Assessing built-up surface dynamics in the Ticino River Basin using multi-source LU/LC datasets: A preliminary comparative study within the INTERREG WINCA4TI project

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Abstract

This study developed within the INTERREG VI-A Italy–Switzerland project WINCA4TI (Water Interactions with Nature, Climate, and Agriculture for the Ticino Hydrographic Basin), investigates land use and land cover (LU/LC) changes focusing on built-up surface evolution in the Swiss portion of the Ticino watershed. LU/LC data are essential for tracking environmental change, modeling nutrient flows, and guiding sustainable land management. We analyzed and compared three key LU/LC datasets available for Switzerland: the national Arealstatistik, the European CORINE Land Cover (CLC), and the Ticino Cantonal Land Cover Cadastre. These datasets differ in spatial resolution, classification systems, and acquisition methodologies. Data were harmonized regarding the coordinate system, spatial extent, and thematic classification to ensure consistency. The study focused on the "built-up surfaces" category defined in the MODIFFUS 3.1 nutrient model. The analysis used open-source tools, such as QGIS and open data, ensuring a reproducible and transferable workflow. Results reveal significant discrepancies in the absolute values and temporal trends of built-up surfaces, depending on the dataset used. While Cadastre and Arealstatistik yield similar estimates when filtered for building-related categories, CORINE reports higher values, reflecting its suitability for national-scale analysis but limited precision in smaller, alpine regions. The findings emphasize the importance of dataset selection and class harmonization in LU/LC-based analyses, especially for integration into environmental models like MODIFFUS. This preliminary work lays the foundation for a broader comparison involving all land use categories. It supports future modeling of diffuse nutrient loads and climate adaptation strategies across the transboundary Ticino basin.

1. Introduction

Understanding land use and land cover (LU/LC) dynamics is essential for environmental monitoring, territorial planning, and ecological modeling. In mountainous and pre-alpine contexts such as southern Switzerland, LU/LC changes reflect natural pressures and anthropogenic transformations, influencing biodiversity, hydrological regimes, and water quality. These processes are particularly relevant within the Ticino River basin, which spans Switzerland and Italy and is subject to increasing land and climate pressures.

This study is part of the INTERREG project WINCA4TI, Water Interactions with Nature, Climate, and Agriculture for the Ticino hydrographic basin, which focuses on improving cross-border management of natural resources in the transboundary watershed shared by Switzerland and Italy. The project investigates the interactions between water, ecosystems, and socio-economic activities in a transboundary setting. One of the main goals is to improve knowledge about water-related dynamics to support sustainable land and water governance across the basin. In this context, analyzing LU/LC datasets is fundamental for assessing landscape transformation and setting the baseline for future applications, including hydrological and nutrient transport models. Among these applications, hydrological and nutrient flux models, such as the Stoffflussmodell (Braun et al., 1991), MODIFFUS (Prasuhn and Braun, 1994, Prasuhn and Mohni, 2003), and the most recent MODIFFUS 3.0 (Hürdler et al., 2015) and 3.1 (Hutchings et al., 2023), rely on LU/LC information to simulate the distribution and flow of substances like nitrogen and phosphorus within watersheds. Although this study does not implement such models directly, its findings contribute foundational insights for future spatially explicit applications by evaluating the reliability and compatibility of available LU/LC datasets. In this context, a previous research on Lake Lugano (Ferrario, 2009) highlighted how diffuse nutrient loads from various land uses impact eutrophication processes, emphasizing the need for robust LU/LC data.

In Switzerland, three main LU/LC datasets are available:

- The CORINE Land Cover provides polygonal data based on a minimum mapping unit of 25 hectares.
- The national Arealstatistik uses a point-based interpretation on a regular 100 × 100 m grid.
- The Cantonal Land Cover Cadastre of Ticino offers high-resolution, polygonal mapping with annual updates and detailed thematic granularity.

While all are valuable, their direct comparison is challenging due to differences in spatial coverage, reference systems, and classification logic. Previous efforts have explored harmonization strategies (Bundesamt für Statistik, 1998), downscaling methods (Giuliani et al., 2022), and data fusion using expert systems or neural networks (Giuliani, 2024), underlining the

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relevance of improving LU/LC integration for environmental monitoring.

Based on these three datasets, this study analyzes and compares the LU/LC evolution within the Swiss portion of the Ticino River basin. The comparison highlights differences in spatial coverage, classification systems, and thematic accuracy. To ensure compatibility, all datasets were harmonized to the same coordinate system and clipped using a common spatial extent derived from the hydrological basin boundaries and the 2011 coverage of the Cadastre, which represents the minimum geometry available.

While the complete quantitative analysis of all land use categories is reserved for a forthcoming extended publication, this paper presents a focused comparison based on a selected land use class: built-up areas. The goal is to assess how different data sources capture land change dynamics over time and to critically reflect on the implications for environmental monitoring and modeling, particularly given potential integration into models such as MODIFFUS.

2. Data and Materials

This study relies on three land use/land cover datasets that represent the primary sources of spatial land information in Switzerland: the CORINE Land Cover (CLC), the national Arealstatistik from the Swiss Federal Statistical Office (FSO), and the Cantonal Land Cover Cadastre of Ticino. These datasets differ significantly in methodology, resolution, classification, and temporal coverage.

CORINE Land Cover (CLC) (CORINE, 2025) is a European-wide dataset coordinated by the Copernicus Land Monitoring Service. It is publicly available and was downloaded as an ESRI File Geodatabase from the Copernicus Open Access Hub. Data were extracted by manually defining a bounding box slightly larger than the canton of Ticino, rather than using predefined NUTS-2 boundaries (CH07), to ensure consistency with the more precise cadastral geometry. The dataset is provided in EPSG:3035 (ETRS89 / LAEA Europe). The CLC vector product has a spatial resolution of 25 hectares and a minimum mapping unit (MMU) of 25 ha, with a thematic accuracy of 85%. The available years are 2000, 2006, 2012, and 2018. The classification system consists of 44 hierarchical land use/land cover classes, ranging from artificial surfaces (e.g., continuous/discontinuous urban fabric: 111, 112) to forests, wetlands, and water bodies.

Arealstatistik (Opendata.swiss, 2025a) is the Swiss official land use statistics managed by the Federal Statistical Office (FSO). It is based on photo-interpretation of aerial imagery performed on a regular point grid of 100 m × 100 m, with each point representing the center of a 1-hectare plot. The dataset is delivered in GeoPackage format with point features, covering the entire Swiss territory, and is available for five periods: 1979/1985, 1992/1997, 2004/2009, 2013/2018, and 2020/2025 (ongoing). It is natively referenced in EPSG:2056 (CH1903+ / LV95), the official national coordinate reference system used for all geospatial data in Switzerland. Each record includes classification attributes for three nomenclatures: land use (NOLU04), land cover (NOLC04), and a combined land use/cover scheme (NOAS04), available at different aggregation levels of 72, 27, 17, and 4 classes. Data can be freely downloaded from the Swiss open data portal (Opendata.swiss, 2025b).

Ticino Land Cover Cadastre is a high-resolution dataset maintained by the canton of Ticino. It is composed of vector polygon files available annually from 2011 to 2025. The dataset is not directly open access, but was made available for research, provided as ESRI Shapefiles. 2011/2017 were originally in EPSG:21781 (CH1903 / LV03) and converted to EPSG:2056. The 2011 layer, although incomplete, was used as a spatial reference mask for clipping all datasets to a consistent analysis extent. The classification scheme consists of over 30 detailed land use/land cover classes (e.g., Building, Dense forest, Meadow, Vineyard, Stream) and is based on cadastral registration rather than remote sensing interpretation.

The Hydrological Basin Mask (Figure 1) was applied to ensure consistent spatial analysis. All datasets were clipped to a custom extent defined by the intersection of the Ticino river basin (as defined by Hydromaps.ch (Hydromaps.ch, 2025), Basin ID 9805, 1622.5 km²) and the 2011 Cadastre extent. Although the basin includes a small portion of the Grisons canton, only the area within the Ticino canton was retained due to data availability constraints.

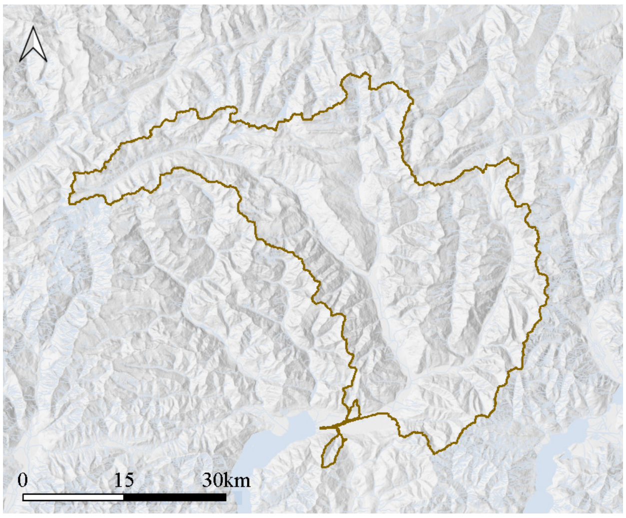

Figure 1. ©HADES, Hydrological Basin Mask, modified by D'Ambrosio.

All data processing and spatial harmonization were conducted using QGIS version 3.26.3 (QGIS Development Team, 2022), an open-source GIS platform. Coordinate transformations, clipping, geometry repairs, and format conversions (e.g., to GeoPackage) were performed using QGIS tools and the GDAL library.

3. Methodology

This study aims to analyze the evolution of built-up surfaces within the Swiss portion of the Ticino River basin using three different LU/LC datasets: CORINE Land Cover, the national Arealstatistik, and the Land Cover Cadastre of the Canton of Ticino. As outlined earlier, the methodological approach followed a structured geoprocessing workflow based on QGIS.

3.1 Dataset Harmonization and Preprocessing

All datasets were reprojected into the official Swiss coordinate reference system (EPSG:2056 – CH1903+ / LV95). For the

CORINE dataset, originally in EPSG:3035, reprojection was performed using ogr2ogr from GDAL, as shown in the example below:

```
ogr2ogr -f "ESRI Shapefile" -t_srs EPSG:2056 -s_srs
EPSG:3035 output.shp input.shp
```

To define a consistent spatial extent across all datasets, a reference geometry was created by intersecting the hydrological basin of the Ticino River (Basin ID 9805), obtained from Hydromaps.ch, with the 2011 geometry of the Land Cover Cadastre. Since the 2011 cadastre represents the most conservative coverage in terms of spatial extent, it was used to clip all datasets for consistency. Geometries were repaired using QGIS tools and exported in GeoPackage format to ensure topological consistency and avoid common issues associated with the shapefile format, such as limitations on field names, geometry validity problems, and lack of support for UTF-8 encoding. These repairs were necessary to prevent errors in downstream spatial analyses and data integration tasks. The Arealstatistik dataset, composed of point features, did not require any geometry repair.

3.2 Land Use Class Selection

To ensure a consistent comparison between datasets with differing classification systems and resolutions, this study focuses exclusively on the "Built-up surfaces" category, referred to as Siedlung überbaut in the MODIFFUS 3.1 land use classification (Hutchings et al., 2023). This category comprises constructed areas characterized primarily by impervious surfaces, including buildings and related infrastructure, but explicitly excludes transportation networks and green urban areas.

Dataset	Selected Class Description
Arealstatistik (NOAS04)	1 – Industrial and artisanal buildings
	3 – Single and two-family houses
	5 – Terraced and row houses
	7 – Multi-family buildings
	9 – Public buildings
	11 – Agricultural buildings
	13 – Unspecified buildings
	22 – Airports
	24 – Energy supply facilities
	25 – Water treatment plants
	26 – Other supply/disposal facilities
	27 – Landfills
	29 – Construction sites
	30 – Abandoned settlement areas
	32 – Sports facilities
	36 – Cemeteries
	68 – Winter sports infrastructure
CORINE Land Cover	111 – Continuous urban fabric
	112 – Discontinuous urban fabric
	121 – Industrial or commercial units
Ticino Cadastre	Building
	Airport

Table 1. Selected land use classes corresponding to built-up surfaces across datasets.

Given the substantial thematic variability across land use datasets, a harmonization step was necessary. Table 1 lists the specific land use classes selected within each dataset to define the "Built-up surfaces" category used in this analysis. These selections reflect the closest conceptual match to the MODIFFUS 3.1 definition and enable a meaningful thematic comparison across datasets.

The inclusion of each class was carefully considered in relation to the thematic criteria of MODIFFUS 3.1, which aggregates various detailed categories of Arealstatistik into 18 broader land use classes (Table 2) for modeling nutrient loads. Notably, while the Cadastre provides very high-resolution data and thematically precise geometries, Arealstatistik and CORINE required more interpretative filtering due to their coarser classification and different spatial representations. This harmonized categorization ensures that built-up area estimates are thematically aligned across all datasets. This enables reliable quantitative and temporal comparisons of urban expansion within the Swiss section of the Ticino River basin.

Land Use Main Areas	Land Use Category
Agricultural land	Arable land (incl. artificial meadows)
	Alpine agricultural land
	Horticulture
	Fruit cultivation
	Viticulture
	Permanent meadows
Settlement areas	Urban green space
	Built-up area
	Roads (outside settlements)
	Roads (inside settlements)
Unproductive land	Unproductive vegetation
	Standing water bodies
	Flowing water bodies
	Rock, debris, sand
	Glaciers
Forests	Forests $\leq$ 1200 m
	Forests $>$ 1200 m

Table 2. MODIFFUS 3.1 land use classification (Hutchings et al., 2023) .

3.3 Surface Area Computation

For Arealstatistik, built-up surfaces were computed by counting the number of point features matching the selected categories. Since each point represents the centroid of a 100 × 100 m grid cell, every point corresponds exactly to 1 hectare. Filtering and aggregation were performed using the Group Stats plugin in QGIS, enabling direct computation of total surface area in hectares based on the selected attribute values. A series of preprocessing steps was necessary for the CORINE and Cadastre datasets to ensure valid area calculations. Geometries were first repaired to address topological issues, then dissolved by category to merge contiguous features and eliminate internal boundaries that could lead to double-counting. A new attribute field was then calculated to express surface area in hectares using the formula:

$$\text{area(\$geometry)/1000}$$

The resulting field already contained the per-feature area in hectares, allowing direct use for analysis without additional summation. To facilitate consistent comparison across datasets

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and years, all surface values were normalized relative to the shared clip geometry (74'034 ha) used for analysis, defined by the intersection of the Ticino River basin mask and the 2011 extent of the Cantonal Land Use Cadastre. This method allowed results to be expressed in absolute area (ha) and relative share (%), providing a common reference framework for interpreting changes in built-up surfaces.

3.4 Temporal Alignment Considerations

Although the study examined all available years for each dataset to understand the evolution of built-up areas, direct comparisons were limited to 2011 and 2018, the only periods where all three datasets offered sufficiently aligned data for meaningful comparison. For 2011, Cadastre 2011, CORINE 2012, and Arealstatistik 2004/2009 were used; for 2018, Cadastre 2018, CORINE 2018, and Arealstatistik 2013/2018 were selected. This temporal alignment minimized discrepancies from asynchronous data collection and allowed for a robust comparative assessment.

4. Results

The analysis of built-up area evolution across the three LU/LC datasets, Cadastre (Cantonal Land Cover Cadastre), Arealstatistik (Swiss Federal Area Statistics), and CORINE Land Cover, reveals notable discrepancies in both absolute values and temporal trends, highlighting the complexity of harmonizing land use information derived from different methodologies and resolutions. These differences highlight the complexity of harmonizing land use information derived from datasets initially designed for distinct purposes. Although all three data sets provide valuable information, their combined use requires careful normalization, reclassification, and awareness of their limitations. As such, any integrative LU/LC analysis must consider the data's spatial and temporal alignment and the conceptual alignment of land use definitions.

4.1 Cadastre Dataset

The Cadastre data, based on precise vector geometries derived from direct cadastral measurements, displays a consistent and gradual increase in built-up surface, reaching a peak of 553 ha in 2022, followed by a slight decrease to 542 ha in 2025 within the Swiss portion of the Ticino River basin (Figure 2). This growth trend aligns with expectations given the progressive urban expansion and continual data updates by the cantonal authorities. The category includes only "Building" and "Airport", ensuring a narrowly defined and consistently applied classification across years. Landfills were excluded from the Cadastre as they are grouped with gravel pits, unlike in Arealstatistik, where they are classified separately. These classification differences also contribute to the variation in results across datasets. The slight decline observed in 2025 is atypical and remains unexplored; it may result from update delays, reclassification, or real land use changes, warranting further investigation.

4.2 Arealstatistik Dataset

The Arealstatistik dataset, based on a point sampling method with 100×100 m resolution and reclassified into MODIFFUS 3.1 built-up categories, presents larger values for built-up areas due to its broader interpretation (Figure 3). For the 2013/2018 period, the total built-up surface amounts to 923 ha, compared

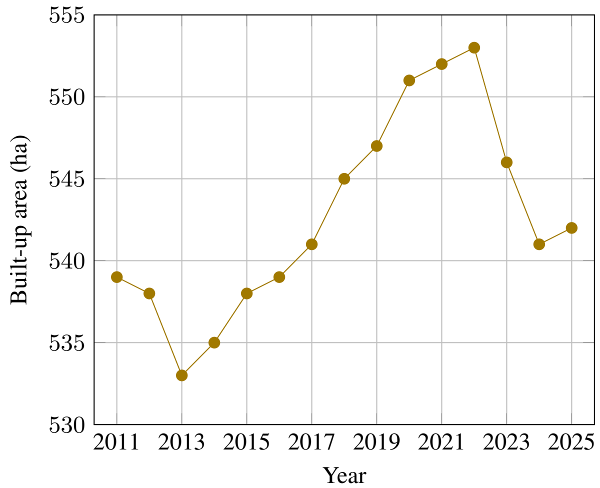

Figure 2. Temporal trend of built-up area from 2011 to 2025 according to the Ticino Land Cover Cadastre.

to 545 ha for the Cadastre in the overlapping year 2018. However, when only considering categories directly corresponding to "Building", the value drops to 529 ha, strikingly close to the Cadastre figure. This similarity suggests a strong consistency between datasets when definitions and thematic granularity are aligned. Nevertheless, Arealstatistik includes additional categories such as construction sites, decommissioned areas, and sports infrastructure, which fluctuate over time and blur the long-term growth trend, leading to lower totals in previous periods (e.g., 824 ha in 1997/1992 and 883 ha in 1985/1979).

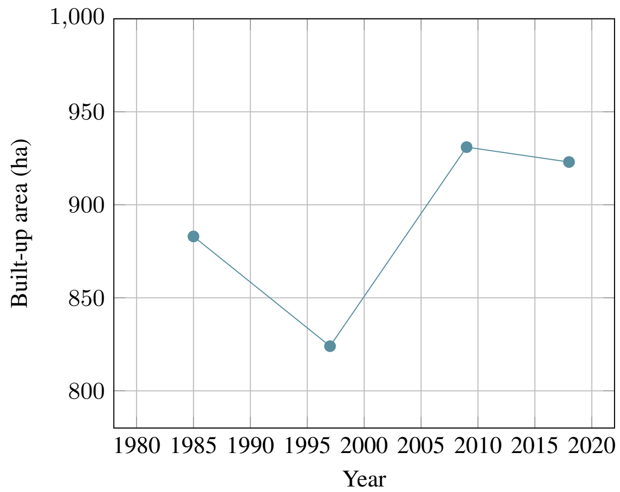

Figure 3. Temporal trend of built-up surfaces from 1979/1985 to 2013/2018 based on Arealstatistik data.

4.3 CORINE Land Cover Dataset

In contrast, CORINE Land Cover estimates are significantly higher, reporting 3221 ha of built-up land in 2018 (Figure 4). The CORINE classification groups all urban and industrial areas under three broad categories: continuous urban fabric (111), discontinuous urban fabric (112), and industrial/commercial units (121), with no further thematic disaggregation. Moreover, the continuous urban fabric class (111) is not even present within the clipped boundaries of the Ticino basin, indicating that CORINE's coarser spatial resolution (minimum mapping unit of 25 ha) and satellite-based classification are less suitable

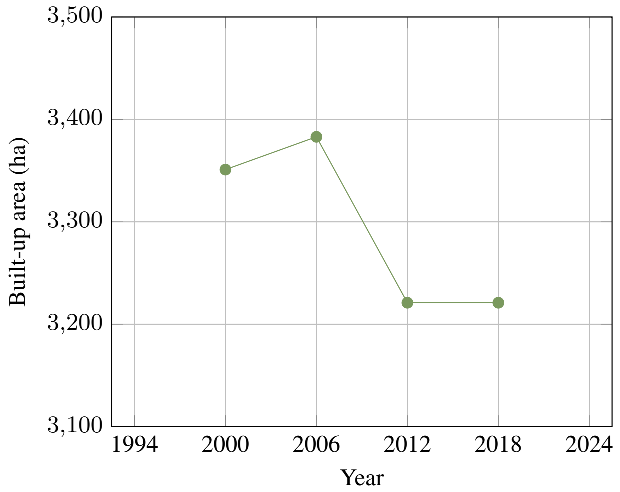

Figure 4. Temporal trend of built-up surfaces based on CORINE Land Cover data.

for detecting detailed urban dynamics in smaller or topographically complex regions such as Ticino. Interestingly, the dataset suggests a decreasing trend in built-up area over time, with values dropping from 3383 ha in 2006 to 3221 ha in 2018, which is counterintuitive given observed urban expansion.

4.4 Comparative Observations

The comparison underscores several key points:

- The Cadastre, with its high spatial and thematic resolution, offers the most reliable estimate of actual built-up area growth over time.
- Arealstatistik provides reasonably aligned results when carefully filtered to match the MODIFFUS compatible "Building" categories.
- Due to its coarser resolution and generalized classes, CORINE appears to overestimate built-up areas and misrepresent local dynamics, making it less suitable for high-precision, subregional analyses.
- Differences in nomenclature, classification logic, and source data (satellite vs aerial vs direct measurement) lead to substantial variations in results, even when nominally analyzing the same land use category.

These discrepancies highlight not only the challenges in data harmonization but also the importance of understanding the context and purpose of each dataset. CORINE, for instance, was never intended for parcel-level analysis but serves as a tool for continental-scale assessments. Arealstatistik, despite its lower resolution, maintains consistent thematic coding and can be used effectively for long-term trend analysis. The Cadastre, being a legal dataset, reflects actual land parcel registration rather than land cover per se, which makes it highly accurate but potentially more conservative in detecting transitional land uses.

A comparison of 2018 values (Figure 5) and the temporal evolution from 2011 to 2018 (Table 3) clearly illustrates these disparities and highlights the importance of dataset selection in LU/LC-based studies. The 2018 analysis utilizes data from

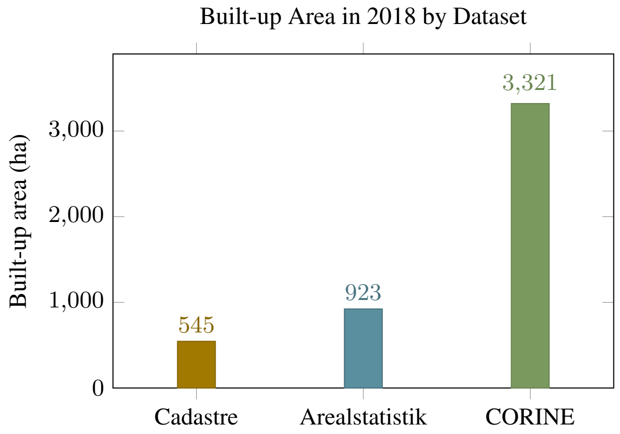

Figure 5. Built-up surface area in 2018 by datasets.

the Cadastre and CORINE datasets, alongside the 2013/2018 survey period from Arealstatistik. The 2011 analysis is based on the 2011 Cadastre data, the 2012 CORINE layer, and the 2004/2009 Arealstatistik period.

Dataset	2011 (ha)	2018 (ha)	2011 (%)	2018 (%)	Change (%)
Cadastre	539	545	0.72	0.73	+1.11
Arealstatistik	824	923	1.1	1.23	12.01
CORINE	3383	3221	4.52	4.30	-4.79

Table 3. Built-Up Area Comparison (2011 vs 2018).

5. Discussion

This comparative analysis reveals substantial differences in built-up area estimates across the three land use datasets analyzed. While each source provides valuable information, their methodological, spatial, and thematic discrepancies lead to divergent interpretations of LU/LC dynamics, particularly in a geographically constrained and topographically complex area like the Swiss portion of the Ticino watershed.

The Cadastre, based on official cadastral surveys and updated annually with high spatial accuracy, shows a consistent and gradual increase in built-up area over time. This trend aligns with expectations of incremental urban development and benefits from the precision of direct land parcel measurements. Since only two land cover classes ("Building" and "Airport") were used to represent built-up surfaces, the results reflect a focused and conservative definition of urban growth.

In contrast, Arealstatistik provides built-up surface estimates by classifying point samples, each representing 1 hectare. While the aggregated totals for building-related classes (e.g., 529 ha in 2018) are remarkably close to the Cadastre's estimates (524 ha), the broader "built-up area" category includes additional land use types such as construction sites, industrial zones, and disused settlements. This leads to higher totals (e.g., 923 ha in 2018), but also introduces fluctuations not strictly related to long-term urbanization trends. For instance, some land classified as "built-up area" (e.g., construction sites) in one survey period may revert to non-urban classes in the next, such as grassland or urban green, depending on its use at the time of survey. This temporal inconsistency can obscure real development patterns.

On the other hand, CORINE Land Cover consistently overestimates built-up area, reporting 3221 ha in 2018, more than five times the Cadastre's value. This discrepancy arises from its coarse spatial resolution (minimum mapping unit of 25 ha, based on satellite imagery with 100 m pixel size), limited thematic granularity (only three relevant urban classes), and generalized mapping approach. Additionally, CORINE lacks a "continuous urban fabric" class within the study area, reflecting its limited ability to capture compact urban settlements in smaller alpine basins like Ticino. Contrary to expected development patterns, the apparent decrease in built-up area over time in the CORINE dataset further illustrates its limitations in small-scale or high-resolution applications.

Importantly, the similarity between Cadastre and Arealstatistik building-only values (e.g., 524 vs. 529 ha in 2018) is encouraging. It suggests that, despite their different methodologies and spatial resolutions, both datasets can converge when carefully filtered using a shared classification logic, such as that defined by MODIFFUS 3.1. This funding underlines the importance of clear LU/LC class selection, mainly when used as input for environmental models.

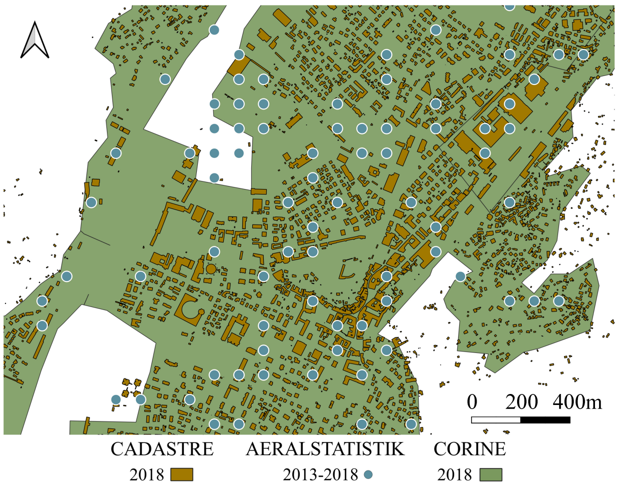

Figure 6. Built-up surface area in the Ticino watershed according to the three datasets used: Cadastre (2018), Arealstatistik (2013/2018), and CORINE Land Cover (2018).

Nevertheless, discrepancies in class definitions across datasets remain a significant source of uncertainty. For instance, many categories considered built-up in Arealstatistik (e.g., wastewater treatment plants, energy supply infrastructure) are often mapped differently or not explicitly distinguished in the Cadastre, where they may fall under more generic land cover types such as "garden," "lawn," or "other hard covering." This highlights how thematic harmonization, not just spatial or temporal alignment, is critical for integrated LU/LC analysis.

These findings also point to broader implications for models such as MODIFFUS, which rely heavily on accurate land use data to estimate diffuse nutrient emissions. Since different LU/LC datasets yield different built-up area estimates, model outputs such as nitrogen and phosphorus loads could vary significantly depending on the input source. This emphasizes the need for careful dataset selection and class mapping when performing watershed-scale modeling or scenario assessments.

Finally, while this paper focuses on only one LU/LC category, built-up surfaces, future research will expand the comparison to all 18 MODIFFUS categories. Earlier models (Prasuhn and Mohni, 2003) used only 10 broader land use classes, with urban zones treated as a single aggregated category. Under those conditions, generalized datasets like CORINE were better suited to serve as LU/LC inputs. However, as modeling frameworks evolve toward greater thematic resolution, more detailed and accurate datasets like the Cadastre or Arealstatistik will likely prove more reliable.

6. Conclusions

This study presented a comparative assessment of three land use/land cover (LU/LC) datasets, Arealstatistik, CORINE Land Cover, and the Ticino Land Use Cadastre, focusing on the "Built-up surfaces" category within the Swiss part of the Ticino watershed. We quantified built-up areas across multiple years through harmonized spatial preprocessing and consistent class mapping based on MODIFFUS 3.1 land use definitions. We revealed significant differences in absolute values, trends, and thematic granularity.

The results show that:

- The Cadastre dataset, with its high spatial accuracy and detailed geometry, offers a consistent and realistic representation of built-up area evolution over time, confirming expected patterns of gradual urban expansion.
- Arealstatistik, while lower in spatial resolution, provides comparable values when filtered to include only building-related categories, demonstrating its potential as a robust LU/LC source for long-term analyses.
- CORINE Land Cover substantially overestimates urban surfaces due to its coarser resolution and broad classification logic, making it less suited for localized or high-resolution studies like this one.

These discrepancies directly affect downstream applications, particularly process-based models like MODIFFUS, which depend on reliable LU/LC data to estimate diffuse nutrient emissions. The analysis highlights the importance of carefully selecting LU/LC sources based on a given study's scale, thematic requirements, and modeling objectives. While this work focused on a single LU/LC category, future research will extend the comparison to all MODIFFUS land use classes. This broader analysis will further support integrated environmental modeling and spatial planning in alpine and pre-alpine regions, where land use dynamics and climate pressures increasingly intersect.

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