Received: 2 November 2022 | Revised: 6 March 2023 | Accepted: 17 April 2023

DOI: 10.1002/hyp.14887

NOTE

WILEY

Long-term hydrological and biogeochemical datasets from a Mediterranean forest site (Montseny, NE Spain)

Anna Avila[1] | **Ferran Rodà**[1,2]

[1]CREAF, Campus Universitat Autònoma de Barcelona, Catalonia, Spain

[2]Department of Animal and Plant Biology and Ecology, Universitat Autònoma de Barcelona, Catalonia, Spain

Correspondence
Avila Anna, CREAF, Campus Universitat Autònoma de Barcelona, E08193 (Cerdanyola del Vallès), Catalonia, Spain.
Email: anna.avila@uab.cat

Funding information
European comission; Hispano-American project; Spanish Government

Abstract

We present here, and make freely available, two long-term datasets on the hydrology and hydrochemistry of two small catchments totally or partially covered by holm oak (*Quercus ilex*) forests. Data have been collected over four decades of research on the ecology of Mediterranean evergreen forests. The datasets contain data on water fluxes in precipitation and runoff, and on the ion concentrations and fluxes in precipitation, throughfall and streamwater. Among other applications, these data have been used to obtain catchment budgets of water and elements, to document decadal changes in atmospheric deposition and streamwater chemistry, to assess the role of Saharo-Sahelian dust on forest nutrient cycling, and to model habitat suitability for an endangered amphibian under future climates. To encourage their further use by the scientific community, in this paper we summarize the data context and methods, and give a nutshell of obtained results. We provide the links to these datasets on the Zenodo platform.

KEYWORDS

atmospheric deposition, forest ecosystem functioning, holm oak, La Castanya, long-term trends, Mediterranean catchment, Montseny, *Quercus ilex*, streamwater chemistry, terrestrial ecology

1 | INTRODUCTION AND ANTECEDENTS

The chemistry of streamwater draining undisturbed catchments is determined by the biogeochemical processes that occur within the catchment such as weathering of minerals, ion exchange in soils and plant uptake, by the climate of the area and by the nature of the atmospheric inputs. By analysing the patterns of solute variation and input–output budgets of elements, inferences can be made regarding the hydrological and ecological processes occurring at the scale of the small basin. With this in mind, hydrological and biogeochemical studies in the Montseny holm oak (*Quercus ilex*) forests started in 1978 supported by funds from a Hispano-American project, later followed by a suite of projects from the European Commission and the Spanish and Catalan Governments. The objective was to study the biogeochemistry of small Mediterranean catchments based in the small catchment approach developed at Hubbard Brook, New Hampshire, USA (Likens et al., 1977). This approach, combined with information from element cycling in adjoining plots allowed to characterize for the first time in Spain the circulation of water and elements in Mediterranean holm oak forests (Escarré et al., 1984; Rodà et al., 1999).

Later on, in the mid 1980s, evidence of relevant environmental changes in atmospheric deposition and climate warming prompted interest in developing a long-term record at this site. Long-term data series are needed to understand the magnitude and direction of environmental changes, since patterns may not be obvious at short-term scales. The Montseny catchments (Catalonia, NE Spain) provide one of the longest records for a Mediterranean site and participates in the International Long term Ecological Research Network (ILTER) established to address the global response of ecosystems to environmental changes.

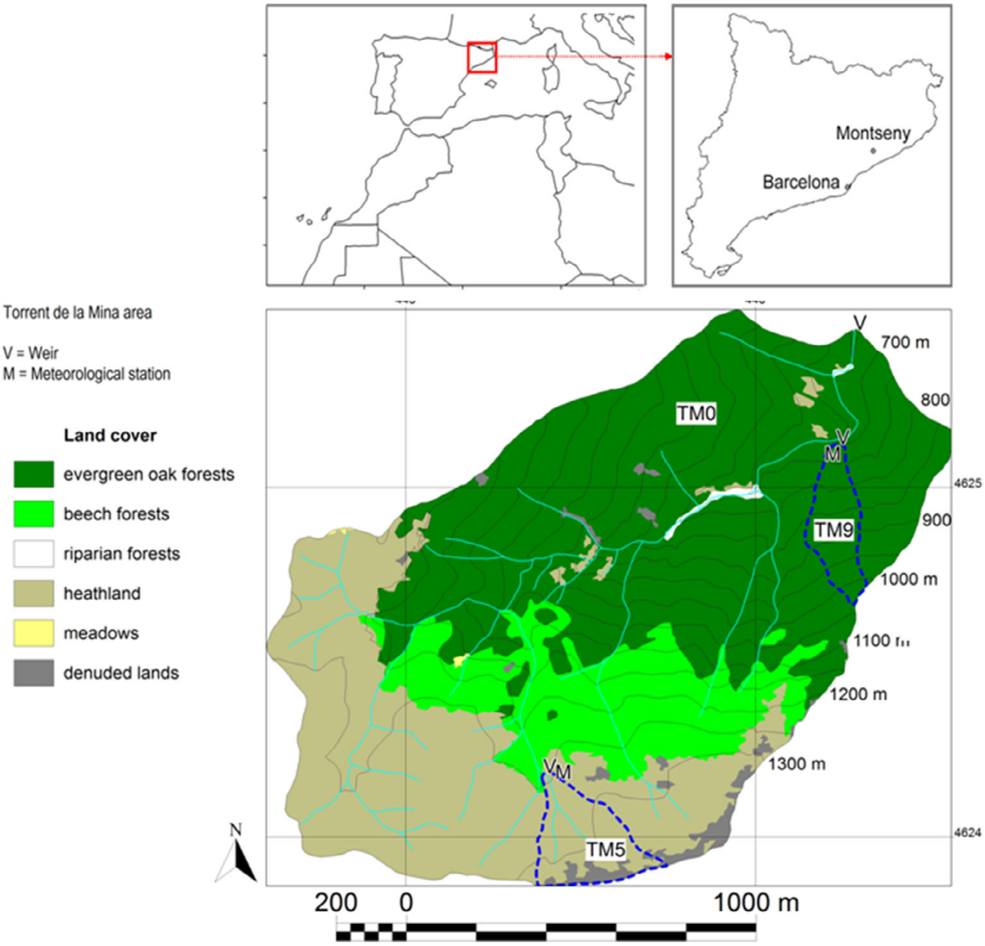

FIGURE 1 Topography and vegetation map of the Torrent de la Mina catchment. TM0 is the main catchment and nested within it are TM9 and TM5. The location of the weirs (V) and meteorological stations (M) is shown.

Further research and new hypothesis testing may take advantage of the collected data series in these long-term study sites. This is the motivation for the publication of the quality-checked original stream and atmospheric deposition chemistry files of well curated small catchments at Montseny whose links accompany this paper.

2 | SITE DESCRIPTION

La Castanya valley is 40 km to the NNE of Barcelona and 27 km from the Mediterranean coast (41.775°N/2 353°E). Climate is subhumid mesomediterranean: annual precipitation is around 900 mm with a typical summer drought, but interannual variability is very high. The bedrock is a metamorphic phyllite, with quartz, chlorite, albite and muscovite as major minerals.

In Torrent de la Mina stream, a major stream draining La Castanya valley, three catchments were instrumented: the main catchment (named TM0), and two small tributaries nested within TM0 (TM9 in the lower slopes of TM0 and TM5 in the upland plateau; Figure 1). However, in this data note concerning long-term data, only data from TM0 and TM9 will be presented, as TM5 only operated from 1982 to 1985.

A gauging station was built in each stream, consisting of a water stilling pond and a V-notch weir. V-notch angle varied according to the size and water flow of each catchment: 120° at TM0 and 60° at TM9. TM9, located in the lower slopes of TM0, has a steeper relief and is totally covered by holm oak (Table 1). In TM0, two distinct physiographic units can be distinguished: (1) holm-oak and beech forests on the steep side slopes, and (2) heathlands and grasslands on the upland rolling plateau (Figure 1). Soils in the steep slopes of TM0 and TM9 are colluvial, stony, well drained, and spatially heterogeneous due to the rugged topography. Typically, they are shallow with a 0-5-cm organic layer and depths varying between 0.25 and 1.5 m (Hereter, 1990; Hereter & Sánchez, 1999; Rodà et al., 1999). They are classified as Entisols (Lithic Xerorthents) or Inceptisols (Typic, Lithic or Dystric Xerochrepts; Soil Survey Staff, 1992). Soils at the rolling slopes of the upland plateau of TM0 have a 3-cm deep organic layer and a 19-cm deep A horizon. The soil organic carbon content in the slopes is lower than at the upland plateau (Hereter, 1990).

3 | METHODS

3.1 | Water fluxes and chemical data

Hydrological and chemistry data were monitored for different periods at the two catchments: from 1983 to 1997 at TM9, and for a non-continuous record in the period 1990–2018 at TM0.

TABLE 1 Site characteristics

Catchment	Area (ha)	Min. Altitude (m)	Max. Altitude (m)	Mean slope of main stream (°)	Prevailing direction of main stream	Vegetation
TM9	5.9	710	1036	35	N	100% holm oak
TM0	200.4	650	1343	26	NE	52% holm oak 15% beech 30% heathland and grassland 3% rock outcrops

TABLE 2 Time periods and instrumentation used for hydrological recording

Catchment	Period	Instrument	Recording method
TM9 (60° V notch)	1983–1997	WeatherMeasure limnograph	continuous record of water level on paper
TM0 (120° V notch)	1990–2002/2007–2010	OTT limnograph	continuous record of water level on paper
	2010–2018	Schlumberger diver	pressure probe; 15 min data

Water level measurements were initially recorded on paper, using WeatherMeasure (TM9) and OTT (TM0) limnographs with float-type devices installed in the respective stilling wells. In 1997, measurements at TM9 were discontinued. After 2010, TM0 was equipped with automatic pressure sensors recording water level at 15 min intervals (Table 2).

In each field visit (weekly or biweekly), water stage was manually read from the limnimetric scale (LS) located in each weir; these water stage readings were used to calibrate the relationship between the water level in the weirs and the record of the limnograph or the water level sensor data. Digitalization of the limnograph curves obtained before 2010 was done manually by taking into account representative points of water level variation (Figure 2). After 2010, 15-min water levels were downloaded from the diver data logger.

Stream flow (q) was determined using rating curves. At TM9 the rating curve was empirically calibrated with discharge measurements obtained with a bucket, resulting in the following equation:

q (L/s) = 10^(−1.61353 + 1.62225*(Log LS) + 0.45808*(Log LS)^2), where LS is limnimetric scale in cm.

At TM0 we used the theoretical calibration for a 120° V notch weir taken from Gregory and Walling (1973):

q (m^3/s) = 2.47 * LS^2.5, with LS in meters.

Before 2010, drainage values (D_i) were obtained by integrating stream flow at uneven readings at times t_i and $t_i - 1$ (Figure 2), which tracked the variation of the hydrographs:

$$D_i = q_i{}^*(t_i - t_{i-1}) + [(q_i - q_{i-1})^*(t_i - t_{i-1})/2],$$

being q_i the instantaneous water flow and $q_{i\text{-}1}$ that for the previous reading. After 2010, it was obtained by integrating flow at the regular 15 min steps (units of water flow were L/s at TM9 and m^3/s at TM0). Annual drainage was obtained by summing the partial readings up to the year. Using the methodology described above and owing to our careful calibrations of both water level and water flow, we estimate that the maximum uncertainty associated to our drainage data may be lower than 10% on average.

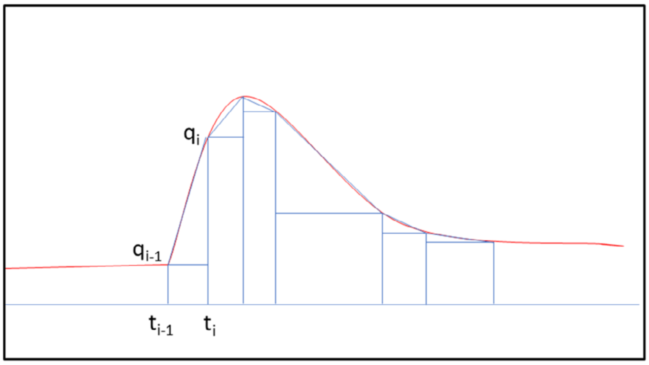

FIGURE 2 Hydrograph decomposition tracking flow variation.

Weekly or biweekly grab samples of streamwater were collected several meters upstream from the respective stilling ponds in distilled water-cleaned high-density polyethylene 250 mL bottles. More frequent samples were obtained during storms from 1983 to 1990 at TM9, collected with an automatic sampler (Avila et al., 1992). The hydrological and biogeochemical variables which are provided in the Zenodo datasets are listed in Table 3.

3.2 | Atmospheric deposition data

Atmospheric deposition was monitored from 1978 through 2019 with some interruptions and small changes in location because measurements were undertaken for different research projects. In the period 1978–1980 bulk deposition (BD) and throughfall (TF) were collected near the TM0 weir. In 1983, BD and TF deposition collectors were located near the TM9 weir (BD collected from 1983 to 2000, TF from 1995 to 1997), and in 2002 they were moved 700 m to the NE to be included in the Montseny EUSAAR station (European Supersites for

TABLE 3 List of hydrological and biogeochemical variables measured. Conductivity and ion concentrations were measured for atmospheric deposition (bulk deposition, BD or wet deposition, WD), throughfall (TF), and streamwater

Variable (units)
Limnimetric scale (cm)
Stream flow (L/s for TM9, m^3/s for TM0)
Water output flux (L m^{-2})
Precipitation (L m^{-2})
Throughfall volume (L m^{-2})
Conductivity (µS cm^{-1})
pH
H^+ conc (µeq L^{-1})
Alk conc (µeq L^{-1})
Na^+ conc (µeq L^{-1})
K^+ conc (µeq L^{-1})
Ca^{2+} conc (µeq L^{-1})
Mg^{2+} conc (µeq L^{-1})
NO_3^- conc (µeq L^{-1})
NH_4^+ conc (µeq L^{-1})
SO_4^{2-} conc (µeq L^{-1})
Cl^- conc (µeq L^{-1})
Dust particulate matter (mg m^{-2}) temp_water (°C)
temp_air_max (°C)
temp_air_min (°C)
temp_air_current (°C)
temp_air_mean (°C)
temp_air (°C)
temp_soil_max (°C)
temp_soil_min (°C)
temp_soil_current (°C)

Atmospheric Aerosol Research; www.eusaar.net) that runs the Environmental Geochemistry and Atmospheric Research team from IDAEA-CSIC (Pey et al., 2010). At this location, BD was measured for the period 2002–2019, wet deposition (WD) for 2002–2007 and 2014–2019 and TF for 2011–2013. Bulk deposition and throughfall collectors consisted of 19-cm diameter polyethylene funnels connected to polyethylene bottles (10 L for BD; 2 L for TF). Wet deposition was sampled with an Anderson instrument (ESM Andersen, G78-1001). Despite the location changes, we deem that the atmospheric deposition data series is robust since deposition instruments stood <1 km distance between the different locations and there were neither inhabited houses nor roads (except the track to reach the site) in the neighbourhood. In the EUSAAR site, parallel BD and WD sampling allowed comparison between the two methods: very high correlation between them was found for the different ions, BD exceeding WD by around 37% for base cations (Izquierdo & Avila, 2012).

3.3 | Analytical methods

Streamwater and atmospheric deposition samples were taken to the laboratory the same day of collection. Within 48 h of sampling, pH was measured in unfiltered samples with an Orion pH meter and alkalinity was determined by a conductometric titration (Golterman et al., 1978). Water aliquots (60 mL) were filtered through a 0.45 µm pore-size membrane filter and stored frozen for later analysis. Ion chromatography (Dionex, Sunnyvale, USA) was used for Cl^-, NO_3^- and SO_4^{2-} throughout the study period. Base cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) where analysed by atomic absorption/emission spectroscopy and NH_4^+ by colorimetry (FIA Tecator) from 1983 to 2002. From 2002 on, all ions were analysed by ion chromatography using specific columns for cations (Dionex ACG4) and for anions (Dionex AS4). Data quality was evaluated with (1) synthetic solutions prepared in the laboratory with known ionic concentrations, accepting a 10% deviation of theoretical values, and (2) an ionic ratio (cation sum/anion sum) accepting a 20% variation respect the expected value (= 1.00). More details on sample processing and analysis are described in Avila (1996), Rodà et al. (1993) and Avila et al. (2020).

Annual mean concentrations were volume-weighted for all ions, except for H^+. Mean H^+ required to be derived from acidity/alkalinity mean values, since pH is not a conservative variable when pH values in a period alternate from acidic to alkaline values (Liljestrand, 1985), as is here the case for precipitation. Annual volume-weighted mean alkalinity (alk) was transformed to mean pH with the equation: $pH = \log(alk) + 5.2$ (units in µeq L^{-1}), a relationship derived from the equilibrium equations of the CO_2 - carbonate system (Stumm and Morgan, 2012).

Some rain events during African-dust intrusions left a visible particulate residue on funnel walls. Such samples were filtered, particulate matter (PM) deposition was determined and chemical (ICP-MS and ICP-AOE), mineralogical (X-Ray diffraction) analyses were performed on PM (Avila et al., 1997).

Element input or output from the catchment was calculated as the sum of the element inputs or outputs for each sample in the period of interest (e.g. month, year). For a given precipitation or streamwater sample (Si), ion input or output fluxes were calculated as the product of its ion concentrations by the water flux corresponding to S_i:

Ion input flux S_i = Concentration in bulk deposition S_i * Precipitation S_i.

Ion output flux S_i = Concentration in streamwater S_i * Drainage S_i.

With S_i concentrations in µeq L^{-1} and water fluxes in L m^{-2}.

To calculate outputs, drainage for S_i is considered corresponding to the period starting at the point midway from S_i to the previous sample S_{i-1} and ending at the point midway from S_i to the next sample S_{i+1}. This mode of calculation has been found adequate for weekly or biweekly stream sampling frequencies, as is here the case (Rekolainen et al., 1991; Swistock et al., 1997). The comparison of input and output fluxes allowed to calculate element budgets for the catchments.

3.4 | Streamwater characterization

The Torrent de la Mina streamwaters were well buffered, with Na^+ and Ca^{2+} co-dominating as main cations and alkalinity as the main counterpart, both in TM0 and TM9 (Avila et al., 1995, 1999). Mean pH was 7.44 and 7.53 for TM0 and TM9 (Avila et al., 1999). Solute variation at TM9 was explained as the mixing of groundwater and deep-soilwater components, contributing 70 and 30% of annual runoff, respectively (Avila et al., 1996; Piñol et al., 1992). The two catchments responded rapidly to changes in atmospheric deposition: an alkalinity increase was found associated to declining sulfate deposition (Avila & Rodà, 2012). This responsiveness may be explained by a low-residence time of water in these catchments compared to other geographical areas (Bernal et al., 2013). Nitrogen was strongly retained in the catchments, with only 2% of total N deposition being exported as inorganic N in streamwater. However, higher nitrate concentrations in the stream and N export occurred during the wettest months (November and March). Moreover, this pattern showed an increasing trend in time, suggesting the onset of N saturation in the catchments (Figure 3; Avila et al., 2020).

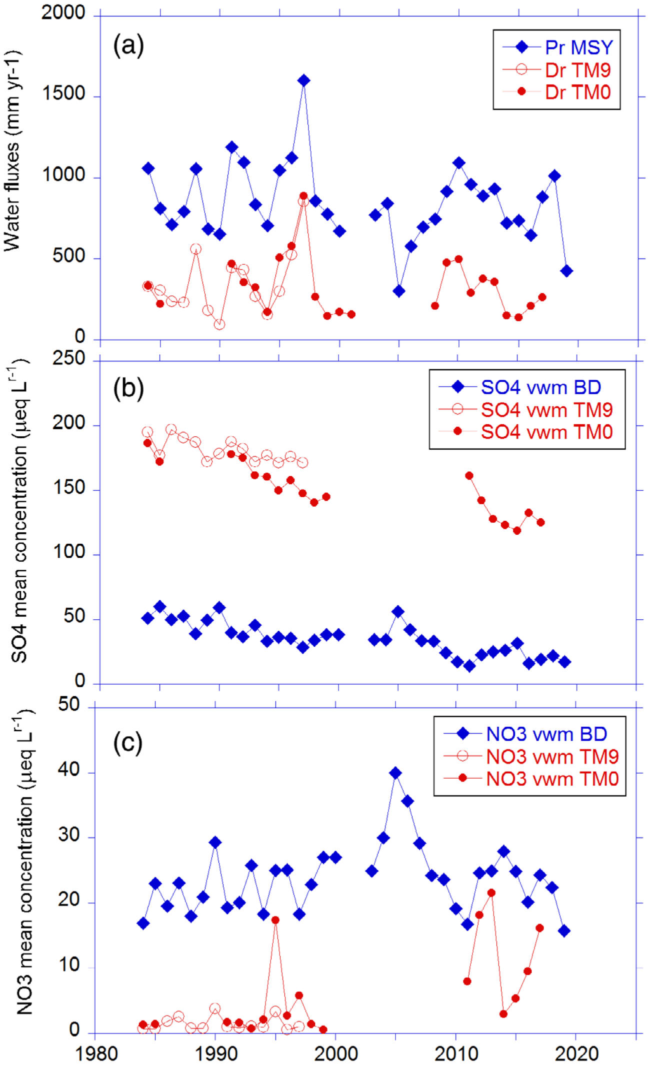

FIGURE 3 Temporal variation in: (a) hydrological fluxes, (b) sulfate: volume-weighted mean annual concentrations in bulk deposition (BD) and in TM0 and TM9 streamwater, and (c) nitrate: volume-weighted mean annual concentrations in bulk deposition (BD) and TM0 and TM9 streamwater.

3.5 | Atmospheric deposition characterization

Rainwater in Montseny was rarely acidic, since sulfate and nitrate acid anions in precipitation were largely neutralized by base cations and ammonium (Rodà et al., 1993). Annual mean pH values ranged from 4.92 to 7.18 with a median of 6.79. All annual mean pH values below 5.50 only occurred before 1990.

4 | MAIN BIOGEOCHEMICAL RESULTS

Biogeochemical research at Montseny has shown the responsiveness of forested ecosystems to changes in atmospheric deposition (Avila et al., 2020; Avila & Rodà, 2012; Bernal et al., 2013). Models have been applied to predict the effects of forest management (Neal et al., 1995) and climate change on stream chemistry (Avila et al., 1996). Mineral dust, originated in North Africa (Avila et al., 2007) has been found to be an important contributor of nutrients and alkalinity to these forest ecosystems (Avila et al., 1997, 1998). Also, the specific response to nitrogen deposition of streams draining Mediterranean forests, as compared to other forest types, was demonstrated (Templer et al., 2022). Recently, the stream hydrological response to climate change scenarios from IPCC and to land use changes was modelled in the context of LIFE-Tritó project. The aim was to predict the vulnerability of the critically endangered Montseny newt (*Calotriton arnoldi*) to expected habitat changes in future scenarios (Ledesma et al., 2019). In this work, the combination of hydrological modelling, climatology and knowledge of the species ecology provided an example of the use of data gathering and processing to help in the management of an endangered species.

Frequent episodes of African dust transport (Avila & Peñuelas, 1999) were important contributors of alkalinity and of dissolved and particulate elements to this site (Avila et al., 1997, 1998; Castillo et al., 2017). Back trajectory analysis revealed that the main atmospheric transport pathway to Montseny is from the Atlantic Ocean, delivering dilute and circumneutral rainwaters while acid episodes predominated in local and European trajectories (Izquierdo, Avila et al., 2012). Nitrogen deposition was higher with air masses coming from Mediterranean/south-east European provenances (Izquierdo et al., 2014). Significant declining trends of S deposition since the 1980s (Avila & Rodà, 2002) and N deposition (starting in the mid-2000s) have been found (Aguillaume et al., 2016; Avila et al., 2020).

The role of African episodes as contributors of phosphorus deposition in Montseny and in the near Mediterranean coast was analysed by Izquierdo, Benítez-Nelson, et al. (2012) and Longo et al. (2014).

Because of concern on the negative eutrophying effects of N deposition, particular attention was devoted to characterize the N inputs to Montseny (Avila et al., 2002; García-Gómez et al., 2018; Rodà et al., 2002). Throughfall sampling and leaf washing experiments were undertaken at different times along the recording period to distinguish dry deposition from canopy exchange at the canopy level (Avila et al., 2017; Rodrigo et al., 2003). Lately, the role of the leaf microbiome was assessed using a multiple isotope approach (involving δ^{15}N, δ^{18}O and Δ^{17}O in NO_3^- in wet deposition and throughfall) and quantification of amoA genes: microbial nitrification contributed but the dominant flux for nitrate in throughfall was atmospheric (Guerrieri et al., 2020).

In summary, the Montseny catchments have shown distinctive characteristics compared to more temperate catchments, such as: (1) the hydrology is strongly controlled by evapotranspiration, which accounts for 2/3 of the incoming precipitation (Piñol et al., 1999), (2) nevertheless, there is a quick hydrologic response, as residence time of water in the TM0 is estimated around 4–5 months (Bernal et al., 2013), (3) inorganic N is strongly retained in the system, with nitrate being the only inorganic nitrogen form detected in stream waters (detection limit = 0.5 μeq/L) mostly during stormflows; as a consequence, 98% of dissolved inorganic deposition is retained in the catchments (Avila et al., 2020). The lack of relationship between inorganic N inputs and outputs in the Montseny catchments contrasts with the finding that N deposition is a strong driver of stream N export in temperate catchments (Templer et al., 2022). On the other hand, similarly to other catchments worldwide and corresponding to a general declining sulfate deposition trend, sulfate concentrations in Montseny stream waters have decreased, while alkalinity has increased (Avila & Rodà, 2012) providing more alkaline waters in these already well buffered streams, a striking fact for waters draining on silicate bedrock.

5 | DATASETS AND AVAILABILITY

We provide two datasets of open data for further exploration, syntheses and hypothesis testing. Files are provided for: (1) stream water flow and streamwater chemistry, doi:10.5281/zenodo.7228249; and (2) atmospheric deposition, doi: 10.5281/zenodo.7228266. They are freely available and no embargo applies to them.

ACKNOWLEDGEMENTS

In a study covering such a long-time span and broad scope, a multitude of researchers and field and laboratory technicians have collaborated. We provide here a list (in alphabetic order; PhD notation besides a name indicates that the person completed a PhD related to this data series) and we apologize for any involuntary omission: Laura Aguillaume (PhD), Jordi Bartolomé, Cristina Belillas (PhD), Susana Bernal, Keith Beven, David Bonilla (PhD), Miquel de Cáceres, David Carreras, Sonia Castillo (PhD), Lluís Comas, Antoni Escarré, Helena Estevan, Miguel Escudero (PhD), Lluís Ferrés, Irene Fraile, Carles Gené, Carlos A. Gracia, Ester Granados, Víctor Granda, Rebeca Izquierdo (PhD), Xavier Mayor, Carme Melción, Colin Neal, Noemi Perez, Josep Piñol, Roger Prat, Xavier Querol, Angela Ribas, Anselm Rodrigo (PhD), Jordi Serrano, Jaume Terradas and Claret Verdú. We thank Josep Piñol and Jaume Terradas for helpful comments and support. Jerome Latron kindly reviewed and suggested edits on the final version.

Funding was initially provided by the Hispano-American cooperative project num. 0370 on “Nutrient circulation in forested ecosystems studied in small catchments” which was followed by the projects of the (European Commission ENCORE-European Network of Catchments Organized for Research on Ecosystems) and DM2E-Aide à la géstion de l'espace Mediterranéen en voie de désertification grace à la modélisation des écoulements et de l'érosion des sols sur des bassins versants répresentatifs. The Spanish Government contributed with the following funds: 2129/83 CAYCIT Project “Balances de nutrientes en pequeñas cuencas experimentales en el Montseny”; LUCDEME (CSIC - ICONA) Project “Respuestas de pequeñas cuencas en ecosistemas mediterráneos. Monitorización, experimentación y modelización”; Proyecto CICYT Project “Vias hidrológicas, procesos de tamponamiento y modelización hidroquímica en cuencas forestales mediterráneas”; CICYT (AMB93-0349) Project “Trascolación y escorrentía cortical en bosques mediterráneos: implicaciones hidrológicas y biogeoquímicas”; CICYT (HID97-0581) Project “Influencia del transporte sólido en la calidad de los recursos hídricos: Uso de trazadores radioisotópicos e indicadores geoquímicos para determinar áreas fuente y procesos generadores de sedimento en suspensión”; CICYT (CLI99-0439) Project “Medida, análisis y modelización de los procesos de intercambio de gases entre la atmósfera y la vegetación mediterránea. Interacción con el clima”; CICYT (REN2001-0659-C03) Project “Impacto de las intrusiones atmosféricas africanas en la calidad del aire de Canarias y de la Península Ibérica”; MEC (CGL2005-07543/CLI) Project “Origen, transporte y deposición del aerosol atmosférico africano en Canarias y la Península Ibérica a partir de su caracterización aerobiológica y química”; MICINN Project (VI Plan Nacional I + D + I, Investigación Científica, Desarrollo e Innovación Tecnológica) CGL2009-13188-C03-01 Efectos de la deposición de nitrogeno en encinares mediterráneos (EDEN); Consolider-Ingenio MONTES Project (CSD2008-00040) “Los montes españoles y el cambio global: amenazas y oportunidades”. CTP Interreg-Poctefa Project “Red de observatorios de ecosistemas sensibles (lagos y turberas) al cambio climático en el Pirineo (REPLIM)”. LIFE-Tritó Project European Commission (LIFE15 NAT/ES/000757). MICINN Project (VI Plan Nacional I + D + I, Investigación Científica, Desarrollo e Innovación Tecnológica) CGL2017-84687-C2-2-R “Impacto del depósito de N en zonas vulnerables españolas: tendencias temporales e interacciones a nivel de ecosistema y paisaje”.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available at https://zenodo.org, reference number 10.5281/zenodo.7228249 10.5281/zenodo.7228266.

ORCID

Anna Avila https://orcid.org/0000-0002-4137-0839

REFERENCES

Aguillaume, L., Rodrigo, A., & Avila, A. (2016). Long-term effects of changing atmospheric pollution on throughfall, bulk deposition and streamwaters in a Mediterranean forest. *Science of the Total Environment*, *544*, 919–928.

Avila, A. (1996). Time trends in the precipitation chemistry at a montane site in northeastern Spain for the period 1983-1994. *Atmospheric Environment*, *30*, 1363–1373.

Avila, A., Aguillaume, L., García-Gómez, H., Izquieta, S., Alonso, R., Elustondo, D., & Santamaría, J. M. (2017). Quantitative study on nitrogen deposition and canopy retention in Mediterranean evergreen forests. *Environmental Science Pollution Research*, *24*, 26213–26226.

Avila, A., Alarcón, M., Castillo, S., Escudero, M., García Orellana, J., Masqué, P., & Querol, X. (2007). Variation of soluble and insoluble calcium in red rains related to dust sources and transport patterns from North Africa to northeastern Spain. *Journal Geophysical Research*, *112*, D05210.

Avila, A., Alarcón, M., & Queralt, I. (1998). The chemical composition of dust transported in red rains: Its contribution to the biogeochemical cycle of a holm oak forest in Catalonia (Spain). *Atmospheric Environment*, *32*, 179–191.

Avila, A., Bellot, J., & Piñol, J. (1999). Element budgets in catchments. In F. Rodà, J. Retana, C. A. Gracia, & J. Bellot (Eds.), *Ecology of Mediterranean Evergreen oak forests. Ecological studies 137* (pp. 283–296). Springer.

Avila, A., Bonilla, D., Rodà, F., Piñol, J., & Neal, C. (1995). Soilwater chemistry in a holm oak (*Quercus ilex*) forest: Inferences on biogeochemical processes for a montane-Mediterranean area. *Journal of Hydrology*, *166*, 15–35.

Avila, A., Molowny-Horas, R., & Camarero, L. (2020). Stream chemistry response to changing nitrogen and sulfur deposition in two mountain areas in the Iberian Peninsula. *Science of the Total Environment*, *711*, 134697.

Avila, A., Neal, C., & Terradas, J. (1996). Climate change implications for streamflow and streamwater chemistry in a Mediterranean catchment. *Journal of Hydrology*, *177*, 99–116.

Avila, A., & Peñuelas, J. (1999). Increasing frequency of Saharan rains over northeastern Spain and its ecological consequences. *Science of the Total Environment*, *228*, 153–156.

Avila, A., Piñol, J., Rodà, F., & Neal, C. (1992). Storm solute behaviour in a montane Mediterranean forested catchment. *Journal of Hydrology*, *140*, 143–161.

Avila, A., Queralt-Mitjans, I., & Alarcón, M. (1997). Mineralogical composition of African dust delivered by red rains over northeastern Spain. *Journal of Geophysical Research-Atmospheres*, *102*(D18), 21977–21996.

Avila, A., & Rodà, F. (2002). Assessing decadal changes in rainwater alkalinity at a rural Mediterranean site. *Atmospheric Environment*, *36*, 2881–2890.

Avila, A., & Rodà, F. (2012). Changes in atmospheric deposition and streamwater chemistry over 25 years in undisturbed catchments in a Mediterranean mountain environment. *Science of the Total Environment*, *434*, 18–27.

Avila, A., Rodrigo, A., & Rodà, F. (2002). Nitrogen circulation in a Mediterranean holm oak forest, La Castanya, Montseny, northeastern Spain. *Hydrology and Earth System Sciences*, *6*(3), 551–557.

Bernal, S., Belillas, C., Ibáñez, J. J., & Avila, A. (2013). Exploring the long-term response of undisturbed Mediterranean catchments to changes in atmospheric inputs through time series analysis. *Science of the Total Environment*, *458*, 535–545.

Castillo, S., Alastuey, A., Cuevas, E., Querol, X., & Avila, A. (2017). Quantifying dry and wet deposition fluxes in two regions of contrasted African influence: The NE Iberian Peninsula and the Canary Islands. *Atmosphere*, *8*, 86. https://doi.org/10.3390/atmos8050086

Escarré, A., Gracia, C., Rodà, F., & Terradas, J. (1984). Nutrient cycling and vertical structure in evergreen-oak forests. In G. I. Agren (Ed.), *State and change of forest ecosystems, report 13* (pp. 181–191). Department of Ecology and Environment.

García-Gómez, H., Izquieta-Rojano, S., Aguillaume, L., González-Fernández, I., Valiño, I., Elustondo, D., Santamaría, J. M., Avila, A., Bytnerowicz, A., Bermejo, V., & Alonso, R. (2018). Joining empirical and modelling approaches to estimate dry deposition of nitrogen in Mediterranean forests. *Environmental Pollution*, *243*, 427–436.

Golterman, H. L., Clymo, R. S., & Ohnstad, M. A. M. (1978). *Methods for physical and chemical analysis of freshwaters* (2nd ed., p. 124). Blackwell Scientific Publications.

Gregory, K. J., & Walling, D. E. (1973). *Drainage basin form and process* (p. 456). Edward Arnold.

Guerrieri, R., Lecha, L., Mattana, S., Cáliz, J., Casamayor, E., Barceló, A., Michalski, G., Peñuelas, J., Avila, A., & Mencuccini, M. (2020). Seasonal partitioning between atmospheric deposition and canopy microbial nitrification into throughfall nitrate fluxes in a Mediterranean forest. *Journal of Ecology*, *108*, 626–640.

Hereter, A. (1990). *Els sòls forestals del massís del Montseny*. PhD Thesis,. University of Barcelona.

Hereter, A., & Sánchez, J. R. (1999). Experimental areas of Prades and Montseny. In F. Rodà, J. Retana, C. Gràcia, & J. Bellot (Eds.), *Ecology of Mediterranean Evergreen forests* (pp. 15–27). Springer.

Izquierdo, R., Alarcón, M., Aguillaume, L., & Avila, A. (2014). Effects of teleconnection patterns on the atmospheric routes, precipitation and deposition amounts in the North-Eastern Iberian Peninsula. *Atmospheric Environment*, *89*, 482–490.

Izquierdo, R., & Avila, A. (2012). Comparison of collection methods to determine atmospheric deposition in a rural Mediterranean site (NE Spain). *Journal of Atmospheric Chemistry*, *69*, 351–368.

Izquierdo, R., Avila, A., & Alarcón, M. (2012). Trajectory statistics of atmospheric transport patterns and trends in precipitation chemistry of a rural site in NE Spain in 1984-2009. *Atmospheric Environment*, *61*, 400–408.

Izquierdo, R., Benítez-Nelson, C. R., Masqué, P., Castillo, S., Alastuey, A., & Avila, A. (2012). Atmospheric phosphorus deposition a near-coastal rural site in the Iberian Peninsula and its role in marine productivity. *Atmospheric Environment*, *49*, 361–370.

Ledesma, J. L. J., Montori, A., Barrera-Escoda, A., Cunillera, J., & Avila, A. (2019). Future hydrological constraints of the Montseny brook newt (*Calotriton arnoldi*) under changing climate and land cover. *Ecology and Evolution*, *9*, 9736–9747.

Likens, G. E., Bormann, F. H., Pierce, R. S., Eaton, J. S., & Johnson, N. M. (1977). *Biogeochemistry of a forested ecosystem*. Springer.

Liljestrand, H. M. (1985). Average rainwater pH, concepts of atmospheric acidity, and buffering in open systems. *Atmospheric Environment*, *19*, 487–499.

Longo, A., Ingall, E. D., Diaz, J. M., Oakes, M., King, L. E., Nenes, A., Mihalopoulos, N., Violaki, K., Avila, A., Benitez-Nelson, C. R., Brandes, J., McNulty, I., & Vine, D. J. (2014). P-NEXFS analysis of aerosol phosphorus delivered to the Mediterranean Sea. *Geophysical Research Letters*, *41*, 4043–4049. https://doi.org/10.1002/2014GL060555

Neal, C., Avila, A., & Rodà, F. (1995). Modelling the long-term impacts of atmospheric pollution deposition and repeated forestry cycles on stream water chemistry for a holm oak forest in northeastern Spain. *Journal of Hydrology*, *168*, 51–71.

Pey, J., Querol, X., & Alastuey, A. (2010). Discriminating the regional and urban contribution in the North-Western Mediterranean: PM levels and composition. *Atmospheric Environment*, *44*, 1587–1596.

Piñol, J., Avila, A., & Escarré, A. (1999). Water balance in catchments. In F. Rodà, J. Retana, C. A. Gracia, & J. Bellot (Eds.), *Ecology of Mediterranean Evergreen oak forests. Ecological studies 137* (pp. 273–282). Springer.

Piñol, J., Avila, A., & Rodà, F. (1992). The seasonal variation of streamwater chemistry in three forested Mediterranean catchments. *Journal of Hydrology*, *140*, 119–141.

Rekolainen, S., Posch, M., Kämäri, J., & Ekholm, P. (1991). Evaluation of the accuracy and precision of annual phosphorus load estimates from two agricultural basins in Finland. *Journal of Hydrology*, *128*, 237–255.

Rodà, F., Avila, A., & Rodrigo, A. (2002). Nitrogen deposition in Mediterranean forests. *Environmental Pollution*, *118*, 205–213.

Rodà, F., Bellot, J., Avila, A., Escarré, A., Piñol, J., & Terradas, J. (1993). Saharan dust and the atmospheric inputs of elements and alkalinity to Mediterranean ecosystems. *Water, Air and Soil Pollution*, *66*, 277–288.

Rodà, F., Retana, J., Gracia, C. A., & Bellot, J. (1999). *Ecology of Mediterranean Evergreen oak forests* (p. 373). Ecological Studies 137.

Rodrigo, A., Avila, A., & Rodà, F. (2003). The chemistry of precipitation, throughfall and stemflow in two holm oak (*Quercus ilex* L.) forests under a contrasted pollution environment in NE Spain. *The Science of Total Environment*, *305*, 195–205.

Soil Survey Staff. (1992). SMSS technical monograph N° 19. In *Keys to Soil Taxonomy* (5th ed.). Virginia, Pocahontas Press.

Stumm, W., & Morgan, J. J. (2012). *Aquatic chemistry: Chemical equilibria and rates in natural waters*. John Wiley & Sons.

Swistock, B. R., Edwards, P. J., Wood, F., & Dewalle, D. R. (1997). Comparison of methods for calculating annual solute exports from six forested Appalachian watersheds. *Hydrological Processes*, *11*, 655–669.

Templer, P. H., Harrison, J. L., Pilotto, F., Flores-Díaz, A., Haase, P., McDowell, W. H., Sharif, R., Shibata, H., Blankman, D., Avila, A., Baatar, U., Bogena, H. R., Bourgeois, I., Campbell, J., Dirnböck, T., Dodds, W. K., Hauken, M., Kokorite, I., Lajtha, K. … Taka, M. (2022). Atmospheric deposition and precipitation are important predictors of inorganic nitrogen export to streams from forest and grassland watersheds: A large-scale data synthesis. *Biogeochemistry*, *160*, 219–241. https://doi.org/10.1007/s10533-022-00951-7

How to cite this article: Avila, A., & Rodà, F. (2023). Long-term hydrological and biogeochemical datasets from a Mediterranean forest site (Montseny, NE Spain). *Hydrological Processes*, *37*(5), e14887. https://doi.org/10.1002/hyp.14887