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Methodological approach to harmonise geomorphological nomenclature through the ISPRA geodatabase: a case study on Lombardy Region datasets (Italy)

Abstract: Franceschi L., Bosino A., Cipolloni C., De Amicis M., *Methodological approach to harmonise geomorphological nomenclature through the ISPRA geodatabase: a case study on Lombardy Region datasets (Italy).* (IT ISSN 0391-9838, 2026). In recent years, in Italy, the official guidelines for geomorphological mapping, provided by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), have been implemented within a document called 'Quaderno 13' (Q13). The document provides national guidelines for the representation of geomorphological landforms and features, as well as the associated geodatabase. However, over time, different authorities have contributed to cartographic production, and geomorphological data still show a substantial lack of homogeneity, with differences, especially in the use of terminologies and associated symbology. In this framework, the paper aims to propose an operational methodology to harmonise the existing geomorphological data, aligning the prior terms with the Q13 legend, as well as the data structure. As a case study, geoenvironmental data from the Lombardy Region are processed following the proposed methodology to test the effectiveness of the approach.

Key words: Geomorphological nomenclature, Harmonisation, Quaderno 13, ISPRA guidelines, INSPIRE directive, OGC data model.

Riassunto: Franceschi L., Bosino A., Cipolloni C., De Amicis M., *Approccio metodologico all'armonizzazione della nomenclatura geomorfologica mediante il geodatabase ISPRA: un caso di studio sul dataset della Regione Lombardia (Italia).* (IT ISSN 0391-9838, 2026). In Italia, le linee guida ufficiali per la mappatura geomorfologica sono fornite dall'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) attraverso il documento noto anche come "Quaderno 13" (Q13) che definisce sia le modalità di rappresentazione delle forme sia la struttura del relativo geodatabase. Dalla sua prima pubblicazione, il Q13 è stato aggiornato più volte riflettendo sia l'evoluzione della disciplina geomorfologica sia il passaggio dalla cartografia tradizionale a quella digitale. Tuttavia, le diverse autorità che contribuiscono alla produzione cartografica nazionale mostrano una certa recalcitranza ad adottare tali linee guida. Quanto descritto porta a una mancanza di omogeneità tra i prodotti geomorfologici presenti sul territorio nazionale, con differenze marcate soprattutto nell'uso della terminologia e della simbologia associata. In questo contesto, l'articolo proposto mira a proporre una metodologia operativa utile all'armonizzazione delle nomenclature geomorfologiche esistenti, allineando i termini precedenti alla legenda Q13. La metodologia è applicata ai dati geoambientali della Regione Lombardia, utilizzati come caso studio per valutarne l'efficacia.

Termini chiave: Nomenclatura geomorfologica, Armonizzazione, Quaderno 13, linee guida ISPRA, Direttiva INSPIRE, OGC data model.

INTRODUCTION

Geothematic mapping is the representation of georeferenced data that represents natural and human-made features of the Earth. In detail, geothematic mapping represents an advancement of basic geological cartography, providing a fundamental backdrop for specialised analyses like geomorphology or hydrogeology or geophysics (Console *et al.*, 2017). Its purpose is to provide critical data for a deeper knowledge of an area (D'Orefice and Graciotti, 2015). Geomorphological maps are a specific type of geothematic maps that are designed to provide a detailed description of the Earth's surface and the natural and anthropogenic processes which shape it, emphasising various aspects such as descriptive (morphography), quantitative (morphometry), genetic (morphogenesis), chronological (morphochronology) and dynamic (morphodynamics) (Dramis *et al.*, 2011; Stott, 2013). Geomorphological maps are key tools for resource (Tognetto *et al.*, 2021) and land management (Quesada-Román *et al.*, 2023), but the use of widespread stan-

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dards could improve their use and interoperability and the comprehensive nature of these elements makes them invaluable for research, management and environmental planning purposes (Bishop *et al*., 2012). Although one of the first systematic representations of geomorphological symbology goes back to Klimaszewski (1953, 1963) and attempts to compile applicable international legends date back to at least the 1960s (e.g., Tricart, 1965; Bashenina *et al*., 1968; Demek J. and Commission on Morphological Survey and Mapping, 1971, Panizza, 1972), a globally recognised geomorphological legend is still missing. To date, many European nations have developed their own methodologies that provide valuable recommendations for designing geospatial database structures and representing landforms (Dramis and Bisci, 1998; Rădoane *et al*., 2011).

For example, in France and Germany, authorities such as the *Centre national de la recherche scientifique* (CNRS) and the *Bundesamt für Geowissenschaften* (BGR) have established criteria adapted to their geomorphological contexts (Schoeneich and Raynard, 1992). In Spain, the *Instituto Geológico y Minero de España* (IGME) provides "Normas de organización de la información del Mapa Geomorfológico Nacional digital" (IGME, 2022), a collection of rules for geomorphological representation with a special focus on the construction of a digital database. In Poland, the *Państwowy Instytut Geologiczny Państwowy Instytut Badawczy* (PIG-PIB) promoted the "Instrukcja Opracowania I Wydania Szczegółowej Mapy Geologicznej Polski W Skali 1:50.000" (PIG, 2004) to produce a detailed geological map of Poland, which also includes guidelines on geomorphological symbolism.

The Italian geomorphological maps have a long history, developed through the contributions of many specialists, and the genetic approach is often the first used in compiling a geomorphological map (Castiglioni, 1982). However, the turning point was reached in 1994 with the publication of "Carta geomorfologica d'Italia – 1:50.000. Guida al rilevamento. Quaderni del Servizio Geologico Nazionale, III, 4" (Brancaccio *et al*., 1994), also known as "Quaderno 4". This publication introduced, for the first time in Italy, the national guidelines to standardise symbology and nomenclature. In the following years, new updated versions were published in 2018 and in 2021, considering the geodatabase associated with each landform (Campobasso *et al*., 2018, 2021, 2023).

However, it is possible that some Italian geomorphological datasets currently available online do not fully comply with ISPRA's official guidelines, either due to their historical origin or because they have been developed independently of the reference document. The purpose of this study is to present a practical guideline to assist data owners and users (i.e., local authorities as regions, etc.) in aligning their geomorphological products with established standards. The need for harmonising data is not new in the geosciences: for example, Strasky *et al.* (2016) demonstrated the importance of standardising lithostratigraphic nomenclature across Switzerland to resolve inconsistencies accumulated over decades of regional mapping. Their work led to a uniform national geological dataset and improved interoperability, clarity, usability, and integration across various environments. This highlights how harmonisation can provide substantial scientific and technical benefits, also in the field of geomorphology. In fact, our study harmonises the nomenclature of the existing geo-environmental map dataset of Lombardy according to the Q13 indications, addressing existent inconsistencies and promoting a standardised approach. Harmonising geomorphological nomenclature according to the standards outlined in Campobasso *et al.* (2021) is a key step in adopting a universally shared "coding system" among Italian regions. This will ensure clarity and consistency within geomorphology, thereby reducing misunderstandings and promoting the comparability of Italian data.

Although data harmonisation is a well-established practice across several geoscientific domains (Strasky *et al*., 2016; Pantaloni *et al*., 2021), it is usually addressed through qualitative or descriptive approaches. This work, beyond the qualitative alignment of terms, also introduces a quantitative perspective to evaluate the effectiveness of the harmonisation process by measuring both the proportion of unique geomorphological values successfully harmonised relative to the total number of relevant terms in the original dataset, and the proportion of mapped geometries effectively harmonised. These indicators, called Nomenclature Harmonisation Percentage, N (%) and Geometries Harmonisation Percentage, G (%), provide an objective measure of the degree of harmonisation achieved and support the comparison of heterogeneous datasets derived from different sources and periods, complementing the operational workflow proposed in this study. The combined use of N and G allows distinguishing between nomenclature harmonisation (diversity of geomorphological terms) and cartographic harmonisation (distribution of harmonised features over the dataset).

MATERIALS AND METHODS

Harmonisation workflow

The workflow is organised into six operational steps that provide a clear and practical procedure for harmonising historical and multi-source geomorphological data with the standards set out in the national guidelines (Q13), as shown in fig. 1.

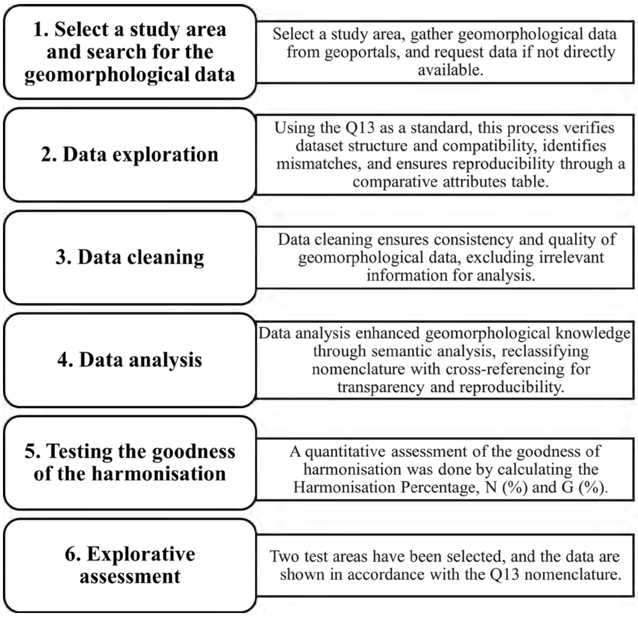


Figure 1 - Diagram summarising the six-step workflow for geomorphological data harmonisation in accordance with Q13 standards.

The steps described before aim to provide an operational and replicable approach:

1. *Select a study area and search for the corresponding geomorphological data*: The initial phase identifies the study area and collects the associated geomorphological data. Once the area is defined, the relevant information can be found by searching through official national or regional geoportals. Using appropriate keywords is crucial for obtaining accurate and comprehensive results. For example, it is preferable to use the national language. The search process may return a wide variety of resources, including individual shapefiles, geopackages, or more in general, the geospatial datasets integrated into broader mapping projects. Therefore, it is necessary to carefully assess the available materials to select those most suitable for the research objectives. In some cases, geomorphological data are not directly downloadable from geoportals or institutional websites; thus, it may be necessary to formally request the data from the authority or institution.
2. *Data exploration*: This step aims to verify that the data provided by the search conforms to this structure, and it is informed by the exploratory data analysis (EDA) approach (Tukey, 1977). This phase consists of an early and rapid analysis to visualise the dataset, to understand its structure and quality, before proceeding to a more in-depth analysis. This step verifies the compatibility of the database with the data model described in the Q13 guidelines (fig. 2). It aims to detecte potential mismatches in attribute naming, classification levels, or code definitions that could affect the subsequent harmonisation process.

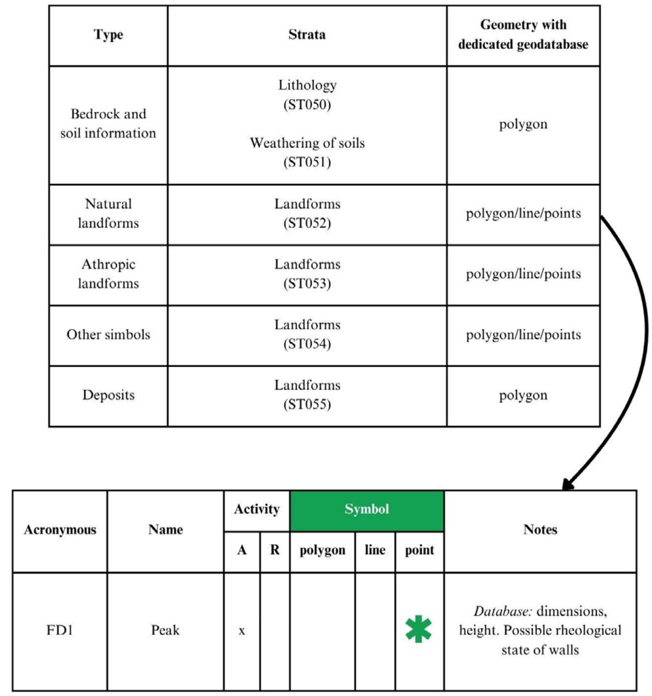


Figure 2 - Schematic overview of the Quaderno 13 (ISPRA) geodatabase structure, including an example of table relationships and the required attribute compilation and symbology for one geomorphological feature (source: Campobasso *et al.*, 2021).

3. *Data cleaning:* This phase is essential when the data are not standardised, as well as the data belonging to different sources, with the aim of selecting only geomorphological data and to identify and delete any possible duplicates Data cleaning guarantees data consistency, quality and reliability, which are essential conditions for any solid and comparable analysis (Rahm and Do, 2000), especially when it integrates a large amount of data from different sources.
4. *Data analysis:* This step is conducted to enhance the qualitative knowledge of the content, and it is carried out only for vector layers containing geomorphological information. A semantic analysis was performed on the terms used to describe the landforms. In cases of uncertainty, a standardised decision protocol and operator notes could be used to ensure transparency and reproducibility. For this reason, a flagging system was implemented to guarantee traceability of decisions throughout the reclassification process. This approach enables transparent documentation of uncertainties. Tab. 1 presents the criteria applied in the harmonisation process:
5. *Testing the goodness of the harmonisation*: Subsequently, to quantitatively assess the effectiveness of the nomenclature harmonisation process, the Nomenclature Harmonisation Percentage, N (%) and Geometries Harmonisation Percentage, G (%), were calculated. N (%) expresses the proportion of geomorphologically

Table 1 - Decision framework adopted for the harmonisation process. For each case, the table reports the applied action, the resulting output, and the corresponding flag.

Condition	*Action*	*Output*	*Flag*
Direct correspondence with Q13			
Lexical variation (e.g., singular/plural)	Reclassification to Q13 term	Harmonised	F1 – Inconsistencies in nomenclature
Lack of correspondence within Q13	Interpretation based on context (maps, DTM, orthophotos)	Harmonised	F2 – Lack of specificity in the nomenclature attributed to the landform
Indirect correspondence	Interpretation of the meaning	Harmonised	F3 – Semantic gap
Geomorphological feature or not represented in Q13	No assignment	Not harmonised	F4 – Classification gap

meaningful unique values that were successfully harmonised (N_u^h) with respect to the total number of geomorphological unique values contained in the original dataset (N_u), excluding non-geomorphological entries ($N_n g$). Particularly, N_u^h is intended to be the number of distinct Q13-standardised terms obtained after harmonisation, i.e., different original values – such as *cassa di espansione* and *vasca d'espansione* – that converge into the same Q13 class – "Cassa di espansione delle piene" (AN26) – are counted only once. This metric provides a synthetic indicator of the degree of nomenclature consistency achieved through the proposed operational procedure.

$$N\ (\%) = \frac{N_u^h}{N_u - N_n g} \times 100$$

In addition to the Nomenclature Harmonisation Percentage, which evaluates the alignment of unique geomorphological terms, a complementary indicator was introduced to assess the cartographic impact of the harmonisation process. G (%) quantifies the proportion of geometries in the dataset that are associated with harmonised nomenclature. This metric therefore reflects the extent to which the harmonisation procedure affects the mapped features themselves rather than only the diversity of terms. G (%) is calculated as the ratio between the number of geometries linked to harmonised geomorphological values (G_h) and the total number of geometries representing geomorphological features in the dataset ($G_t - G_n g$), excluding non-geomorphological entries.

$$G\ (\%) = \frac{N_h}{G_t - G_n g} \times 100$$

In this sense, N (%) specifically quantifies the degree of nomenclature alignment by measuring the proportion of unique geomorphological terms successfully harmonised with the Q13 standard, whereas G (%) reflects the amount of geomorphological information effectively recovered, accounting for the spatial occurrence of features within the dataset.

6. *Explorative assessment*: At the end, the updated vector layers were incorporated into a project structured according to the framework promoted by the Q13 guidelines, ensuring the reconstruction of the information layers dedicated to both natural and anthropogenic landforms.

Implementation in Lombardy dataset

The workflow described above was then applied to the geomorphological dataset of the Lombardy Region to test its applicability to a real-world dataset characterised by heterogeneous nomenclature and multiple data sources. For this purpose, the geoenvironmental data of the Lombardy region (Northern Italy) were selected as a case study due to the diversity of its geomorphological, geological, and environmental contexts (Burnelli *et al.*, 2023). Indeed, this diversity, ranging from the Alpine chain to the Po Valley and including the pre-Alpine hills and a portion of the Northern Apennines, encompasses a wide variety of landforms and geomorphological processes.

1. *Select a study area and search for the corresponding geomorphological data*: In this study, the search was conducted using the Lombardy Region geoportal (https://www.geoportale.regione.lombardia.it/; accessed in March 2025). The keyword "Carta Geomorfologica Applicata" was used, as local databases commonly adopt the national language for indexing.
2. *Data exploration*: Preliminary data exploration of the Lombardy region project began by opening it in a GIS environment. During the data exploration phase, a preliminary assessment of the dataset's structure and attributes was performed through the GIS data management interface. Particularly, this phase was approached by a brief analysis of the data's properties, the visualisation rules used and a cursory reading of the attribute tables of the vector layers in the project. To ensure reproducibility, a comparative table was created that correlates the attributes and codes of the original dataset with the relevant Q13 elements.
3. *Data cleaning*: In our case, it was first necessary to exclude non-geomorphological data and to check that there was no repetition of information – data with

an environmental, ecological, or hydrological nature, which is therefore of no interest to the Q13 guidelines, have been directly removed from the following steps.

4. *Data analysis*: In our case, we analysed the attribute tables by downloading the data directly from the ArcGIS project in Comma-Separated Value (CSV) format. To facilitate reading and content analysis, this data was transformed into a format easily openable in Excel. These preliminary steps enabled an in-depth analysis of the nomenclature attributed to the geometries in the maps produced by the Lombardy Region, as well as to verify its possible discrepancies with the Q13. Although the ISPRA guidelines provide an official descriptive framework for landform categories, they do not currently include a formalised, term-by-term controlled vocabulary. Therefore, the semantic analysis was guided by the definitions provided by Goudie (2004), Ciccacci (2019), and Bosino *et al.* (2023). The assignment of the new nomenclature was carried out on an Excel spreadsheet in which, for each morphotype, the original nomenclature, the information layer in which it is contained, the regional nomenclature and the new nomenclature according to Campobasso *et al.* (2021), including the abbreviation, were indicated. To reduce the subjectivity inherent in this phase, each reclassification was based on cross-referencing with official topographic and geological maps, high-resolution imagery, and DTM analysis. At this stage, the abbreviation provided by Campobasso *et al.* (2021), i.e. field acronyms, will be added to the project to ensure consistency with national guidelines.
5. *Testing the goodness of the harmonisation*: In this phase, the H(%) and G (%) were calculated using Excel. The spreadsheet is availble as supplementary materials.
6. *Explorative assessment*: To clarify the applied methodology, two test areas have been selected, and the data are shown in accordance with the Q13 nomenclature. The first area was named “Study-area: Fan” (STA_F) and the second was called “Study area-plain” (STA_P). The two study areas, which are both approximately 18 km², were selected to provide the most comprehensive representation of the geomorphological diversity of the Lombardy region as well as to highlight the issues of harmonisation. The first area is primarily characterised by gravitational landforms, while the second area is predominantly representative of fluvial landforms. The selection of two areas with different characteristics was made to demonstrate the broad applicability of the proposed methodology as well as its limitations. At the end, to improve the representation, the data from the two areas were plotted on the respective sheets of the regional technical map (1:10,000) downloaded from the regional Geoportal. In particular, the study area STA_F is entirely contained within sheet B8A5, and the study area STA_P is located within sheets C7A1 and C7B1.

RESULTS

Among the available resources, the project titled “Carta Geomorfologica Applicata” (CGA) (https://www.protezionecivile.servizirl.it/cartageomorfologica, last access in October 2025) was selected due to its high level of detail and completeness, as well as it is distributed under the CC-BY 4.0 license, which ensures open accessibility and reusability consistent with the aims of this study. Although not directly downloadable through public platforms, the Lombardy Region provided us the project containing the geospatial data of the Lombardy applied geomorphological map following a formal process of request. The contents of the given ArcGIS project were analysed during the exploration phase, which revealed a hierarchical structure in the organisation of geospatial information. Data exploration was carried out using the *Catalog* panel of ArcGIS Pro, a tool that provides structured access to the content and organisation of GIS projects. This interface was used to examine the hierarchical structure of the CGA project, which revealed six main data sets: *altri_dati*, *basi_ambientali_pianura*, *dissesti_IFFI*, *DUSAF*, *geoambientali*, and *Opere_Difesa_Suolo*, comprising 42 thematic vector layers (i.e. *VS_GHIACCIAI*, *WIZ_U32WG_VS_SIT_BASI_ELELIN*, *fr_co*, *aree_fluviali_e_bacini*, *CO_GEO_WGSOPERE_FIUMI_PL*) distributed unevenly among them for a total of more than 550 morphotypes present in the project (i.e. *ghiacciai*, *cresta rocciosa*, *conoidi IFFI*, *alvei artificiali e cordi d’acqua artificiali*, *forme fluv. fluvioglac. e lac. - conoidi di deiezione (Cartografia Geoambientale)*, *ODS - opere lineari corsi d’acqua pianura*). An example of the hierarchical structure is shown by tab. 2.

Subsequently, during the data cleaning phase, the attribute tables for each vector layer were analysed. Layers containing non-geomorphological information were excluded from further analysis. For instance, the vector layer *SL_GEO_WGS*, belonging to the *geoambientali* dataset, was omitted because it contains lithological data that were not relevant to the harmonisation of geomorphological nomenclature. An amount of 225 of unique value were excluded from the subsequent phase of analysis.

The semantic and comparative analysis of the geomorphological nomenclature, performed during the data analysis phase, revealed a heterogeneous use of terms across the different datasets, reflecting the coexistence of multiple regional and disciplinary conventions. Several terms used in the CGA were found to diverge from those recommended by the Q13 guidelines (Campobasso *et al.*, 2021). The systematic cross-checking with official topographic and geological maps, together with the consultation of high-resolution orthophotos and digital terrain models, enabled the refinement of these classifications and the identification of equivalent or analogous morphotypes according to the national standard. The analysis revealed several groups

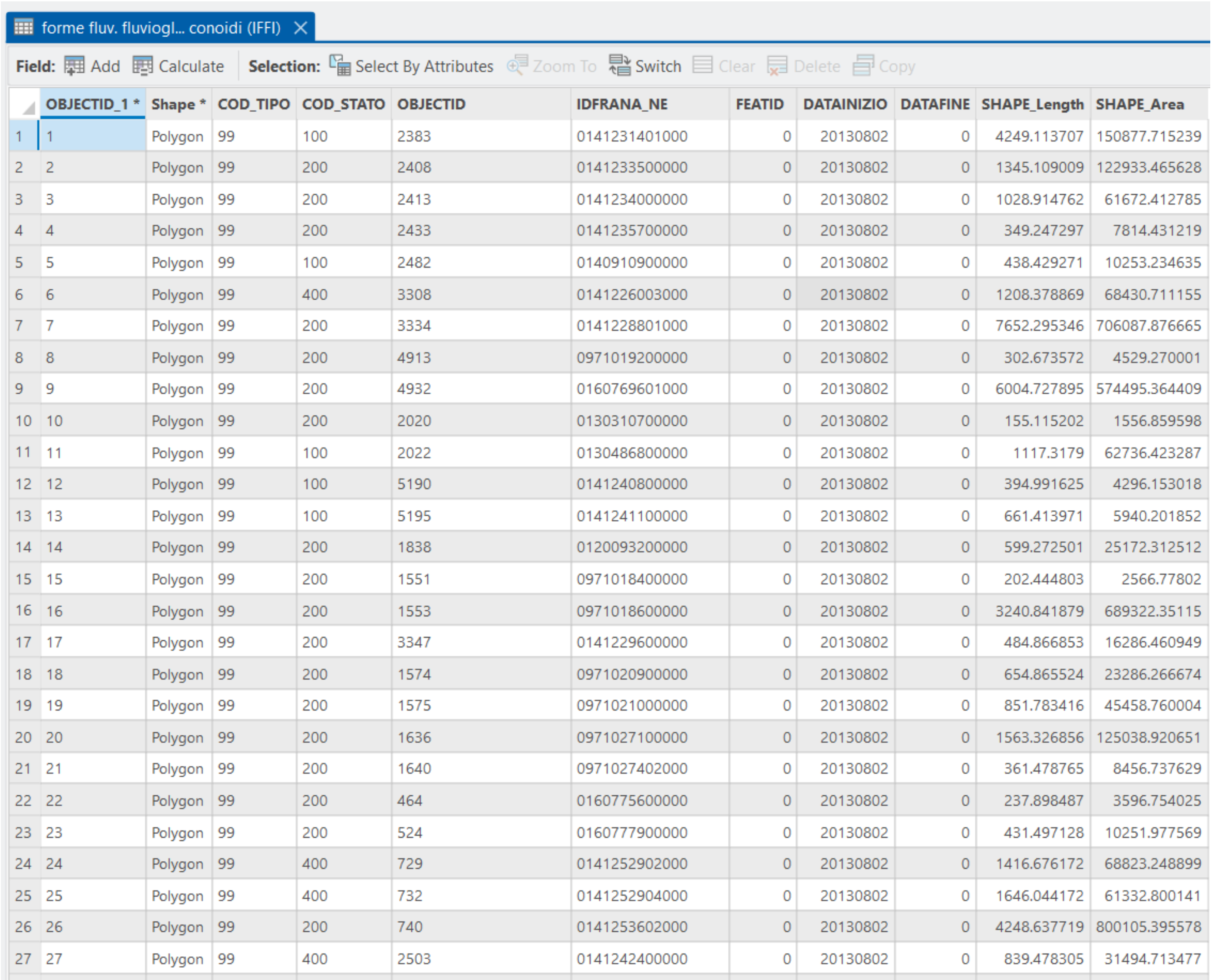
Table 2 - The Hierarchical organisation of geomorphological data from the Lombardy region's cartography.

Dataset	*Vector layers (i.e.)*	*Morphotype (i.e.)*	*Geometry*
altri_dati	VS_GHIACCIAI_2007	*ghiacciai* (glaciers)	polygon
basi_ambientali_pianura	WIZ_U32WG_VS_SIT_BASI_ELELIN	*cresta rocciosa* (rock ridge)	line
dissesti_IFFI	fr_co	*Conoidi IFFI* (IFFI fans)	polygon
DUSAF	aree_fluviali_e_bacini	*alvei fluviali e corsi d'acqua artificiali* (fluvial channel and artificial watercourses)	polygon
geoambientali	CO_GEO_WGS	*forme fluv. fluvioglac. e lac. - conoidi di deiezione (Cartografia Geoambientale)* (Fluvial, fluvioglacial and lacustrine landforms – alluvial fans)	polygon
Opere difesa del suolo	OPERE_FIUMI_PL	*ODS - opere lineari corsi d'acqua pianura* (linear hydraulic works in lowland watercourses)	line

of inconsistencies within the geomorphological nomenclature. These sources were used only to support the interpretation of the morphotypes and not to reassess the original geomorphological survey. These inconsistences and issues, together with the adopted strategies to address them, are deeply explained below:

- *F1 – Inconsistencies in nomenclature.* The Lombardy region's data often has a nomenclature declined in the plural, contrary to Q13, which always uses the singular. For example, the name *Contropendenze* appears in the regional cartography, which, in Q13, corresponds to the symbol *Contropendenza* (GR4). In this case, the solution can be easily achieved by directly substituting the nomenclature from the attribute table.
- *F2 – Lack of specificity in the nomenclature attributed to the landform.* In some cases, the nomenclature used in the Lombardy regional dataset employs more general terms (hypernyms), whereas the classification proposed in the ISPRA Q13 guidelines adopts more specific categories (hyponyms). A clear example is the use of the term *conoide*, which is used to identify all types of fan morphotypes, without distinguishing between those defined in Q13, such as *conoide alluvionale* (FD 40), *conoide fluvio-glaciale* (FD 41), or *conoide misto, da processi fluviali e debris flows* (FD 42). This generalisation limits the possibility of accurate categorisation within harmonised datasets. For instance, although the attribute table of the *forme fluv. fluvioglac. e lac. - conoidi (IFFI)* layer (fig. 3) includes some physical characteristics of the landforms, it does not provide sufficient information about dynamics to determine the precise morphogenetic type. As a result, one may know that a landform is a fan, but cannot ascertain whether it is alluvial, fluvioglacial, or mixed. One solution could be to retrieve information from other sources or the scientific literature to help distinguish these different morphotypes. Secondly, if deemed necessary, a new geomorphological survey campaign can be envisaged; surveys can be carried out either directly (i.e. via field survey) or indirectly (i.e. via remote sensing). In our case, to resolve this inconsistency and identify the specific nature of the fans, we consulted the IFFI national catalogue and we made a further check using remote sensing methods (as i.e. Google Earth).
- *F3 – Semantic gap.* Sometimes, there is no close match between the project's nomenclature and that presented in Campobasso *et al.* (2021). However, it is possible to find a meaning correspondence. The issue was attempted to be solved through a semantic analysis. For example, the landforms classified as *alveo abbandonato* in the cartography of the Lombardy Region can, with a certain degree of certainty, be traced back to the morphotype *Traccia di corso d'acqua estinto* (FD30).
- *F4 – Classification gap.* In some cases, geomorphological features identified in the original datasets were not represented within the Q13 classification system. For example, the feature *aree a forte dinamismo* was not included in the Q13 as a morphotype. This is a spatially extensive area affected by multiple and potentially heterogeneous processes; although the geomorphological nature of the feature is clear, a lack of correspondence with the forms currently present in Q13 and the conservative approach adopted have prevented its harmonisation. Given its broad and non-specific nature, assigning it to a discrete landform category would have implied an oversimplification and a loss of geomorphological meaning.

The introduction of H (%) allowed a quantitative evaluation of the nomenclature harmonisation process. In fact, 418 is the total number of unique values in the original dataset (N_u). However, 225 of these referred to non-geomorphological elements ($N_n g$); some of them were referred to lithology, such as *serpentiniti* (serpentinites) or others were referred to land use, such as *tessuto residenziale sparso* (scattered residential fabric). The nomenclature was har-


forme fluv. fluviogl... conoidi (IFFI)

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	OBJECTID_1 *	Shape *	COD_TIPO	COD_STATO	OBJECTID	IDFRANA_NE	FEATID	DATAINIZIO	DATAFINE	SHAPE_Length	SHAPE_Area
1	1	Polygon	99	100	2383	0141231401000	0	20130802	0	4249.113707	150877.715239
2	2	Polygon	99	200	2408	0141233500000	0	20130802	0	1345.109009	122933.465628
3	3	Polygon	99	200	2413	0141234000000	0	20130802	0	1028.914762	61672.412785
4	4	Polygon	99	200	2433	0141235700000	0	20130802	0	349.247297	7814.431219
5	5	Polygon	99	100	2482	0140910900000	0	20130802	0	438.429271	10253.234635
6	6	Polygon	99	400	3308	0141226003000	0	20130802	0	1208.378869	68430.711155
7	7	Polygon	99	200	3334	0141228801000	0	20130802	0	7652.295346	706087.876665
8	8	Polygon	99	200	4913	0971019200000	0	20130802	0	302.673572	4529.270001
9	9	Polygon	99	200	4932	0160769601000	0	20130802	0	6004.727895	574495.364409
10	10	Polygon	99	200	2020	0130310700000	0	20130802	0	155.115202	1556.859598
11	11	Polygon	99	100	2022	0130486800000	0	20130802	0	1117.3179	62736.423287
12	12	Polygon	99	100	5190	0141240800000	0	20130802	0	394.991625	4296.153018
13	13	Polygon	99	100	5195	0141241100000	0	20130802	0	661.413971	5940.201852
14	14	Polygon	99	200	1838	0120093200000	0	20130802	0	599.272501	25172.312512
15	15	Polygon	99	200	1551	0971018400000	0	20130802	0	202.444803	2566.77802
16	16	Polygon	99	200	1553	0971018600000	0	20130802	0	3240.841879	689322.35115
17	17	Polygon	99	200	3347	0141229600000	0	20130802	0	484.866853	16286.460949
18	18	Polygon	99	200	1574	0971020900000	0	20130802	0	654.865524	23286.266674
19	19	Polygon	99	200	1575	0971021000000	0	20130802	0	851.783416	45458.760004
20	20	Polygon	99	200	1636	0971027100000	0	20130802	0	1563.326856	125038.920651
21	21	Polygon	99	200	1640	0971027402000	0	20130802	0	361.478765	8456.737629
22	22	Polygon	99	200	464	0160775600000	0	20130802	0	237.898487	3596.754025
23	23	Polygon	99	200	524	0160777900000	0	20130802	0	431.497128	10251.977569
24	24	Polygon	99	400	729	0141252902000	0	20130802	0	1416.676172	68823.248899
25	25	Polygon	99	400	732	0141252904000	0	20130802	0	1646.044172	61332.800141
26	26	Polygon	99	200	740	0141253602000	0	20130802	0	4248.637719	800105.395578
27	27	Polygon	99	400	2503	0141242400000	0	20130802	0	839.478305	31494.713477

Figure 3 - The attribute table of the vector layer "fr_co" (shapefile) from Lombardy Region's project (datasource: Regione Lombardia).

monised for 72 unique values (N_u^h), giving a harmonisation rate of 37.31%. The calculated values show that a substantial proportion of the original geomorphological nomenclature could be successfully aligned with the Q13 guidelines after excluding non-geomorphological entries from the analysis. This result highlights the effectiveness of the proposed operational procedure in reducing semantic fragmentation within historical and heterogeneous datasets, and provides an objective measure to support the qualitative assessment of the harmonisation process.

The G (%) reaches 67.81%, indicating that a substantial proportion of mapped features can be successfully aligned with the Q13 nomenclature with a relatively modest time and resource effort. This result emphasises the effectiveness of semantic analysis as a tool for recovering and standardising a significant portion of legacy geomorphological information. However, the obtained value is affected by the presence of anthropogenic landforms. Approximately 3% of these features could not be harmonised, primarily because no corresponding categories exist in the current Q13 classification. For instance, features such as *trincea drenante* or *vasca di accumulo* could be considered for inclusion within the Q13 classification, as they represent anthropogenic landforms that influence key geomorphological processes, particularly those related to water flow and sediment dynamics. This limitation reflects the still-evolving nature of the anthropogenic component within the Q13 framework.

The final stages of the workflow involved integrating the updated vector layers into a unified GIS project compliant with the Q13 framework. During the update phase, the field acronyms proposed by Campobasso *et al.* (2021) were systematically added to the attribute tables, ensuring consistency with the national nomenclature and improving the dataset's interoperability. Subsequently, all revised layers were incorporated into a newly structured project designed according to the Q13 data model. This allowed the recon-

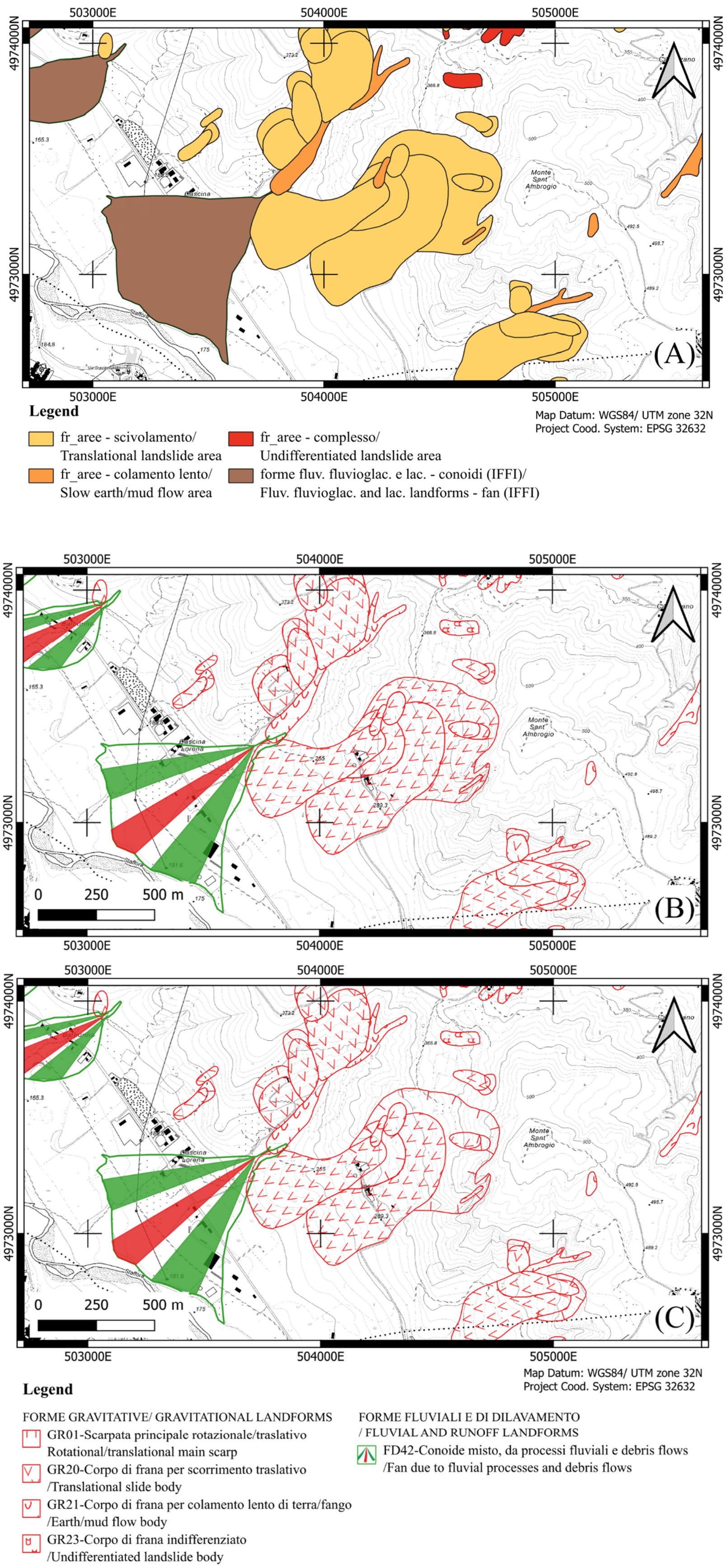

Figure 4 - (A) Original map, before harmonisation, showing various geomorphological features: cones, landslide areas and slow flows. (B) Map harmonised according to the proposed methodology, with reclassification of features. (C) Map highlighting a discrepancy due to the quality of the original data and not to the harmonisation methodology (Datasource: Regione Lombardia).

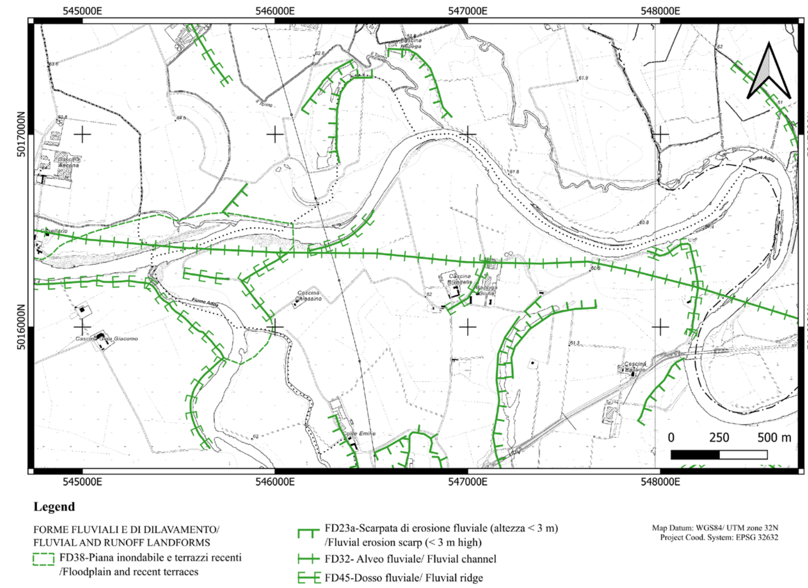

Figure 5 - Geomorphological data after the harmonisation according to Q13 (Campobasso *et al.*, 2021, datasource: Regione Lombardia).

struction of thematic information layers for both natural and anthropogenic landforms, resulting in a coherent, standardised geomorphological product aligned with ISPRA's official guidelines. Following the steps described in the proposed methodology has resulted in a harmonised project in terms of nomenclature; however, this process did not correct the inconsistencies in the original data. For instance, as shown in fig. 4A, in the STA_F study area, prior to harmonisation, it was possible to distinguish a fan area and a landslide area. The application of the methodology resulted in the map shown in fig. 4B, where, thanks to satellite images, it was possible to identify the fan as having its origin in fluvial and debris flow processes, while the landslide areas were simply reclassified as translational slide body, earth/mud flow body, and undifferentiated landslide body following the original data. Although formally correct, the map highlights a geomorphological classification error. As clearly visible on the map, the main translational scarps were mislabelled as a translational slide body. This case does not reflect a weakness in the methodology, but rather a critical issue related to the quality of the original data. Only the consultation of the IFFI catalogue enabled the production of a new map, shown in fig. 4C, that ensures formal consistency not only in nomenclature but also in geomorphological aspects.

Another critical issue was found in the STA_P area, where the element originally named *incisione a fondo piatto (meandri)* was reclassified as *alveo fluviale* (FD32), following the guidelines provided by Campobasso *et al.* (2021) and Bosino (2023). Moreover, as shown in fig. 5, this form does not follow the natural course of the river as displayed on the Regional Technical Map. This inconsistency is due to the quality of the original data: since this is an environmental information database (dataset: basi_ambientali_pianura), we believe that the acquisition and representation scales adopted in the regional project do not coincide. This case demonstrates that harmonising nomenclature is an important process; however, in cartographic representation, the reliability of the source data remains fundamental to ensuring map accuracy.

NEXT IMPROVEMENT FOR DATA MODEL STANDARDISATION

The nomenclature alignment process is only the first step towards data harmonisation, which requires not only harmonisation of terminology but also management of this terminology through nationally and internationally recognised controlled vocabularies that allow for its integration into broader contexts. Likewise, the entire database structure should be aligned with standard data models, specifically the Geology INSPIRE model (INSPIRE Maintenance and Implementation Group, 2024) or the more extensive OGC GeoSciML 4.1 model (OGC 2017), which supports the management of geomorphological content in both cartographic and conceptual terms.

The GeoSciML data model, in fact, through the use of the GeoSciML-Lite application schema, contains a GeomorphologicUnitView Feature type class developed for the purpose of harmonizing and encoding geomorphological cartographic content. This class then allows for interlinking with the more complex and extensive GeoSciML-Basic model, in which all scientific content associated with each landform or geomorphological process can be modelled.

This realignment to the international standard model is an essential step to make the data more interoperable with systems and to facilitate the integration of the various geomorphological databases.

Table 3: Attribute reorganisation scheme illustrating the separation of the original fields and their reassignment in accordance with international standards.

n_foglio	description
Sigla *(this represent the Q13 harmonised value described in the previous section)*	geomorphologicFeatureType geomorphologicFeatureType_uri unitType unitType_uri
attivita	activity activity_uri
eta	geologicHistory
Data_geocr	representativeNumericAge representativeAge_uri
Crono_rel	any link
note_di_campagna	metadata_uri
caratteristiche_litologiche	lithology representativeLithology_uri
data_ril Data_ev	metadata_uri
descrizione_litologia *and other attributes in the database*	Source managed via specification_uri

The following steps in the harmonisation process of the entire database will be to associate the harmonised Q13 nomenclature with the geomorphological landform vocabulary (Cipolloni *et al*., 2025) and then reorganise the data. This last process involves decoupling the geomorphologic information archived in the associated path shown in table 3.

DISCUSSION AND CONCLUSION

The assessment of the proposed methodology carried out in the two study areas, STA_F and STA_P, was not intended to generate detailed geomorphological maps, but rather to highlight potential critical issues that could arise throughout the entire data harmonisation process, using Q13 guidelines. It is important to emphasise that the harmonisation of nomenclature constitutes only the first phase of this broader process, which also involves subsequent stages of data integration and standardisation. In this context, the study itself is subject to some limitations: i) the completeness of the initial data, which originates from a variety of products and does not focus solely on geomorphological data; ii) the reclassification phase introduces a degree of subjectivity. In some cases, a conservative approach was adopted to minimise the risk of error, leading to the decision not to assign an alternative nomenclature. Since the focus of our work was primarily on harmonising the nomenclature rather than revising the geomorphological data themselves, this decision had a limited impact. The combined use of a qualitative flagging system and the quantitative assessment provided by the H and G indicators contributes to making the harmonisation procedure largely reproducible, reducing operator-dependent subjectivity to a residual component, although it cannot be completely eliminated due to the interpretative nature of certain geomorphological classifications. Instead, the obtained harmonisation values can be considered satisfactory, especially considering that the source dataset is a geo-environmental map, originally designed to integrate heterogeneous thematic information rather than to strictly follow a geomorphological standard. In addition, the harmonisation process was intentionally conservative, avoiding forced reclassification in ambiguous cases. Therefore, the achieved results indicate that a substantial portion of the original geomorphological information can be recovered and aligned with Q13 through a relatively efficient and reproducible workflow.

The harmonisation results also suggest that some categories of morphogenetic processes are more readily translated into the Q13 nomenclature than others. Landforms associated with well-established geomorphological frameworks, such as fluvial or slope processes, generally show clearer semantic correspondence. Conversely, features described using locally specific terminology or complex morphogenetic interpretations tend to present greater difficulties in the harmonisation process. This issue is particularly relevant considering the absence of a glossary associated with the forms in Q13, which leaves room for considerable operator interpretation and thus increases the risk of ambiguity and inconsistencies and it highlights the potential value of developing more explicit glossaries or controlled vocabularies for certain process categories. The historical collection of geomorphological data collected by local authorities allows for the identification of discrepancies between the nomenclatures of morphotypes in the data of the Lombardy Region and the actual Q13 (Campobasso *et al.*, 2021) indications. Inconsistencies include discrepancies in nomenclature, lack of specificity in the naming of landforms, lack of correspondence between nomenclatures and discrepancies in geometric representation. The proposed solutions here include direct replacement of nomenclatures, retrieval of information from the scientific literature, semantic analysis and adaptation of symbology. Defining an operational procedure for the harmonisation of nomenclature across datasets from different sources and time periods represents only an initial step. Nonetheless, nomenclatural standardisation is a necessary and preliminary prerequisite for achieving data interoperability, enabling cross-regional integration, automated processing, and the development of shared tools for hazard assessment and spatial planning, also for a future possible involvement of non-specialist users (Franceschi *et al.*, 2025).

Beyond its immediate methodological implications, the inclusion of quantification of nomenclature and geometries harmonisation highlights the potential value of legacy geomorphological datasets. Recent studies highlight that anthropogenic landforms are not merely secondary features, but actively contribute to geomorphodiversity and landscape evolution, often to a degree comparable to natural landforms (Brunelli *et al.*, 2025). At the same time, modern geomorphological mapping approaches increasingly recognise the need to represent complex and polygenetic systems, including human-induced processes and landforms within structured geodatabases (Faccini *et al.*, 2021; Pica *et al.*, 2024). From this perspective, the limited representation of anthropogenic morphotypes in the current Q13 classification suggests the need to further develop this component to better reflect the actual complexity of contemporary landscapes.

The systematic recovery and alignment of pre-existing nomenclatures may provide a solid basis for reactivating and updating national mapping initiatives, such as the CARG project, by capitalising on existing information rather than duplicating survey efforts. In this perspective, nomenclature harmonisation can be seen as a strategic preliminary step that facilitates data reuse, promotes interoperability, and enhances the long-term scientific value of heterogeneous datasets, with potential benefits for future geomorphological analyses and applied research. Recent contributions, such as La Licata *et al.* (2023); Bosino *et al.* (2024, 2026), confirm the scientific relevance of integrating harmonised nomenclature into structured geomorphological geodatabases, showing how this approach can improve data usability, spatial analysis, and risk assessment in complex landscape contexts.

The increasing shift towards digital and application-oriented geomorphological mapping highlights the need for consistent and standardised datasets, as heterogeneity in nomenclature and classification still represents a major limitation for data integration and usability (Piana *et al.*, 2017). The work offers a methodology to harmonise geomorphological datasets through the ISPRA guidelines. The work reported in this paper aims to provide a *modus operandi* that can be used to identify problems inherent in geomorphological data from various sources. Based on the methodology discussed above, a proposal for resolution has been developed and quantified, which is the first step towards semantic and syntactic harmonisation with the European INSPIRE Geology or the international OGC GeoSciML 4.1 Data models.

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REFERENCES

Bashenina N.V., Gellert J., Joly F., Klimaszewski M., Scholz E., 1968. *Project of the Unified Key to the Detailed Geomorphological Map of the World*. Folia Geographica (Krakow, Polska Akademia Nauk). Series Geographica- Physica Volume II, 11-12. and 18.

Bishop M.P., James L.A., Shroder J.F., Walsh S.J., 2012. *Geospatial technologies and digital geomorphological mapping: concepts, issues and research*. Geomorphology, 137 (1), 5-26. https://doi.org/10.1016/J.GEOMORPH.2011.06.027

Bosino A., Bufalini M., Ferrando A., 2023. *Geomorfologia di terreno delle forme fluviali, fluvio-glaciali e dovute al dilavamento. Atlante pratico per il rilevamento e la cartografia*. Dario Flaccovio Editore, Palermo, 165 pp.

Bosino A., La Licata M., Franceschi L., Hafiz A., Maggi V., Maerker M., Szatten D., De Amicis M., 2024. *Multi-strata geomorphological database (MorphDB): a methodological breakthrough in geomorphological mapping approach*. Geografia Fisica e Dinamica Quaternaria, 47, 147-160. https://doi.org/10.4454/yd45h97j

Bosino A., Barbadori F., Confuorto P., Godone D., De Amicis M., Raspini F., Aliu S., Nardini O., Hafiz A., Pelacani S., Trecate D.F., Maerker M., Cignetti M., 2026. *Geomorphological mapping of the Becca d'Aver deep-seated gravitational slope deformation (Aosta Valley, Italy) based on multi-scale and multi-sensor analysis*. Earth Surface Processes and Landforms, 51 (5), e70298. https://doi.org/10.1002/esp.70298

Brancaccio L., Castiglioni G.B., Chiarini E., Cortemiglia G., D'Orefice M., Dramis F., Graciotti R., La Posta E., Lupia Palmieri E., Onorati G., Panizza M., Pannuzi L., Papasodaro F., Pellegrini G.B., 1994. *Carta geomorfologica d'Italia - 1:50.000. Guida al rilevamento*. Quaderni del Servizio Geologico Nazionale, s. III, 4, 42 pp.

Burnelli M., Melelli L., Alvioli M., 2023. *Land surface diversity: A geomorphodiversity index of Italy*. Earth Surface Processes and Landforms, 48 (15), 3025-3040. https://doi.org/10.1002/esp.5679

Burnelli M., Pica A., Del Monte M., Delchiaro M., Melelli L., Reame F., Vergari F., Alvioli M., 2025. *Does anthropogenic morphogenesis contribute to geomorphodiversity in urban environments?* Geomorphology, 471, 109582. https://doi.org/10.1016/j.geomorph.2024.109582

Campobasso C., Carton A., Chelli A., D'Orefice M., Dramis F., Graciotti R., Guida D., Pambianchi G., Peduto F., Pellegrini L., 2018. *Aggiornamento ed integrazioni delle linee guida della Carta Geomorfologica d'Italia alla scala 1:50000 e banca dati geomorfologica*. Quaderni del Servizio Geologico Nazionale, III, 13 (1), 95 pp.

Campobasso C., Carton A., Chelli A., D'Orefice M., Dramis F., Graciotti R., Guida D., Pambianchi G., Peduto F., Pellegrini L., 2021. *Aggiornamento ed integrazioni delle linee guida della Carta Geomorfologica d'Italia alla scala 1:50000 e banca dati geomorfologica*. Quaderni del Servizio Geologico Nazionale, III, 13 (1), Versione 2.0, 153 pp.

Campobasso C., Pambianchi G., Peduto F., Cestari A., Chelli A., Congi M., D'Orefice M., De Amicis M., Dramis F., Graciotti R., Guida D., Palmieri V., Pellegrini L., Valiante M., Ventura R., 2023. *Proposta di un nuovo modello di cartografia geomorfologica a indirizzo applicativo Carta geomorfologica d'Italia - 1:50.000*, Quaderni del Servizio Geologico Nazionale, III, 13 (2), 37 pp.

Castiglioni G.B., 1982. *La cartografia geomorfologica tra ricerca di base e ricerca applicata.* Bollettino della Società Geografica Italiana, XI, 609-632.

Ciccacci, S., 2019. *Le forme del rilievo. Atlante illustrato di Geomorfologia*. Mondadori Università, Roma, 514 pp.

Cipolloni C., Congi M. P., Giulianelli E. 2025. *Taxonomy of natural geomophologic landforms*. ISPRA. https://doi.org/10.15161/oar.it/twvn8-w2x84

Console F., Pantaloni M., Tacchia D. (Eds), 2017. *La cartografia del Servizio Geologico d'Italia. Memorie Descrittive della Carta Geologica d'Italia, 100.* ISPRA – Servizio Geologico d'Italia, Roma, 300 pp.

D'Orefice M., Graciotti R., 2015. *Rilevamento geomorfologico e cartografia: realizzazione, lettura, interpretazione*. Dario Flaccovio Editore, Palermo. 43-76.

Demek J. and Commission on Morphological Survey and Mapping, 1971. *Manual of Detailed Geomorphological Mapping*. Jaromir Demek Editor, Brno, Czechoslovakia Academia of Sciences. 1st version Preliminary edition.

Dramis F., Bisci C., 1998. *Cartografia geomorfologica. Manuale di introduzione al rilevamento ed alla rappresentazione degli aspetti fisici del territorio*. Pitagora Editore, Bologna, 27-43.

Dramis F., Guida D., Cestari A., 2011. *Nature and aims of geomorphological mapping*. Developments in Earth Surface Processes, 15, 39-73. https://doi.org/10.1016/B978-0-444-53446-0.00003-3

Faccini F., Giardino M., Paliaga G., Perotti L., Brandolini P., 2021. *Urban geomorphology of Genoa old city (Italy).* Journal of Maps, 17 (4), 51-64. https://doi.org/10.1080/17445647.2020.1777214

Franceschi L., Bosino A., La Licata M., De Amicis M., 2025. *Geomorphological mapping and social sciences: a qualitative review*. Geosciences, 15 (7), 271. https://doi.org/10.3390/geosciences15070271

Goudie A., 2004. *Encyclopedia of Geomorphology*. Routledge, London, 1156 pp.

Instituto Geológico y Minero de España (IGME), 2022. *Normas de organización de la información del Mapa Geomorfológico Nacional digital, Versione 3.0.* Vicedirección Técnica de Sistemas de Información Geológica, Madrid.

Klimaszewski M., 1953. *Problems of the geomorphological field mapping in Poland*. Przegląd Geograficzny, 25 (3), 30-32.

Klimaszewski M., 1963. *Problems of geomorphological mapping*. Geographical Studies, 46, 179 pp.

La Licata M., Bosino A., Bettoni M., Maerker M., 2023. *Assessing landscape features and geomorphic processes influencing sediment dynamics in a geomorphologically highly active Mediterranean agroecosystem: the upper Val d'Arda case study (Northern Apennines, Italy).* Geomorphology, 433, 108724. https://doi.org/10.1016/j.geomorph.2023.108724

Panizza M., 1972. *Schema della legenda per carte geomorfologiche di dettaglio.* Bollettino della Società Geologica Italiana, 91, 207-237.

Piana F., Fioraso G., Irace A., Mosca P., d'Atri A., Barale L., Falletti P., Monegato G., Morelli M., Tallone S., Vigna G.B., 2017. *Geology of Piemonte region (NW Italy, Alps-Apennines interference zone).* Journal of Maps, 13 (2), 395-405. https://doi.org/10.1080/17445647.2017.1316218

Państwowy Instytut Geologiczny (PIG), 2004*. Instrukcja opracowania i wydania Szczegółowej mapy geologicznej Polski w skali 1:50.000.* Ministerstwo Środowiska, Warszawa.

Pantaloni M., Campo V., Congi M.P., Monti G.M., Primerano P., Ventura R., 2021. *The INSPIRE harmonisation: the Geological Map of Italy at 1:100,000 scale*. Proceedings of the ICA, 4, 85. https://doi.org/10.5194/ica-proc-4-85-2021

Pica A., Lämmle L., Burnelli M., Del Monte M., Donadio C., Faccini F., Lazzari M., Mandarino A., Melelli L., Perez Filho A., Russo F., Stamatopoulos L., Stanislao C., Brandolini P., 2024. *Urban geomorphology methods and applications as a guideline for understanding the city environment*. Land, 13 (7), 907. https://doi.org/10.3390/land13070907

Quesada-Román A., Umaña-Ortíz J., Zumbado-Solano M., Islam A., Abioui M., Zangmo Tefogoum G., Kariminejad N., Mutaqin B.W., Pupim F., 2023. *Geomorphological regional mapping for environmental planning in developing countries.* Environmental Development, 48, 100935. https://doi.org/10.1016/J.ENVDEV.2023.100935

Rădoane M., Cristea I., Rădoane N., 2011. *Geomorphological mapping. evolution and trends*. Revista de Geomorfologie, 19-39.

Rahm E., Do H.H., 2000. *Data cleaning: problems and current approaches*. IEEE Data Engineering Bulletin, 23 (4), 3-13.

Schoeneich P., Reynard E., 1992. *Comparaison des systèmes de légende français, allemand et suisse: principes de la légende IGUL*. Cartographie géomorphologique et cartographie des risques, 19-21 juin 1992, Diablerets–Randa.

Stott T., 2013. *Review of research in fluvial geomorphology 2010-2011.* Progress in Physical Geography, 37 (2), 248-258. https://doi.org/10.1177/0309133313477124

Strasky S., Morard A., Möri A., 2016. *Harmonising the lithostratigraphic nomenclature: towards a uniform geological dataset of Switzerland.* Swiss Journal of Geosciences, 109 (2), 123-136. https://doi.org/10.1007/s00015-016-0221-8

Tognetto F., Perotti L., Viani C., Colombo N., Giardino M., 2021. *Geomorphology and geosystem services of the Indren-Cimalegna area (Monte Rosa massif - Western Italian Alps)*. Journal of Maps, 17 (2), 161-172. https://doi.org/10.1080/17445647.2021.1898484

Tricart J., 1965. *Principes et méthodes de la géomorphologie*. Masson, Paris, 496 pp.

Tukey J.W., 1977. *Exploratory data analysis.* Addison-Wesley, Reading (MA), 688 pp.

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