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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

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Long-term stable water isotope and runoff data for the investigation of deforestation effects on the hydrological system of the Wüstebach catchment, Germany

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Abstract

The Wüstebach catchment belongs to the German TERENO (Terrestrial Environmental Observatories) network and was partially deforested (∼21%) by the Eifel National Park in 2013. In this data paper, we provide 11-year precipitation and stream water isotope data and the corresponding runoff discharge rates recorded in the Wüstebach catchment (from 2009 to 2019). In addition, we provide an overview of available datasets and access information for environmental data of the Wüstebach catchment that are discoverable with associated metadata at the Web-based TERENO data portal. We anticipate that this comprehensive data set will give new insights in how deforestation influences the hydrological system, for exampole, in terms of transit time distribution, fraction of young water and water flow paths at the catchment scale.

KEYWORDS

catchment, deforestation, runoff, stable isotopes

1 | INTRODUCTION

The separation of precipitation into drainage, groundwater recharge and evapotranspiration on its way through a catchment and along the various water flow paths can be strongly influenced by deforestation-induced changes. One method of studying these changes is to use the stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$) as tracers of water flow paths (Stockinger et al., 2019). In previous decades, several studies analysed the response of water balance components to deforestation, but studies using long-term stable isotope data to analyse the effects on the travel time of runoff components, for example, subsurface water flow, are still lacking.

In this data paper, we provide long-term precipitation and stream water isotope data measured in the Wüstebach catchment together with respective discharge observations. In the past 10 years, the Wüstebach catchment has been intensively studied, notably with respect to its hydrological (Baatz et al., 2015; Graf et al., 2014; Rosenbaum et al., 2012; Stockinger et al., 2015, 2016, 2017; Wiekenkamp et al., 2016a; Wiekenkamp et al., 2016b) and biogeochemical (Bol et al., 2015; Gottselig et al., 2017; Weigand et al., 2017; Wu et al., 2017) properties. Figure 1 shows the extensive hydrological instrumentation of the Wüstebach catchment, which is comprehensively presented in Bogena et al. (2015) and Bogena et al. (2018). From August to September 2013, 8.6 ha of the catchment area of the Wüstebach were cleared to allow natural succession to a mixed beech (*Fagus sylvatica*) forest (Figure 1). This deforestation has impacted the hydrological system of the Wüstebach catchment in many ways (Wiekenkamp et al., 2020; Wiekenkamp et al., 2016a). Evapotranspiration in the clear-cut area was first reduced by approximately 50% and returned towards pre-cut values during the first 2 years (Ney et al., 2019). Wiekenkamp et al. (2016a) analysed the effects of the deforestation on the runoff generation in the Wüstebach catchment. They found that the lower evapotranspiration caused an increase in

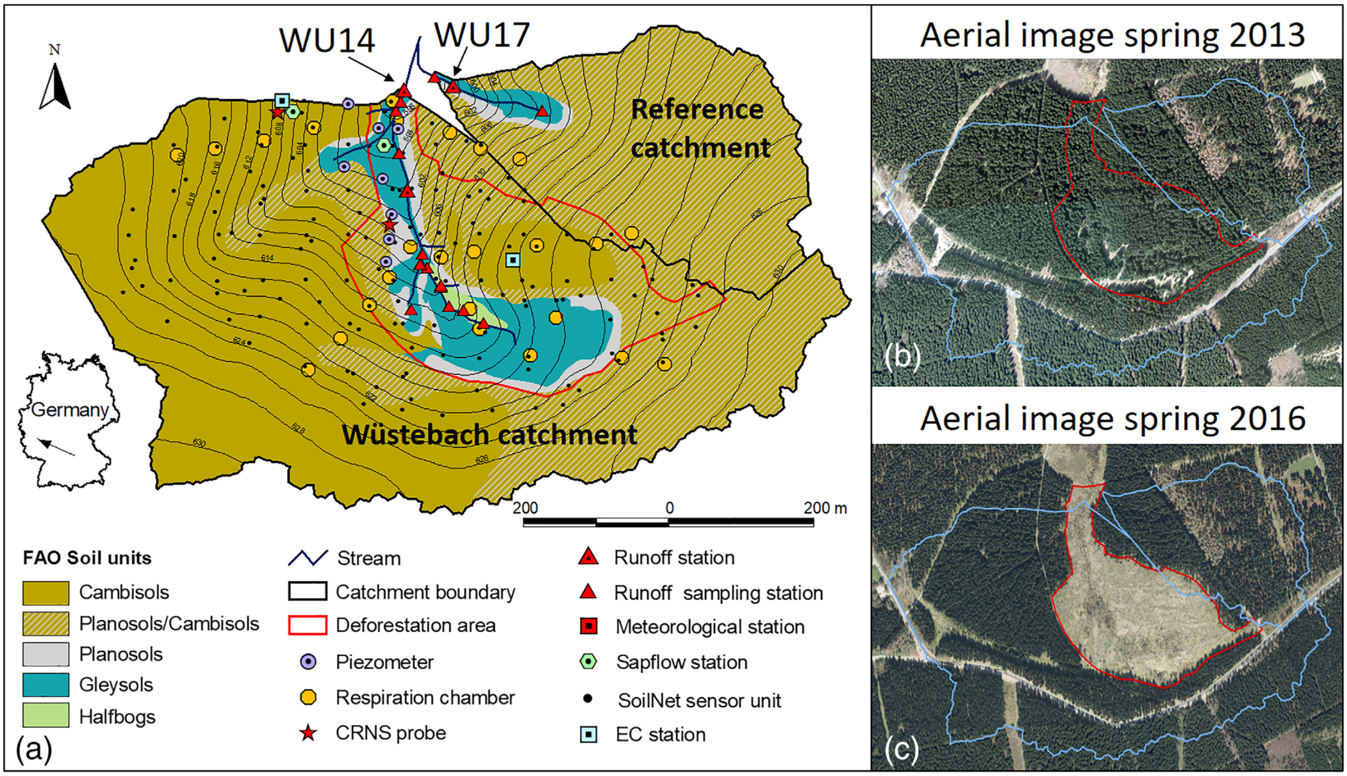

FIGURE 1 Map with the most important soil types and the instrumentation of the Wüstebach and reference catchments (a) as well as the deforestation area before (b) and after the clear-cut (c) (adapted from Bogena et al., 2018). The locations of runoff gauging stations WU14 and W17 are also shown. Data source: District Council Cologne (aerial photograph)

soil water content in the deforested portion of the catchment in the first 2 years after deforestation, especially during the summer periods, which led to a greater number of high flows. In addition, Wiekenkamp et al. (2020) found that the partial clear-cut increased the occurrence of preferential flow in the deforested area.

2 | SITE DESCRIPTION AND METHODS

The experimental Wüstebach headwater catchment (39 ha; WU14, Figure 1) belongs to the Lower Rhine/Eifel Observatory of the TERENO network (Bogena et al., 2012; 2018) located in the Eifel National Park (50°30′16″N, 06°20′00″E). A smaller tributary catchment (11 ha) located northeast of the Wüstebach catchment serves as an uncut reference site for the clear-cut experiment ('reference catchment', WU17, Figure 1). The Wüstebach catchment covers altitudes ranging from 595 m a.s.l. in the northern part to 628 m a.s.l. in the south. The subsoil consists of Devonian slate that is covered by a periglacial solifluction layer with a maximum depth of 2 m. Cambisols and Planosols mainly occur on the slopes of the hills, while Gleysols and Histosols have developed under the influence of the groundwater in the riparian zone in the valley (Figure 1). The catchment is mainly covered by Norway spruce (*Picea abies L.*) and characterized by a humid, temperate climate with warm summers and mild winters with an annual average temperature of approximately 7°C. The average annual precipitation and runoff are approximately 1200 and 700 mm, respectively.

Discharge measurements and water sampling in the Wüstebach catchment started in June 2009. Discharge is measured at 10-min intervals at the catchment's outlets equipped with a self-made V-notch weir for low flow measurements and a Parshall flume (ecoTech Umwelt-Messsysteme GmbH, Germany) to measure medium to high flows. The water levels in both weir types is measured with a pressure sensor (PDL, ecoTech Umwelt-Messsysteme GmbH, Germany) with a measurement accuracy of ≤0.25%. The water levels are converted into discharge using well-known stage-discharge equations. Discharge data of the two discharge gauging weirs are combined based on water levels measured in the V-notch weir: For water levels lower than 5 cm discharge values from the V-notch weir are used, for water levels larger than 10 cm discharge values from the Parshall flume are used and the weighted mean of both discharge values is calculated for water levels between 5 and 10 cm (Bogena et al., 2015).

Precipitation water for isotopic analysis is sampled at the Schöneseiffen meteorological station located approximately 3 km to the northeast of the Wüstebach catchment at 620 m a.s.l. The samples are collected with weekly resolution in a cooled storage rain gauge equipped with 2.3-L glass bottles (Stockinger et al., 2014) and as of September 2012 additionally with half-daily resolution using a cooled automated sampler (NSE 181/KS-16, Eigenbrodt GmbH & Co. KG, Germany; 250 mL PE bottles).

For the weekly stream water sampling (grab samples) at the catchment outlets (WU14, WU17), HDPE bottles were pre-rinsed with stream water and then completely filled to avoid headspace. However, some headspace of precipitation samples is unavoidable and depends on the precipitation amount. The samples were filtered in the laboratory (0.45 μm) and then stored at 4°C (Bogena et al., 2015). Water isotope analyses were carried out using isotope-ratio mass spectrometry with high-temperature pyrolysis (IRMS, Delta V advantage, Thermo Scientific; HT-O, Hekatech, Germany) in the first year and cavity ringdown spectrometry (L-2120-I, L-2130-I, Picarro) afterwards. For cavity ringdown spectrometry analyses 1 mL of sample was repeatedly injected five times of which only the last two measurements were used to calculate raw values to avoid memory effects. Three in-house standards, calibrated against international standards, were used to calibrate raw values and two additional control standards were used to monitor instrument performance and long-term stability of analyses. The analytical uncertainty of analyses with all instruments is <0.1‰ for δ^{18}O and <1.0‰ for δ^2H. The δ^{18}O and δ^2H values are expressed in δ notation relative to VSMOW (Vienna Standard Mean Ocean Water) water on a scale normalized to SLAP (Standard Light Antarctic Precipitation) according to Brand et al. (2014).

3 | DATA DESCRIPTION

3.1 | Daily runoff

From the 10-min runoff data we extracted the runoff values during sampling, so that each stable isotope sample is provided with the instantaneous runoff. The full 10-min data is also available via the TERENO data portal TEODOOR (http://teodoor.icg.kfa-juelich.de/). Average daily runoff during the 10.5-year record of WU14 was 1.79 and 1.24 mm/day for the 8.2-year long record of WU17 (Figure 2). The highest recorded runoff of WU14 was 16.25 mm/day during the winter of 2010/11 and 18.46 mm/day for WU17 during the winter of 2018/19 (Figure 2). Although there is a winter maximum of precipitation, snow typically accounts for less than 10% of annual precipitation and a snow cover typically does not last more than 3–4 weeks per year. The summer periods are characterized by low flow conditions, especially for WU17 (Figure 2).

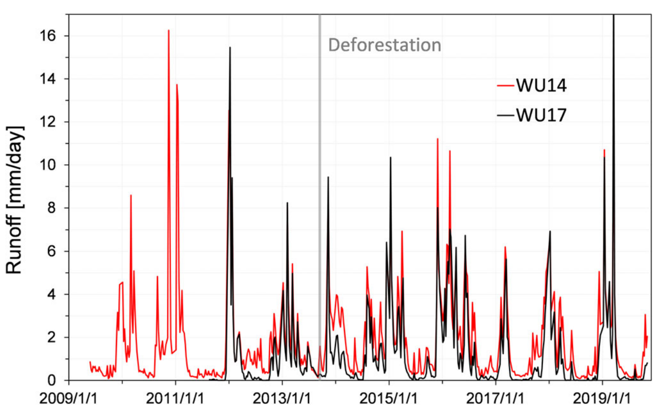

FIGURE 2 Runoff data of the two runoff gauging stations WU14 and WU17

3.2 | Stable isotopes of stream and precipitation water

The weekly δ-values of the stream water stable isotopes ranged between −8.74‰ and −7.34‰ (δ^{18}O) and −57.1‰ and −45.6‰ (δ^2H) for WU14 and between −8.69‰ and −7.45‰ (δ^{18}O) and −56.4‰ and −46.7‰ (δ^2H) for WU17 (Figure 3). Both δ^{18}O and δ^2H values show a considerable decreasing long-term trend from 2009 to 2014 and a less pronounced increasing trend from 2014 to 2019. In contrast, the daily δ-values of precipitation water do not show comparable trends and their variability was considerably larger ranging between −20.8‰ and 2.38‰ for δ^{18}O and −163.2‰ and −45.4 ‰ for δ^2H. The relationships between δ^2H and δ^{18}O of WU14 and WU17 are similar (R^2: 0.84 and 0.83, respectively), with their overall local water lines (LWL) of stream water being less steep (5.90 and 5.63, respectively) compared to the local meteoric water line (LMWL) of precipitation (7.64), indicating fractionation effects due to evaporation in the catchment (Figure 4).

4 | FUNDING AND DATA OWNERSHIP

The Agrosphere Institute of the Forschungszentrum Jülich funds the operation of the Wüstebach catchment, including instrumentation maintenance and salaries of all field and laboratory technicians. These data were collected using support by TERENO (Terrestrial Environmental Observatories) funded by the Helmholtz-Gemeinschaft and can be used without any further approval or charges. For the use of the data in a publication, presentation or other research material, please quote the data according to the TERENO disclaimer.

5 | DATA SET CONTRIBUTORS

Heye R. Bogena is administrative and research lead of the Wüstebach catchment experiment. Michael Stockinger is a former scientist on the project and Andreas Lücke is a lead scientist and coordinates the stable isotope sampling and laboratory analysis. We thank Ferdinand Engels, Rainer Harms, Werner Küpper, Martina Krause, Sirgit Kummer and Holger Wissel for supporting the sampling, stable isotope analysis and regular maintenance of the experimental set-up.

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DATA AVAILABILITY STATEMENT

The described long-term stable water isotope and runoff data set is directly accessible via a digital object identifier (DOI) and is freely available at: https://doi.org/10.34731/y6tj-3t38. Please note, the download of the data is possible under the category "Transfer options" of the landing page. The data is stored in an Excel spreadsheet with 4 worksheets. No gaps were filled in the data sets. Data will receive new DOIs with each update; preceding versions will not

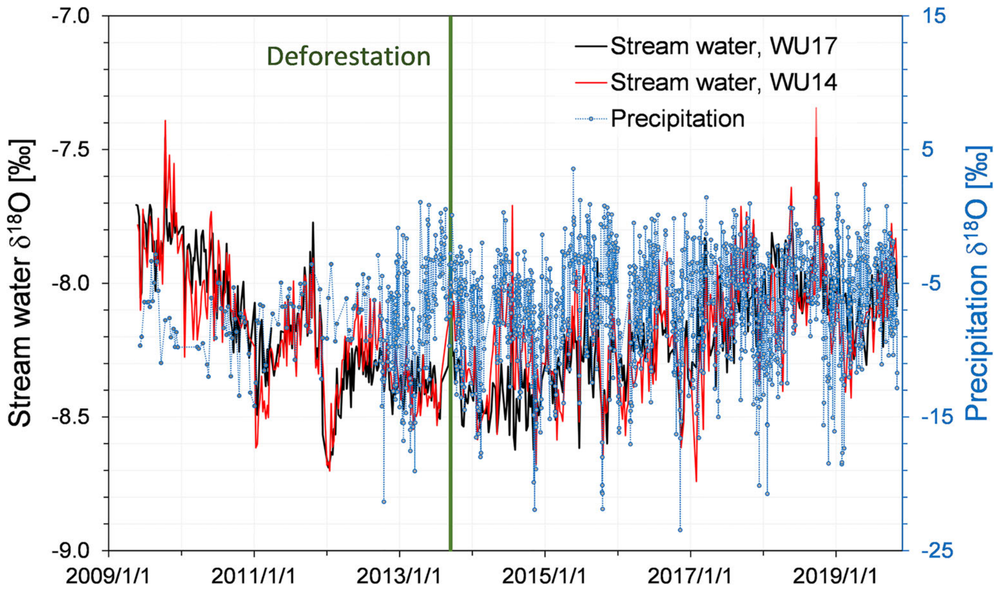

FIGURE 3 Stream water isotope data ($\delta^{18}O$) of the two runoff gauging stations WU14 and WU17 and precipitation isotope data from the meteorological station Schöneseiffen (δ^2H is not shown as it is closely correlated with $\delta^{18}O$, see Figure 4)

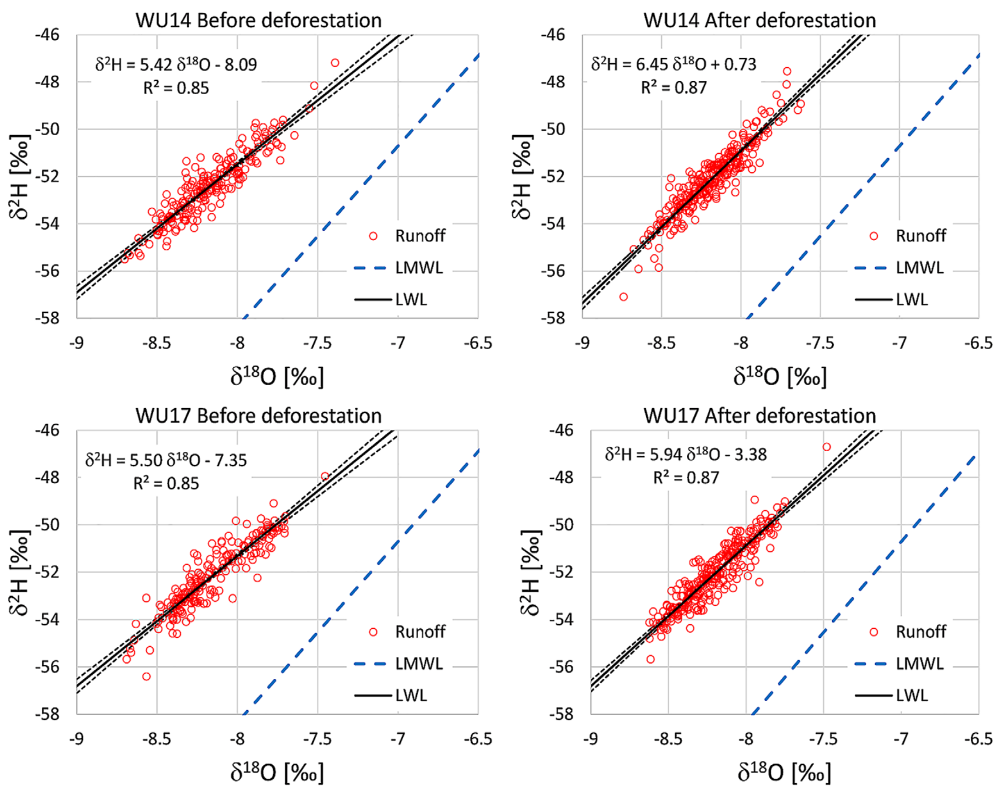

FIGURE 4 Stream water δ^2H plotted against $\delta^{18}O$ of runoff stations WU14 (above subplots) and WU17 (below subplots) before the deforestation (left subplots) and after the deforestation (right subplots). The local meteoric water line (LMWL) and the local water line (LWL) are also shown (the black dashed lines indicate the 95% confidence interval). Interestingly, the LWL slope of WU14 is considerably smaller before (5.42) than after the clear-cut in 2013 (6.45), while the respective LWL slopes of WU17 are more similar (5.50 vs. 5.94). This indicates an overall lower isotopic fractionation effect in the Wüstebach catchment area after the deforestation and suggests the hypothesis that the clear-cut is the main reason for the higher inclination of the LWL slope of WU14 after deforestation. One possible reason could be that after deforestation a larger amount of precipitation water leaves the catchment via preferential flow paths (Wiekenkamp et al., 2020), which reduces the isotopic fraction via surface evaporation. However, a more elaborate data analysis and further investigations are needed to resolve this issue

disappear or be overwritten, but will link to the most recent version. Further data from instrumentation in the Wüstebach catchment shown in Figure 1 are freely available via the TERENO data portal TEODOOR (http://teodoor.icg.kfa-juelich.de/). Inquiries about data and research collaborations can be directed to the lead author (h.bogena@fz-juelich.de).

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