Identifying trends in the water cycle of the “Gave de Pau” and “Gave d’Oloron” catchment areas in the northern Pyrenees

Arnaud Wuilleumier, Jean-Jacques Seguin

Identifying trends in the water cycle of the “Gave de Pau” and “Gave d'Oloron” catchment areas in the northern Pyrenees

A. Wuilleumier[(1)] and J-J. Seguin[(2)]

(1) BRGM - Direction Régionale Nouvelle-Aquitaine. Parc Technologique Europarc - 24, Avenue Léonard de Vinci - 33600 PESSAC - France. a.wuilleumier@brgm.fr
(2) BRGM – Scientific centre. 2, avenue Claude Guillemin - BP 36009 - 45060 – Orléans Cedex 2 – France. jj.seguin@brgm.fr

ABSTRACT

Studies carried out in France show that the south-western part of the country will be one of the regions most affected by climate change impacts. This study aimed to identify trends in the different components of the water cycle in this region. The study was performed using statistical methods commonly used to analyse hydrological time series, such as the Mann-Kendall and Pettitt non-parametric tests. The tests were applied to several variables, including rainfall, effective rainfall, mean annual discharge, low-flow discharge and piezometric level. Over the long term (1959-2014) and based on Météo France data, the study identified significant negative trends in evapotranspiration in both catchment areas, and in effective rainfall in the Gave d’Oloron basin. Regarding river discharge, significant negative trends were identified for the 1965-2011 period in the mean annual discharge of the 8 rivers studied and in low-water discharge for 6 of the rivers. The Sen slopes calculated show drastic reductions in mean discharge over the same period (up to 50%). However, the same test applied over a longer period was not always significant (1912-2016, Gave d’Oloron), which underlines the importance of the period chosen for analysis. Regarding piezometric levels, significant positive trends were identified in the mean annual water level during the period for which data was available (2001-2015). It is important to note that significant positive trends were also identified in the mean annual discharge of rivers over the same period.

Key words: North Pyrenean catchment basins, hydrology, trend, Mann-Kendall test, Pettitt test.

INTRODUCTION

Climate change has become a major concern in recent years because of its social and environmental impacts, which are already evident in various regions across the world. In 2010 in France, the Ministry for the Environment, Energy and the Sea launched the "Explore 2070" project, which is using different climatic, demographic and socio-economic scenarios to develop strategies in view of potential climate change impacts on hydrosystems and coastal environments by 2050-2070 (see Amraoui, 2012, for a summary of the nationwide study in France). At a more local scale, numerous studies are under way or already completed on the consequences of climate change for surface and groundwaters. The study presented in this article concerns two hydrosystems in south-western France. It was conducted under a 5-year regional agreement on groundwater (2015-2020) between the Nouvelle Aquitaine Region, the French State and the BRGM.

AIM AND DATA USED

The aim of the study was to identify potentially climate-related changes in the catchment basins of two rivers, the Gave de Pau and the Gave d'Oloron, which both rise in the Pyrenees (Figure 1). The research involved analysing available time series for rainfall, ETP, effective rainfall, discharge rates in both rivers and their tributaries and the levels of the groundwater tables that connect with the two rivers.

The discharge time series analysed were collected from 12 hydrometric stations (Figure 1). At 10 of these, measurements were taken daily for periods of 43 years (1920-1962) to 105 years (1912-2016). For the other two, the measurement period was 28 years (1927-1954) (Table 1). Spectral analysis of all 12 discharge time series clearly shows a "peak" every 12 months and a secondary "peak" every 6 months (Figure 2). The 6-month cycle corresponds to the rainfall-snowmelt regime of the two rivers, which is determined by late autumn rains and snowmelt in the spring.

For the groundwater table levels, 20 piezometers had recorded measurements but of these, only 6 had produced enough data to be statistically significant. The discharge measurements (taken daily) are recent (2002-2016). Over the common measurement period, there is a high correlation between river discharge rates and the levels of the connecting water tables.

The climate, rainfall and ETP data were extracted from the national SAFRAN system run by Météo France. This system interpolates the meteorological variables on a daily basis into a regular 8 km x 8 km grid. For the study, 13 grid cells were selected, running north to south across the two catchment basins (Figure 1).

METHODOLOGY

The methodology used essentially relies on statistical tests applied to several variables characterising the water level and river discharge time series. These are:

- the annual (hydrological year) averages, medians, minima and maxima from the time series,
- the minimum monthly average discharge in each calendar year (QMNA),
- the minimum monthly average piezometric level in each calendar year (HMNA).

The river variables analysed also included:

- base flow (which refers to river water that derives from stored sources, such as delayed discharge from groundwater), for which we used the Base Flow Index (Gustard et al., 1992),
- the frequency of maximum monthly discharge rates.

The final step was to calculate effective rainfall, for which we used Thornthwaite's method with the SAFRAN grid data for rainfall and ETP, which we then cross-referenced with the discharge and water level data.

The statistical tests used are those proposed by Kundzewicz et al. (2000), i.e. the Mann-Kendall test for trend detection and the Pettitt test to detect change points (Pettitt, 1979). To check for any autocorrelated data in the time series analysed, we used a modified version of the Mann-Kendall test (Hamed and Rao, 1998). These tests were all applied to the variables listed above.

ANALYSIS OF THE TIME SERIES FOR DISCHARGE

Identifying trends

When all of the measurement periods are considered (some time series cover more than 100 years), at least one of the variables in 8 stations out of 12 are characterised by a drop in discharge which is significant (5% risk threshold) to very significant (1% risk threshold), and 7 stations show a drop in QMNA and/or the average annual flow rate. An example is given in Figure 4, showing the average annual discharge of the Saison river at Mauléon, for which the Mann-Kendall and Pettitt tests are highly significant (p-value below 10-4).

The share of the discharge represented by the drop was calculated by applying the Sen slope (Sen, 1968) to the period selected for the tests. The annual averages then showed estimated drops of 50% to 60% in the module for the Neste de Cap de Long discharge (O0105110) between 1948 and 2011 and for the Saison river at Mauléon-Licharre (Q7322510) between 1967 and 2011. A smaller and (statistically) non-significant drop was identified at the stations for the Gave de Pau at Saint-Pé-de-Bigorre (1959-2016), the Gave d'Ossau at Oloron-Sainte-Marie (1912-2013), the Gave d'Estaing at Estaing (1927-1954) and the Ouzom at Arthez-d'Asson (1927-1954), and a significant drop for the Lourdios-Ichère at Lourdios-Ichère (1920-1962). A significant to very significant drop in QMNA appears at 5 stations, and a non-significant drop at 3 or 4 other stations (if we include the Gave de Pau station at Bérenx, where the QMNA dropped to 9.5% of QMNA5 between 1923 and 2016).

A common measurement period was chosen to ensure homogeneous results: the Mann-Kendall test (modified by Hamed and Rao) was applied to the average discharge and QMNA produced by 8 hydrometric stations with virtually complete time series over 45 years (1967-2011). All show a significant downward trend (Table 2) in the annual average discharge and 6 show a downward trend in QMNA. Applying the Sen slope over 45 years shows that the average annual discharge at all stations dropped by up to and over half of the module over the period studied. An interesting point is that in stations where no (statistically) downward trend was identified over a longer period (Q7412910, Q5501010), there is a systematic drop during the 1967-2011 period. Boe and Habets (2014) have shown a climate-related cycle that could account for these observations.

The Base Flow Index

The Base Flow Index (BFI) is the ratio of the base flow (water which is assumed to enter the river from a hydrosystem over a certain lapse of time) over the entire river discharge. The calculation method used was developed by the Wallingford Institute of Hydrology (Gustard et al., 1992).

As very long time series were available for discharge, there were grounds for investigating whether the BFI had varied over several decades. The time series were therefore subdivided into 2 or 3 periods of about 30 years each. Depending on stations and periods, the BFI varies from 0.51 (Saison river at Mauléon-Licharre, 1967-1980) to 0.76 (Gave de Pau at Saint-Pé-de-Bigorre, 1959-1980). Except for the Gave d'Oloron at Escos and the Neste de Cap de Long, the BFI dropped between period 2 (from the late 1940s to 1980) and period 3 (1981 to 2016), reflecting a drop in the base flow share of the total discharge. Although this implies a relative increase in the share of rapid input into the rivers, it does not imply an increased contribution in absolute values (the observed drops in effective rainfall in fact suggest the reverse). This is illustrated by the Gave de Pau measurements at Bérenx, for example. The average module is 81.6 m^3/s over the entire period from 1923 to 2016, 76.5 m^3/s from 1923 to 1945, 87.8 m^3/s from 1948 to 1980 and 76.9 m^3/s for the last period in the time series. Once the BFI is known for each of the three periods, it is possible to calculate the shares of rapid input and base flow input in the total discharge (Table 3). This shows very slight variations in rapid input, and a very significant increase (+20%) in the base flow share from 1948 to 1980.

Given the rainfall-snowmelt regime of river discharge in the two catchment basins, the drop in the BFI should not be interpreted necessarily as a decline in groundwater input into the rivers, as it could also indicate a drop in snowmelt input. This still needs to be analysed, although the shrinking glaciated areas in the Pyrenees would tend to support this hypothesis (Figure 5).

ANALYSIS OF THE TIME SERIES FOR WATER LEVELS

Because only a few years of water level measurements were available, the period analysed is much shorter than for discharge (2002-2016). The analysis shows an upward trend (significant and non-significant) in the averages from 5 piezometers out of 6. The results are more varied for the other variables, and do not point to any clear conclusions. The contradiction between this upward trend and the results for average annual discharge is only apparent, because it disappears when the latter are tested for the same period as for the water levels. Both variables are then highly correlated and both show an upward trend. This result clearly shows the importance of the period chosen to apply the tests.

ANALYSIS OF THE TIME SERIES FOR EFFECTIVE RAINFALL

A long-term downward trend (1959-2014) appears for effective rainfall as well as for discharge: this trend is significant for the upstream reaches of the Gave d'Oloron but not significant for those of the Gave de Pau. The trend is essentially due to an upward trend in ETP, with a change point in the second half of the 1980s. Figure 6 shows the trend calculated for effective rainfall in the Gave d'Oloron catchment area, which is significant at the 5% risk threshold (p-value 0.026), superimposed over the curve calculated for average discharge at station Q7002910 (also significant at the 5% risk threshold - p-value 0.021).

CONCLUSION

By applying statistical tests to different periods and to a large number of characteristic variables of the water cycle, it becomes possible to compile an anthology of information on a given area. In the case of the Gave de Pau and Gave d'Oloron catchment basins, multi-variable analysis shows a significant decline in river discharge from 1967 to 2011, which is consistent with the trend for effective rainfall over the same period. This does not contradict the upward trend in piezometric levels identified over a much shorter period (2002-2016), which is consistent with the trend in average annual discharge over that same period. Finally, analysis of the Base Flow Index from 1948 to 1980 and from 1981 to 2016 shows the declining share of base flow input entering most of the rivers in these catchment basins. This point still needs to be correlated with changes in the area of glacial surfaces in the Pyrenees.

REFERENCES

Amraoui, N. (2012) - Changement climatique – Explore 2070. BRGM/RP-61483-FR vol. 9.

Boe J., Habets F. (2014) - Multi-decadal river flow variations in France. Hydrol. Earth Syst. Sci., 18, 691–708.

Gustard, A., Bullock, A., Dixon, J. M. (1992) - Low flow estimation in the United Kingdom. Wallingford, Institute of Hydrology, (IH Report No.108).

Hamed, K.H., Rao, A.R. (1998) - A modified Mann–Kendall trend test for autocorrelated data. J. Hydrol., 204, 219–246.

Kundzewicz, Z. W. & Robson, A. (eds), (2000) - Detecting Trends and Other Changes in Hydrological Data. World Climate Programme - Water, World Climate Programme Data and Monitoring, WCDMP-45, WMO/TD no. 1013. World Meteorological Organization, Geneva, Switzerland.

Pettitt, N. (1979) – A non parametric approach to the change point problem. App. Statist. 28, n°2.

Seguin J.J., Wuilleumier A. (2017) - Recherche d'évolutions climatique et hydrologique dans les bassins versants des Gaves de Pau et d'Oloron. Final report. BRGM/RP-66802-FR.

Sen, P.K. (1968) - Estimates of the regression coefficient based on Kendall’s tau. J. Am. Stat. Assoc. 63, 1379–1389.

ACKNOWLEDGEMENTS

This study was supported financially by the European Union ERDF programme, the Nouvelle Aquitaine Region, the Pyrénées-Atlantiques *Département* and the Adour-Garonne Water Agency.

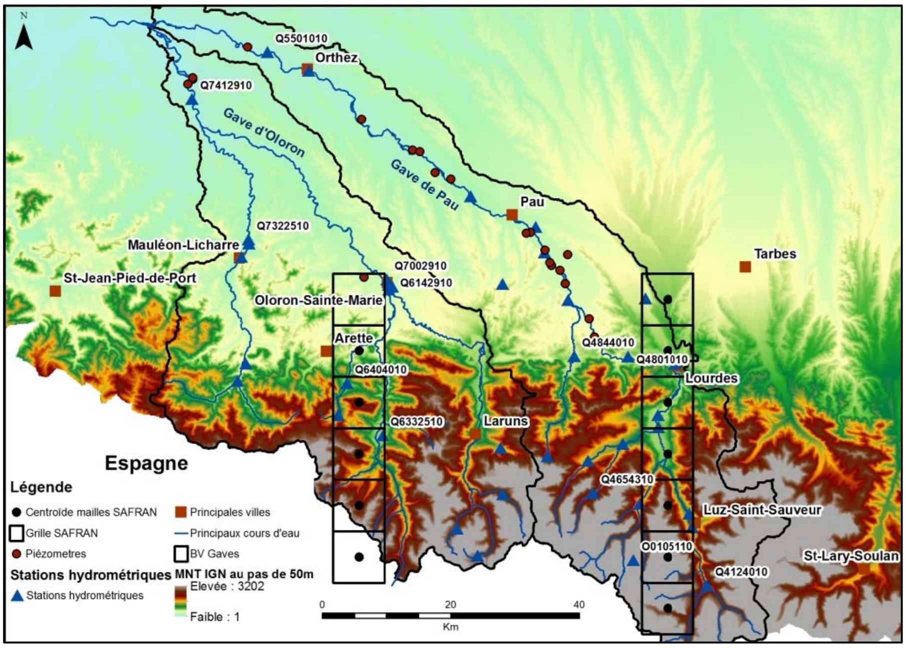

Figure 1 Locations of the piezometers and gauging stations producing the data analysed in the study.

Code	Name of river	Period	Basin (km^2)
O0105110	The Neste de Cap de Long at Aragnouet [Les Edelweiss]	1948-2011	5
Q4124010	The Gave d'Héas at Gèdre	1948-1995	84
Q4801010	The Gave de Pau at Saint-Pé-de-Bigorre [bridge at Rieulhes]	1959-2016	1120
Q5501010	The Gave de Pau at Bérenx [bridge at Bérenx]	1923-2016	2575
Q6142910	The Gave d'Ossau at Oloron-Sainte-Marie [Oloron-Sainte-	1912-2013	488
Q6332510	The Gave d'Aspe at Bedous [bridge at Escot]	1948-2011	425
Q7002910	The Gave d'Oloron at Oloron-Sainte-Marie [Oloron-SNCF]	1912-2016	1085
Q7322510	The Saison river at Mauléon-Licharre [Berrogain Laruns - Cibi]	1967-2011	480
Q7412910	The Gave d'Oloron at Escos	1949-2016	2456
Q6404010	The Lourdios-Ichère river at Lourdios-Ichère	1920-1962	46
Q4844010	The Ouzom river at Arthez-d'Asson	1927-1954	129
Q4654310	The Gave d'Estaing at Estaing [Las Counces]	1927-1954	38.5

Table 1 – List of hydrometric stations used for the study

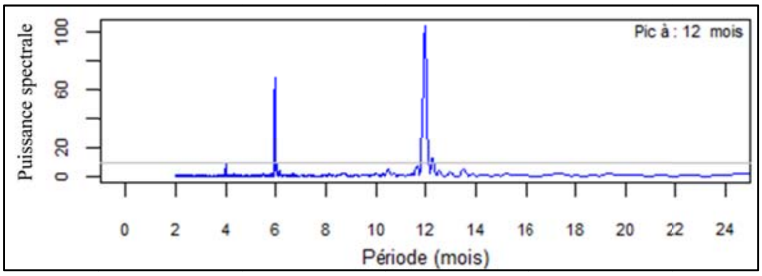

Figure 2 – Spectral analysis of the time series for the Gave de Pau at station Q4801010

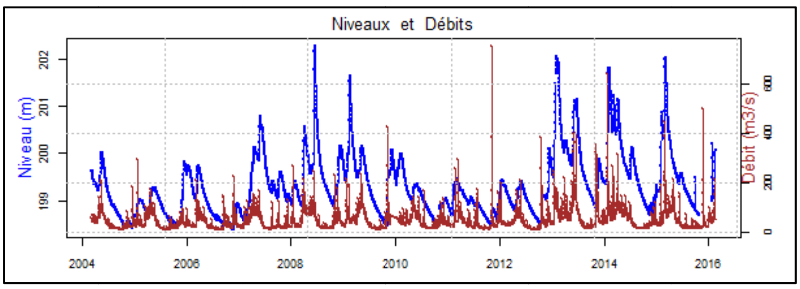

Figure 3 – Discharge in the Gave d'Oloron (Q7002910) and water table levels measured by piezometer 10295X0032

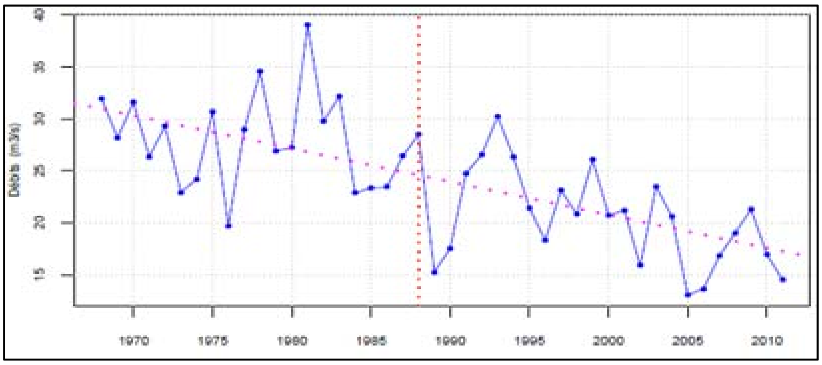

Figure 4 – The Mann Kendall and Pettitt tests applied to Saison river discharge (Q7322510)

Station	Début	Fin	Nb années retenues	Valeurs moyennes		Module (m3/s)	Pente Sen (m3/s par an)	Proportion baisse	QMNA		Pente Sen (m3/s par an)	QMNA moyen	Proportion baisse
O0105110	01/01/1967	31/12/2011	43		TS	0.26	-0.003	-44%	pente nulle		0.000	0.017	0%
Q4801010	01/01/1967	31/12/2011	45		TS	46.03	-0.270	-26%		TS	-0.233	20.6	-51%
Q5501010	01/01/1967	31/12/2011	45		TS	81.10	-0.802	-45%		TS	-0.338	31.8	-48%
Q6142910	01/01/1967	31/12/2011	44	Baisse	TS	19.49	-0.216	-50%	Baisse	TS	-0.073	5.59	-59%
Q6332510	01/01/1967	31/12/2011	45		S5	23.45	-0.111	-21%		S5	-0.047	6.64	-32%
Q7002910	01/01/1967	31/12/2011	45		TS	51.68	-0.375	-33%		S5	-0.133	16.4	-36%
Q7322510	01/01/1967	31/12/2011	45		TS	23.88	-0.300	-57%		S5	-0.057	5.39	-47%
Q7412910	01/01/1967	31/12/2011	45		S10	101.78	-0.369	-16%	BNS		-0.120	26.5	-20%

Table 2 - Results of applying the Mann-Kendall test to average annual values and QMNA measured at hydrometric stations providing time series for the 1967-2011 period.

Période	Module (m3/s)	BFI	Q de base (m3/s)	Q rapide (m3/s)
1924-1945	76.5	0.656	50.2	26.3
1948-1980	87.8	0.691	60.7	27.1
1981-2016	76.9	0.666	51.2	25.7

Table 3 - The Gave de Pau at Bérenx – percentages of base flows and rapid flows deducted from the BFI values calculated.

Figure 5 – Retreat of the Ossoue glacier from 1911 to 2012 (Association Moraine)

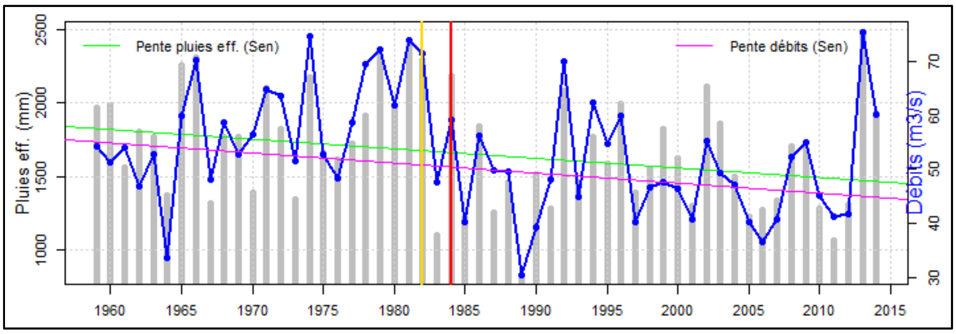

Figure 6 – Sen curve calculated for annual effective rainfall in SAFRAN grid-cell 1761 and for average annual discharge at station Q7002910. The vertical yellow line shows the change point date for effective rainfall; the vertical red line shows the change point date for river discharge.