results showed a low concentration in the upstream part (Lahmar, 2010). This concentration increases going downstream (Alary, 1998). Another explanation that may be reliable is that the concentration can be influenced by the phenomenon of oxidation-reduction between the different elements (Aranguren, 2008). This phenomenon is proportional to the duration of the stay of water in the watercourse and the existence of several chemical elements capable of reacting in a solvent medium (Fabre, 1978).

The slopes can be introduced in this study. After extracting the map of the slopes of the Cesse, we deduce that the values of the concentrations of the chemical facies are inversely proportional to the DEM of the slopes (Figure 15). The most important values of the slopes coincide with the less important values in chemical facies.

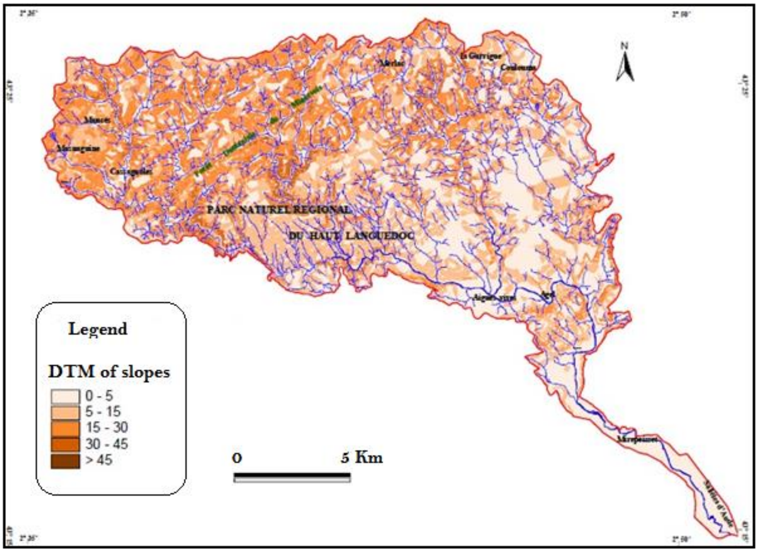

Figure 15: Slope map of the Cesse basin (Lahmar, 2010)

Anthropogenic factors

Anthropization contributes to the catalysis of chemical reactions through direct or indirect releases (El Morhit et al., 2008). The Cesse basin is experiencing a strong anthropization in the form of factories such as glassworks and pottery ovens. According to Chabal (2001), the potters of Sallèles d'Aude have burned considerable quantities of wood, in just over three centuries, to cook ceramics and building materials. Huge layers of ash and charcoal were found near the deposits and in recent alluvial deposits. Similarly, according to Garray et al. (2002) and Ballais et al (2011), following the multiple interventions of rectifications and calibrations, the minor course in common of the Aude and the Cesse had to undergo a strong modification.

The junction canal favored a strong sedimentation in its upstream part. The current bed is thus disconnected from the original bed and the roof shape of the major bed seems to be linked to the strong anthropization of the environment (Lahmar, 2010). This strong anthropization catalyzes the phenomenon of transfer of chemical elements from upstream to downstream of the Cesse basin. In addition, the decomposition of waste in the bottoms of rivers allows the release of chemical elements or substances allowing the acceleration of chemical kinetics. Therefore, we could consider other analyzes necessary to prove this hypothesis: such as bacteriological analyzes of the soil. This technique can be useful in determining bacteria of anthropogenic origin. We could take sedimentary cores in refuge areas such as the confluence area between the Aude, the Cesse and the ‘Canal de Midi’.

CONCLUSIONS

It therefore appears that the chemical analysis tool of water, combined with mapping by interpolation remains incomparable for tracing the movements of the chemical facies of the waters of the Cesse. Examination of the variation in the chemical composition of the water from the Cesse shows that most of the elements present a high concentration in the downstream part of the basin, but in varying proportions.

The observation of the physico-chemical parameters of the waters of the Cesse makes it possible to control their qualities. Monitoring variables such as salinity is important for the study of other issues such as the study of aquifers in the territory in question. The waters of the Cesse are generally of average quality with the exception of the sections located in the ‘Montagne Noire’ where the water is often of good quality. The technique of chemical analysis combined with mapping made it possible to study the distribution of chemical facies of the waters of the Cesse. Moreover, the conjunction of the results obtained with the geological data of the study area allowed the identification of the issues of high concentration of mineral element. By analogy, we can carry out other studies on the small basins of the Mediterranean in order to obtain a usable database.

Finally, it would have been interesting to follow the soluble carbonate phase resulting from karst and its redistribution in various forms (travertine, limestone sludge, eutrophic peat bogs, etc.) in the low valleys and riparian areas of the Cesse and its main tributaries.

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