Review 2 :

We thank the anonymous reviewer for its detailed and very constructive review. We have carefully taken it into account and believe it will improve the article.

The authors argue that groundwater seasonality is a main driver of seasonality in hydrological and sediment transport processes. Unfortunately, the paper presents little evidence for this hypothesis. Thus, this conclusion is not entirely supported by the data presented. The values for the contribution of surface runoff (or groundwater) to total discharge at the outlet are missing in Table 4 and 5, and in Figure 5b it is not possible to see if there are significant differences in %SR between the two seasons. Indeed, the values presented in Table 4 show a higher percentage of mean V_GW/(mean V_GW+ mean V_SR) in spring/summer (79%) than in autumn/winter (76%) and my (very quick and dirty, so please correct me if I'm wrong!) calculation from emma_results.csv in the supplementary material also returned higher GW contribution in summer. This is contradictory to the reported higher GW contribution in autumn.

Thanks for this remarks that allowed us to better define the terms and the controlling factors. We think that it is indeed not the variability of the contribution of GW that matters, but the variability of GW flow itself. But we acknowledge that they were some ambiguities in the manuscript. We thus made several modifications, that are explained below :

- Table 4 has been modified to include the percentage of SR at peak flow, as well as the percentage of volume of SR at the flood scale. The differences between the two seasons are not significative. But what it noteworthy is that GW flow rate represents an important proportion of flow rate, both at peak flow (around 70%) and at flood scale (around 80%). That's why we argue that it is primary the seasonal variabilities of GW that influence the seasonal variabilities of flow rate leading to SS deposition in spring/summer (when GW inputs are low) and sediment remobilization in winter (when GW input is high).
  The abstract has been modified to insist on this GW flow contribution and seasonality, especially the second and third paragraphs, like that :

  « Hydrological analyses reveal that groundwater flow is the dominant contributor to streamflow, accounting for approximately 75\% of the event flow on average. Groundwater response varies substantially between seasons, with mean peak flows increasing from $2.5\pm2.1,\mathrm{m^3,s^{-1}}$ in spring/summer (May-September) to $5.9\pm5.4,\mathrm{m^3,s^{-1}}$ in autumn/winter. While both surface runoff and groundwater flows increase with event rainfall accumulation, groundwater flow shows a stronger dependence on rainfall accumulated over the preceding 15 days, emphasizing the influence of antecedent catchment wetness and long-term hydrological connectivity. Hydrosedimentary analyses further demonstrate that suspended sediment concentrations (SSC) correlate more strongly with surface runoff flow rate than with flow rate (Q), emphasizing the dominant role of surface runoff in sediment detachment and transport on hillslopes. Marked seasonal differences in hydrosedimentary processes were observed. Spring/summer events, driven by short and intense rainfall, produce low-flow responses with high suspended sediment concentration and exhibit anticlockwise

SSC-Q hysteresis loops. This suggests that these fine sediments are mobilized from sources located relatively far from the outlet. The high suspended sediment concentrations and moderate flow rate in the river network likely lead to to sediment deposition in the river network. Conversely, autumn/winter events, driven by prolonged low-intensity rainfall, and characterized by enhanced groundwater flow, produce high flow responses, with low suspended sediment concentration, and clockwise SSC-Q hysteresis loops. This hysteresis shape indicates close sediment sources that are likely associated with riverbed sediment remobilization. These findings reveal a fundamental seasonal shift from primary (i.e. hillslope mobilization) to secondary (i.e. riverbed re-mobilization) erosion processes, controlled by the seasonal variations of groundwater flow throughout the year.. »

- In the result part 4.2, the sentence : « Figure 5.b shows that part of this variability can be attributed to seasonal effects: floods occurring in June and September tend to show higher SR contributions than those in autumn/winter months, which are associated with higher flow rates. » has been suppressed.

- In the result part 4.2, the sentence « Table \ref{table:valeurs_ete_hiver} also show that, during both seasons, GW is the main contributor of water, representing around 70\% of flow rate at peak flow and around 75\% of water flow at flood scale. » is added line 334.

- The followingsentence was added line 339: « Table \ref{table:pearson_correlation_all} also indicates that Q_{max} and V are highly correlated to $Q_{GW,max}$ and V_{GW} respectively. » emphasizingthat variabilities of flow are mainly controlled by groundwater flow.

- In the discussion part 5.1, the following sentence was added line 384 : « The high proportion of GW flow (around 75\% at the flood scale, see table \ref{table:valeurs_ete_hiver}) associated with the very high correlation between hydrological variables (Q_{max}, V) and GW-related variables ($Q_{GW,max}$, V_{GW}) indicate that the flow rate variabilities are mainly governed by the GW flow variabilities. ».
- In the conclusion, line 531, the beginning of the third paragraph has been modified by : « This study underscores the fundamental role of GW input representing around 75\% of flood water flow. Its seasonal variability shapes both hydrological and hydrosedimentary seasonal functioning in this medium-scale Mediterranean catchment. »
- In all the manuscript, references to GW or SR contributions have been modified by GW or SR flows.

The explanation of high rain intensity in spring/summer -> high detachment -> high SSC; low flow -> transport limitation -> deposition, negative HI, low total SS export vs. higher Ptot and high sediment availability in autumn/winter -> high flow, low SSC but high SS export is convincing. However, in my opinion, no evidence is presented that this is governed by groundwater. Indeed V_GW, V_SR and V seem to be highly correlated. The high cross-correlation in the data set makes it hard to identify single drivers of seasonality. I would rather argue that the seasonality is governed by precipitation and not by groundwater seasonality.

We agree that precipitation is the primary climatic driver of seasonal hydrological variability. However, we argue that the remobilization and deposition processes are governed more directly by flow conditions than by precipitation itself. At the Galabre catchment, we have shown that the seasonal variability in streamflow is mainly controlled by groundwater contributions (very high correlation between flow rate and GW rate in table 5), which account for approximately 80% of the event water volume during both summer and winter. Consequently, the seasonal changes in flow conditions that regulate sediment remobilization are largely associated with groundwater discharge.

Of course, groundwater variability ultimately results from climatic forcing, including precipitation. However, the relationship between precipitation and groundwater flow is indirect as evapotranspiration, which also exhibits a strong seasonal dynamics, is also involved in this relationship. Thus the link between precipitation and groundwater flow and involves complex hydrological processes that are beyond the scope of this study. In contrast, our measurements allow us to directly estimate the respective contributions of groundwater and surface runoff during flood events. For this reason, we relate sediment remobilization and deposition processes to flow rate and GW flow variations, which represents the most direct hydrological control available from our observations.

2) Please give some more details about event selection and the performance of the Eckhardt filter. It seems to perform quite poorly if only 27 out of 87 events have a RMSE below 0.5 m3s-1. This threshold is quite high given the values shown in Fig. 2a. Please give the reasons for this poor performance and discuss them.

86 events represent all the single peak events between October 2019 and June 2025. Among these events, only 30 floods are covered by at least 4 chemical measurements. Thus the reason for the change from 80 to 30 is not due to poor performance of the Eckhardt filter as to the availability of chemical analyses. Nevertheless the Eckardt filter was applied on these 30 events and the criteria has been modified to select only the events with a relative root mean square error<0.5 and a maximum SR discharge >0.05m3/s (because very low SR flow are too much uncertains). This resulted in 26 flood events. This has been better explained line 271-275.

Due to this new selection of events, Table 4, 5, 6 have been slightly modified, as well as figures 6 and 8. But these modifications do not change the main results and messages of the article. The only result that is slightly modified is the better correlation between V_s and V_{SR} than V_{GW} in Table 5.

It has been modified in the result part line 360 as :
« Table~\ref{table:pearson_correlation_all} also shows that V_s correlates more strongly with SR-related variables ($Q_{\text{SR,max}}$, V_{SR}) than with GW-related variables ($Q_{\text{GW,max}}$, V_{GW}). ».

3) Please be consistent with expressions throughout the manuscript (e.g. discharge or flow rate; surface runoff contribution or EM_Sr contribution or %SR; spring-summer or spring/summer or April-September, …)

All « discharge » have been modified in « flow rate », the « EM_Sr contribution » has been modified by « SR contributions » and « spring-summer » by « spring/summer »

4) The introduction would benefit from considering further (recent) literature. I have added some recommendations in the specific comments, but there are probably more studies dealing with river – groundwater dynamics. For some statements, references are needed, see my specific remarks.

Most of the proposed articles have been added in the text, and references about the river-groundwater dynamics have also been added in the introduction line 102-104. As "Several studies have shown that groundwater flow can account for a substantial proportion of streamflow during flood events in mountainous catchments across a wide range of catchment sizes \citep{trust2025quantifying,baraer2015contribution,ribolzi2000contribution,fischer2026contrasting,cras2007hydrological}" and in the discussion part, line 387 : "This high contribution of GW flow is consistent with other estimations done in other small and medium-scale mountainous catchments \citep{trust2025quantifying,baraer2015contribution,ribolzi2000contribution}, but is much higher than GW contributions reported in a nearby headwater catchment covered 80% by badlands \citep{fischer2026contrasting}."

5) The paper is very long. Please try to shorten the text. In the discussion section, please avoid long repetitions or results. The parts that are linked to methods development (3 approaches for solving EMMA equations) are quite independent from the rest of the paper that focusses on process understanding. Consider moving them to the Appendix or supplementary information? In this way, the complexity and the length of the paper would be reduced.

We agree that the paper is quite long and complex, and we tried to shorten it. The part dealing to the method development as well as previous figure 4 has been moved to Appendix, lines 550-563. The discussion part 5.1 has been also reduced.

SPECIFIC COMMENTS

line 4. Is it really 86 flood events or rather 27?

Yes, it is a mistake. It is 26 flood events. It has been modified line 4

line 4 replace „spanning“ with „from“?

Yes, it has been modified line 4

line 5 “Surface runoff contributions during floods vary from 0 to 50% of the instantaneous flow rate, with higher proportions during the dry spring/summer season (May–September) and lower values in autumn/winter” no evidence for this statement is given in the paper, see my general comment.

We agree that this was not clear. We mentionned contributions, whereas it is rather the absolute discharge that varies. This line was modified as follows : « Hydrological analyses reveal that flood groundwater flow represents, on average, 75\% of floodwater export. Groundwater flow also shows clear seasonal contrasts, with average peak flood groundwater flow rates of $2.5 \pm 2.1 m3/s$ in spring/summer (May–September), and $5.9 \pm 5.4 m3/s$ in autumn/winter. »

line 11 where is the evidence for this statement? This is contradictory to line 365-369 and Table 5.

The evidence of this statement is given by Table 7 and lines 376-381. Lines 353-355 and Table 5 deals with indicators calculated at the flood scale, whereas the statement line 11 was dealing with correlation of instantaneous measurements.

line 41 not sure if “constrained” is the correct word here...

It was replaced by “poorly understood”.

line 30: consider adding Glaser et al., 2023 https://doi.org/10.1016/j.jhydrol.2023.129600;

Yes, the reference has been added.

line 65 references for climate change are missing, consider adding e.g. Borelli et al., https://doi.org/10.1073/pnas.2001403117 and Eekhout and de Vente https://doi.org/10.1016/j.earscirev.2022.103921

Yes, it has been added.

line 67 References are needed. E.g. Slabon and Hoffmann, 2024 https://doi.org/10.1029/2022WR032628

This reference has been added as well as the following one:

https://doi-org.insu.bib.cnrs.fr/10.1029/2019WR025222Digital Object Identifier (DOI)

line 103 References are needed. It is not groundwater but streamflow that remobilizes deposited sediment.

It has been modified by « ... whereas GW, due to its contribution to streamflow, contributes mainly to the remobilization of riverbed previously deposited sediments, i.e., secondary erosion. » line 107.

References have been added on the importance of GW contribution to streamflow line 104.

line 105 this statement needs justification.

This statement refers to the previous sentence, explaining that SR and GW flows have distinct impacts on primary and secondary erosion. Thus, it seems logical that separating the contribution of SR and GW flows could enable to study separately primary and secondary erosion, and thus to better understand the dynamics of these two processes.

line 108 What are the results of these studies?

Some references have been added in addition to a sentence line 139 : « These studies highlighted the dilution effect of GW via the reduction of the dispersion in the relationship between SSC and SR flow rate (Q_{SR}), in comparison to the SSC/Q relation. Others also pointed out the role of GW input to sustain flow rate and to enable bed sediment remobilization »

line129 Beckers et al. (https://doi.org/10.1186/s12302-025-01213-7) identified intra-event pollution patterns and linked them to hydrological processes.

Yes, they showed that pollution pattern can vary between events, and they link it to hydrological processes. However, the statement line 149 deals specifically with the EMMA method, in which the chemistry of the end-members (EM) are generally consider not to vary between events. The novelty of the approach developped in this study is to make vary the chemistry of the end-members, depending on the hydrological state of the catchment. Thus the link between their study and ours is not direct and we prefer not to include this reference.

line 143 replace “despite” with “even though” or "although"

Yes, it has been modified by « even though »

line 147 not sure if “in light of” is the correct formulation.... “by means of” ?

It has been modified by « by means of »

line 181 has electrical conductivity been used for any of the analyses?

No, electrical concductivity has not been used in the results of this article. Thus it was removed from the presentation of data, line 190.

line 190 “crosses”: do you mean stars?

Yes, it is stars, this was modified.

line 191 what do you mean with “gutters”? Surface runoff sampler?

Yes, it has been modified by « surface runoff collectors » line 200.

line 198 what do you mean with “points”?

« Points » are the measurements that enable to create the calibration curve.

The sentence has been reformulated line 207 by « ... using seven calibration standards with known elemental concentrations covering the concentration range typically encountered in continental waters. »

line 204 replace the comma after “dataset”

Yes, this comma has been deleted.

line 207 please add a reference for EMMA.

References have been added lines 217.

line 210 please add a reference for Eq.1

A reference has been added line 218.

Section 3.2.3 needs additional explanations, e.g. Rule of One, residual diagnostic test of Hooper.

As these diagnostic tools are not essential and doesn’t not constitute an innovation of the overall approach used in this study, we decided not to explicitly explain them in the methodological part but to rather point to the articles that explain them. Although the article does not go into further detail about these tests in order to shorten the methodological part, here are a few brief explanations. "The Rule of One" states that the last retained principal component in the PCA space must explain at least a proportion of \(1/n\) of the total variance, where \(n\) is the number of tracers used. The diagnostic tool of \cite{hooper2003diagnostic} involves performing a residual analysis, which consists of calculating the differences between the observed and projected variables in the PCA space. A random distribution of residuals suggests that the mixing space is appropriately defined. Conversely, the presence of structure in the residuals indicates a poor fit within the mixing subspace, which may signal a violation of key EMMA assumptions—such as non-conservative solute behavior or an underestimated system dimensionality (i.e., missing an EM).

Section 3.5 might be shortened, as HI is not fundamental for the paper and the equations 5-7 are probably given in Lloyd et al., it is not necessary to repeat them here, imo.

Yes, the equations 5 to 7 have been removed.

line 297 and following please delete the colors it is confusing in the text. Rather add a legend in the respective figure.

The colors have been removed lines 297-304 and the associations between geologies and colors have been added in the legend of figure 3.

line306: Do you refer to intra-event temporal variability or inter-event variability here? Please specify.

It designs the temporal variability of the chemistry of end-members between different spatial campaigns. So it rather refer to Inter-event variability. It has been specified by modifying line 309 by the following sentence : « ... and temporal variability, as the chemistry of individual tributaries changes between the time of the different spatial campaigns. »

line 322 uncertainty “of”?

Yes, it has been corrected.

line 330 this is hard to see in Figure 5a, can you add a loess filter or something similar?

We prefer not to add a LOESS smoothing curve because the data are highly dispersed, and the resulting trend could be misleading by suggesting a more robust relationship than is actually supported by the observations. Instead, we believe it is more appropriate to present the full variability of the data, allowing readers to appreciate the range and scatter of the measurements without introducing a potentially overinterpreted trend.

We make figure 4.a more clear in changing the color of the dataset.

line 331 what do you mean here with "during flood events"?

It means that all the chemical measurements that are used to perform these hydrograph decomposition are taken during flood events, and not during low flow periods. Because during low flow periods, no surface runoff is expected to occur.

To improve clarity throughout the text, all "flood events" have been modified by "rainfall-runoff events"

line 333 "floods occurring in June and September tend to show higher SR contributions" this is hard to see in Fig. 5b.

This sentence has been deleted.

line 358 replace "improved" with "higher" or "elevated".

Yes, it has been modified by « higher ».

line 374 "event": you mean "events", right?

Yes, it has been modified by "events".

line 387 "within a medium-sized ..." ?

Yes, it has been modified.

line 388 consider restructuring, this phrase is very long.

It has been reformulated line 375 as : « The wealth of available data, combined with the development of original analytical methods, provided new insights into hydro-sedimentary processes within meso-scale Mediterranean catchment. First, an EMMA approach was developed to adjusts end-member chemical signatures according to the catchment's hydrological state, thereby accounting for variations in groundwater age \citep{rademacher2005old, ortega2025subsurface}. Second, this method was applied to an extensive chemical dataset comprising 579 samples collected over multiple hydrological years and seasons. Finally, the chemically based hydrograph separations were used to calibrate the Eckhardt filter at the event scale, enabling high-frequency hydrograph decomposition for 26 events. »

line 390-393 I don't understand this sentence.

This sentence means that the great proportion of quarternary and gypsum end-member at low flow periods can be explained by two possible reasons : i) water during lowflow periods can mainly come from areas dominated by gypsum and Quaternary outcrops or (ii) during low flow periods, water can come from deeper groundwater circulating throughout the catchment, where gypsum may occur beneath the marl, molasse, or limestone formations shown the geological map.

However, this sentence is a side issue of the article. As the discussion part is already long, we decided to remove this sentence.

line 395 Table ??

It has been corrected.

line 398 where did you report this correlation? %SR,max is not in the preceding tables... (notably not in Table 6)

This sentence has been removed as we decided not to focus on the percentage of SR, but rather on the SR and GW flows and as there was a mistake in Table 6.

line 400 and l. 420 parenthesis around the reference

Yes, it has been corrected

line 486 which assumptions of Esteves et al.?

The assumption is explained in the following sentence, line 476-478 but we agree that it was not clear. The point between the two sentences has been replaced by a « : », line 476

Figure 1: it would help to add a map of France with the location of the catchment.

Is has been added in fig1.

Figure 3: very nice figure! please add a legend. Consider adding EM labels (SR, Gypsum, Sedimentary, Quaternary) in the figure

The legend of the different colors has been added in the legend of the figure.

Figure 4: do the blue points represent instantaneous samples or event averages? Please specify how you define uncertainties here. Consider moving the figure to the appendix to shorten the paper.

The blue points represent the instantaneous measurements during spatial campaigns.

The way uncertainties are calculated has been added in the legend : « Uncertainties associated with each relation are represented in grey, defined as the maximum deviation between the fitted curve and the measurements. »

This figure has been put in the Appendix part, in order to shorten the text.

Figure 6: typo in the legend: autumn

The typo has been corrected.

Figure 8: in the caption (e) and (f) are mentioned, they are missing in the figure. Are the transparent points missing in (d)?

It was a mistake because fig (e) and (f) were presented in a previous version of the article. It has been corrected by removing (e) and (f) from the caption.

Fig 9 very nice overview! please export the figure in higher resolution. As the figure is schematic, I would remove the axis labelling on the figure with the hydrograph/SSC time series. The absolute values are not necessary and also misleading (does peak flow really differ by more than factor 10 from ~20m3s-1 in autumn/winter to 1.5 m3ms-1 in May-Sep?). Also please be consistent with the terms (use either discharge or flow rate consistently. Please be consistent with full stop as the decimal separator (instead of comma).

This figure has been simplified by removing the y-axis labels, using the term "flow rate" consistently throughout, and standardizing the use of decimal points. However, we chose to retain the quantitative values on the graphs, as they also correspond to the quantitative information provided on the left side of the figure.

Table 2 caption: What do you mean with composition? Do you mean loadings?

Yes, it is loadings. This was modified.

Table 4 and Table 5: It would be interesting to add %SR

Indicators of SR contribution were added in Table 4, but not in Table 5 as we will not use the concept of SR contribution to formulate our hypotheses.

Table 4: Abbreviation SSF has not been introduced, right? SS export should be Vs right? Please be consistent with abbreviations.

Indicators of suspended sediment fluxes have been removed because they are not used in the analysis.

Table 5 or somewhere in the methods section: which statistical test did you do to obtain p-values?

A definition of the p_value was added in the methods, line 286 : « The p_{value} associated with each correlation is calculated, testing the null hypothesis of no linear correlation between the variables. Only correlations wth $p_{value}<0.05$ are kept. ».

Table 6: I suggest omitting the table as there is hardly any information and the paper is already quite long and has a lot of tables and figures.

We agree, this table was removed. The information of this table was inserted in the legend of Table 5.

Table 8: please use the common abbreviation ‘r’ for Pearson correlation coefficient. ‘PC’ already denotes Principal Components.

Yes, the abbreviation PC has been replaced by ‘r’ in Table 7.