https://doi.org/10.5194/essd-2026-157
Preprint. Discussion started: 24 June 2026

Italian Fluvial Sediment Transport Database: A Comprehensive Hub for Archiving and Analyzing Hydrological Data

Marco Luppichini[1], Francesco Comiti[2], Andrea Andreoli[3], Barbara Aldighieri[4], Paolo Billi[5], Irene Maria Bollati[6], Andrea Brenna[6], Diletta Chirici[7], Paolo Ciavola[5], Silvia Cilli[5], Marco Donnini[8], Simona Francalanci[9], Lorenzo Innocenti[9], Laura Longoni[10], Luca Mao[11], Ivan Marchesini[8], Ilenia Murgia[7], Giacomo Pellegrini[11], Daniele Penna[7,8,12], Lorenzo Picco[2], Riccardo Rainato[13], Leonardo Schippa[14], Luca Solari[9], Gianluca Tronti[6], Bruno Testa[4], Matteo Verdone[7], Monica Bini[1,15,16]

1. Department of Earth Sciences, University of Pisa, Via S. Maria 52, 56126 Pisa, Italy
2. University of Padua, Italy
3. Free University of Bozen-Bolzano, Italy
4. Consiglio Nazionale delle Ricerche – Istituto di Geologia Ambientale e Geoingegneria (CNR-IGAG), Via Mario Bianco 9, 20131 Milano, Italy
5. Department of Physics and Earth Sciences, Università degli Studi di Ferrara, Via Saragat 1, 44122 Ferrara, Italy
6. Earth Science Department "A. Desio", Università degli Studi di Milano, Italy
7. Department of Agricultural, Food, Environmental and Forestry Sciences and Technologies, University of Florence, Via San Bonaventura 13, 50145 Firenze, Italy
8. Consiglio Nazionale delle Ricerche – Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI), Via della Madonna Alta 126, 06128 Perugia, Italy
9. Department of Civil and Environmental Engineering, University of Florence, Via S. Marta 3, 50139 Firenze, Italy
10. Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano (MI), Italy; monica.corti@polimi.it; laura.longoni@polimi.it
11. Department of Geography, Climate, Catchments, Coasts and Communities Research Group, University of Lincoln, Brayford Pool, Lincoln LN67TS, UK
12. Forest Engineering Resources and Management Department, Oregon State University, Corvallis, OR, USA
13. Regione Veneto, Italy

14. Department of Civil, Chemical Environmental and Materials Engineering, University of Bologna, Italy

15. CIRSEC – Centro Interdipartimentale di Ricerca per lo Studio degli Effetti del Cambiamento Climatico, University of Pisa, Italy

16. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy

Corresponding author: Marco Luppichini, marco.luppichini@dst.unipi.it

Abstract

Fluvial sediment transport plays a key role in geomorphological and hydrological processes, influencing river morphology, watershed and coastal sediment balances, and the environmental response to climatic and anthropogenic changes. In Italy, the availability of homogeneous and long-term data is strongly limited due to the discontinuity of monitoring activities and the fragmentation of existing sources. This study presents the development of a relational database and web application specifically designed for the collection, storage, and consultation of sediment transport data, aimed at integrating and enhancing heterogeneous datasets from both historical and contemporary monitoring networks: the Italian Sediment Transport Database (ISTD). The database architecture, developed in PostgreSQL with the PostGIS extension, enables a direct link between observational data and their associated geographical, instrumental, and methodological metadata, ensuring traceability, interoperability, and the possibility to perform multi-temporal analyses. The web interface, built using open-source technologies, allows controlled data entry and interactive data exploration through maps, tables, and export functions. Analysis of the archived datasets highlights strong instrumental, temporal, and spatial heterogeneity: some physical-chemical parameters (e.g., pH and electrical conductivity) show standardized measurement protocols, whereas sediment transport variables exhibit high methodological variability. Time series range from sub-daily to annual observations, with denser coverage in northern Italian basins (e.g., Po, Adige, Piave, Tagliamento) since 1924. Despite these inconsistencies, integration within a unified relational framework enhances the value of a largely underused data heritage. The experience gained through this project enabled the identification of both the limitations and the potential of Italy's sediment monitoring system, providing operational guidance for methodological standardization, metadata improvement, and data harmonization at the national scale. The ISTD represents a concrete step toward establishing a shared sedimentological archive that supports scientific research, environmental management, and sustainable river basin planning.

Keywords: Sediment transport database, Fluvial monitoring, Data standardization, Hydro-sediment dynamics, Italian river basins

1 Introduction

Sediment transport in rivers plays a key role in geomorphological and hydrological processes, shaping the morphological evolution of fluvial environments, influencing the sediment balances at the catchment scale and in coastal areas (Fortesa et al., 2021; Vercruysse et al., 2017; Zarfl & Dunn, 2022). Sediments carried by rivers contribute to the genesis of floodplains, deltas, and sediment replenishment in coastal systems, processes that have significant ecological and economic implications (Leatherman et al., 2000; Luppichini & Bini, 2025; K. Zhang et al., 2004). Their dynamics result from a complex interplay of multiple watershed local characteristics, including climatic conditions, geomorphological features, geological substrate, vegetation cover, and anthropogenic activities (Cox et al., 2021; Wei et al., 2023; J. Zhang et al., 2024). This interdependence among the aforementioned factors is central to the study of fluvial systems and represents a critical research field for understanding the mechanisms driving these phenomena and for developing targeted strategies for sustainable land management (Asselman, 1995; Gurnell et al., 2002; Hooke, 2006; Naik & Jay, 2011).

The extent and nature of these interactions vary considerably accross watershed. For example, climatic fluctuations, including changes in precipitation patterns and temperature, along with the intensification of natural disturbances, directly affect sediment mobilization and transport by modyfing both sediment availability and the transport capacity of river flows (Jadhav et al., 2024). Furthermore, anthropogenic activities such as afforestation-deforestation dynamics, urban expansion, infrastructure development, in-channel sediment mining and water resource management have profoundly modified sediment transport regimes. These interventions can intensify erosion in mountainous catchments, disrupt natural sediment flows through the construction of dams and weirs, and reduce sediment transport capacity via water abstraction or river channelization and training (Asselman, 1995; Favaro & Lamoureux, 2015; Naik & Jay, 2011; Rodríguez-Blanco et al., 2016; Surian & Rinaldi, 2004; Thodsen et al., 2008).

Despite the importance of these phenomena, a comprehensive understanding of the interactions between climatic and anthropogenic factors is often hampered by a lack of systematic monitoring data and the fragmented accessibility of existing records. This condition, with some degree of variability, is widely observed at the global scale (Walling & Fang, 2003). In particular, the scarcity of long, continuous, and coherent time series represents a significant obstacle to quantifying the specific contribution of each factor to total sediment transport and to accurately predicting how climatic changes or anthropogenic pressures may alter sediment balances in the future (Luppichini et al., 2024).

In Italy, this issue is particularly pronounced. From the 1930s to the 1990s, the Italian Hydrographic and Ocean Service (S*ervizio Idrografico e Mareografico Italiano*, SIMI) played a crucial role in systematically collecting suspended sediment transport data from major rivers across the country. However, with the dissolution of the service in the 1990s, the responsibility for monitoring was transferred to regional authorities, which faced significant challenges in maintaining continuity (Billi & Spalevic, 2022). In some virtuous cases, monitoring activities persisted but often with limited resources and reduced operational capacity. This has led to a highly fragmented data landscape: on one hand, there are paper-based historical records that are difficult to access and are not fully exploited; on the other hand, more recent data have been collected sporadically by public agencies or research groups, often without national-level coordination. The lack of a centralized platform designed to collect and harmonize these datasets has hindered their use for long-term analyses and to support water and land management policies.

To address this critical issue, the present work has two main objectives. The first is to create and strengthen a network of experts who, both in Italy and abroad, have been collecting data on sediment transport for several decades. Establishing this network aims to foster knowledge exchange and best practices, encouraging greater collaboration among institutions, universities, and land management authorities. The second objective is to develop a centralized database designed to store both historical and future data, integrating them into a single, accessible, and well-structured repository.

Comparable harmonization efforts have long been implemented in hydrology through international initiatives such as the Global Runoff Data Centre (GRDC) (Färber et al., 2025) and the Global Streamflow Indices and Metadata archive (GSIM) (Do et al., 2018). These databases integrate streamflow records from multiple national agencies and research institutions, applying standardized metadata structures and quality-control procedures to ensure consistency and comparability across regions. In contrast, sediment transport data are still largely fragmented, often dispersed among individual research projects or local monitoring programs. The development of the present database represents a first step toward a similar level of coordination in the field of fluvial sediment monitoring, promoting interoperability and long-term data accessibility.

The adopted IT infrastructure, consisting of the database architecture, server environment, and web-based interface, combines a solid and well-organized backend with a flexible and intuitive frontend. This approach ensures not only data security and integrity but also broader dissemination of information, making it accessible to both technical experts and users with limited expertise. The availability of a centralized platform marks a significant step forward in addressing the current gaps in sediment transport monitoring, providing a valuable tool for land management and scientific research. In the long term, this initiative could facilitate greater integration of sediment data at the European level, contributing to a more comprehensive understanding of sediment dynamics in response to climate change and anthropogenic pressures.

2 Material and Methods

The design of the database and its graphical interface was carried out in close collaboration with the research groups and technical partners involved, to understand their specific needs for storing and accessing sediment transport data. This participatory process enabled the identification of the most effective approaches to standardize data formats and ensure consistency and interoperability across heterogeneous datasets. The data were subsequently stored in a PostgreSQL database, while their entry, consultation, and updating were managed through a custom-developed web application designed to provide a structured and user-friendly tool for data management and integrated analysis.

2.1 PostgreSQL Database

The database was developed in PostgreSQL and installed on a server machine accessible via the HTTPS protocol (https://lca.dst.unipi.it/). PostgreSQL is an open-source relational database management system (RDBMS), known for its adherence to SQL standards and advanced features. It is designed to handle workloads ranging from small individual databases to large-scale management systems, typical of complex applications. PostgreSQL has been extended with the PostGIS library, which adds support for geospatial data, making it an advanced tool for storing, managing, and analyzing spatial and geographic data. It complies with the standards of the Open Geospatial Consortium (OGC), including the Simple Features for SQL and SQL/MM Spatial (Strobl, 2008).

The relational schema is shown in Figure 1. The information has been divided into 15 tables that allow for the storage of highly varied data.

The "watershed" table represents the highest level of the geographic system and describes the watersheds, which represent the fundamental territorial unit for monitoring sediment transport. This table includes spatial information (*geom*), enabling integration with GIS systems, and descriptive attributes for the 272 main watersheds of Italy (http://sdi.isprambiente.it/geoserver/hy/bacini_principali/wfs?service=wfs&version=2.0.0&request=GetCapabilities). Each watershed is linked to the corresponding river (in the "rivers" table). The "rivers" table represents the main watercourses that flow through the watersheds. Each river is associated with a watershed via the field *id_watershed*. This relationship allows rivers to be organized by their respective watersheds. The monitored rivers are described using a unique identifier (id) and a textual description (*description*), useful for identifying the river. The rivers serve as reference points for data acquisitions.

The "acquisition" table is the main repository for the data obtained from river monitoring. Each acquisition is geolocated using coordinates (*coordx, coordy using the WGS84 coordinate reference system*) and includes the monitored river (*id_river*), the measured parameter (*id_parameter*), the instrument used (*id_instrument*), the responsible user (*id_user*), additional information such as data availability (*availability*), specific reference (*reference*), and the monitoring section code (*section_code*). The acquisitions are also linked to a detail of the measurement type through *id_meas_type*.

The monitored parameters are defined in the "parameter" table. Each parameter describes a measurable element (e.g., pH, flow rate, velocity, suspended sediment concentration, etc.) and includes a textual description (*description*), a link to a general category through the field *id_categorize*, associated with the "macro_categories" table, which groups the parameters into broader categories (e.g., sediment concentration, river flow, chemical analysis, grain size, etc.). Parameters can be measured using different units of measurement and instruments, as described in the "parameter_has_unit" and "parameter_has_instruments" tables. The "instruments" table lists the tools used to collect field measurements. The "parameter_has_instruments" relationship establishes which instruments are used to measure each parameter. Each parameter is measured in a specific unit (e.g., °C, mg/L), defined in the "meas_unit" table. This n:n association is managed through the "parameter_has_unit" table.

Finally, the collected data are stored in the "data" table, which archives the actual numerical values recorded during acquisitions. Each record in the table includes the measured value (*value*), the collection date (*date*), and a reference to the specific acquisition via *id_acquisition*.

This approach allows for the direct connection of the measured data to the geographical context, the monitored parameter, the instrument used, and the monitoring conditions.

Each data entry is linked to a responsible user (in the "users" table), which contains information about the system users, including personal details (*name*, *surname*, *email*) and technical information (*affiliation, associated schema, last login date*). It is related to the "user_type" table, which categorizes users based on their role or authorization. Users can be active or inactive (in the "activations" table) and can have different roles (editor or viewer) with varying permissions on the database through the web application management system.

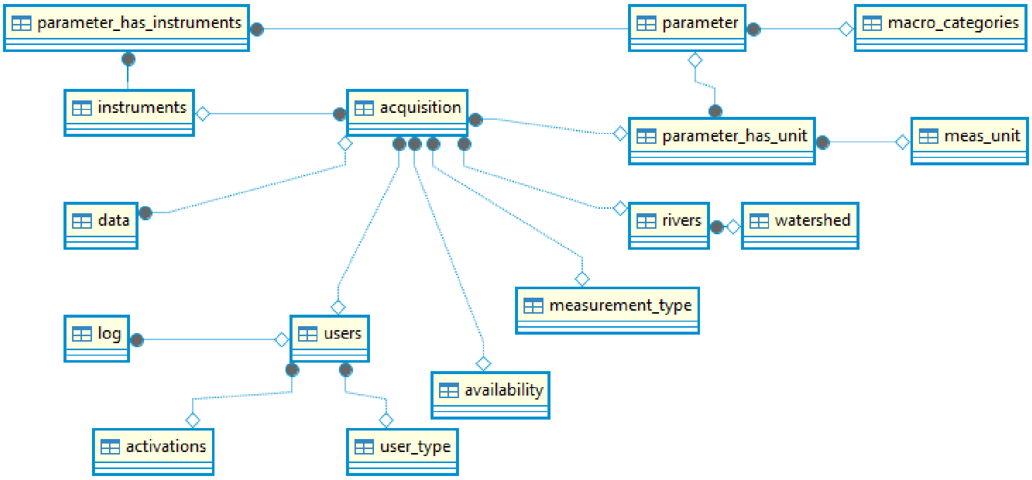


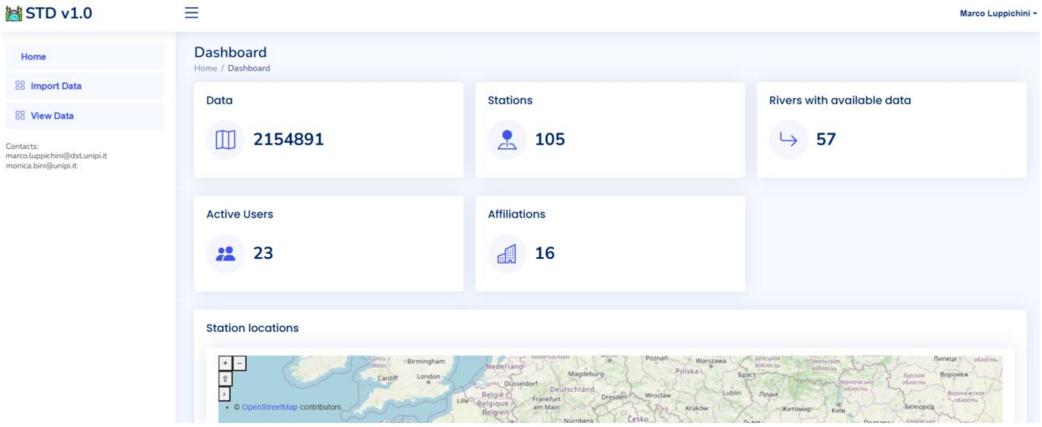
Figure 1 Relational schema of the database PostgreSQL

2.2 Web application

The web application (Figure 2; https://lca.dst.unipi.it/SedimentTransport) was developed to facilitate and control the database population and to provide tools for visualizing the data contained within it. It was built using open-source JavaScript and PHP libraries, primarily based on tools such as Bootstrap and OpenLayer. Access to the web application is granted after completing a registration form, during which the user selects their login credentials. Once the user is created, they must be approved by the database administrators, who will assign a user role (editor or viewer).

The application features a two-section layout (Figure 2): on the left, there is a menu with various options (Home, Import Data, View Data), while the main screen is displayed in the center. The homepage provides summary information such as the number of records in the database ("Data"), the number of measurement points ("Stations"), the number of rivers with at least one data entry ("Rivers with available data"), the number of active users in the last six months ("Active Users"), and the number of user affiliations ("Affiliations").

The homepage, which appears as shown Figure 2, also displays a map with the measurement points available in the database. Additionally, a table is shown summarizing the data in the database. The maps in the web application are interactive: when clicking on the layers, specific information about the measurement site is displayed.



Dashboard

Contacts:
marco.luppichini@dst.unipi.it
monica.bini@unipi.it

Data: 2154891
Stations: 105
Rivers with available data: 57
Active Users: 23
Affiliations: 16

© OpenStreetMap contributors

Figure 2 Home page of the web application (accessed on 16 February 2026)

The data entry process is carried out through the "Import Data" page. This feature is visible and accessible only to users with an editor role and consists of an initial form for general information to complete the acquisition table in the database (such as the river, measurement point, measured parameter, etc.). The dropdown menus are interconnected, and the available options change based on previous selections, guiding the user in selecting the correct entries.

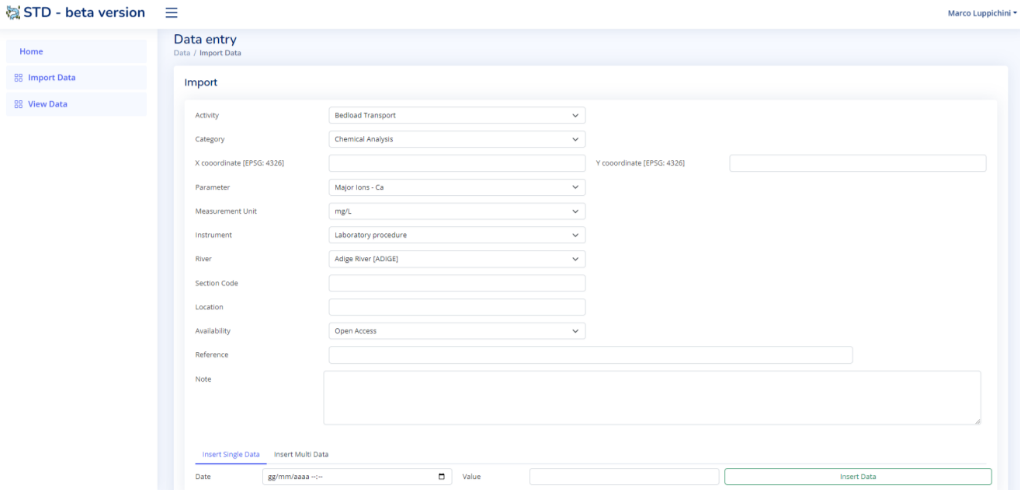
The second part of the form consists of a tab with two options: "Insert Single Data" or "Insert Multi Data" (Figure 3). The "Insert Single Data" tabFigure 3 allows the user to enter one record at a time by selecting the date and entering the corresponding value. The "Insert Multi Data" tab allows multiple values to be entered by uploading a Microsoft Excel file containing a specific template (the Excel file template is provided in the Supplementary Materials). The template consists of only two columns: "date" and "value". A data validation procedure is performed on the Excel file before writing data to the database. Any errors or successful operations are displayed to the user via appropriate alerts.

For data consultation and download, the "View Data" page can be used, accessible from the left-hand menu of the application (Figure 4). The page contains a map showing the locations of the measurement stations. By clicking on the points, users can access information about the historical time series associated with the selected station.

The page also includes a table that lists all the information associated with each data record. Through the provided form, users can query the data by applying filters, and the requested data will be displayed in a table that can be further filtered.

Data in the table can be searched using the "Search" function or by applying column filters in the last row of the table. Data can be exported in various formats using the "Copy", "Excel", "CSV", "PDF", or "Print" options.

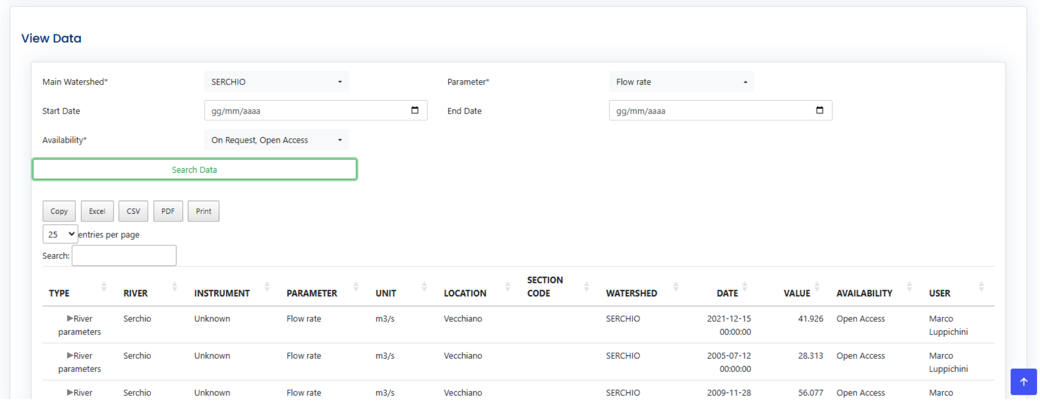
Data imported under a specific availability limit (on request) are only partially visible to users who are not the data owner. However, users can request the full data by contacting the data owner.



Activity: Bedload Transport
Category: Chemical Analysis
X cooordinate [EPSG: 4326]
Y cooordinate [EPSG: 4326]
Parameter: Major Ions - Ca
Measurement Unit: mg/L
Instrument: Laboratory procedure
River: Adige River [ADIGE]
Section Code
Location
Availability: Open Access
Reference
Note
Date: gg/mm/aaaa --:--
Value

Figure 3 Import data page of the web application (accessed on 24 October 2025)

https://doi.org/10.5194/essd-2026-157
Preprint. Discussion started: 24 June 2026



Main Watershed*: SERCHIO
Parameter*: Flow rate
Start Date: gg/mm/aaaa
End Date: gg/mm/aaaa
Availability*: On Request, Open Access
25 entries per page
Search:

TYPE	RIVER	INSTRUMENT	PARAMETER	UNIT	LOCATION	SECTION CODE	WATERSHED	DATE	VALUE	AVAILABILITY	USER
▶River parameters	Serchio	Unknown	Flow rate	m3/s	Vecchiano		SERCHIO	2021-12-15 00:00:00	41.926	Open Access	Marco Luppichini
▶River parameters	Serchio	Unknown	Flow rate	m3/s	Vecchiano		SERCHIO	2005-07-12 00:00:00	28.313	Open Access	Marco Luppichini
▶River	Serchio	Unknown	Flow rate	m3/s	Vecchiano		SERCHIO	2009-11-28	56.077	Open Access	Marco

Figure 4 View data page of the web application (accessed on 24 October 2025)

3 Results

3.1 Data Records

The data collected within the database amount to 1,988,116 records and are characterized by a high degree of spatial, temporal, and instrumental heterogeneity. The database currently includes information from 29 river basins and 39 rivers, distributed across 76 measurement sites. A total of 386 time series are archived. The dataset covers 21 different parameters, acquired using 19 different types of instruments, highlighting the diversity of monitoring approaches and measurement techniques adopted across different hydrological contexts.

Figure 5 shows the percentage distribution of the instruments used to acquire each parameter in the database, expressed as the proportion of total records available for that parameter. The analysis highlights that, in some cases, the instrumentation employed appears to be extremely homogeneous, while in others a considerable heterogeneity emerges, related to the nature of the parameter and the different measurement methodologies available.

Parameters closely linked to basic physico-chemical measurements, such as electrical conductivity and pH, show a clear predominance of a specific instrument (the *conductivity meter* and the *pH meter*, respectively), with percentages close to 100%. A similar pattern can be observed for parameters derived from annual aggregations, such as Annual Bedload Discharge (ABD), which are exclusively associated with specific calculation methods and measuring instruments (e.g., *geophones*).

Conversely, parameters related to instantaneous or monthly sediment transport and hydraulic flow characteristics show greater variability in the instruments used. In particular, the Suspended Sediment Concentration (SSC) was acquired using four different types of instruments (b*ottles*, *DH59*, and *acoustic doppler current profilers*). This heterogeneity reflects the coexistence, within the various monitoring networks, of both direct and indirect approaches to measuring suspended sediment concentration, as well as operational differences between monitoring sites and acquisition periods.

A similar situation can be observed for turbidity, which is measured using optical instruments (e.g., n*ephelometers* and t*urbidimeters*) but with varying percentages, suggesting differences in both the temporal resolution of the observations and the technological availability of the monitoring sites. Hydraulic parameters such as flow height and flow rate also display a more fragmented distribution, with a alternative use of r*adar sensors*, *pressure transducers*, and f*loat gauges*, consistent with the diversity of environmental conditions and the differing operational choices among monitoring stations.

Overall, there is a clear distinction between parameters that benefit from standardized measurement procedures and dedicated instruments and more complex parameters for which the variety of methodological approaches and operational tools constitutes an intrinsic feature of the acquisition process. This differentiation underscores the importance of a database structure capable of accommodating heterogeneous information while retaining details of the instrumental and methodological context associated with each dataset, thereby ensuring traceability and comparability among data derived from different sources.

It is also noteworthy that seven out of the sixteen analyzed parameters show significant percentages of data associated with an instrument classified as *“unknown”* This condition does not result from missing information in the database, but rather from the loss of details regarding the measurement instrument during data collection or transfer. This feature highlights the importance of metadata completeness and instrument traceability for a correct interpretation of hydro-sedimentary datasets.

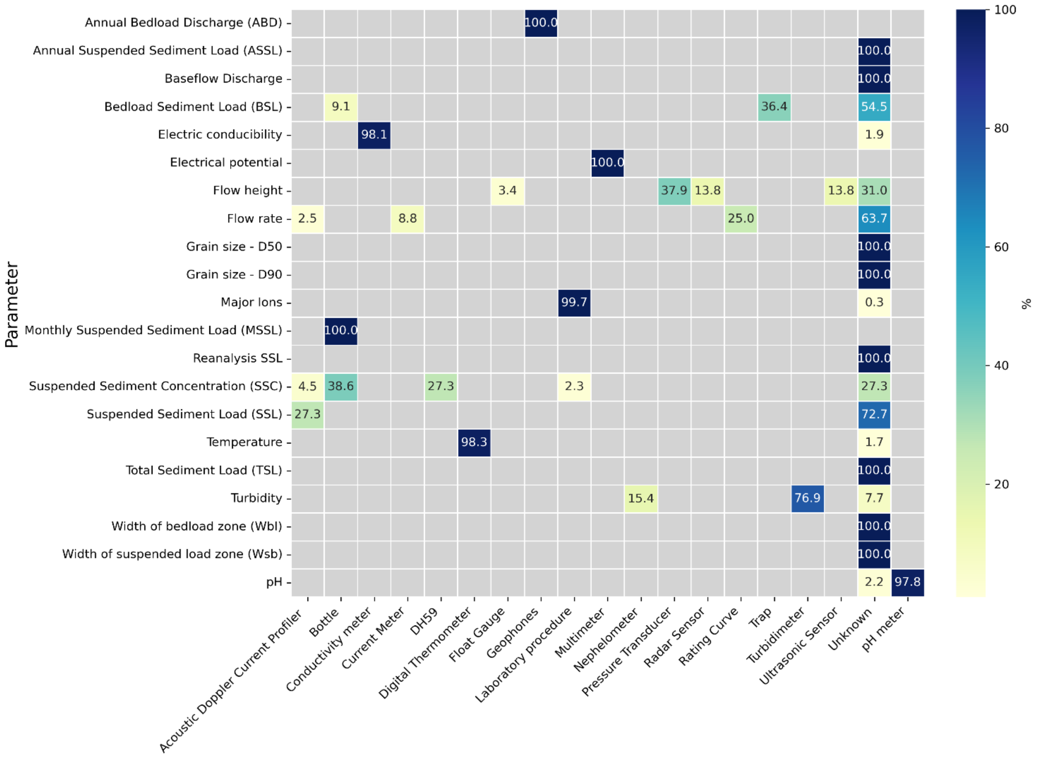


Figure 5 Frequency distribution of instruments used for the acquisition of each parameter stored in the database. Grey cells indicate the absence of values (0%). The figure highlights both homogeneous cases, where a single instrument is dominant, and heterogeneous situations, particularly for sediment transport and hydraulic parameters, where multiple measurement techniques coexist.

Figure 6 summarizes the typical sampling frequencies of the datasets stored in the database. For each parameter, the modal temporal resolution (i.e., the most frequently observed sampling interval) was identified and compared with the full range of observed frequencies, spanning from minimum to maximum values. The cumulative distribution further quantifies the proportion of records associated with each temporal resolution class.

The distribution highlights marked heterogeneity in the temporal resolution of the data, spanning sub-hourly to annual frequencies. Some parameters, particularly those of a physical or hydraulic nature (e.g., flow height), are acquired at high frequencies (2 minutes or 1 hour), consistent with continuous or semi-continuous monitoring activities. Other datasets, especially those related to sediment transport or derived parameters (e.g., ...), show daily or monthly frequencies, typical of manual field measurements or periodic sampling associated with laboratory procedures.

The cumulative curve reveals five main acquisition regimes, corresponding to frequencies of 10 minutes, 15 minutes, 1 hour, 1 day, and 1 month, which represent the prevailing operational scales within the monitoring networks considered. The most pronounced steps in the curve occur at these classes, indicating that a substantial portion of the total data is concentrated in these temporal intervals.

It is also evident that there is a wide variability in the effective acquisition frequency. This behavior reflects the presence of irregular or discontinuous time series, where the nominal frequency does not always correspond to actual data continuity (for example, hourly series characterized by interruptions or inactive periods). This variability underscores the complexity of harmonizing heterogeneous datasets and highlights the importance of a database structure capable of handling both the nominal sampling frequency and its actual temporal regularity

Overall, the figure illustrates how the collected data integrate multi-temporal information, combining continuous acquisitions with periodic or event-based sampling. This temporal diversity enables a more comprehensive representation of sediment and hydraulic dynamics across different spatial and temporal scales.

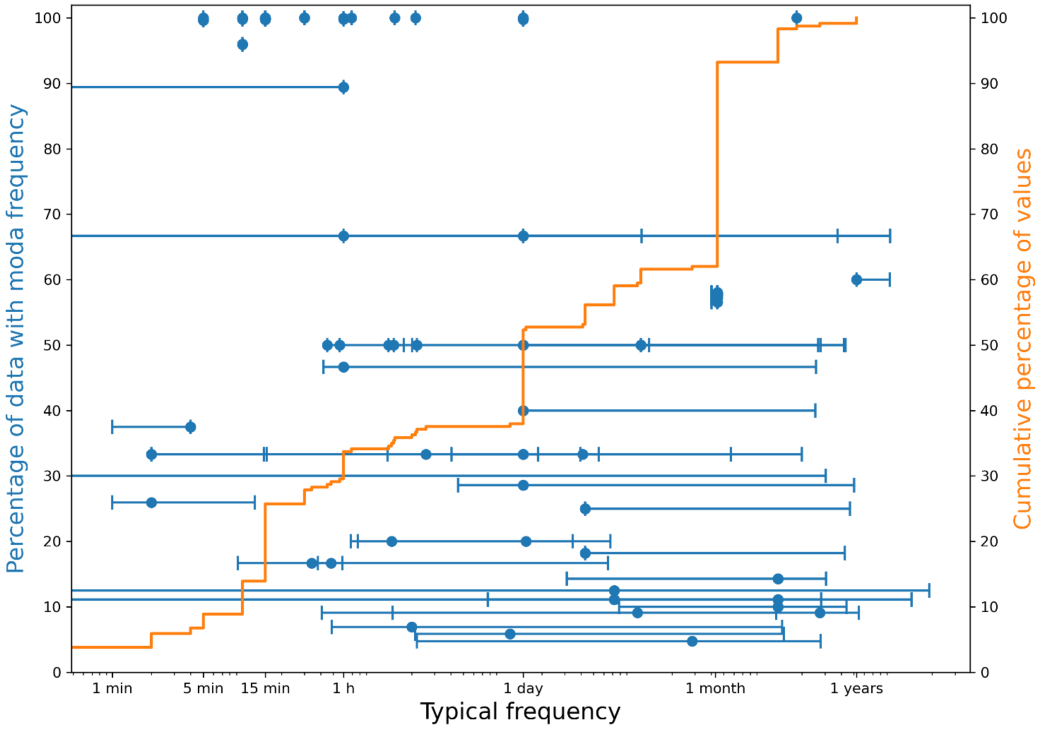


Figure 6 Distribution of typical sampling frequencies (blue dots) with minimum–maximum range (horizontal bars) and cumulative percentage of data (orange line). The figure highlights the coexistence of different temporal resolutions, from sub-hourly to annual, and shows that the most represented frequencies correspond to 10 minutues, 15 minutes, 1 hour, 1 day, and 1 month. The width of the ranges indicates that, in several cases, data acquisition is irregular or not continuous over time.

Figure 7 represents the temporal coverage of the data available for the sixteen parameters included in the database. For each parameter, the temporal coverage of the available time series was reconstructed to identify periods of activity and data continuity. The total number of historical series available for each category is reported to contextualize the extent of the dataset.

The analysis reveals that the temporal extent of the datasets varies widely across parameters, reflecting the diversity of monitoring networks and measurement techniques adopted over time. Some parameters exhibit very long time series, often beginning in the 1940s or 1950s and continuing up to the present day. This is particularly evident for flow rate, which shows the largest number of series and the longest temporal span, making it one of the most consistently monitored variables. Other hydrological parameters, such as flow height and Monthly Suspended Sediment Load (MSSL), also display extended observation periods and numerous records, partly due to the long-standing tradition of monitoring discharge and sediment dynamics in some of the major Italian river basins (e.g., Arno River, Ombrone River).

Conversely, parameters of a more specific nature or associated with newer measurement technologies—such as turbidity, electrical conductivity, pH, and major ions—show shorter and more discontinuous time series, often limited to the past two decades. This reflects both the recent introduction of dedicated automatic sensors and the historical heterogeneity in the availability of physic-chemical data.

Parameters related to sediment transport also exhibit significant variability. While annual datasets such as ABD and Annual Suspended Sediment Load (ASSL) are generally shorter and concentrated within specific periods, others—such as Bedload Sediment Load (BSL) and SSC—show more fragmented temporal coverage, alternating between phases of intensive monitoring and intervals without data acquisition. In several high-mountain catchments, suspended sediment monitoring is often seasonal, as sensors are removed during winter months (typically from November to May) due to harsh environmental conditions. This pattern reflects not only logistical constraints but also the strong morphoclimatic contrasts that characterise Italy, where monitoring strategies are necessarily adapted to markedly different environmental settings.

Overall, the figure highlights the temporal complementarity among the different types of data: some measurements, such as discharge or flow height, provide long and continuous records, while others, more specialized, offer detailed but discontinuous insights into fluvial dynamics and sediment transport processes.

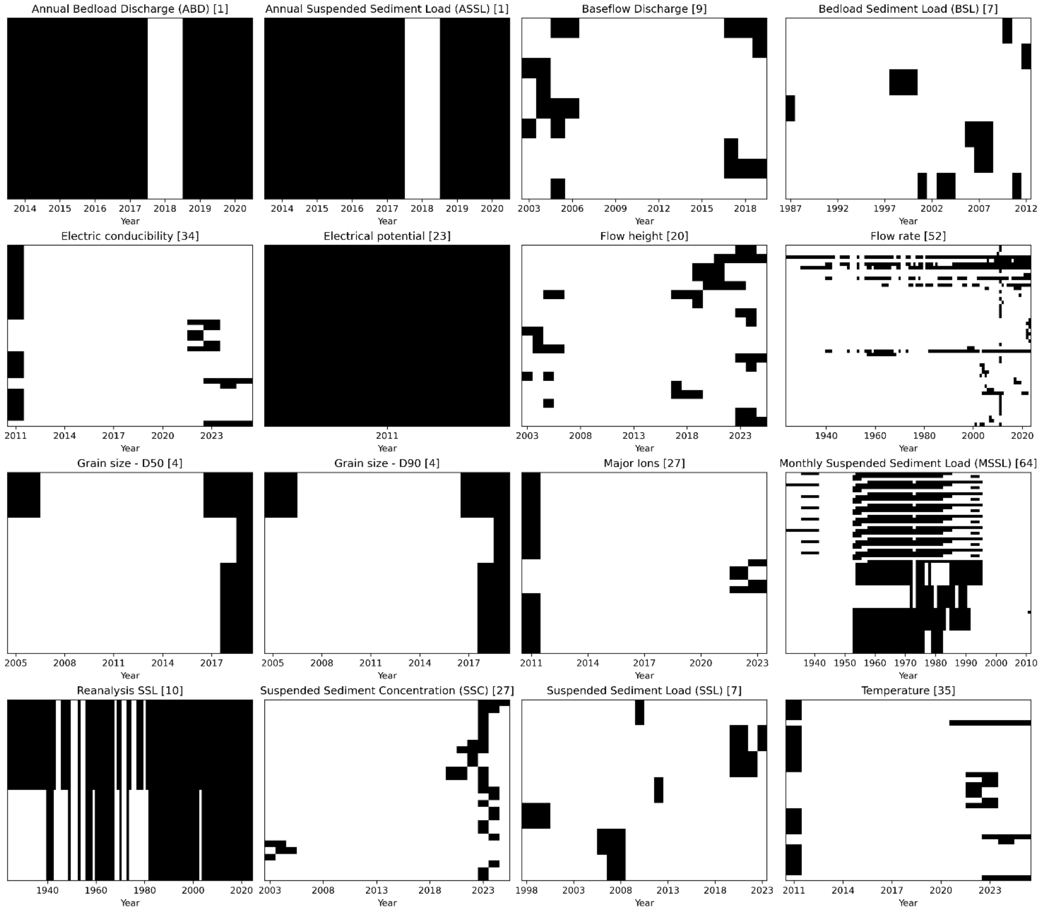


Figure 7 Observation periods for the sixteen parameters included in the database. Each black bar represents the time interval during which a time series is active, while the number in square brackets indicates the total number of series available for each parameter. The figure highlights the marked heterogeneity in the duration and continuity of the datasets, with some hydrological variables (e.g., Flow rate) monitored over several decades and others, of physico-chemical or sedimentological nature, characterized by more recent and fragmented time series.

Figure 8 summarizes the spatial distribution of these data across the analyzed river basins. The four panels respectively show: the number of rivers for which observations are available (top left), the total number data records (top right), the number of monitored parameters (bottom left), and the total number of measurement points in each basin (bottom right). The database currently includes data from 29 river basins out of the 272 that cover the entire Italian peninsula. At present, the dataset is primarily populated with basins from northern and central Italy, while southern regions and the major islands remain underrepresented.

The analysis reveals a notable heterogeneity in spatial coverage and data density. Some basins, particularly those in northern Italy, such as the Po, Adige, and Tagliamento, show a higher concentration of information, both in terms of the number of measurement points and the range of parameters observed. In these cases, monitoring networks are more complex and

https://doi.org/10.5194/essd-2026-157
Preprint. Discussion started: 24 June 2026

include several rivers and sub-basins, reflecting a stronger historical and institutional focus on sediment transport and fluvial dynamics monitoring.

Conversely, the basins of central Italy generally have fewer observation points and monitored parameters. In these areas, monitoring activities are more sporadic or limited to short periods, often associated with specific research projects or local management initiatives.

The panel showing the total number of data also highlights that the amount of available information depends not only on the number of monitoring sites but also on the temporal frequency of observations. Basins with fewer stations but high-frequency monitoring can, indeed, provide data volumes comparable to those of larger networks with lower-frequency time series.

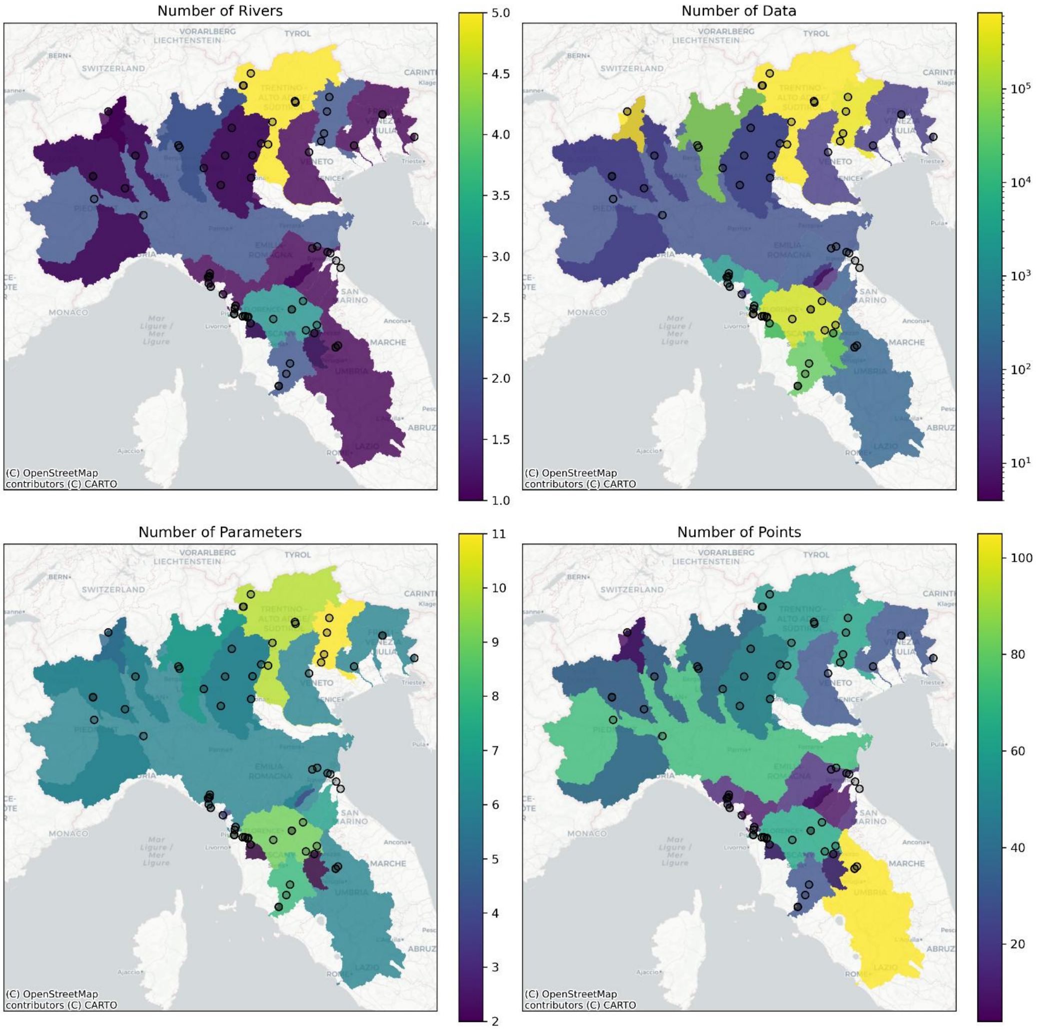


Figure 8 Distribution of sediment transport data by river basin. The panels show (clockwise from top left): the number of rivers analyzed, the total number of recorded data, the number of measurement points, and the number of monitored parameters for each basin. The figure highlights the strong spatial variability in data coverage and density, with higher concentrations in northern Italy compared to central and southern basins. The points indicate the location of the measurement sites.

3.2 Sediment load parameters: basin-scale analysis

The analysis presented in this section focused exclusively on data related to parameters directly connected to sediment transport, including both suspended and bedload components. Specifically, the following parameters were considered: s*uspended sediment concentration deviation (SSCD)*, *suspended sediment load (SSL)*, *suspended sediment concentration (SSC)*, *monthly suspended sediment load (MSSL)*, *annual suspended sediment load (ASSL)*, *annual bedload discharge (ABD)*, *bedload sediment load (BSL)*, *total sediment load (TSL)*, *total suspended solids (TSS)*, *turbidity, grain size – D50* and *grain size – D90*.

Figure 9 shows the actual distribution of sediment transport data, distinguishing between suspended and bedload components. In the top-left panel, river basins highlighted in red correspond to those for which the database contains at least one sediment transport parameter (*watersheds with sediment data*), while the remaining basins, outlined in black, are included in the database but associated only with other types of parameters (hydrological, physico-chemical, etc.).

The other panels provide a detailed view of the number of available data for each specific parameter within every river basin, allowing the identification of the most monitored areas. The SSL and SSC are the most commonly represented parameters, with extensive data in the river basins of northern Italy (particularly the Po and Adige) and central Italy. The MSSL, on the other hand, shows a more localized distribution, with significant values in a few basins, mainly in Tuscany.

Annual parameters such as ASSL and ABD show data concentrated in a single northern basin, reflecting the more complex and resource-demanding nature of these measurements. The BSL shows a similar pattern, with higher values in the Arno basin (central Italy), where direct measurements of bedload transport are available.

The TSL is present only in a limited number of basins, generally derived from the combination of suspended and bedload monitoring data. Finally, turbidity emerges as one of the most widespread parameters in the central and northern basins, due to the greater availability of optical sensors and its direct correlation with suspended sediment concentration.

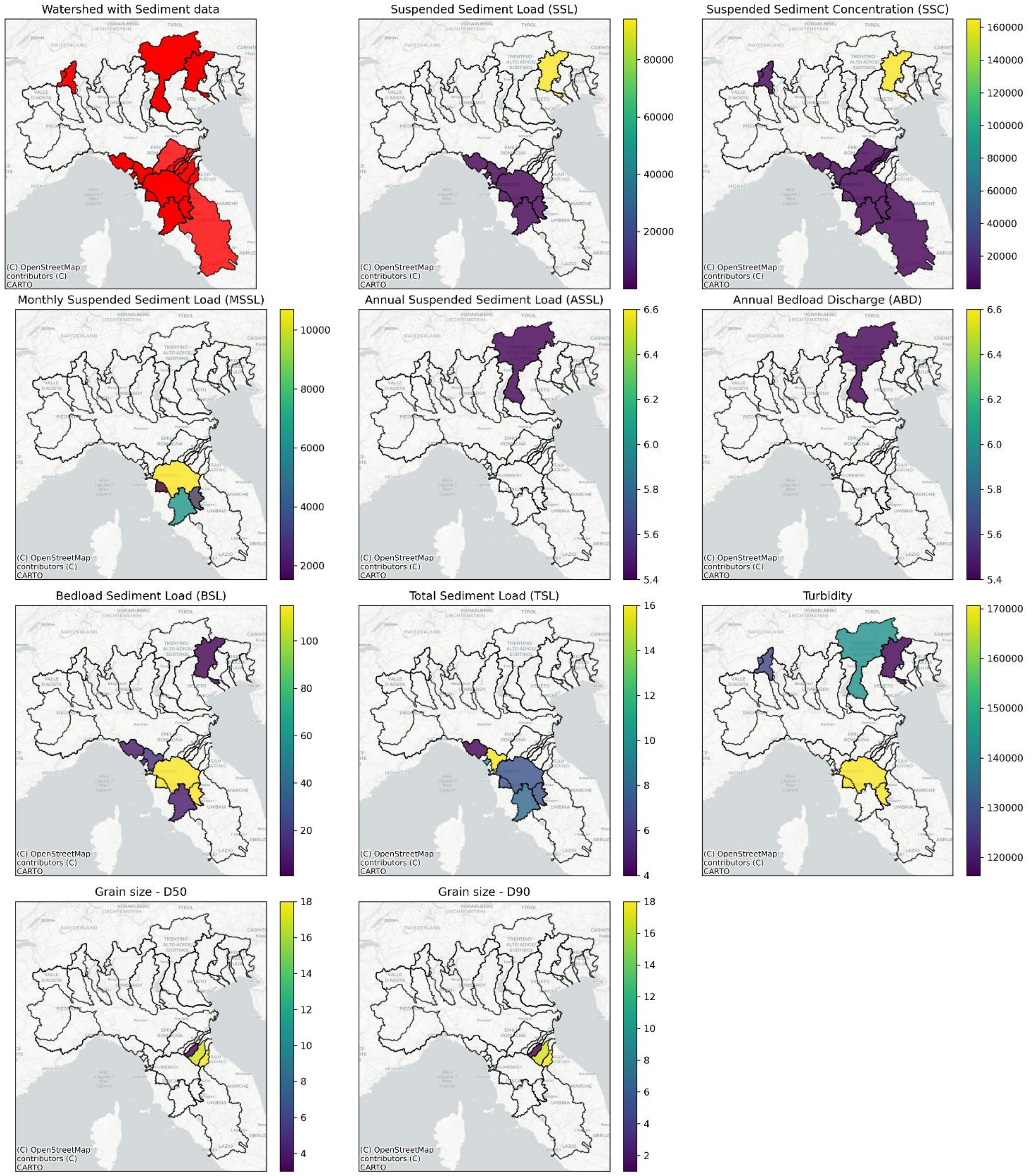


Figure 9 Spatial distribution of sediment transport data for each parameter considered. In the top-left panel (in red), basins containing at least one sediment transport parameter are shown. The other panels illustrate, for each specific parameter, the total number of data available per basin. The figure highlights the uneven spatial coverage of sedimentological parameters, with a higher concentration of information in the river basins of northern and central Italy.

4 Discussion and Conclusions

The aim of this study was to develop a relational database and a web interface dedicated to the storage, consultation, analysis, and export of fluvial sediment transport data. This initiative responds to the growing need in geosciences and environmental management for information systems capable of integrating, standardizing, and making accessible heterogeneous datasets that are historically fragmented and dispersed (Bailo et al., 2023; Parsons & Fox, 2013; Vitolo et al., 2015). This approach is consistent with recent European directives on environmental data sharing and with international open data practices, which emphasize that interoperability and metadata completeness are fundamental elements for the effective use and enhancement of hydrological and sedimentological data (Cho & Crompvoets, 2019; Jacob et al., 2025; Matthews et al., 2023). In this context, the comparison with established hydrological infrastructures such as GRDC (Färber et al., 2025) and GSIM (Do et al., 2018) highlights both the relevance and the current gap in sediment data integration. While streamflow monitoring has progressively evolved toward coordinated international frameworks supported by standardized metadata protocols and long-term institutional cooperation, sediment transport data have not yet reached a comparable level of structural organization. This disparity is not only technical but also institutional, reflecting differences in monitoring continuity, data ownership, and harmonization practices. The database developed in this study contributes to reducing this gap at the national scale by providing a structured environment for data standardization and controlled access. Although it does not yet represent a fully institutionalized infrastructure comparable to large international repositories, it establishes the foundational architecture upon which broader coordination and future integration efforts can be built.

The results, showing the data distribution in the time interval 1924-2025, revealed marked variability in the instrumentation used to measure and monitor the different parameters. Some parameters, such as electrical conductivity or pH, are characterized by nearly uniform instrumentation, reflecting their standardize measurement methods. Conversely, more complex parameters such as Suspended Sediment Concentration (SSC) or Turbidity, show a wide diversification of instruments, indicating the coexistence of direct and indirect measurement approaches. This heterogeneity, while limitating the direct comparability of data, also constitutes an informative resource, as it reflects the diversity of local characteristics and operational contexts in which the monitoring activities were carried out (Fratianni & Acquaotta, 2017; Fredi & Lupia Palmieri, 2017; Wang et al., 2022).

However, the presence of data without information on the measuring instrument ("unknown instrument") highlights the importance of traceability and metadata completeness, a topic already emphasized in the sediment monitoring literature (Walling, 2006).

The analysis of sampling frequencies and the temporal extent of time series revealed considerable temporal heterogeneity in the datasets. Sampling frequencies range from sub-hourly to annual measurements, while the duration of the series varies from a few years to more than seven decades. This discontinuity limits the possibility of conducting consistent and comparable temporal analyses and represents one of the most common challenges in managing long-term environmental data (Ellingsen et al., 2017; Nejad et al., 2024; Syvitski et al., 2005). It is therefore necessary to distinguish between nominal and effective acquisition frequency, document the actual regularity of the series and develop automatic quality control procedures. The proposed database provides a useful platform in this regard, allowing for a rapid visualization and analysis of temporal distribution and data gaps.

From a spatial perspective, the basin-scale analyses showed a high concentration of data in northern Italian basins, particularly the Adige (Bonfrisco et al., 2025) and Piave (Pellegrini et al., 2023; Rainato et al., 2017, 2025), while central Italian basins are less represented – Although data are also available for smaller river basins, such as the Versilia River (Francalanci et al., 2013) – and southern basins are almost entirely absent. This distribution reflects the historical development of monitoring networks, primarily established in areas with higher anthropogenic pressure and hydrogeological risk, but it also highlights the need for a more balanced territorial coverage. Parameters such as SSC and Turbidity are widespread and well-documented, whereas others, such as BSL or TSL, show limited coverage, being measured only at a few locations. This imbalance highlights the technical and operational complexity of bedload measurements and also suggests the need for strategies that combine direct and indirect approaches to broaden the available dataset. It should be noted, however, that the apparent absence of data in southern Italy may reflect both a lower historical monitoring intensity and a limited response to the present data call. Therefore, the current spatial pattern should not be interpreted as a complete lack of sediment monitoring activities in these regions, but rather as an indication of the present state of data collection within the framework of this database. Further engagement with regional institutions may help improve territorial representativeness in future updates. In addition, the database is currently dominated by datasets derived from research initiatives, while data routinely collected by regional and national environmental agencies are still only partially represented. This likely results in a more fragmented picture than the actual potential availability of sediment monitoring data at the national scale, further underscoring the need for stronger institutional collaboration in future database expansions.

The experience gained in building the database made it possible to identify both the limitations and the potential of the data collection and integration process. Among the main limitations are the difficulty of harmonizing pre-existing formats, the lack of uniform metadata, and the need for manual data validation procedures. An additional constraint is that data acquisition currently relies largely on voluntary contributions from individual researchers and institutions conducting monitoring activities, which may affect both the completeness and representativeness of the dataset. Nevertheless, the relational structure and the developed platform demonstrated the effectiveness of a scalable system capable of integrating heterogeneous information and providing a coherent overview of hydro-sedimentary observations at the national scale.

The results of this study suggest several methodological guidelines for the future management of sediment transport data. First, it is essential to promote the standardization of instrumentation and measurement protocols, ensuring the traceability of procedures and the comparability of results. Second, the systematic recording and preservation of metadata—including metadata related to effective acquisition frequency—should become a consolidated practice. Third, spatial coverage of monitoring networks must be rebalanced by strengthening underrepresented areas and promoting the integration of local data into a coordinated national system. Finally, adopting interoperable and open-source data architectures is key to ensuring the scalability and long-term usability of the system.

In conclusion, this work demonstrates that, despite the fragmentation and gaps in the available data, it is possible to build a coherent and functional database capable of enhancing the existing information assets. The gained experience highlights the need to develop dedicated information infrastructures for an integrated management of sediment transport data, supporting both scientific research and environmental planning. This study, therefore, represents a concrete step toward the creation of a national reference system for the monitoring and analysis of fluvial sediment transport. The developed database provides a robust and effective framework for data organization, harmonization, and accessibility, and it is designed as an open and updatable tool, allowing future uploads and continuous integration of new datasets. Its long-term effectiveness, however, will largely depend on the progressive expansion and completion of the dataset through the inclusion of high-quality data, i.e., datasets accompanied by consistent metadata, clear methodological documentation, and adequate temporal and spatial coverage.

5 Author Contributions

Conceptualization: Luppichini M., Bini M., Comiti F.;

Methodology: Luppichini M., Bini M., Comiti F.;

Software: Luppichini M.;

Data curation: Luppichini M., Donnini M., Andreoli A., Innocenti L., Picco L., Chirici D., Brenna A., Billi P.; Longoni L.

Formal analysis: Luppichini M., Bini M.;

Investigation: Luppichini M.;

Visualization: Luppichini M.;

Writing – original draft: Luppichini M., Bini M.;

Writing – review & editing: All authors;

Supervision: Comiti F., Bini M.;

Project administration: Bini M., Comiti F.;

Funding acquisition: Bini M.

6 Competing Interests

The authors declare that they have no conflict of interest.

7 Acknowledgements

This work is the result of the activities carried out within the working group "Geomorphology and sustainable development of alluvial plains under anthropogenic pressure and climate change (GEOALL)" of the Italian Association of Physical Geography and Geomorphology (AIGeo).

8 Funding

This research was funded by the Autorità di Bacino Distrettuale dell'Appennino Settentrionale—Misure di prevenzione tese a supportare ed ottimizzare la pianificazione di gestione, la programmazione e realizzazione degli interventi di cui al PGRA (F54J16000020001).

9 Data availability

The Italian Fluvial Sediment Transport Database, described in this paper, is publicly available at Zenodo: https://doi.org/10.5281/zenodo.18799025 (Luppichini et al., 2026). The archived version (v1.0) represents a frozen and citable release of the PostgreSQL relational database and includes the complete dataset and database structure necessary to ensure reproducibility and long-term accessibility.

The database can also be explored through a dedicated web application (https://lca.dst.unipi.it/SedimentTransport/), which provides dynamic access to the data following a brief registration procedure. While the web interface facilitates data consultation and querying, the Zenodo archive constitutes the reference version for citation and reproducibility purposes.

10References

Asselman, N. E. M. (1995). The impact of climate change on suspended sediment transport in the river Rhine. In S. Zwerver, R. S. A. R. van Rompaey, M. T. J. Kok, & M. M. Berk (Eds.), *Studies in Environmental Science* (Vol. 65, pp. 937–942). Elsevier. https://doi.org/https://doi.org/10.1016/S0166-1116(06)80119-6

Bailo, D., Paciello, R., Michálek, J., Cocco, M., Freda, C., Jeffery, K., & Atakan, K. (2023). The EPOS multi-disciplinary Data Portal for integrated access to solid Earth science datasets. *Scientific Data*, *10*. https://doi.org/10.1038/s41597-023-02697-9

Billi, P., & Spalevic, V. (2022). Suspended sediment yield in Italian rivers. *CATENA*, *212*, 106119. https://doi.org/https://doi.org/10.1016/j.catena.2022.106119

Bonfrisco, M., Coviello, V., Vignoli, G., Miyata, S., Piantini, M., Engel, M., Nadalet, R., Dinale, R., & Comiti, F. (2025). Temporal variability of bedload vs suspended sediment load and respective hysteresis cycles in a glacier-fed Alpine river. *Journal of Hydrology*, *660*, 133215. https://doi.org/https://doi.org/10.1016/j.jhydrol.2025.133215

Cho, G., & Crompvoets, J. (2019). The INSPIRE directive: some observations on the legal framework and implementation. *Survey Review*, *51*, 310–317. https://doi.org/10.1080/00396265.2018.1454686

Cox, J., Huismans, Y., Knaake, S., Leuven, J., Vellinga, N., Vegt, M., Hoitink, A., & Kleinhans, M. (2021). Anthropogenic Effects on the Contemporary Sediment Budget of the Lower Rhine-Meuse Delta Channel Network. *Earth's Future*, *9*. https://doi.org/10.1029/2020ef001869

Do, H. X., Gudmundsson, L., Leonard, M., & Westra, S. (2018). The Global Streamflow Indices and Metadata Archive (GSIM) – Part 1: The production of a daily streamflow archive and metadata. *Earth System Science Data*, *10*(2), 765–785. https://doi.org/10.5194/essd-10-765-2018

Ellingsen, K., Yoccoz, N., Tveraa, T., Hewitt, J., & Thrush, S. (2017). Long-term environmental monitoring for assessment of change: measurement inconsistencies over time and potential solutions. *Environmental Monitoring and Assessment*, *189*, 1–16. https://doi.org/10.1007/s10661-017-6317-4

Färber, C., Plessow, H., Mischel, S. A., Kratzert, F., Addor, N., Shalev, G., & Looser, U. (2025). GRDC-Caravan: extending Caravan with data from the Global Runoff Data Centre. *Earth System Science Data*, *17*(9), 4613–4625. https://doi.org/10.5194/essd-17-4613-2025

Favaro, E. A., & Lamoureux, S. F. (2015). Downstream patterns of suspended sediment transport in a High Arctic river influenced by permafrost disturbance and recent climate change. *Geomorphology*, *246*, 359–369. https://doi.org/https://doi.org/10.1016/j.geomorph.2015.06.038

Fortesa, J., Ricci, G., García-Comendador, J., Gentile, F., Estrany, J., Sauquet, E., Datry, T., & De Girolamo, A. (2021). Analysing hydrological and sediment transport regime in two Mediterranean intermittent rivers. *Catena*, *196*, 104865. https://doi.org/10.1016/j.catena.2020.104865

Francalanci, S., Paris, E., & Solari, L. (2013). A combined field sampling-modeling approach for computing sediment transport during flash floods in a gravel-bed stream. *Water Resources Research*, *49*(10), 6642–6655. https://doi.org/https://doi.org/10.1002/wrcr.20544

Fratianni, S., & Acquaotta, F. (2017). The Climate of Italy. In M. Soldati & M. Marchetti (Eds.), *Landscapes and Landforms of Italy* (pp. 29–38). Springer International Publishing. https://doi.org/10.1007/978-3-319-26194-2_4

Fredi, P., & Lupia Palmieri, E. (2017). Morphological Regions of Italy. In M. Soldati & M. Marchetti (Eds.), *Landscapes and Landforms of Italy* (pp. 39–74). Springer International Publishing. https://doi.org/10.1007/978-3-319-26194-2_5

Gurnell, A. M., Piegay, H., Swanson, F. J., & Gregory, S. V. (2002). Large wood and fluvial processes. *Freshwater Biology*, *47*(4), 601–619. https://doi.org/https://doi.org/10.1046/j.1365-2427.2002.00916.x

Hooke, J. M. (2006). Human impacts on fluvial systems in the Mediterranean region. *Geomorphology*, *79*(3), 311–335. https://doi.org/https://doi.org/10.1016/j.geomorph.2006.06.036

Jacob, D., Ehrenmann, F., David, R., Tran, J., Mirande-Ney, C., & Chaumeil, P. (2025). An ecosystem for producing and sharing metadata within the web of FAIR Data. *GigaScience*, *14*. https://doi.org/10.1093/gigascience/giae111

Jadhav, H., Kandekar, A., & Das, S. (2024). Climatic and Anthropogenic Influences on Long-Term Discharge and Sediment Load Changes in the Second-Largest Peninsular Indian Catchment. *Water*. https://doi.org/10.3390/w16243648

Leatherman, S. P., Zhang, K., & Douglas, B. C. (2000). Sea level rise shown to drive coastal erosion. *Eos, Transactions American Geophysical Union*, *81*(6), 55–57. https://doi.org/https://doi.org/10.1029/00EO00034

Luppichini, M., & Bini, M. (2025). 40-Year shoreline evolution in Italy: Critical challenges in river delta regions. *Estuarine, Coastal and Shelf Science*, *315*, 109166. https://doi.org/https://doi.org/10.1016/j.ecss.2025.109166

Luppichini, M., Comiti, F., Andreoli, A., Aldighieri, B., Billi, P., Bollati, I. M., Brenna, A., Chirici, D., Ciavola, P., Cilli, S., Donnini, M., Francalanci, S., Innocenti, L., Longoni, L., Mao, L., Marchesini, I., Murgia, I., Pellegrini, G., Penna, D., … Bini, M. (2026). *Italian Fluvial Sediment Transport Database (version 1.0)* . Zenodo. https://doi.org/10.5281/zenodo.18799025

Luppichini, M., Lazzarotti, M., & Bini, M. (2024). Climate change as main driver of centennial decline in river sediment transport across the Mediterranean region. *Journal of Hydrology*, *636*, 131266. https://doi.org/https://doi.org/10.1016/j.jhydrol.2024.131266

Matthews, F., Verstraeten, G., Borrelli, P., Vanmaercke, M., Poesen, J., Steegen, A., Dégre, A., Rodríguez, B., Bielders, C., Franke, C., Alary, C., Zumr, D., Patault, E., Nadal-Romero, E., Smolska, E., Licciardello, F., Swerts, G., Thodsen, H., Casalí, J., … Panagos, P. (2023). EUSEDcollab: a network of data from European catchments to monitor net soil erosion by water. *Scientific Data*, *10*. https://doi.org/10.1038/s41597-023-02393-8

Naik, P. K., & Jay, D. A. (2011). Distinguishing human and climate influences on the Columbia River: Changes in mean flow and sediment transport. *Journal of Hydrology*, *404*(3), 259–277. https://doi.org/https://doi.org/10.1016/j.jhydrol.2011.04.035

Nejad, A. S., Alaiz-Rodríguez, R., McCarthy, G., Kelleher, B., Grey, A., & Parnell, A. (2024). SERT: A transformer based model for multivariate temporal sensor data with missing values for environmental monitoring. *Comput. Geosci.*, *188*, 105601. https://doi.org/10.1016/j.cageo.2024.105601

Parsons, M. A., & Fox, P. A. (2013). Is Data Publication the Right Metaphor? *Data Science Journal*. https://doi.org/10.2481/dsj.WDS-042

Pellegrini, G., Mao, L., Rainato, R., & Picco, L. (2023). Surprising suspended sediment dynamics of an alpine basin affected by a large infrequent disturbance. *Journal of Hydrology*, *617*, 128933. https://doi.org/https://doi.org/10.1016/j.jhydrol.2022.128933

Rainato, R., Mao, L., García-Rama, A., Picco, L., Cesca, M., Vianello, A., Preciso, E., Scussel, G. R., & Lenzi, M. A. (2017). Three decades of monitoring in the Rio Cordon instrumented basin: Sediment budget and temporal trend of sediment yield. *Geomorphology*, *291*, 45–56. https://doi.org/https://doi.org/10.1016/j.geomorph.2016.03.012

Rainato, R., Pellegrini, G., Lenzi, M. A., & Picco, L. (2025). Interaction between climatic conditions, water- and sediment-fluxes in an alpine basin: Long-term monthly and seasonal analysis. *Geomorphology*, *472*, 109590. https://doi.org/https://doi.org/10.1016/j.geomorph.2024.109590

Rodríguez-Blanco, M. L., Arias, R., Taboada-Castro, M. M., Nunes, J. P., Keizer, J. J., & Taboada-Castro, M. T. (2016). Potential impact of climate change on suspended sediment yield in NW Spain: A case study on the corbeira catchment. *Water (Switzerland)*, *8*(10). https://doi.org/10.3390/w8100444

Strobl, C. (2008). PostGIS. In S. Shekhar & H. Xiong (Eds.), *Encyclopedia of GIS* (pp. 891–898). Springer US. https://doi.org/10.1007/978-0-387-35973-1_1012

Surian, N., & Rinaldi, M. (2004). Channel adjustments in response to human alteration of sediment fluxes: examples from Italian rivers. *IAHS Publication*, *288*, 276–282.

Syvitski, J. P. M., Vörösmarty, C. J., Kettner, A. J., & Green, P. (2005). Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. *Science*, *308*(5720), 376–380. https://doi.org/10.1126/science.1109454

Thodsen, H., Hasholt, B., & Kjærsgaard, J. H. (2008). The influence of climate change on suspended sediment transport in Danish rivers. *Hydrological Processes*, *22*(6), 764–774. https://doi.org/https://doi.org/10.1002/hyp.6652

Vercruysse, K., Grabowski, R., & Rickson, R. (2017). Suspended sediment transport dynamics in rivers: Multi-scale drivers of temporal variation. *Earth-Science Reviews*, *166*, 38–52. https://doi.org/10.1016/j.earscirev.2016.12.016

Vitolo, C., El-Khatib, Y., Reusser, D., Macleod, C., & Buytaert, W. (2015). Web technologies for environmental Big Data. *Environ. Model. Softw.*, *63*, 185–198. https://doi.org/10.1016/j.envsoft.2014.10.007

Walling, D. E. (2006). Human impact on land–ocean sediment transfer by the world's rivers. *Geomorphology*, *79*(3), 192–216. https://doi.org/https://doi.org/10.1016/j.geomorph.2006.06.019

Walling, D. E., & Fang, D. (2003). Recent trends in the suspended sediment loads of the world's rivers. *Global and Planetary Change*, *39*(1), 111–126. https://doi.org/https://doi.org/10.1016/S0921-8181(03)00020-1

Wang, J., Haining, R., Zhang, T., Xu, C., Hu, M., Yin, Q., Li, L., Zhou, C., Li, G., & Chen, H. (2022). Statistical Modeling of Spatially Stratified Heterogeneous Data. *Annals of the American Association of Geographers*, *114*, 499–519. https://doi.org/10.1080/24694452.2023.2289982

Wei, D., Liu, S., Wu, Y., Feng, S., Gao, H., Qin, C., Ren, D., Tang, W., & Zhang, Y. (2023). Impacts of human activities and climate change on water and sediment evolution in four large subtropical river basins in China. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2023.110958

Zarfl, C., & Dunn, F. (2022). The delicate balance of river sediments. *Science*, *376*, 1385–1386. https://doi.org/10.1126/science.abq6986

Zhang, J., Wang, J., Zhao, N., Shi, J., & Wang, Y. (2024). Analysis of Changes in Runoff and Sediment Load and Their Attribution in the Kuye River Basin of the Middle Yellow River Based on the Slope Change Ratio of Cumulative Quantity Method. *Water*. https://doi.org/10.3390/w16070944

Zhang, K., Douglas, B. C., & Leatherman, S. P. (2004). *GLOBAL WARMING AND COASTAL EROSION*. www.ipcc.ch