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Inventory and functional classification of ponds based on Sentinel-2 NDWI data in the Sovytsia Kitsmanska River basin (Ukraine)

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RESEARCH ARTICLE

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Abstract. The article presents a methodology for creating a unified digital database of ponds in the Sovytsia Kitsmanska River basin and their classification by area and degree of current utilisation using open geospatial data and the desktop GIS QGIS 3.34. Within a single GIS project, Sentinel-2 L2A satellite images, Google orthophotos, OpenStreetMap and Visicom cartographic basemaps, as well as the Copernicus DEM were integrated, which ensured full coverage of the basin and made it possible to reliably visually identify pond basins and associated waterlogged areas. Based on the NDWI index calculated in the QGIS raster calculator, the contours of open water surfaces and waterlogged areas were delineated, digitised as polygons and merged into a GeoPackage database, followed by reprojection to the metric coordinate system WGS 84 / UTM zone 35N for correct area determination. For each pond, the area of the water surface was calculated in square metres, hectares and square kilometres, and a two-level classification scheme was implemented: by functional status (actively exploited, abandoned, under reclamation) and by five area classes (<0.5; 0.5–1; 1–5; 5–10; >10 ha). In total, 397 ponds were identified in the basin, of which 259 are actively exploited, 81 are abandoned and 57 are under reclamation. It is shown that the most numerous are the smallest water bodies (with an area of up to 0.5 ha), which account for about two fifths of the total number but provide only a small share of the total water surface area. In contrast, the largest ponds (>10 ha), being relatively few in number, accumulate most of the area of regulated waters. The proposed methodology demonstrates that combining open satellite data, index analysis (NDWI), manual vectorisation and the statistical tools of QGIS makes it possible to obtain a simple, reproducible and scalable scheme for the inventory of small water bodies. The resulting database and pond classification can be used for quantitative assessment of flow regulation, identification of priority areas for reclamation and support of decision-making in the field of local water use and spatial planning in agricultural landscapes.

Ponds are an important element of agricultural landscapes and local water systems, yet small water bodies often remain “invisible” to conventional statistics and large-scale inventories, which complicates the assessment of their contribution to flow regulation and the provision of ecosystem services. In the Sovytsia Kitsmanska River

basin, over a long period a dense network of ponds of various purposes and conditions has formed, and the information about them in available sources is fragmented and unsystematic. In such a situation, methods that make it possible, on the basis of open geospatial sources and GIS tools, to carry out a complete inventory of ponds, accurately determine their area and consistently describe the degree of their current use become particularly relevant. The aim of this study is to create a unified digital database of ponds in the Sovytsia Kitsmanska basin in the QGIS environment and to develop a two-level classification that combines a division by water surface area with the functional status of ponds. The proposed scheme is intended to provide a simple and reproducible basis for further analysis of the structure of the pond network, monitoring of changes and support of practical decisions in the field of local water use and spatial planning

1. INTRODUCTION

In Ukraine, a long-standing set of challenges persists related to the conservation of small and medium-sized rivers, the environmental condition of their catchments, and the completeness of representation of water bodies in the official water-resources inventory (Hopchak & Basiuk, **2014**; Hopchak, **2021**;Vyshnevskyi, **2000;** Kostyshyn et al., **2006**; Hrebin et al., **2014;** Kovalchuk et al., **2023**; Kozmuk et al., **2007**; Palamarchuk & Zakorchevna, **2001**). Within this context, one of the least well-inventoried components of the water fund remains artificial water bodies, primarily ponds. They constitute the most widespread form of small water bodies, densely distributed along the valleys of small rivers, their tributaries, and gully–ravine systems, especially in agriculturally developed landscapes.

Ponds play a significant role in shaping local runoff, regulating flood and stormflow waves, trapping and storing sediments, reducing the export of pollutants, and meeting the needs of irrigation, fish farming, recreation, and local water supply for rural areas (Vyshnevskyi, **2000;** Kostyshyn et al., **2006**; Hrebin et al., **2014**). At the same time, many of these impoundments were constructed in different historical periods, often without unified design standards or consistent project documentation; a considerable number of ponds have been reconstructed, some have fallen into disrepair, and others have been transformed. As a result, the spatial characteristics and actual functional status of a large proportion of ponds are not harmonised across different information systems: the water cadastre, the land cadastre, local land-management documentation, and actual land use (Palamarchuk & Zakorchevna, **2001;** Kozmuk et al., **2007**).

The legal framework governing the functioning of ponds is defined by the Water Code of Ukraine, the Land Code of Ukraine, and the special Law of Ukraine of 2011 amending the Water and Land Codes with respect to riparian buffer strips [Law of Ukraine, 2011; Land Code of Ukraine, 2001; Water Code of Ukraine, 1995]. These documents specify the concept of artificial water bodies, general requirements for their use, the attribution of land under ponds and hydraulic structures to the water-fund lands, as well as restrictions on economic activities in adjacent areas. However, in practice the legislative provisions are applied only fragmentarily: some ponds lack an appropriate legal status, their boundaries have not been delineated in the field or represented in digital form, which complicates both water-resources management and enforcement of water-protection regulations (Hopchak & Basiuk, **2014;** Yushchenko, **2019**).

Regional syntheses of the water fund and land resources of Bukovyna demonstrate that ponds and small reservoirs constitute a substantial share of artificial water bodies in Chernivtsi Oblast (Kostyshyn et al., **2006**; Kozmuk et al., **2007;** Hrebin et al., **2014).** At the same time, reference and cadastral materials often record only the largest impoundments, whereas small and medium-sized ponds scattered across headwater and minor catchments remain partially unaccounted for or are described without precise coordinates and surface areas. This creates a significant gap between actual water use within the agricultural landscape and the official statistics on the regional water fund. In parallel, contemporary hydrology and geoecology are showing growing interest in combining the river-basin approach with digital inventories of water bodies and their representation in systems of digital atlas cartography (Kovalchuk et al., **2023**).

The Sovytsia Kicmanska River basin within Chernivtsi Oblast is a representative example of an agriculturally transformed river-basin system with a high density of ponds of different sizes and functional types. A considerable proportion of these water bodies is located directly in the valley of the main watercourse or on its tributaries, while others are situated in gullies and on hillslopes. For many ponds, up-to-date information is lacking regarding water-surface area, shoreline configuration, degree of flow regulation, and the current mode of use. This makes it impossible to properly assess their contribution to the basin's hydrological regime and ecosystem services.

In this context, geoinformation and remote-sensing methods for the inventory of small water bodies acquire particular importance, as they make it possible to address, simultaneously, the tasks of detection, accurate delineation, and classification of ponds based on satellite imagery and open-access cartographic data (Kovalchuk et al., **2023;** EU Water Framework Directive, **2006**). The use of Sentinel-2 satellite scenes in combination with water indices (in particular NDWI) enables the semi-automatic extraction of open-water surfaces, while the QGIS environment provides integration of these outputs with a digital elevation model, the river network, and the administrative–territorial division.

In this article, we consider the Sovytsia Kitsmanska River basin as a model area for detailed pond inventory based on Sentinel-2 satellite imagery and for constructing a digital pond database in QGIS. The aim of the study is to develop a single, internally consistent database of ponds within the Sovytsia Kitsmanska basin, including the determination of their surface area and planform configuration, as well as to elaborate a two-level classification that accounts for both size characteristics and the degree of development/use (intensity of exploitation) of these water bodies. The resulting database and classification are viewed as an essential geoinformation foundation for further hydrological and geoecological research, for comparing the actual structure of the water fund with official reference data, and for supporting integrated river-basin management of small rivers in Western Ukraine.

2. MATERIALS AND METHODS

2.1. Geoinformation environment and integration of heterogeneous data in QGIS. The data foundation of this study is a single geoinformation project created in the desktop GIS QGIS 3.34, within which all spatial datasets required for the identification and analysis of ponds and associated wetland areas in the catchment of the small river Sovytsia Kitsmanska were integrated. QGIS acts as an aggregator of sources that differ in origin and spatial resolution, ensuring their spatial consistency, a common coordinate reference system, and the possibility of subsequent metric calculations of areas and lengths. This approach is consistent with current practice in hydrological and water-management research, where QGIS is increasingly used as a primary environment for working with open cartographic web services, satellite imagery, and derivative terrain models (QGIS Development Team, **2024**; Velychko & Dupliak, **2025**; Zoological Society of London, **2023**).

To provide the most complete and up-to-date visualisation of the basin state, several online basemaps were connected via the XYZ tiles mechanism. The Google satellite basemap was loaded in the lyrs=s mode, which provides high-resolution orthophotos of sufficient quality for reliable visual identification of pond outlines, drainage and reclamation canals, dam structures, field tracks, shelterbelts, and small built-up elements. The connection was implemented in the standard way for QGIS by adding a new XYZ resource with the (Джерело; Dahal, **2020**) , after which the

"Google" layer served as a background for manual on-screen digitising and visual validation of other layers.

The temporal currency of the Google satellite basemap was verified using Google Earth / Google Earth Pro, where the acquisition date of the satellite scene is displayed for the same territory. For the Sovytsia Kicmanska basin area, it was established that the up-to-date orthophotos actually pulled into QGIS correspond to an acquisition from early autumn 2024. This matches autumn land-use and hydrological conditions, when most field operations have been completed, the vegetation cover is partially reduced, and the outlines of open water surfaces and waterlogged sections of ponds are clearly discernible. Such temporal referencing is important for correctly comparing these data with other satellite products and for subsequent interpretation of pond status (actively operated, abandoned, under reclamation) (Yu et al., **2020**; Smith et al., **2022**).

A second basic source was the vector-oriented OpenStreetMap basemap, connected as an XYZ service (https://tile.openstreetmap.org/{z}/{x}/{y}.png). It was used as a structural "framework" for spatially referencing the hydrography and ponds to the road network, settlement boundaries, linear engineering infrastructure, and hydrographic features. Such integration of open vector databases with remote-sensing data in QGIS is typical of contemporary studies on the inventory of waterbodies and wetlands (Amoah, **2022**; Kim et al., **2022).**

An important refinement of local hydrography and land-use elements was provided by large-scale Visicom Maps, which were connected to the QGIS project as a separate web basemap. In contrast to OpenStreetMap, Visicom cartography offers a higher density of mapped features and a more precise depiction of small-scale elements. This is particularly important in an anthropogenically transformed basin, where the channels of small rivers are often straightened or diverted into artificial canals, and pond outlines are partly obscured by tree and shrub vegetation. Comparing the modelled river network and ponds delineated from satellite imagery with Visicom Maps made it possible to refine the locations of individual water bodies, their connections with drainage canals, and the actual configuration of pond basins.

One of the satellite bases for interpreting water bodies and waterlogged areas comprised Sentinel-2 L2A imagery from 26.10.2025. These multispectral scenes (bands B1–B12), with spatial resolution ranging from 10 m to 60 m, were obtained via the Copernicus Data Space Browser and imported into QGIS as separate GeoTIFF layers for each band. The use of a true-colour composite allowed us to visually distinguish open water surfaces from waterlogged segments of pond basins. The combination of Sentinel-2 data with high-resolution Google orthophotos enabled us to simultaneously ensure metric accuracy of measurements and a high degree of reliability in visual image interpretation (Buzey & Pasichnyk, **2025**; Rapinel et al., **2019, 2023;** Pasichnyk, **2024**; Pasichnyk et al**., 2025**).

All of the above sources – Google Satellite, OpenStreetMap, Visicom Maps, Sentinel-2 L2A – were integrated into a single QGIS project. The working coordinate reference system for on-screen visualisation was WGS 84 / Pseudo-Mercator (EPSG:3857), which underlies most web basemaps. For any metric computations (pond surface area, channel length, drainage density of the hydrographic network), vector and raster layers were exported or reprojected to WGS 84 / UTM zone 35N (EPSG:32635), which provides metric units (metres) and minimises distortions within the territory of Chernivtsi Oblast. This practice – combining web basemaps in a "screen" projection with analytical layers in a metric UTM system – is standard in most contemporary studies where QGIS is used as an environment for integrating open geospatial data and performing hydrological calculations (QGIS Development Team, **2024**; Velychko & Dupliak, **2025**).

Water bodies identified through visual image interpretation – the main river channel, tributaries, drainage canals, and ponds with varying degrees of integrity – were digitised on top of the aforementioned basemaps as vector features (line and polygon layers). A dedicated polygon layer/database in GeoPackage format was created for ponds, in which each pond is represented by an individual polygon tied to a common coordinate reference system and, in subsequent stages, supplied with a set of attributes (area, use category, operational status). Such a unified polygonal database of water bodies is consistent with methodological recommendations for digitising pond layouts in QGIS (Zoological Society of London, **2023**) and aligns with current practice in building geoinformation databases for analysing aquaculture and other pond-based systems (Yu et al., **2020;** Buzey & Pasichnyk, **2025;** Pasichnyk, **2024).**

In summary, QGIS 3.34 in this study performs several key functions: (1) integrating heterogeneous open-source datasets (web basemaps, Sentinel-2 imagery) within a single spatial framework; (2) ensuring their spatial and temporal consistency; (3) creating and editing the vector database of ponds and the hydrographic network; and (4) preparing data for subsequent analytical operations – calculation of areas, classification of ponds by size and degree of development/use, and analysis of the structure of flow regulation within the Sovytsia Kitsmanska basin.

2.2. Spectral analysis of satellite imagery and use of the QGIS Raster Calculator.

After the visual delineation of pond outlines and the main elements of the hydrographic network, the next step was spectral discrimination of surface types within the pond basins and on the adjacent floodplain. For this purpose, all available Sentinel-2 L2A bands (B1–B12) for the scene dated 26 October 2025 were loaded into the QGIS project, and subsequent analysis was performed using the Raster Calculator tool with the following expression: NDWI = (B3 − B8) / (B3 + B8). This approach is consistent with current practice in mapping wetlands and small waterbodies, where it is recommended to combine classical visual image interpretation with the construction of simple spectral indices and threshold-based class separation in open-source GIS environments, primarily QGIS (Buzey, Pasichnyk, **2025**; QGIS Development Team, **2024**; Vudvud et al., 2024; Amoah, 2022; Pasichnyk et al., **2025**).

At the first stage, basic raster layers with a harmonised spatial resolution of 10 m were prepared for the selected Sentinel-2 scene for the key bands required to calculate NDWI: the green band (B3) and the near-infrared band (B8). To visualise the NDWI results for the Sovytsia Kitsmanska basin, a map was produced corresponding to that shown in Fig. 1. The NDWI raster was displayed using the “singleband gray” rendering mode without inversion of the colour ramp: low and negative index values are rendered in dark-gray to almost black tones, whereas high positive values correspond to light-gray and white tones. Under such settings, the open water surface of the river and ponds, where NDWI attains its highest values, appears on the map as distinct white patches of various shapes and sizes, clearly visible against the darker background of agricultural land and built-up areas. Transitional zones with partial vegetation cover, shallow water, or waterlogged soils exhibit intermediate index values and are accordingly represented in light- or medium-gray tones, forming “halos” around the white patches of open water.

Along the main valley of the Sovytsia Kitsmanska River, the map clearly shows a chain of elongated white patches corresponding to water-filled channel reaches and a system of ponds of varying surface area; distinct clusters of bright patches mark groups of ponds within rural settlements, whereas small white “threads” indicate minor canals or local widenings of the river channel. Subsequent visual cross-checking against the Sentinel-2 true-colour composite and the Google and Visicom basemaps demonstrated that this interpretation accurately reflects the real spatial pattern: white NDWI patches coincide with pond basins and open-water reaches of the river, light-gray tones correspond to reedbeds and wet floodplain meadows, while the dark background is associated with arable land, forest stands, and built-up areas. This confirms the correctness of the applied threshold and supports the use of this NDWI map as a primary reference layer for subsequent vectorisation of surface-water bodies and waterlogged areas.

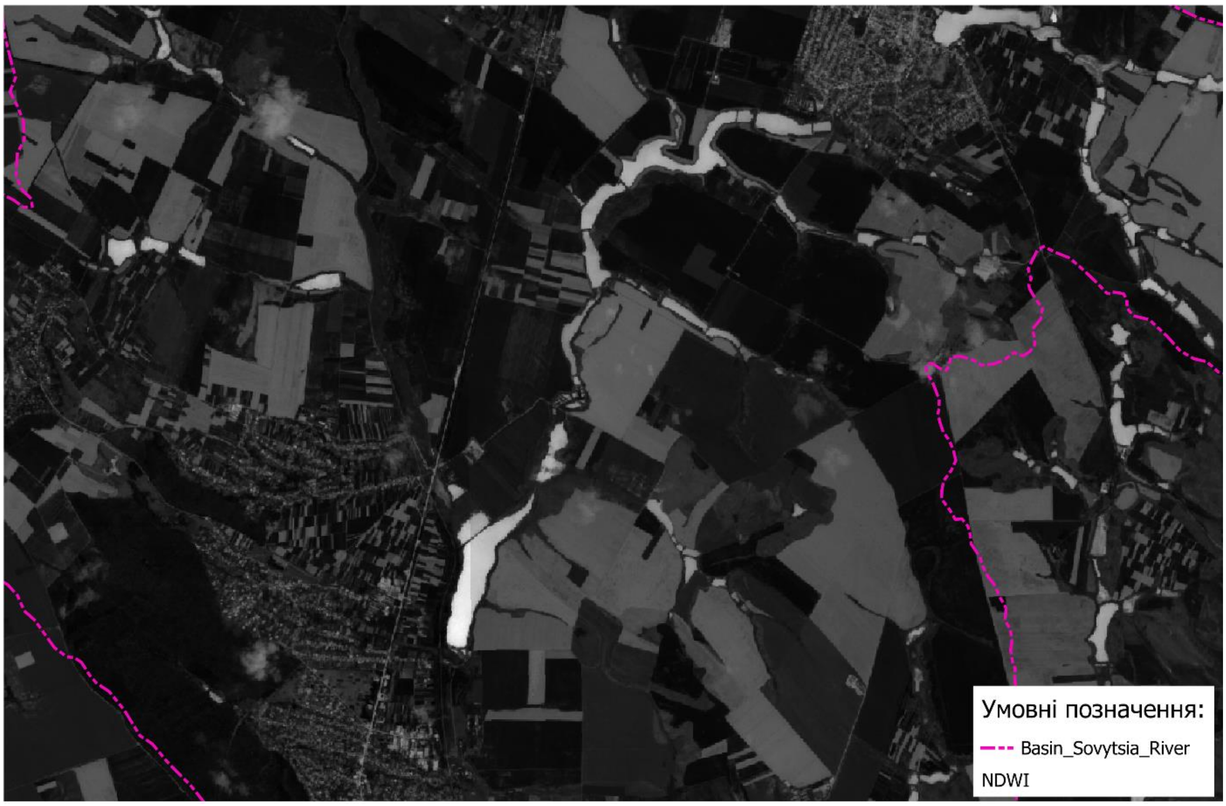

Fig. 1. Spatial distribution of NDWI values in the middle course of the Sovytsia Kitsmanska River (10 m spatial resolution) with the river basin outline.

2.3. Methodology for determining pond areas in the QGIS environment

The digitised pond polygons (based on the aforementioned maps and the NDWI layer generated in this study) were merged into a single GeoPackage database, which provides a convenient means of storing and editing a large number of features, supports topological control, and allows the dataset to be continuously extended with new attribute fields. This approach is consistent with recommendations on the use of open-source GIS in conservation practice and hydrology, where GeoPackage is regarded as a primary format for QGIS-based projects due to its combination of capacity, performance, and portability (Chaskovskyi et al., **2021**; Nielsen et al., **2017**; QGIS, **2024**). The initial digitisation of pond outlines was carried out in a project using the geographic coordinate reference system WGS 84 (EPSG:4326), in which coordinates are expressed in degrees of latitude and longitude. Under these conditions, the use of built-in area-calculation functions leads to substantial planimetric errors, a problem that is well known and explicitly highlighted in manuals on the application of QGIS to hydrological tasks (Van Der Kwast & Menke, **2022**; Passy & Thery, **2018**).

To ensure metric correctness of the calculations, the working pond layer was reprojected to the Universal Transverse Mercator projection WGS 84 / UTM zone 35N (EPSG:32635), which is appropriate for the territory of Chernivtsi Oblast and uses metre-based coordinates. Reprojection was performed via the “Export → Save Features As…” command, selecting the GeoPackage format, a new layer name, and the EPSG:32635 coordinate reference system. The result was the layer “area — data_base_ponds_of_sovytsia_kitsmanska”, which was subsequently treated as the base layer for all metric operations. Similar steps are described in studies on catchment delineation and hydrological computations for small rivers, where the necessity of switching from geographic coordinates to projections with a metric scale is emphasised (Enriquez, **2022**; Bespalko & Hutsul, **2021**).

The subsequent determination of polygon areas was carried out directly in the attribute table of the "area — data_base__ponds_of_sovytsia_kitsmanska" layer using the Field Calculator. Since the further analysis of ponds – comparison with land use, assessment of the share of pond area in the catchment structure, and interpretation of results in the text of the article – is most convenient in hectares, the next step was to create the Area_ha attribute. To this end, the already computed area in square metres was used so as to avoid repeated geometric operations. In edit mode of the attribute table, the Field Calculator was set to "Update existing field", the Area_ha field was chosen as the target, and the following expression was entered in the expression window: "Area_m2" / 10000. Thus, the transformation was performed not by recomputing $area, but by a simple unit conversion, which minimises the risk of discrepancies between different attributes and follows the logic of "one geometric computation – multiple derived fields" (Nielsen et al., **2017**; QGIS, **2024**). After confirming the command, QGIS sequentially processed all records, populating Area_ha with pond areas in hectares to the specified level of precision.

For the purposes of generalised hydrological assessments and comparison with other area-based indicators within the basin, an additional field Area_km2 was created, in which pond area is expressed in square kilometres. In this case, the Field Calculator expression "Area_m2" / 1,000,000 was used. As a result, each pond is characterised by three mutually consistent areal metrics (see Fig. 2): the water-surface area in square metres (Area_m2), in hectares (Area_ha), and in square kilometres (Area_km2). This practice of parallel storage of area values in different units is widely used in studies that assess the degree of flow regulation and the role of small waterbodies in shaping the catchment water balance (Passy & Selles, **2018**).

For each of the defined pond classes, the fields Area_m2, Area_ha, and Area_km2 were successively computed in the same projection, WGS 84 / UTM zone 35N (EPSG:32635), which ensured full comparability of areas between groups and enabled subsequent calculation of total areas and statistical descriptors within each pond type. The attributes obtained in this way are further used for quantitative evaluation of the contribution of actively operated ponds to runoff regulation, for analysing the potential for restoring the hydrological regime in reclamation sites, and for spatial delineation of zones occupied by degraded (abandoned) waterbodies.

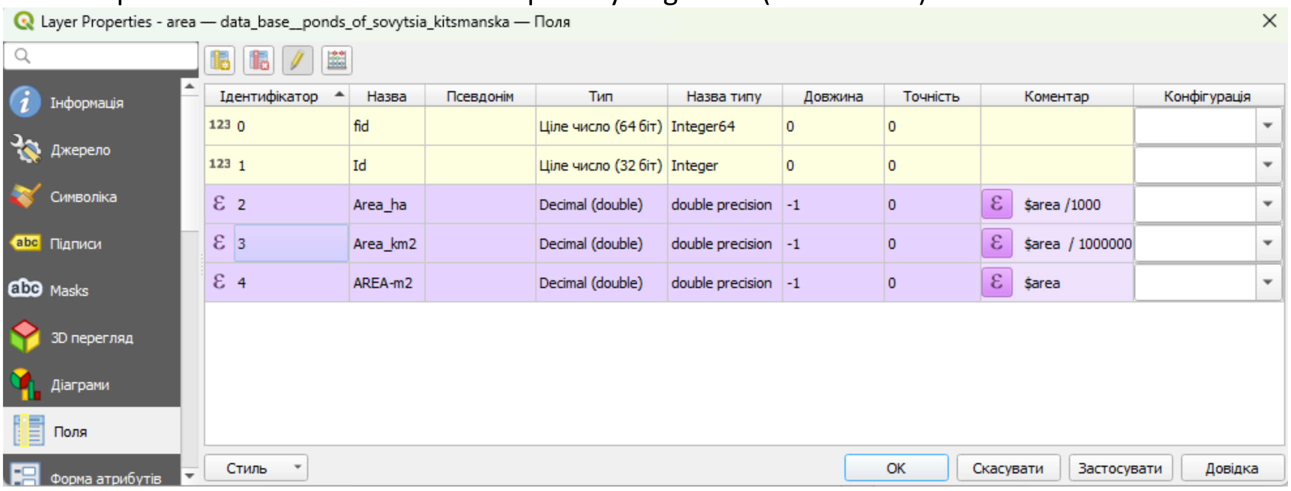

Fig. 2. Configuration of attribute fields for storing pond areas (m², ha, and km²) in the data_base_ponds_of_sovytsia_kitsmanska layer in QGIS 3.34.

After completion of the attribute transformations, all edits in the GeoPackage layer were saved by exiting the edit mode. The resulting fields then served as the basis for statistical analysis within QGIS. Using the "Statistical Summary" tool ("View – Statistical Summary – Statistics"), the following metrics were derived for the Area_ha field: total pond area within the Sovytsia Kitsmanska basin, minimum, maximum, mean and range of pond areas, as well as the standard deviation. In addition, the attribute table records were sorted by Area_ha values in order to identify groups of the smallest and largest ponds, which were subsequently used in the size-based classification. Similar procedures – combining geometric calculations with the basic statistical tools of QGIS – are described in studies devoted to hydrological applications of this GIS, particularly for calculating the areas of reservoirs, catchments, and inundation zones (Van Der Kwast & Menke, **2022**; Falasy & Cooke, **2024**).

2.4. Classification of ponds by area and degree of development

Based on the area characteristics obtained in QGIS, a two-level classification scheme was developed that divides ponds into classes according to their functional status (degree of development/use) and size. This approach is in line with current trends in the inventory of small waterbodies, where both size (water-surface area) and functional state (active, abandoned, under reclamation) jointly determine the role of a waterbody in the hydrological regime and ecosystem services of the basin (Yu et al., **2020**; Smith et al., **2022**; Wachholz et al., **2025**).

The first level of classification concerned the functional status of ponds, i.e. the degree of their development and actual use. On the basis of a combined analysis of:

1. identification of water surfaces on Sentinel-2A multispectral imagery using the NDWI index;
2. visual interpretation of Google and Sentinel-2A satellite imagery, as well as Visicom and OpenStreetMap basemaps;
3. presence/absence of clear signs of use (access roads, hydraulic infrastructure, feeding platforms, etc.) and the occurrence of dense vegetation over a substantial part of the pond area,

all ponds were allocated to three categories of functional status:
– "actively operated" – open water surface predominates, waterlogged or marshy zones occupy less than 50% of the pond basin; there are clear indications of regular water use or fish farming;
– "abandoned" – more than 50% of the basin area is covered by marsh vegetation or shallow overgrown zones; hydraulic infrastructure is visibly degraded or absent;
– "under reclamation" – a substantial part of the pond basin has been drained; earthworks are evident; the basin is segmented into areas of differing depth, with possible combinations of open water, fresh earth embankments, and local vegetation patches.

The second step was the classification of ponds by area. From a technical standpoint, class assignment was performed entirely within QGIS by means of the Field Calculator, where appropriate expressions were specified to derive the size classes directly from the Area_ha and Area_km2 attributes.

A similar three-tier logic of "active – abandoned – under rehabilitation" is applied in studies devoted to the monitoring of fish ponds and aquaculture. For example, Dumalag et al. (**2024**), using radar data, classify fishponds as active, abandoned and other states based on surface structure and the dynamics of surface-water inundation (Dumalag et al., **2024**), while Gusmawati et al. (**2018**) distinguish active and inactive (including overgrown) shrimp-farm ponds according to the characteristics of the water surface in multi-temporal very-high-resolution imagery (Gusmawati et al., **2018**). In manuals on mangrove ecosystem rehabilitation, fish ponds are likewise divided into operational, "inner abandoned" and those earmarked for reconversion to natural vegetation (Primavera et al., **2012**).

For the Sovytsia Kitsmanska River basin, we propose five pond-area classes:
1 – less than 0.5 ha;
2 – 0.5–1 ha;
3 – 1–5 ha;
4 – 5–10 ha;
5 – more than 10 ha.

The practical implementation of this classification was carried out in QGIS 3.34 through stepwise selection and filtering of features using expressions applied to the Area_ha field. For the first group (ponds smaller than 0.5 ha), the “Select by Expression” dialog was used with the logical expression "Area_ha" > 0 AND "Area_ha" < 0.5, which excludes zero or erroneous area values and retains only genuinely very small ponds. After applying the expression, QGIS highlighted all corresponding polygons in yellow; the number of objects in this group was determined from the Selected indicator in the bottom line of the attribute table and, where necessary, refined using the “Field Statistics” tool (with the Count value for the Area_ha field calculated under the “selected features only” option). In an analogous manner, the expression "Area_ha" > 0.5 AND "Area_ha" < 1 was used for the second group, "Area_ha" > 1 AND "Area_ha" < 5 for the third, "Area_ha" > 5 AND "Area_ha" < 10 for the fourth, and "Area_ha" > 10 for the fifth, largest group.

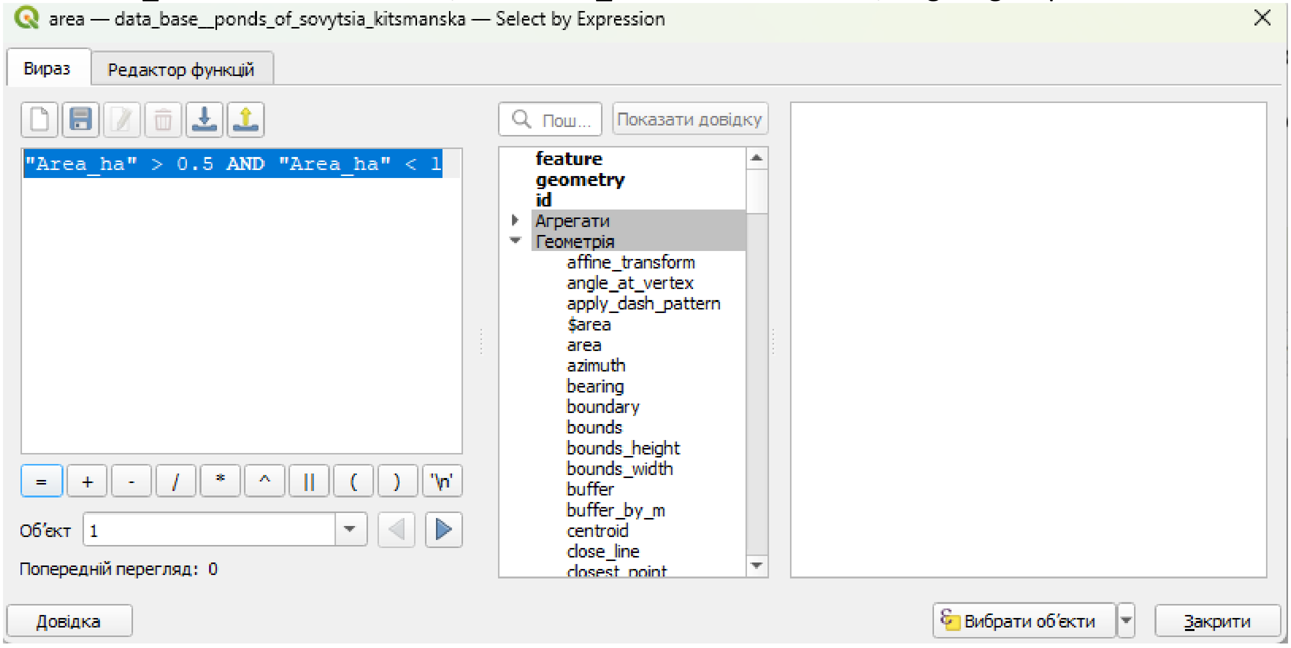

Fig. 4. Selection of pond polygons with an area of 0.5–1.0 ha in the area_data_base_ponds_of_sovytsia_kitsmanska layer using the Select by Expression tool in QGIS 3.34.

After each step, the selected features were, where necessary, additionally filtered using the “Show only selected features” mode. This made it possible to analyse the area statistics separately within each size interval while retaining the linkage to the original layer and the full dataset. Such stratification combines threshold values for “micro-” and “small” wetlands and ponds (0.5–1 ha), which are widely reported in the literature, with the commonly used upper limit of 5 ha for classifying a waterbody as a pond (Wang et al., **2025;** Valerio et al., **2024**; Wachholz et al., **2025**). A number of studies have shown that waterbodies smaller than 0.5–1 ha are often “invisible” to global or regional inventories, yet at the same time have high ecological significance (Smith et al., **2022**; Kim et al., **2022**); therefore, the smallest, separate class in our scheme is justified not only cartometrically but also ecologically.

In addition, the above-described procedure of area calculation and class assignment was applied in full to three thematic layers corresponding to different functional types of ponds in the Sovytsia Kitsmanska basin. The layer “area — data_base__ponds_of_sovytsia_kitsmanska” represents actively operated ponds; the layer “area — data_base_reclamation_ponds_of_sovytsia_kitsmanska” contains ponds that are in a stage of reclamation; and the layer “area — data_base_abandoned_ponds_of_sovytsia_kitsmanska” comprises abandoned ponds (Figs. 5–10).

The classification scheme for ponds proposed in this study is grounded in open methodological sources but has been adapted to the local specifics of the Sovytsia Kitsmanska basin. Unlike purely remote-sensing-based classifications that rely solely on radar or optical indices (Yu et al., **2020**; Dumalag et al., **2024**), we combine spectral indicators with detailed visual interpretation and local expert knowledge of the basin. This combined approach is consistent with recommendations from recent review papers on small waterbodies and wetlands, which emphasise that "composite" indicators (size + condition + land-use context) are the most informative for decision-making in water-resources management and spatial planning (Amoah, **2022**; Wachholz et al., **2025**).

3. RESULTS AND DISCUSSION

3.1. Integration of open data sources in QGIS and the spatial pattern of ponds

The integration of the Copernicus DEM, Sentinel-2 L2A imagery (True Color composite for 26 October 2025), online basemaps from Google, OpenStreetMap and Visicom, as well as vector layers of hydrography and administrative boundaries in the QGIS 3.34 environment made it possible to construct a single digital hydrographic model of the Sovytsia Kitsmanska River basin. It was precisely the combination of these sources that enabled the detection and on-screen digitising of all ponds in the basin. Once the digitising and classification procedures were completed, each pond was assigned attributes describing its area and utilisation status, and all layers were transformed into a common map projection, which ensured the correctness of subsequent metric calculations.

Visually, the largest waterbodies form chains in the upper, middle and lower parts of the valley, which is clearly visible in the QGIS map window (see Fig. 3). This structure confirms that even within a relatively small lowland catchment, the anthropogenic transformation of the valley has a distinct hierarchical character: small ponds tend to cluster near the mouth reaches of minor gullies and polder systems, whereas larger impoundments are associated with the main valley and its largest tributaries.

The results obtained are consistent with studies that highlight the advantages of the open-source QGIS software for comprehensive integration of hydrological and cartographic data. Nielsen et al. **(2017)** and Van der Kwast & Menke **(2022)** demonstrate that QGIS supports a full modelling workflow for aquatic ecosystems, which fully corresponds to the logic of the processing chain implemented in our study. Placidi et al. (2024) emphasise the importance of careful GIS data post-processing for ecological assessments; in our case, it was precisely the transition from heterogeneous raster and vector inputs to a unified, structured GeoPackage database that became the key prerequisite for the reliability of subsequent quantitative calculations.

3.2. Classification of ponds by area and degree of development

The area-based classification was complemented by a functional typology of ponds according to their degree of utilisation. Based on analysis of surface conditions using all of the aforementioned source materials, each group of ponds in the compiled database was aggregated into a separate polygon layer with corresponding identifiers and labelled as follows:

– "actively operated" – stored in the database as Data_Base_ponds_of_Sovytsia_Kitsmanska;

– "abandoned" – Data_Base_abandoned_ponds_of_Sovytsia_Kitsmanska;

– "under reclamation" – Data_Base_reclamation_ponds_of_Sovytsia_Kitsmanska.

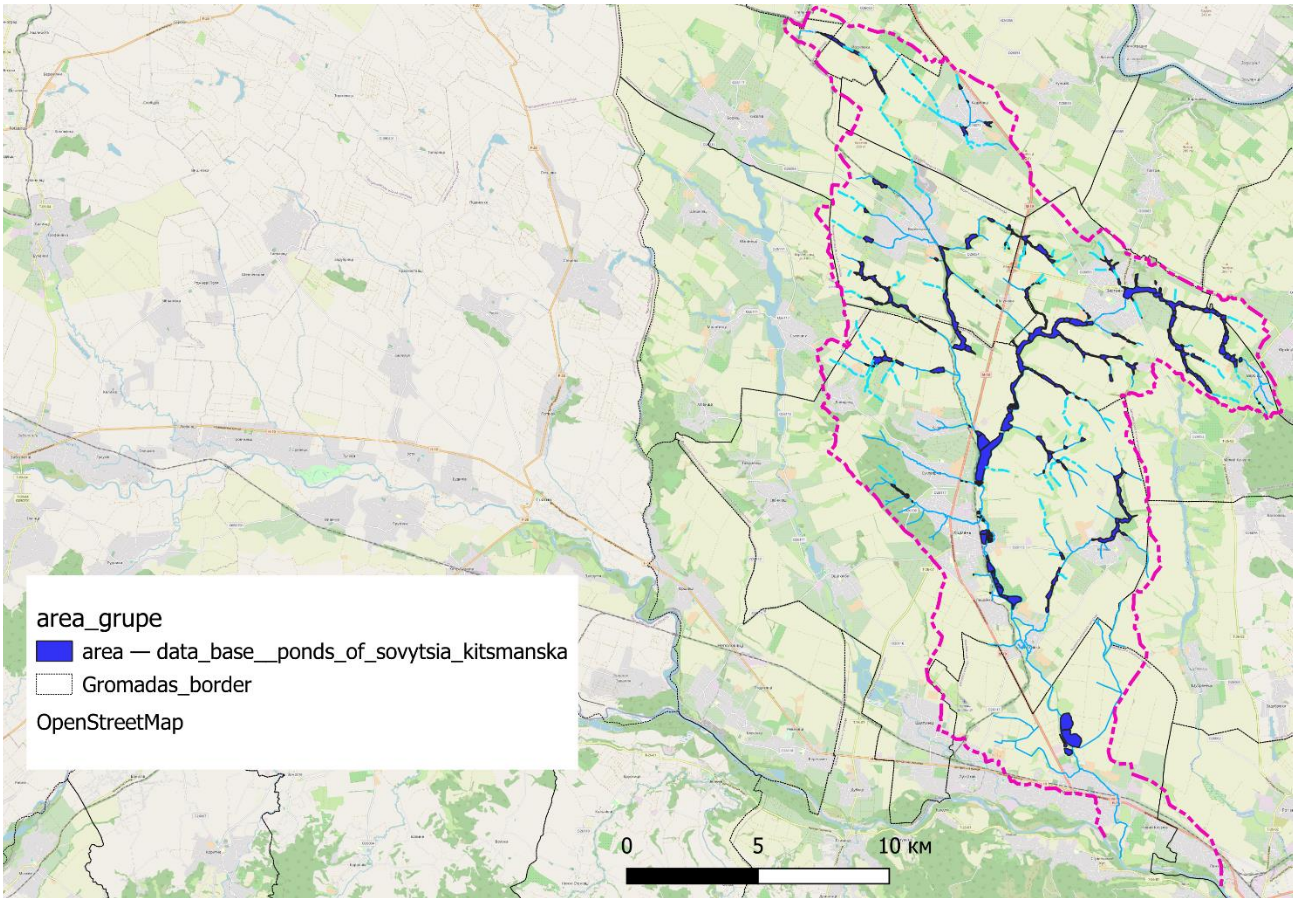

Fig. 5. Spatial distribution of ponds in the Sovytsia Kitsmanska River basin based on OpenStreetMap data.

Figure 6 presents an example of the visual identification of ponds by their current degree of development on a section of the Sovytsia Kitsmanska valley near the town of Zastavna, where all three classes are represented simultaneously. The group of ponds labelled as 1 (Figs. 6–9) corresponds to actively operated waterbodies. On Google and Sentinel-2 (True Color) imagery they are characterised by a continuous open water surface with no extensive patches of emergent aquatic or shoreline vegetation. These features are unambiguously interpreted as operational on the cartographic basemaps OpenStreetMap and Visicom, where their outlines are mapped as waterbodies, and in the vector layer they are classified as ponds_of_Sovytsia_Kitsmanska. NDWI values for this group are consistently high and positive, which is rendered on the index image in light tones and confirms the presence of open water across the entire pond basin.

Group 2 corresponds to ponds in an abandoned state. On the OpenStreetMap and Visicom basemaps their outlines are still depicted as water features; however, analysis of Google and Sentinel-2 imagery shows that approximately half of the basin area is already covered by reed and sedge communities. In the database they are assigned to the class abandoned_ponds_of_Sovytsia_Kitsmanska and are displayed as green polygons. The NDWI index for this group shows substantially lower and spatially heterogeneous values: some sections retain light tones (remnants of open water), whereas overgrown parts appear in darker shades, indicating a reduced area of open water compared with the historical pond footprint. Thus, comparison of the vector classification with Google, Sentinel-2 and NDWI data clearly captures the transition from fully operated to partially degraded and abandoned waterbodies.

Group 3 (Figs. 6–9) comprises ponds in a reclamation stage, for which satellite imagery reveals a mosaic of patches with residual water surface, newly converted agricultural land and strips of moist soils. Accordingly, NDWI yields intermediate values (gray tones) for these features, effectively reflecting their transitional character between actively operated and abandoned ponds.

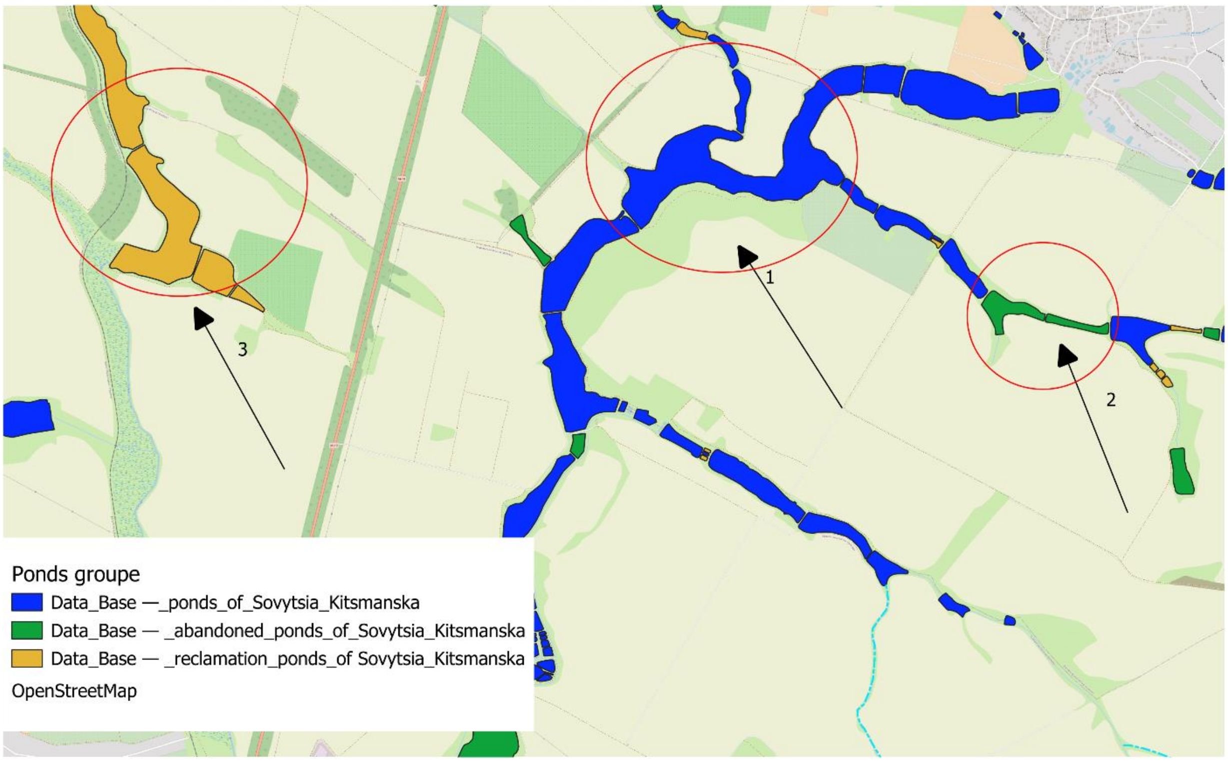

Fig. 6. GIS-based identification and classification of ponds by current degree of development in the Sovytsia Kitsmanska River basin based on OpenStreetMap data.

The results obtained show good agreement with international studies. Yu et al. **(2020),** Gusmawati et al. **(2018),** Smith et al. **(2022),** and Jamroen et al. **(2024)** demonstrate that combining satellite imagery, manual vectorisation in QGIS, and subsequent classification of ponds into active, abandoned, and reclaimed categories constitutes an effective strategy for the spatial inventory of aquaculture and agricultural waterbodies. Primavera et al. **(2012)** and the methodological materials of the Zoological Society of London (2023) emphasise the importance of explicitly identifying "inner abandoned ponds". In our case, a similar approach is transferred to an inland lowland basin, where abandoned ponds with marsh vegetation may function as local buffer wetlands that are important for biodiversity conservation and for attenuating flood peaks.

The implementation of the two-level classification scheme effectively completed the stage of database construction and opened the way to a genuinely quantitative analysis of the structure of the pond network in the basin. Once the area of each polygon had been reliably determined and two attributes assigned – functional status (active, abandoned, under reclamation) and size class (less than 0.5, 0.5–1, 1–5, 5–10, more than 10 ha) – we obtained a fully harmonised dataset suitable for automated calculation of the number of ponds in each category, their total area, mean, minimum and maximum values, and the range of variation. This "classification → statistics" logic is widely applied in contemporary studies devoted to the inventory of small waterbodies and pondscape analysis, where GIS-based databases are used to assess not only the total number of ponds, but also their distribution by size and utilisation status (Yu et al., **2020**; Smith et al., **2022**; Wachholz et al., **2025)**.

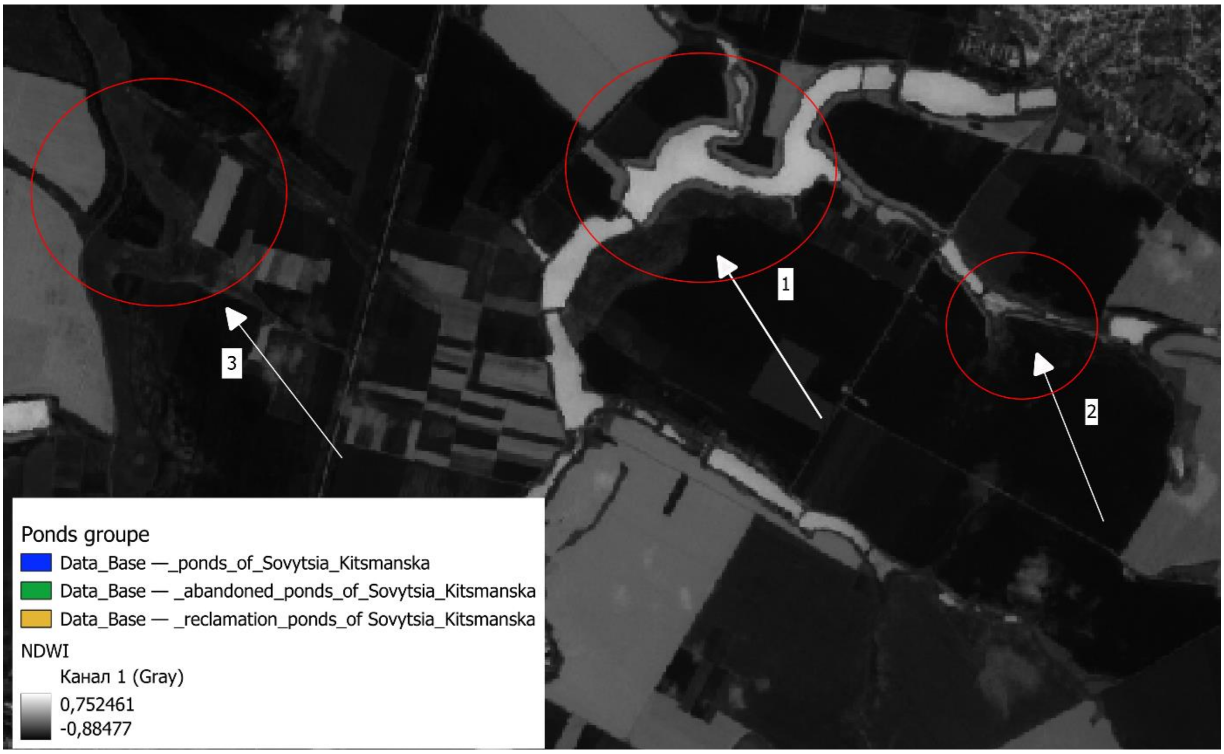

Fig. 7. Example of visual identification of ponds by degree of development based on NDWI data in the Sovytsia Kitsmanska River basin as of October 2025.

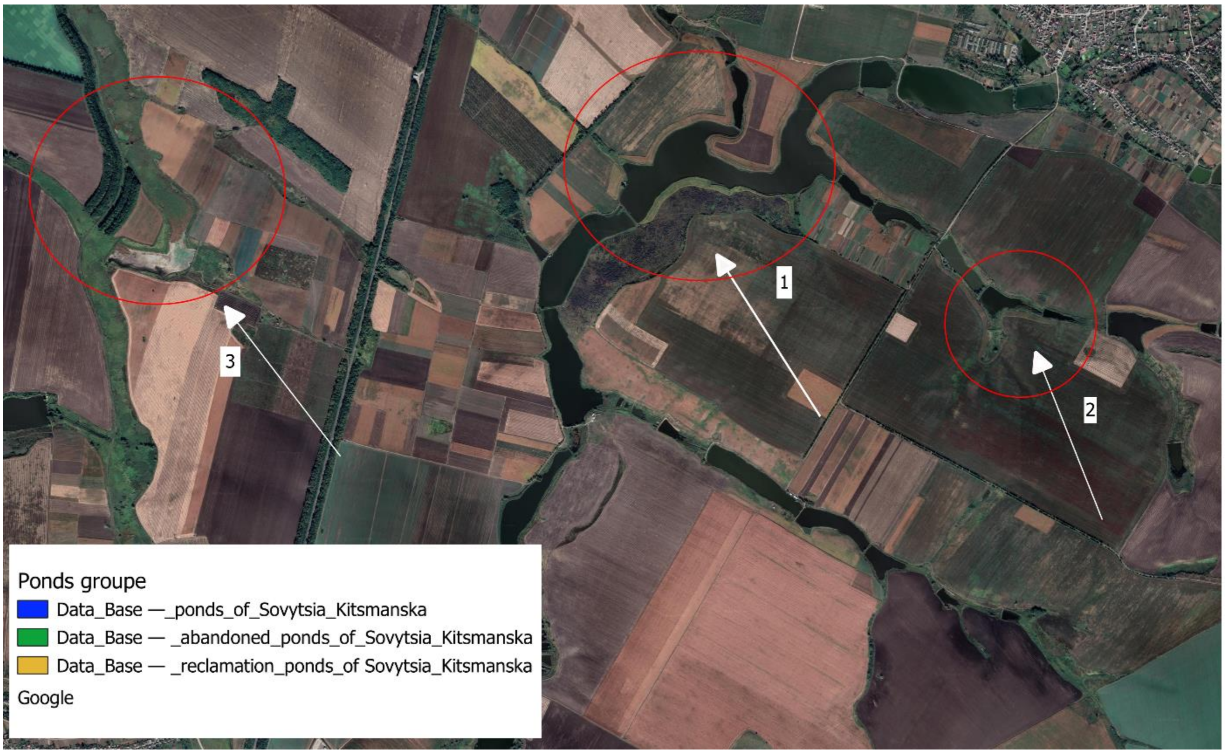

Fig. 8. Example of visual identification of ponds by current degree of development based on Google Maps imagery in the Sovytsia Kitsmanska River basin as of September 2024.

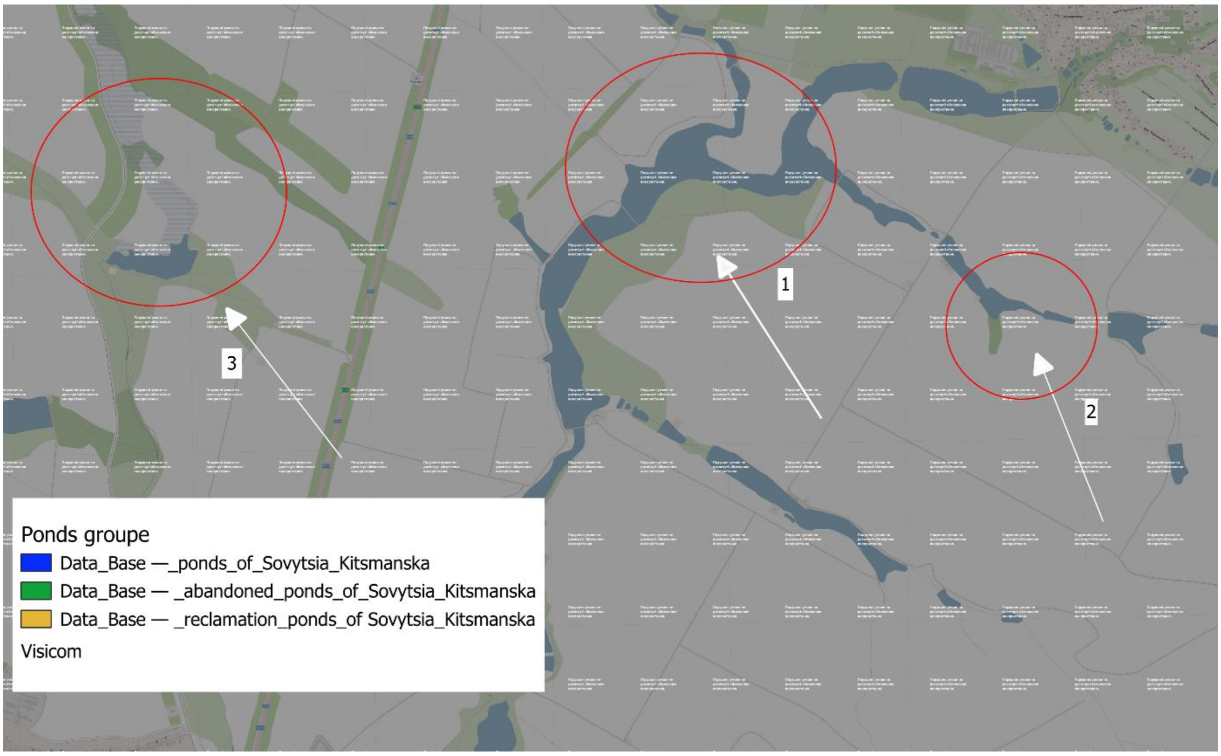

Fig. 9. Example of visual identification of ponds by current degree of development based on Visicom map data in the Sovytsia Kitsmanska River basin.

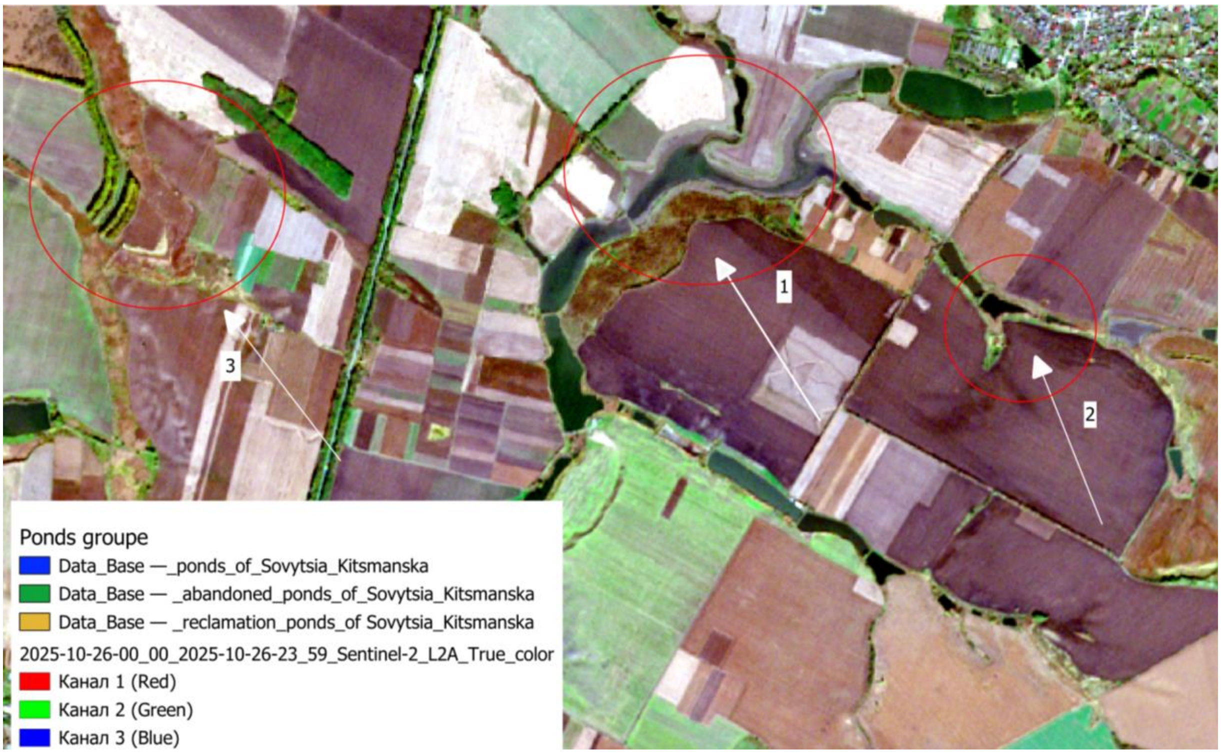

Fig. 10. Example of visual identification of ponds by degree of development based on Sentinel-2A satellite imagery in the Sovytsia Kitsmanska River basin as of October 2025.

In our case, all calculations were performed directly in QGIS 3.34: for each combination of "functional status × size class", we determined the number of polygons, total area, mean area of an individual pond, as well as minimum and maximum values. This made it possible to characterise the internal homogeneity or, conversely, heterogeneity of each group. The resulting indicators were then grouped into three summary tables: for actively operated ponds (Table 1), abandoned ponds (Table 2), and ponds under reclamation (Table 3). The combined analysis of these tables allows us to trace how the distribution of areas and the number of features changes between size classes in different functional states, and to evaluate the contribution of individual categories to overall flow regulation and to the configuration of wetlands within the basin. Below we present a detailed review of the patterns identified on the basis of the data in Tables 1–3.

In summary, combining detailed size-based classification with functional subdivision into active, reclaimed and abandoned ponds allows us to move beyond simple inventory towards full-fledged analysis. This approach is consistent with recommendations from recent pondscape studies, in which small waterbodies (<1–2 ha) are treated as a distinct group because of their large numbers and high ecological significance, whereas larger features are functionally close to small reservoirs or complex pond systems.

According to Tables 1–3, a total of 397 ponds were identified in the basin, of which 259 are actively operated, 81 are classified as abandoned and 57 as being under reclamation. Thus, operational waterbodies account for roughly two-thirds of the total (≈65%), while abandoned and reclaimed ponds together make up more than one-third of all features. This indicates a high degree of transformation of the pond network and a substantial potential for restoring the hydrological regime of the valley. Similar ratios between “active” and “non-functional” ponds are reported for other European regions with a long history of agricultural land use.

Table 1. Structure of actively operated ponds in the Sovytsia Kitsmanska River basin by size classes.

Statistic	Less than 0.5 ha	0,5–1 ha	1–5 ha	5–10 ha	More than 10 ha	Total
Number of ponds	121	35	68	24	11	259
Total area, ha	20,3627	27,4476	162,102	155,872	250,056	615,8403
Mean area in the group, ha	0,16829	0,784217	2,3839	6,4947	22,7323	2,377760
Minimum area, ha	0,0077	0,508172	1,0364	5,0715	10,7052	0,0077
Maximum area, ha	0,4986	0,996658	4,8155	9,9383	56,7669	56,7669
Range (max–min), ha	0,4909	0,488485	3,7792	4,8667	46,0616	56,75899

When turning to an analysis of the areal structure, it becomes evident that the most numerous class is that of the smallest waterbodies: ponds with an area of less than 0.5 ha account for about 41% of the total number of features (162 out of 397). However, they represent only about 1.7% of the total water-surface area in the basin. A similar effect of “numerically dominant but areally subordinate” small waterbodies has been described for a number of European and Asian catchments, where small ponds play an important role in maintaining local biodiversity and hydrological connectivity, yet have little influence on integral indicators of the volume of regulated flow. In our case, small ponds predominate within both the actively operated and the abandoned groups and function as local waterbodies for irrigation, small-scale fish farming, livestock watering, and slope erosion control.

Table 2. Structure of abandoned ponds in the Sovytsia Kitsmanska River basin by size classes.

Statistic	Less than 0.5 ha	0,5–1 ha	1–5 ha	5–10 ha	More than 10 ha	Total
Number of ponds	35	4	37	4	1	81
Total area, ha	5,839	3,324	82,989	26,390	18,790	137,331
Mean area in the group, ha	0,167	0,831	2,243	6,597	18,790	1,695
Minimum area, ha	0,009	0,720	1,001	5,145	18,790	0,009
Maximum area, ha	0,491	0,997	4,442	8,765	18,790	18,790
Range (max–min), ha	0,482	0,277	3,441	3,621	0,000	18,780

The second class (0.5–1 ha) is quantitatively much smaller (12% of the total number of ponds), yet its share in the cumulative area is already slightly higher than that of the smallest ponds, at about 2.3%. Within the group of actively operated ponds, this category accounts for 13.5% of their number and for 4.5% of the total pond area, which indicates the importance of such medium-sized waterbodies for current forms of economic use. For abandoned and reclamation-stage ponds, the share of this class is smaller, which may reflect a tendency either towards complete overgrowth of the smallest waterbodies or, conversely, towards incorporating larger ponds into systems of hydromelioration measures or restoration projects.

Table 3. Structure of ponds under reclamation by size classes in the Sovytsia Kitsmanska River basin.

Statistic	Less than 0.5 ha	0,5–1 ha	1–5 ha	5–10 ha	More than 10 ha	Total
Number of ponds	6	10	22	4	15	57
Total area, ha	1,561	7,235	52,422	30,218	833,503	924,939
Mean area in the group, ha	0,260	0,724	2,383	7,554	55,567	16,227
Minimum area, ha	0,122	0,566	1,176	5,507	10,261	0,122
Maximum area, ha	0,458	0,937	4,950	8,571	211,807	211,807
Range (max–min), ha	0,336	0,371	3,774	3,064	201,545	211,685

The third class (1–5 ha) is key in terms of both number and area for most functional groups. Ponds in this class account for almost one-third of all features (about 32%) and provide nearly 18% of the total water-surface area in the basin. Among abandoned ponds, waterbodies of 1–5 ha clearly dominate both numerically (≈46%) and by area (over 60% of the group's total area), which indicates their particular vulnerability to changes in land-use regime and the cessation of economic use. Similar patterns, whereby medium-sized ponds prove to be the least stable in terms of long-term maintenance, have been demonstrated for other agrarian landscapes, including in England and Bangladesh, where this class of waterbodies is most frequently subjected to intensive drainage or repurposing.

The fourth class (5–10 ha) is represented by 32 ponds (≈8% of the total number), yet already contributes more than 12% of the cumulative area of waterbodies. Within the group of actively operated ponds, this category is almost comparable in area to the 1–5 ha class, while among abandoned and reclamation-stage ponds, waterbodies of 5–10 ha often correspond to a "transitional" stage between small, low-profit ponds and large hydraulic structures. From an ecological perspective, this group is important because such basins form local centres of sediment, nutrient and biomass accumulation and may either function as buffers or, conversely, act as sources of secondary pollution, depending on the prevailing mode of operation.

Finally, the largest ponds, with an area of more than 10 ha, although they represent only about 7% of the total number of features (27 waterbodies), account for almost two thirds of the entire water-surface area in the basin (≈66%). This pattern is particularly pronounced in the group of ponds under reclamation: 15 waterbodies in this class provide more than 90% of the group's total area, whereas the share of small and medium-sized ponds is negligible. This means that, from a hydrological standpoint, it is precisely the large reclamation-stage ponds that determine the degree of flow regulation in the Sovytsia Kitsmanska system and the potential impact of future conservation or water-management measures.

Thus, the size-based classification makes it possible to clearly associate each functional group with its "own" size range: active ponds are represented across the full spectrum of classes, though small and medium-sized waterbodies predominate; abandoned ponds are mainly medium-sized basins that have lost their economic function; and reclamation-stage ponds are relatively few in number but predominantly very large in area, and therefore potentially exert the strongest influence on flow regime and water quality in the valley. This structure is fully consistent with current concepts of the role of ponds and small wetlands as "small but numerous" elements of the hydrographic network, for which size is a key factor determining both hydrological effectiveness and ecological resilience.

4. CONCLUSIONS

This study has developed an integrated digital database of ponds in the Sovytsia Kitsmanska River basin based on open-access Sentinel-2 satellite data, the NDWI index, and QGIS tools. This has made it possible, for the first time, to obtain a complete, metrically consistent picture of the spatial distribution of small waterbodies in an agricultural landscape. The proposed two-level classification scheme, which combines size classes with functional status (actively operated, abandoned, under reclamation), has shown that the pond network is structurally heterogeneous: small waterbodies with an area of up to 0.5 ha are numerically dominant, whereas the main share of the total water-surface area is concentrated in a limited number of large basins exceeding 10 ha. This confirms the key role of individual large ponds in regulating streamflow and water storage in the basin, against the background of a highly "fine-grained" spatial pattern of the pond network.

The methodology developed here is characterised by simplicity of implementation, reliance entirely on open data, and high reproducibility, and can be directly transferred to other small river basins in Ukraine without substantial additional costs. It provides a foundation for further quantitative analysis of flow regulation, assessment of the role of different pond groups in the hydrological regime, and planning of measures for the reclamation and restoration of abandoned waterbodies. In the longer term, combining the constructed database with dynamic satellite observations and hydrological measurements will make it possible to move from a one-off inventory to regular monitoring of changes in the status of small waterbodies under conditions of increasing anthropogenic pressure and climate change.

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Інвентаризація та функціональна класифікація ставків за даними Sentinel-2 NDWI в басейні річки Совиця Кіцманська (Україна)

Ключові слова: басейн річки Совиця Кіцманська, ставки, малі водойми, QGIS, NDWI, Sentinel-2, геоінформаційний аналіз, площа водного дзеркала, класифікація ставків.

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Анотація. У статті подано методику створення єдиної цифрової бази ставків у басейні річки Совиця Кіцманська та їх класифікації за площею й ступенем сучасної освоєності із застосуванням відкритих геопросторових даних і настільної ГІС QGIS 3.34. У межах одного ГІС-проєкту інтегровано супутникові знімки Sentinel-2 L2A, ортофото Google, картографічні підкладки OpenStreetMap і Visicom, а також модель рельєфу Copernicus DEM, що забезпечило повне покриття басейну й можливість надійної візуальної ідентифікації чаш ставків і пов’язаних із ними заболочених територій. На основі індексу NDWI, розрахованого в растровому калькуляторі QGIS, виокремлено контури відкритої водної поверхні та перезволожених ділянок, які були оцифровані у вигляді полігонів і зведені в базу GeoPackage з подальшим перепроєктуванням до метричної системи координат WGS 84 / UTM zone 35N для коректного визначення площ. Для кожного ставка обчислено площу дзеркала води у квадратних метрах, гектарах і квадратних кілометрах, а також реалізовано дворівневу класифікаційну схему: за функціональним статусом (активно експлуатовані, занедбані, на стадії рекультивації) та п’ятьма площинними класами (<0,5; 0,5–1; 1–5; 5–10; >10 га). Загалом у басейні ідентифіковано 397 ставків, з яких 259 активно експлуатуються, 81 є занедбаними та 57 перебувають на стадії рекультивації. Показано, що найчисельнішими є найменші водойми (площею до 0,5 га), які формують близько двох п’ятих від загальної кількості, але забезпечують лише незначну частку сумарної площі водного дзеркала. Натомість найбільші ставки (>10 га), маючи порівняно невелику кількість, акумулюють більшу частину площі зарегульованих вод. Запропонована методика демонструє, що поєднання відкритих супутникових даних, індексного аналізу (NDWI), ручної векторизації та статистичних інструментів QGIS дозволяє отримати просту, відтворювану й придатну до масштабування схему інвентаризації малих водойм. Сформована база даних і класифікація ставків можуть використовуватися для кількісної оцінки зарегульованості стоку, виявлення пріоритетних ділянок рекультивації та підтримки рішень у сфері місцевого водокористування й просторового планування в агроландшафтах.

Ставки є важливим елементом сільськогосподарських ландшафтів та місцевих водних систем, проте дрібні водойми часто залишаються «невидимими» для звичайної статистики й великих інвентаризацій, що ускладнює оцінку їхнього внеску в регулювання стоку та надання екосистемних послуг. У басейні річки Совиця Кіцманська протягом тривалого часу сформувалася щільна мережа ставків різного призначення й стану, відомості про які в наявних джерелах є фрагментарними та несистемними. У такій ситуації особливо актуальними стають методи, що дозволяють на основі відкритих геопросторових джерел і засобів ГІС виконати повну інвентаризацію ставків, точно визначити їхню площу та узгоджено описати ступінь сучасного використання. Метою цієї роботи є створення єдиної цифрової бази ставків у басейні Совиці Кіцманської в середовищі QGIS і розроблення дворівневої класифікації, яка поєднує поділ за розміром дзеркала води з функціональним статусом. Запропонована схема покликана забезпечити просту й відтворювану основу для подальшого аналізу структури ставкової мережі, моніторингу змін та підтримки практичних рішень у сфері місцевого водокористування й просторового планування.

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