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Application of UAV and GNSS Technologies in Topographic Mapping for Urban Management and Planning in Vietnam

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Abstract

Vietnam's rapid urban transition is generating an urgent demand for topographic information that is accurate, current, three-dimensional, and sufficiently detailed for planning, infrastructure management, construction control, environmental assessment, and disaster-risk reduction. Conventional total-station and leveling surveys remain indispensable for legal control networks and high-precision engineering tasks, but they are often too slow and spatially sparse to support frequent city-scale updating. This article examines the application of unmanned aerial vehicles (UAVs) integrated with Global Navigation Satellite System (GNSS) technologies for large-scale topographic mapping in support of urban management and planning in Vietnam. The study adopts an integrative evidence-synthesis approach, combining peer-reviewed empirical studies conducted in Vietnam, national legislation and technical regulations, official geodetic-infrastructure information, and international standards and research on UAV photogrammetry, direct georeferencing, LiDAR, and three-dimensional city models. Vietnamese case evidence shows that UAV-GNSS workflows can achieve centimeter- to decimeter-level positional accuracy under favorable conditions. A 165 ha survey in Thanh Son District produced a 1:2,000 topographic map from 590 images with a 2.3 cm ground sampling distance and reported northing, easting, and vertical errors of 1.8, 1.4, and 4.7 cm, respectively. A 40 ha construction-monitoring study in Ho Chi Minh City generated multi-epoch orthomosaics and digital surface models with root-mean-square errors below 10 cm. A 1:500 quarry survey reported horizontal and vertical errors below 8.2 and 10 cm and a 60% reduction in field time. These findings demonstrate strong technical potential, while also revealing limitations associated with vegetation, urban canyons, reflective roofs, occlusion, datum transformation, quality control, computing capacity, data governance, privacy, and flight authorization. The article proposes a standardized UAV-GNSS production workflow, an accuracy-based decision framework, a governance architecture, and a phased implementation roadmap for Vietnamese cities. It concludes that UAV-GNSS mapping should be institutionalized as a complementary component of the national geospatial data infrastructure rather than treated as a stand-alone replacement for conventional surveying. The greatest value will arise when high-resolution UAV products are linked to authoritative control networks, cadastral and planning databases, Building Information Modeling, web GIS, and open geospatial standards.

Keywords: UAV Photogrammetry, GNSS, RTK, PPK, Topographic Mapping, Urban Planning, Urban Management, Digital Surface Model, Digital Terrain Model, Vietnam, Geospatial Data Infrastructure

1. Introduction

Urban management is fundamentally a spatial-information problem. Decisions concerning zoning, road alignments, drainage, public transport, redevelopment, building control, public-space design, flood mitigation, utility corridors, land readjustment, environmental protection, and emergency response all depend on knowledge of where objects are located, how high they are, how they relate to neighboring features, and how they change over time. When the base map is outdated, incomplete, or geometrically inconsistent, planning assumptions become difficult to verify, design conflicts increase, and public agencies are forced to rely on fragmented project surveys that cannot be readily integrated. This challenge is particularly important in Vietnam, where urban growth is occurring simultaneously in metropolitan cores, peri-urban districts, provincial cities, industrial corridors, coastal settlements, and rapidly transforming rural-urban transition zones.

Vietnam's urbanization rate was reported by the Ministry of Construction at approximately 44.3% in 2024, reflecting a substantial increase from the early reform period and a continued shift of population and economic activity toward urban areas (Ministry of Construction, 2025) [16]. The World Bank has characterized the country's spatial transformation as a transition from an incipient to a more mature stage of urbanization, accompanied by the outward expansion of major urban regions, industrialization, increased land values, and growing infrastructure demand (World Bank, 2020) [31]. The significance of this transformation extends beyond population concentration. Urban form is becoming more three-dimensional and dynamic: buildings are taller, construction cycles are shorter, road networks are denser, underground infrastructure is expanding, and flood and climate risks increasingly require elevation-aware planning. A city administration that updates its topographic information only at long intervals will therefore operate with a widening gap between the mapped city and the real city.

Traditional ground surveying provides authoritative measurements and remains essential for control establishment, legal boundaries, engineering setting-out, deformation monitoring, and the verification of critical features. However, conventional methods generally measure selected points and lines rather than continuously capturing the visible surface. For large or rapidly changing areas, this point-by-point approach can require substantial field labor, traffic management, access permissions, and repeated visits. Manned aerial photography offers wider coverage but may be economically inefficient for small and medium urban projects, particularly when very high spatial resolution or frequent updates are required. Satellite imagery is valuable for regional monitoring, but its revisit schedule, cloud sensitivity, viewing geometry, and pixel size may limit detailed mapping of individual buildings, narrow roads, drainage elements, small construction changes, and micro-topography.

UAVs occupy an important operational space between ground survey and conventional aerial or satellite remote sensing. A small multirotor or fixed-wing platform can collect overlapping images at low altitude and generate dense point clouds, orthomosaics, digital surface models (DSMs), digital terrain models (DTMs), contours, textured meshes, and three-dimensional building representations through structure-from-motion and multi-view-stereo photogrammetry. When the image block is tied to ground control measured by GNSS, or when the UAV records centimeter-level camera positions through real-time kinematic (RTK) or post-processed kinematic (PPK) techniques, the resulting products can achieve accuracies suitable for many large-scale mapping and urban-management tasks. UAV LiDAR extends these capabilities by directly measuring three-dimensional point returns and providing improved ground penetration in some vegetated environments, although at higher equipment and processing cost.

The technical case for UAV-GNSS integration is stronger than the case for either technology used alone. UAV imagery supplies high spatial density and visual context; GNSS supplies a link to the national reference frame and an independent basis for controlling and testing accuracy. In a conventional ground-control workflow, GNSS receivers establish ground control points (GCPs) and independent checkpoints (CPs) distributed across the project area. In an RTK/PPK direct-georeferencing workflow, precise camera coordinates reduce the required number of GCPs, although independent checkpoints remain necessary for defensible quality assessment. In complex urban environments, the most reliable solution may be hybrid: RTK- or PPK-enabled UAV acquisition, a limited number of well-distributed GCPs, independent checkpoints, selected total-station observations in GNSS-obstructed zones, and targeted terrestrial laser scanning where façades or under-canopy surfaces are important.

Vietnam has created several enabling conditions for this integration. The Law on Survey and Mapping No. 27/2018/QH14 provides a national framework for surveying, mapping, product quality, licensing, and the national geospatial data infrastructure. Decision No. 40/QD-TTg of 2020 approved the development and completion of the national fundamental geographic database, while the National Digital Transformation Program under Decision No. 749/QD-TTg promotes data sharing, digital platforms, and open-data development. The national VNGEONET continuously operating reference station network provides GNSS positioning services for surveying and mapping. More recently, Decree No. 288/2025/ND-CP established an updated legal framework for the management, registration, operation, training, and licensing of unmanned aircraft and other aerial vehicles. Together, these instruments indicate that UAV mapping should be understood not simply as a camera operation, but as a regulated geospatial production activity embedded in national data, security, airspace, and professional-quality systems.

Despite rapid adoption, the evidence base remains fragmented. Many Vietnamese studies are site-specific and focus on technical feasibility, while urban planning agencies need broader guidance on fitness for purpose, accuracy classes, data models, institutional roles, lifecycle costs, update frequency, procurement specifications, and legal compliance. A result described as “centimeter-level” may still be unsuitable if the checkpoints are not independent, the coordinate system is unclear, vertical datum conversion is poorly documented, the terrain is hidden by vegetation, or building façades are absent from a nadir-only image block. Conversely, a dataset with lower absolute accuracy may be highly valuable for detecting construction changes or prioritizing field inspection. The central question is therefore not whether UAV mapping is accurate in the abstract, but whether a given workflow produces data of documented quality that match a defined urban-management decision.

This article addresses that question through four objectives. First, it synthesizes the current technological, institutional, and regulatory status of UAV-GNSS topographic mapping in Vietnam. Second, it analyzes empirical Vietnamese case studies to identify realistic performance ranges and operational lessons. Third, it develops a standardized end-to-end workflow for urban topographic mapping, emphasizing independent accuracy assessment, data interoperability, and lifecycle updating. Fourth, it proposes an implementation roadmap for municipalities, survey organizations, planners, and national geospatial authorities. The article does not claim to present a new field survey; instead, it uses transparent secondary empirical evidence and explicitly identified analytical assumptions to support a nationally relevant technical and policy framework.

2. Conceptual and Technical Foundations

2.1 From Topographic Maps to Urban Geospatial Information Systems

A topographic map is traditionally understood as a scale-dependent representation of terrain, natural features, built objects, hydrography, transport, vegetation, boundaries, place names, and elevation. In contemporary urban management, however, the map is increasingly one view of a broader geospatial database. Planning and operational systems require not only symbols on a map sheet but also object identifiers, attributes, temporal states, quality metadata, links to permits and documents, and the ability to query or analyze features in two and three dimensions. A road centerline, for example, may need width, pavement type, design elevation, construction status, drainage connectivity, ownership, and maintenance history. A building object may need footprint, height, roof type, use, permit status, floor-area indicators, vulnerability class, and links to a Building Information Model.

UAV-derived products are valuable because they can supply several layers from one acquisition. The orthomosaic supports feature interpretation and digitizing; the dense point cloud represents the visible surface; the DSM records elevations of roofs, trees, and other above-ground objects; a classified DTM approximates bare earth; contour lines and breaklines support terrain representation; and a textured mesh can assist visual communication and three-dimensional review. When repeated, the same workflow produces a time series that can identify new buildings, demolition, earthworks, road progress, stockpile changes, vegetation loss, drainage obstruction, or surface deformation. The practical shift is therefore from “making a map once” to maintaining an evidence-based spatial record.

International interoperability standards are important to this transition. The Open Geospatial Consortium's CityGML standard defines a conceptual model and exchange framework for semantic three-dimensional city objects, while common web-service and geospatial database standards enable publishing, querying, and reuse. CityGML is not the only possible format, and many Vietnamese organizations will continue to work with CAD, shapefiles, geodatabases, point-cloud formats, and BIM platforms. Nevertheless, the standard illustrates a key principle: geometry should be linked to meaning. A photogrammetric mesh that looks realistic may be useful for visualization, but a planning information system requires separable and identifiable objects such as buildings, roads, bridges, water bodies, terrain, vegetation, and city furniture.

2.2 UAV Photogrammetry and Structure from Motion

UAV photogrammetry reconstructs three-dimensional geometry from overlapping images acquired from different viewpoints. During processing, image features are detected and matched, camera positions and orientations are estimated through bundle adjustment, and a sparse point cloud is generated. Dense image matching then produces a much larger point cloud from which DSMs, orthomosaics, contours, meshes, and other products are derived. Modern software automates much of this process, but automated processing does not eliminate the need for survey design and quality control. Poor flight geometry, motion blur, reflective surfaces, repetitive roof textures, moving vehicles, water, strong shadows, or insufficient side overlap can produce systematic gaps or distortions.

Ground sampling distance (GSD) is one of the most visible design parameters. It approximates the ground dimension represented by one image pixel and is influenced by camera focal length, sensor pixel size, and flight height above ground. Lower flight height usually produces smaller GSD and more image detail, but also increases the number of photographs, flight lines, battery changes, and processing load. GSD is not equivalent to map accuracy. A 2 cm pixel does not guarantee 2 cm positional accuracy, because accuracy is also influenced by control quality, image geometry, lens calibration, surface texture, processing settings, and error propagation. Nevertheless, GSD provides a useful first-order link between acquisition design and the smallest features that can be reliably interpreted.

Image overlap affects both completeness and geometric strength. For relatively flat open terrain, forward overlap around 75-85% and side overlap around 65-80% are common starting points, but dense urban blocks often require higher overlap and oblique imagery. Nadir-only photography captures roofs and ground surfaces visible from above, while façades and narrow street canyons may be poorly represented. Cross-grid and oblique missions can improve building geometry and reduce doming or systematic deformation. Flight speed must be coordinated with shutter speed and light conditions to avoid motion blur. Terrain-following missions are preferable where elevation varies substantially, because constant elevation above takeoff can create large GSD differences and safety risks.

2.3 GNSS Control, Direct Georeferencing, and Reference Systems

GNSS plays three distinct roles in UAV mapping. First, standard onboard GNSS supports navigation and provides approximate image locations. These positions may be accurate to meters and are useful for initial processing, but are not normally sufficient for high-accuracy mapping without ground control. Second, survey-grade GNSS establishes GCPs and CPs tied to an authoritative coordinate and height system. Third, RTK or PPK systems determine the camera exposure position at centimeter level, enabling direct or assisted georeferencing.

RTK applies corrections in real time from a local base or a network such as VNGEONET. PPK records observations for later processing, reducing dependence on uninterrupted communication links during flight. In both methods, camera-event synchronization and lever-arm calibration are critical. The GNSS antenna phase center is physically separated from the camera perspective center; if this offset is ignored or poorly calibrated, systematic errors can remain even when the GNSS solution itself is precise. The time at which the shutter event is recorded must also match the GNSS time scale accurately.

Direct georeferencing can reduce fieldwork and improve access in construction sites, wetlands, steep terrain, or traffic corridors. International studies have shown that RTK/PPK UAVs can frequently produce horizontal errors of a few centimeters and vertical errors of several centimeters under favorable conditions, even with few or no GCPs (Liu *et al*., 2022; Niu *et al*., 2024) [13, 19]. However, “GCP-free” does not mean “control-free.” At least a statistically and spatially adequate set of independent checkpoints is still required to test the result. In addition, urban multipath, satellite obstruction, network interruptions, base-coordinate errors, incorrect antenna heights, and datum mismatches can degrade direct georeferencing.

The coordinate-reference issue is especially important in Vietnam. A project may involve WGS 84-like GNSS coordinates, the national VN-2000 coordinate system, local projection zones, orthometric heights, ellipsoidal heights, older control points, cadastral datasets, and engineering local coordinates. Each transformation must be documented. A model can be internally precise while being systematically displaced from other authoritative data. Municipal procurement specifications should therefore require the reference frame, projection parameters, height datum, geoid model, transformation method, epoch where relevant, and residuals at independent common points.

2.4 Accuracy, Precision, Completeness, and Fitness for Purpose

Accuracy describes closeness to a reference value; precision describes repeatability or dispersion. A visually sharp orthomosaic can be precise in local geometry but inaccurate in absolute position. Conversely, a product can satisfy overall root-mean-square error (RMSE) requirements while containing local blunders caused by poor matching or hidden surfaces. Quality assessment must therefore consider several dimensions:

1. **Positional accuracy:** Horizontal and vertical differences at independent checkpoints.
2. **Relative accuracy:** Consistency of distances, slopes, and object geometry within the model.
3. **Completeness:** Whether required feature classes and obscured areas are captured.
4. **Thematic accuracy:** Correctness of feature classification and attributes.
5. **Temporal currency:** Whether data correspond to the decision date.
6. **Lineage and reproducibility:** Documentation of acquisition, control, processing, and editing.
7. **Logical consistency:** Topology, coding, and database rules.

For checkpoints with coordinate differences Δx, Δy, and Δz, the common statistics are:

$$RMSE\_x = sqrt[\Sigma(\Delta x\_i^2)/n]; \quad RMSE\_y = sqrt[\Sigma(\Delta y\_i^2)/n]; \quad RMSE\_z = sqrt[\Sigma(\Delta z\_i^2)/n]$$

$$RMSE\_r = sqrt(RMSE\_x^2 + RMSE\_y^2)$$

These statistics should be reported with checkpoint number, distribution, surface type, reference-survey accuracy, and outlier policy. International guidance such as the ASPRS Positional Accuracy Standards, Edition 2, emphasizes accuracy classes linked to tested product performance rather than relying only on map scale. This approach is relevant to Vietnam because the same UAV dataset may support multiple outputs, and digital products no longer fit neatly into a single paper-map scale.

3. Materials and Methods

3.1 Research Design

This article uses an integrative review and applied systems-analysis design. The approach was selected because the research question spans technology, surveying accuracy, urban planning, national geospatial infrastructure, regulation, and organizational implementation. A conventional meta-analysis was not appropriate because the Vietnamese studies use different sensors, control strategies, landscapes, map scales, checkpoint designs, and error measures. Instead, the study synthesizes comparable empirical indicators where possible and interprets them within an explicit fitness-for-purpose framework.

The evidence base contains four categories. The first comprises peer-reviewed or conference studies reporting UAV, GNSS, LiDAR, GIS, or topographic-mapping applications in Vietnam. The second comprises international peer-reviewed research on UAV accuracy, GCP configuration, RTK/PPK direct georeferencing, dense vegetation, and data integration. The third comprises official Vietnamese legal and policy documents concerning survey and mapping, digital transformation, national geographic databases, CORS infrastructure, urbanization, and UAV management. The fourth comprises international standards and institutional documents concerning positional accuracy and three-dimensional urban data.

Vietnamese empirical studies were included when they provided at least one of the following: project area, image or point-cloud characteristics, GSD, map scale, control configuration, accuracy statistic, time or cost comparison, change-detection result, or implemented urban/construction information system. Studies with primarily agricultural or mining applications were included only when the technical result was transferable to urban topographic mapping, such as elevation accuracy, volume estimation, vegetation filtering, or 3D data integration. Results were not pooled into a single "average UAV accuracy" because such an average would obscure important differences in environment and design.

3.2 Analytical Framework

The analysis applies a six-part framework:

- **Purpose:** The urban decision or operational task to be supported.
- **Product:** Required orthomosaic, DTM, DSM, contour, vector map, point cloud, 3D model, or change layer.
- **Performance:** Required positional accuracy, GSD, completeness, and update interval.
- **Production:** UAV platform, sensor, GNSS method, ground control, flight design, processing, and editing.
- **Proof:** Independent checkpoints, quality report, metadata, and acceptance testing.
- **Platform:** Integration with cadastral, planning, BIM, asset-management, and web-GIS systems.

This framework is deliberately decision-led. It prevents agencies from beginning procurement with a preferred drone model or software package before defining the planning problem. For example, a rapid post-flood orthomosaic for situational awareness may prioritize speed and coverage, whereas a 1:500 engineering topographic map for detailed design requires more stringent control, feature extraction, and field completion. Similarly, building-height monitoring may be satisfied by a DSM difference model, while drainage design requires a defensible bare-earth surface with breaklines and verified invert or channel elevations.

3.3 Evidence Interpretation and Limitations

Reported values are reproduced as stated by the source and interpreted cautiously. Some papers report RMSE; others report maximum error or mean error. The terms "accuracy," "error," and "precision" are not always used consistently. In the comparative table and discussion, the statistic type is identified where available, and values described as "below" a threshold are treated as upper bounds rather than exact observations. No unreported field values were invented. Where an implementation scenario is proposed, it is labeled as an analytical or planning scenario rather than empirical evidence.

The review has limitations. Some Vietnamese technical research is published in local journals, proceedings, theses, or Vietnamese-language outlets that are difficult to index internationally. Project cost information is rarely disclosed, and accuracy tests are not standardized across studies. UAV regulation has also evolved rapidly; consequently, legal compliance must be checked against current official procedures at the time of each operation. These limitations reinforce the article's central recommendation for standardized reporting and municipal acceptance protocols.

4. Current Status of UAV-GNSS Mapping in Vietnam

4.1 Demand Generated by Urbanization and Infrastructure Investment

The need for current large-scale mapping is being driven by both urban expansion and the intensification of land use. Metropolitan areas such as Hanoi and Ho Chi Minh City continue to extend into peri-urban districts where agricultural parcels, informal construction, industrial projects, new roads, and residential developments coexist. Provincial capitals and corridor cities are also expanding. In these transition zones, cadastral, planning, construction, and environmental datasets may have different dates, scales, and coordinate quality. A high-resolution UAV survey can provide a common visual and geometric reference for identifying differences, but it cannot by itself resolve legal inconsistencies. Its role is strongest as an evidence layer that guides verification and supports coordinated updating.

Urban planning increasingly requires elevation and surface information. Flood-prone cities need micro-topographic models to identify low points, flow paths, barriers, and drainage catchments. Transport planning needs terrain profiles, bridge approaches, construction progress, and right-of-way evidence. Green-space planning requires canopy and land-cover inventories. Building control requires evidence of new construction, roof expansion, demolition, and height change. Solid-waste and environmental planning requires terrain slope, access, proximity, and land-use constraints. Each application benefits from UAV-derived data, but each also imposes different requirements for temporal frequency, accuracy, and interpretation.

The Vietnamese construction sector is adopting BIM and digital project management, creating a further need to connect project-scale models to geospatial context. BIM typically represents detailed designed or as-built components, while GIS represents broader terrain, parcels, networks, and urban systems. UAV and terrestrial scanning data can connect the two by providing reality-capture surfaces for design verification and progress monitoring. The Hanoi University of Civil Engineering case demonstrated a practical GIS-based environment containing a three-dimensional campus database, design data, and web mapping for information sharing (Luong *et al*., 2023) [14]. Although campus scale is smaller than municipal scale, the institutional lesson is important: data value increases when measurement products are linked to searchable information and shared among stakeholders.

4.2 Surveying, Mapping, and National Geospatial Infrastructure

Vietnam's Law on Survey and Mapping, effective from 2019, establishes requirements concerning survey activities, product quality, licensing, information provision, and national geospatial data infrastructure. It also emphasizes that geospatial information used in socio-economic programs and projects must have clear provenance. This requirement is directly relevant to UAV products. Municipalities should not accept an orthomosaic merely because it is visually detailed; they should require documented control, coordinate reference, acquisition date, processing lineage, and tested accuracy.

Decision No. 40/QD-TTg of 2020 approved the project to build and complete the national fundamental geographic database. This creates a policy opportunity for UAV data to contribute to local updating, provided that feature schemas, metadata, coordinate systems, and quality classes are compatible. UAV mapping is particularly well suited to detecting change and proposing updates, while authoritative national or local mapping agencies retain responsibility for validation and database governance. A sustainable model is therefore a controlled update pipeline rather than uncoordinated submission of raw drone imagery.

The VNGEONET CORS network is a major technical asset. Its official description identifies CORS stations, a central processing and control system, and users as the three main components. Network GNSS services reduce the need to establish a separate local base for every project and support centimeter-level positioning where communication, satellite visibility, and network geometry are adequate. Vietnam initially developed a national core and network RTK station system and planned expansion through state and private participation. The availability of CORS corrections can improve both ground-control measurement and RTK-enabled UAV acquisition, but coverage and performance should be validated for each project area. Local multipath, cellular interruption, long baselines, incorrect mount-point data, or transformation errors can still affect the outcome.

4.3 UAV Regulation and Urban Operational Constraints

Urban UAV mapping intersects with airspace security, aviation safety, privacy, public safety, and data protection. Vietnam announced prohibited and restricted flight zones and made UAV flight-permit applications available through the Ministry of National Defence's public-service portal in 2025. Decree No. 288/2025/ND-CP subsequently created a more comprehensive framework for the management of unmanned aircraft and other aerial vehicles, including registration, use, operation, training, and licensing provisions. For survey organizations, regulatory compliance must be integrated into project planning rather than treated as an administrative step after mobilization.

Urban missions may involve additional risks not present in open rural sites. People, traffic, power lines, cranes, airports, government facilities, high-rise turbulence, radio interference, and limited emergency landing areas require operational risk assessment. Flight planning should consider safe stand-off distances, exclusion zones, observers, weather limits, fail-safe behavior, battery reserve, lost-link procedures, and coordination with site management and local authorities. When operations take place above construction sites or dense neighborhoods, the project should also define how personally identifiable imagery, vehicle plates, windows, and private courtyards will be handled.

4.4 Technology Adoption and Capability Distribution

Vietnamese universities, survey firms, construction companies, mining operators, and public agencies have demonstrated growing capacity in UAV photogrammetry, GNSS-RTK, LiDAR, terrestrial laser scanning, and GIS. Lower-cost multirotor platforms have made high-resolution acquisition accessible, while enterprise RTK drones and compact LiDAR systems have expanded the range of feasible applications. The main capability gap is no longer simply access to hardware. It is the uneven distribution of expertise in calibration, geodesy, statistical quality control, classification, feature extraction, metadata, cybersecurity, database design, and long-term data stewardship.

A procurement model focused on equipment ownership can therefore underperform. Cities may purchase UAVs but lack trained pilots, surveyors, processing workstations, software licenses, reference data, maintenance arrangements, and acceptance procedures. Conversely, outsourced projects may produce attractive outputs that cannot be integrated or updated because the municipality did not specify data formats, coordinate systems, naming rules, metadata, and transfer of raw and processed data. Institutional readiness should be evaluated across people, processes, technology, and governance.

5. Empirical Evidence from Vietnam

Table 1: Selected empirical UAV–GNSS and UAV–LiDAR evidence from Vietnam

Vietnamese case	Survey configuration	Main product	Reported result	Operational significance
Thanh Son District, Phu Tho (Thanh *et al.*, 2023) [25]	165 ha; Phantom 4 Pro; CHCNAV i50 GNSS; 590 images; 2.3 cm GSD	1:2,000 topographic map	RMSE components: 1.8 cm northing, 1.4 cm easting; maximum reported vertical error 4.7 cm	Demonstrates centimetre-level mapping over a peri-urban/rural terrain when control and processing are rigorous.
Binh Chanh District, Ho Chi Minh City (Phung *et al.*, 2022) [21]	About 40 ha; three epochs; Phantom 4 Pro; 28 GCPs/checkpoints	Orthomosaic and DSM for construction-change monitoring	5.5 cm/pixel orthomosaic; 11 cm/pixel DSM; reported RMSE below 10 cm	Shows repeat-survey value for detecting site development and supporting urban construction supervision.
Trai Son Quarry (Tran & Luu, 2026) [26]	UAV photogrammetry with GNSS control; industrial terrain	1:500 map, 1 m contours and volumetric model	Reported horizontal error <0.082 m and vertical error <0.10 m; fieldwork time reduced by 60%	Illustrates high-detail mapping and volumetric analysis transferable to earthworks and infrastructure sites.
Mai Pha, Lang Son (Hoang *et al.*, 2026) [11]	Phantom 3 Pro; GNSS-RTK CORS; polynomial terrain correction under vegetation	Corrected DEM	Best reported configuration: 1,000 checkpoints and 50 m smoothing; 1–2 m elevation accuracy	Highlights the difficulty of optical photogrammetry under dense vegetation and the need for terrain correction or LiDAR.
Vietnamese UAV-LiDAR experiments (Nguyen & Le, 2025) [18]	DJI M300 RTK and Zenmuse L1 at 80, 120 and 150 m	LiDAR terrain products	Lower flight altitude produced higher terrain accuracy	Supports altitude selection based on required density, safety and production efficiency.

Note: Metrics are reproduced or derived from the cited studies and are not directly comparable because survey areas, terrain, control designs, sensors, and error-reporting conventions differ.

5.1 Thanh Son District, Phu Tho Province: 1:2,000 Topographic Mapping

The Thanh Son District study provides one of the clearest Vietnamese demonstrations of UAV-GNSS integration for large-scale topographic mapping (Thanh *et al.*, 2023) [25]. The project covered approximately 165 ha and used a Phantom 4 Pro UAV together with a CHCNAV i50 GNSS receiver. A total of 590 raster images were acquired, with a reported image resolution of 2.3 cm GSD and image dimensions of 5,472 × 3,648 pixels. Processing used Agisoft and Global Mapper to generate the mapping products.

The study reported coordinate errors of 1.8 cm in the northing direction, 1.4 cm in the easting direction, and a maximum height error of 4.7 cm. The resulting digital topographic map was compiled at 1:2,000 scale and described as satisfying documentation requirements for government organizations. These values demonstrate that consumer/prosumer imagery combined with survey-grade GNSS control can achieve high accuracy in an area of meaningful project scale.

Several lessons are transferable to urban mapping. First, high image resolution alone was not the basis of the result; GNSS control and the photogrammetric adjustment linked the image block to the mapping reference system. Second, a 165 ha area is large enough to show operational scalability beyond a single building or small site. Third, the vertical error was larger than the horizontal component, which is consistent with common photogrammetric behavior and emphasizes the need for independent vertical testing. Fourth, the map scale should be interpreted with the feature-extraction and field-completion process, not only the orthomosaic accuracy. Features hidden by vegetation, roof overhang, shadows, or water still require supplementary observation or interpretation.

For urban agencies, the case suggests that 1:2,000 mapping of peri-urban development areas is technically feasible using relatively accessible equipment. However, a municipal production specification should add requirements that are not always fully described in research papers: minimum and independent checkpoint counts, distribution by surface and elevation, camera calibration method, coordinate and height transformation, breakline capture, field verification of obscured features, topological rules, and metadata.

5.2 Ho Chi Minh City: Multi-Epoch Construction and Urban-Growth Monitoring

Phung *et al*. (2022) [21] evaluated a 40 ha residential development in Phong Phu Commune, Binh Chanh District, Ho Chi Minh City. The study used a Phantom 4 Pro and collected data at three epochs over approximately six months. Twenty-eight points were measured for ground control and checking. Structure-from-motion processing generated point clouds, DSMs, and orthomosaics. The orthomosaic and DSM resolutions were reported as 5.5 cm/pixel and 11 cm/pixel, respectively, and horizontal and vertical RMSE values were below 10 cm.

The analytical contribution of this case is its use of multi-temporal data. The authors applied a DEM-of-difference approach to identify changes in shape and height and combined elevation differences with orthomosaic interpretation. Eighteen sample locations were grouped into categories such as new house, completed house, house under construction, and other changes. Urban growth was concentrated in the western and central parts of the project area. The authors recommended combining UAV products with cadastral maps to improve planning and management.

This case demonstrates that update frequency can be more important than achieving the lowest possible error. For construction control, a repeatable 10 cm-class dataset may identify changes of several decimeters or meters that are operationally significant. The time series also supports evidence-based inspection: instead of sending field teams to survey the entire area, managers can use change layers to prioritize locations. Nevertheless, change detection requires consistent processing. Differences in flight height, lighting, camera calibration, vegetation, temporary objects, and surface reconstruction can create apparent change. Stable checkpoints, consistent coordinate control, comparable GSD, and documented thresholds are essential.

The recommendation to integrate cadastral data is important but must be interpreted carefully. UAV imagery can reveal the physical occupation of land, while cadastral maps represent legally recognized parcels and rights. A mismatch may indicate real encroachment, construction, map age, transformation error, or differing survey quality. The UAV layer should trigger investigation rather than automatically redefine legal boundaries.

5.3 Trai Son Quarry: 1:500 Mapping, Volume Estimation, and Productivity

Although the Trai Son quarry application is not an urban residential project, its technical requirements closely resemble major earthwork, landfill, road-cut, and construction-volume tasks in cities. Tran and Luu (2026) [26] used UAV photogrammetry and GNSS-measured GCPs to produce a 1:500 topographic map with 1 m contour intervals and boundaries delineated at 1:1,000 scale. The study reported horizontal accuracy below 0.082 m and vertical accuracy below 0.10 m.

The project calculated 519,324 m^3 of remaining limestone above the +5 m elevation and 84,078 m^3 of excavated volume below +5 m. It also reported a 60% reduction in fieldwork time relative to the conventional approach. These results illustrate three urban-management benefits. First, dense surfaces support volumetric analysis that would require many more discrete ground points using conventional methods. Second, repeat surveys can create auditable records of excavation and filling. Third, reduced exposure of surveyors to steep, active, or hazardous terrain is a safety benefit in addition to a productivity benefit.

For urban projects, the same approach can support construction payment verification, borrow-pit management, landfill-capacity assessment, flood-storage calculation, stockpile inventories, and monitoring of unauthorized filling. However, volume accuracy depends on the quality of both the current surface and the reference or design surface. Vegetation, machinery, temporary material, water, and surface smoothing can bias results. Specifications should therefore define surface classification, breaklines, void treatment, boundary polygons, comparison date, and uncertainty reporting.

5.4 Mai Pha, Lang Son Province: Terrain Extraction Under Vegetation

Photogrammetric DSMs represent the visible surface, not automatically the bare-earth terrain. In vegetated areas, the difference between the two may be substantial. Hoang *et al.* (2026) [11] investigated a method in Mai Pha Commune, Lang Son Province using a Phantom 3 Pro, GNSS-RTK control through CORS, polynomial surface fitting, and smoothing to estimate vegetation thickness and correct the DSM. The study tested smoothing radii of 0, 20, 50, 70, and 100 m and checkpoint sets of 150, 350, and 1,000 points. The best reported result used 1,000 checkpoints and a 50 m smoothing radius, producing elevation accuracy within 1-2 m and meeting the authors' stated requirements for 1:2,000-1:5,000 topographic maps in the study context.

The accuracy is much lower than the centimeter-level results of open or built-surface case studies, but the comparison is not a contradiction. It demonstrates that terrain visibility is a controlling factor. An RGB camera cannot measure ground that is not visible in any image. Statistical surface correction can improve a generalized terrain model, but it cannot reproduce detailed micro-topography under dense vegetation without sufficient ground evidence. For urban planning, this issue arises in parks, peri-urban plantations, riverbanks, informal vegetated drainage corridors, and undeveloped sites.

The operational implication is that sensor and method selection should follow land cover. RGB photogrammetry is efficient for roofs, pavements, exposed soil, and visible surfaces. UAV LiDAR may be preferable when ground returns beneath vegetation are required, although even LiDAR performance depends on canopy density, scan angle, point density, and classification. Ground survey or terrestrial scanning may still be necessary for critical drainage channels or design breaklines.

5.5 UAV-LiDAR Flight-Height Experiments and 3D Integration

Nguyen and Le (2025) [18] investigated UAV-LiDAR terrain mapping at flight heights of 80, 120, and 150 m using a DJI

Matrice 300 RTK with a Zenmuse L1 sensor in hilly terrain. The study found a clear relationship between flight altitude and elevation accuracy: lower altitude produced more accurate terrain maps. The result is technically intuitive because lower altitude generally increases point density and reduces footprint size, but it also increases flight time and the number of strips. The planning decision is therefore a trade-off among accuracy, area, battery capacity, terrain clearance, and processing volume.

A related Vietnamese study integrated UAV structure-from-motion and terrestrial laser-scanning point clouds to construct 3D models of industrial structures (Van *et al.*, 2023) [28]. The workflow used 31 measured ground points, including 10 independent checkpoints, with reported control precision at sub-centimeter to a few-centimeter level depending on the instrument. UAV data efficiently captured roofs and upper surfaces, while terrestrial scanning captured façades and ground-level details. This complementarity is directly relevant to dense urban blocks. No single viewpoint can observe all surfaces; aerial and terrestrial data should be integrated when the planning question requires complete building geometry.

5.6 Hanoi Campus: GIS, 3D Models, and Information Sharing

Luong *et al.* (2023) [14] moved beyond isolated mapping products by implementing a GIS and three-dimensional data environment for the Hanoi University of Civil Engineering campus. The study integrated geospatial measurements, a 3D campus database, design information, and web mapping to support construction data management and sharing. The case highlights a recurring issue in UAV projects: the output should not end as a folder of images and point clouds. It must be transformed into an information system that users can query and maintain.

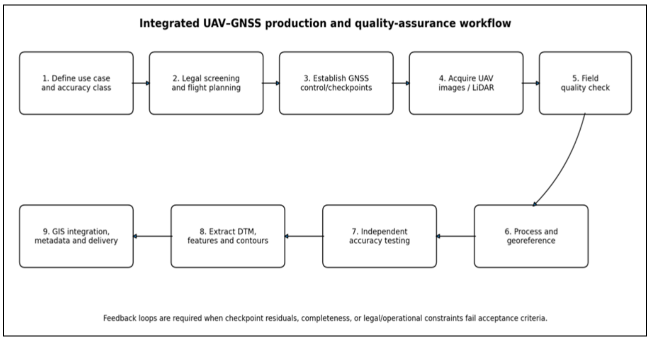
For municipalities, the campus model can be generalized into a multi-scale architecture. Project-level UAV and scanning data feed standardized objects and surfaces into a district or city geodatabase. Selected products are published through web GIS for planners, inspectors, emergency managers, utility agencies, and public communication. Sensitive or high-resolution source data can remain access-controlled, while generalized layers are shared more broadly. The architecture should preserve links to acquisition date and accuracy so that users understand whether a dataset is suitable for visualization, screening, preliminary design, or legal/engineering decisions.

5.7 Synthesis of Vietnamese Performance Evidence

The Vietnamese cases demonstrate a performance range rather than a single accuracy value. In open or clearly visible surfaces with strong GNSS control, horizontal errors of several centimeters and vertical errors below approximately 5-10 cm have been reported. In multi-epoch construction monitoring, sub-decimeter accuracy has supported practical change detection. In vegetated terrain, generalized elevation errors can increase to meters unless LiDAR or additional ground information is used. Field productivity gains can be substantial; the Trai Son case reported a 60% reduction in field time. These findings support three conclusions.

First, UAV-GNSS mapping is technically mature enough for many urban applications. Second, environmental conditions and control design govern results more strongly than the drone brand alone. Third, research demonstrations need to be converted into standard operating procedures, acceptance tests, and interoperable databases before city-wide institutional benefits can be realized.

6. Proposed Integrated UAV-GNSS Workflow for Urban Topographic Mapping



Source: Authors' synthesis based on photogrammetric, GNSS, geospatial-quality, and Vietnamese implementation literature reviewed in this article.

Fig 1: Proposed integrated UAV–GNSS workflow for urban topographic mapping and quality assurance

6.1 Stage 1: Decision Definition and Specification

Every project should begin with a decision statement. Examples include: prepare a 1:500 topographic base for detailed road design; update a 1:2,000 planning map for a peri-urban district; detect construction changes larger than 0.3 m; model flood pathways at 0.1 m vertical resolution; or create an LoD2 building model for solar and shadow analysis. The decision statement is translated into required product, accuracy, resolution, completeness, coordinate system, update date, and delivery format.

A specification should distinguish between visual resolution and positional accuracy. It should state the required GSD or point density, but also the tested horizontal and vertical accuracy class. It should define required feature classes, minimum mapping unit, contour interval, breaklines, building representation, vegetation treatment, and obscured-area completion. It should require an independent accuracy report and specify whether the product is suitable for reconnaissance, planning, design, construction, asset management, or legal use.

6.2 Stage 2: Reconnaissance, Permissions, and Risk Assessment

Desktop reconnaissance should identify airspace restrictions, airports, military or government facilities, tall structures, power lines, construction cranes, public concentrations, takeoff locations, cellular coverage, terrain variation, and sun/shadow conditions. The operator should obtain the required UAV registration, flight authorization, local coordination, and site permissions under the current legal framework, including Decree No. 288/2025/ND-CP and related procedures.

The operational risk assessment should define flight boundaries, maximum height, observers, emergency landing areas, weather limits, battery thresholds, lost-link behavior, and incident reporting. For dense urban sites, missions may need to be divided into smaller blocks or flown during controlled access periods. Privacy and data-security measures should be documented before acquisition, including restricted capture zones, retention periods, access permissions, and procedures for blurring or removing personally identifiable imagery in public products.

6.3 Stage 3: Geodetic-Control Design

The control plan should identify the authoritative horizontal and vertical reference systems and the connection to VNGEONET or local monuments. Existing control must be inspected rather than assumed valid. New GCPs and CPs should be stable, visible, safe to occupy, and distributed around the perimeter and interior, including elevation extremes. Checkpoints must not be used as control in the final adjustment.

The number of points depends on area, shape, terrain, flight blocks, RTK/PPK capability, and required accuracy. International research consistently shows that distribution is often more important than simply increasing point count. A small number of points clustered near the takeoff area cannot control the whole block. For RTK/PPK missions, a reduced GCP set may be sufficient, but independent CPs remain mandatory. GNSS observations should record antenna height, solution type, fix status, observation duration, correction source, coordinate quality, and transformation parameters.

In high-rise or tree-covered areas, GNSS may be unreliable. Total-station traverses, short static GNSS sessions at open sites, or combined networks can transfer control into obstructed zones. Vertical control deserves particular attention because ellipsoidal heights from GNSS must be transformed to the required physical height system using an appropriate geoid or local model.

6.4 Stage 4: Sensor and Mission Design

Sensor selection follows the surface and product. A calibrated RGB camera is the default for high-resolution orthomosaics, visible-surface DSMs, and building footprints. Oblique RGB imagery improves façades and three-dimensional building form. Multispectral or thermal sensors may support vegetation and heat applications but do not replace geometric mapping cameras. LiDAR is considered where vegetation penetration, narrow linear infrastructure, low-texture surfaces, or direct point-cloud acquisition justifies the cost.

Mission design should include target GSD or point density, forward and side overlap, flight-line orientation, cross-strips, oblique angles, terrain following, speed, shutter settings, and expected image count. Dense urban areas benefit from cross-grid missions and controlled oblique imagery. Flights should avoid strong wind, rapidly changing cloud shadows, low sun angles that deepen street-canyon shadows, and wet reflective surfaces. Water bodies may require manual masking or supplementary survey because photogrammetry generally reconstructs them poorly.

A preflight calibration and verification procedure should test camera focus, memory, time synchronization, GNSS correction status, base coordinates, event marking, and control-target visibility. Test images should be reviewed before full acquisition. In repeat monitoring, the mission geometry and processing settings should be kept as consistent as reasonably possible.

6.5 Stage 5: Photogrammetric or LiDAR Processing

Processing begins with data backup and integrity checks. Raw imagery, flight logs, GNSS observations, calibration data, and field notes should be preserved. The photogrammetric workflow typically includes image quality filtering, alignment, camera optimization, control-point marking, bundle adjustment, dense matching, point-cloud cleaning, surface generation, orthorectification, and mosaicking. RTK/PPK camera positions should be assigned realistic accuracy weights rather than treated as error-free.

Quality indicators from bundle adjustment—including reprojection error, control residuals, camera calibration stability, and spatial patterns of error—should be reviewed. A low overall reprojection error does not prove geospatial accuracy. Systematic vertical doming, block tilting, or localized mismatch may still exist. Checkpoints should be withheld until final assessment.

Point-cloud classification distinguishes ground, buildings, vegetation, water, and noise. Automated classification can accelerate production but requires manual review, particularly along retaining walls, steep slopes, curbs, bridges, roof edges, and dense vegetation. DTM generation should preserve breaklines important to drainage and engineering design. Orthomosaics should be inspected for seamline artifacts, moving objects, duplicated vehicles, leaning buildings, and occlusion.

6.6 Stage 6: Vector Mapping, Field Completion, and Database Creation

Topographic mapping requires interpretation and editing beyond automated surface production. Required features are digitized or extracted using standardized codes and topology. Building footprints may be derived from roofs but adjusted to represent the required mapping convention. Road edges, curbs, drainage lines, walls, fences, utilities, and land-cover boundaries should be captured according to the specification. Attributes and object identifiers are added for GIS use.

A targeted field-completion survey addresses obscured or ambiguous features. Instead of repeating a full conventional survey, crews visit only gaps identified from the UAV data. GNSS, total station, mobile mapping, handheld LiDAR, or terrestrial scanning may be used depending on access and accuracy. This hybrid approach captures the principal productivity benefit of UAV mapping while maintaining completeness.

The final geodatabase should separate source observations, derived surfaces, vector features, and presentation products. Metadata should record acquisition date, sensor, flight height, GSD, control method, coordinate reference, processing software and version, checkpoint results, known limitations, and responsible organization. Versioning is essential for repeat surveys.

6.7 Stage 7: Independent Validation and Acceptance

Acceptance testing should be performed by personnel independent of production where practicable. Checkpoint differences are calculated and mapped to reveal spatial bias. Results should be examined by land-cover class and urban form, not only as a single RMSE. For example, open pavement, roof corners, vegetated ground, and narrow street corridors may have different error distributions.

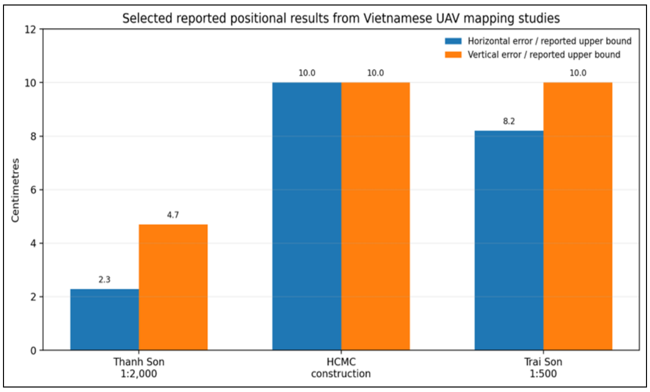
Completeness is assessed against the required feature catalog. Logical tests identify gaps, overlaps, dangles, duplicate identifiers, and invalid geometry. Visual inspection compares orthomosaic, point cloud, DTM, and vector data. A sample of critical features is remeasured. The acceptance report states pass/fail results, limitations, and approved uses. Products that fail a design-grade vertical requirement may still be accepted for visualization or change screening, but the use class must be explicit.

6.8 Stage 8: Publication, Integration, and Update

Validated products are integrated with cadastral, planning, infrastructure, environmental, and BIM data. Web GIS can provide role-based access and time-enabled comparison. Three-dimensional objects may be stored in CityGML-compatible or other semantic formats, while point clouds and meshes are served through optimized streaming formats. Public products should be generalized and privacy-screened where necessary.

Update frequency should be risk-based. Rapidly developing districts may require quarterly or semiannual surveys; stable areas may be updated every two to three years; active construction corridors may require monthly or milestone acquisition; and disaster response may require event-driven mapping. Change-detection algorithms can compare new and baseline products, but human review remains essential before official database updates.

7. Accuracy, Cost, Productivity, and Scalability



Note: Thanh Son horizontal value is the planar combination of the reported northing and easting RMSE components. The Ho Chi Minh City and Trai Son values are plotted at the reported upper bounds. These studies are not direct benchmarks against one another.

Fig 2: Selected reported positional results from Vietnamese UAV mapping studies

7.1 Accuracy Drivers

The reviewed evidence confirms that UAV mapping accuracy is a system outcome. The most important drivers include control quality and distribution, camera calibration, image geometry, GSD, shutter and motion blur, surface texture, RTK/PPK event synchronization, flight altitude, terrain variation, atmospheric and lighting conditions, and processing choices. Urban morphology adds occlusion and GNSS multipath. Vegetation limits bare-earth visibility. These factors interact; therefore, a vendor specification for "2 cm RTK accuracy" cannot be transferred directly to the final map.

The Thanh Son case demonstrates that approximately 2-5 cm errors are achievable for a controlled 1:2,000 survey with 2.3 cm GSD. The Ho Chi Minh City and Trai Son cases show sub-decimeter performance under different operational conditions. International direct-georeferencing studies similarly report centimeter-class results, but typically with carefully calibrated systems and independent checkpoints. A conservative municipal policy should avoid promising universal centimeter accuracy. It should define classes, test each project, and match the class to the decision.

7.2 Comparative Productivity

UAV acquisition can collect millions of surface observations during a short flight, whereas a conventional survey collects selected points. The greatest savings occur in open sites, earthworks, roofs, inaccessible slopes, and repeat monitoring. The 60% fieldwork reduction reported at Trai Son is a useful empirical indicator, although it should not be generalized to every urban project. Dense city centers may require more time for permissions, safety control, multiple small missions, oblique capture, and field completion.

Total project time must include planning, permits, control establishment, processing, editing, validation, and database integration. UAVs shift effort from field to office and computing. An organization that measures only flight time will underestimate labor. Processing can become the bottleneck when image counts and point clouds are large. Efficient workflows require standardized templates, high-performance storage, graphics-processing capability, data backup, and staff trained to identify automated-processing errors.

7.3 Cost Structure and Lifecycle Economics

The cost of UAV-GNSS mapping includes platform and sensor depreciation, GNSS receivers or CORS subscriptions, batteries, maintenance, insurance, pilot and surveyor labor, permits, transport, software, processing hardware or cloud services, field control, validation, data storage, and database management. LiDAR systems add substantial capital cost but may be economical where vegetation or complex structures would otherwise require extensive ground survey.

Lifecycle economics are more favorable than one-time project accounting suggests. A high-quality baseline can be reused for multiple planning and management purposes. Repeat flights can use established control and standardized missions. Change detection can reduce inspection effort. Shared municipal infrastructure—control points, processing environments, data catalogs, and web services—lowers marginal cost across departments. Conversely, isolated project procurements that deliver nonstandard files create duplication and long-term integration cost.

An illustrative municipality should therefore evaluate alternatives over a three- to five-year program rather than compare the price of one UAV survey with one conventional survey. The relevant question is the cost per validated update and the value of faster decisions, reduced field exposure, fewer design conflicts, and coordinated reuse. Because reliable Vietnamese cost datasets are limited, agencies should collect standardized project metrics: area, terrain type, image count, field person-days, processing person-days, permit time, rework, storage, accuracy, and number of downstream users.

7.4 Scalability Limits

Small multirotor UAVs are highly effective for tens to a few hundred hectares, but city-wide mapping requires mission segmentation, multiple crews, fixed-wing or vertical-takeoff platforms, or a combination with manned aerial and satellite data. Data volumes can reach terabytes, especially with oblique imagery and LiDAR. City-wide programs need tiling schemes, cloud-optimized formats, automated quality checks, and update prioritization.

Scalability also depends on airspace and social acceptance. Repeated low-altitude flights over dense neighborhoods are more difficult than surveys of planned development sites. A tiered acquisition strategy is appropriate: satellite or aircraft data for regional context, UAV data for priority zones and rapid updates, mobile or terrestrial systems for street-level detail, and ground survey for critical control and hidden features.

8. Applications to Urban Management and Planning

Table 2: Fitness-for-purpose matrix for major urban UAV–GNSS products

Urban decision / product	Typical source data	Indicative accuracy need	Critical QA checks	Update frequency
Base mapping for detailed planning	Nadir/oblique UAV imagery + GNSS control	Project-specific; commonly decimetre to centimetre class for large-scale mapping	Independent checkpoints, datum verification, obscured-feature survey, topology	At planning revision or major land-cover change
Construction and land-development monitoring	Repeated orthomosaics, DSMs and GNSS reference points	Sufficient to distinguish expected change from survey noise	Stable control, comparable flight geometry, change-detection threshold	Monthly, quarterly or milestone-based
Drainage and flood micro-topography	Bare-earth DTM, breaklines, culverts, channels and benchmarks	Vertical accuracy is usually more important than image sharpness	Vertical datum, ground classification, hydrologic enforcement	Before design and after major earthworks
Road, utility and corridor design	UAV surface model + total station/GNSS for hidden assets	High local relative accuracy and complete feature capture	Cross-sections, breaklines, clearance, underground utility records	Project lifecycle
3D urban model / digital twin	Oblique imagery, LiDAR/TLS, BIM/GIS attributes	Level-of-detail and semantic consistency specified by use case	Geometry, texture, object IDs, CityGML/3D Tiles interoperability	Annual or event-driven

Note: Accuracy requirements must be specified by the responsible authority and tested against independent checkpoints; the entries are decision-oriented guidance rather than universal legal thresholds.

8.1 Planning-Base Maps and Land-Use Monitoring

High-resolution orthomosaics and vector maps can update physical land-use evidence, road access, building footprints, water bodies, and site constraints. Planners can compare existing conditions with approved plans and identify areas requiring review. UAV data are especially valuable in peri-urban zones where land conversion occurs faster than conventional map-update cycles. However, imagery-based land use should be validated against permits, cadastral rights, and field information.

8.2 Construction-Permit and Development-Control Support

Multi-epoch DSM and orthomosaic comparison can identify new structures, height changes, roof extensions, demolition, and encroachment into planned corridors. The Ho Chi Minh City case demonstrates this potential. A municipal workflow could generate candidate-change polygons and send them to inspectors with baseline and current imagery. Automated detection should be treated as screening, because temporary scaffolding, vehicles, vegetation, and reconstruction artifacts can create false positives.

8.3 Transport and Infrastructure Planning

UAV-derived terrain, contours, and imagery support route alternatives, intersection redesign, road widening, bridge approaches, construction progress, and asset inventories. Oblique imagery and point clouds can identify clearances and roadside structures. For detailed engineering, critical levels and hidden drainage features require ground verification. Integration with BIM allows design models to be placed in current terrain and checked for conflicts.

8.4 Drainage, Flood Risk, and Climate Resilience

Fine-resolution DTM data can improve local flow-path and ponding analysis, particularly in flat urban areas where small elevation differences matter. UAV surveys can map embankments, blocked channels, construction fill, and post-disaster sediment. The central technical challenge is obtaining bare-earth elevations beneath vegetation and correctly representing curbs, culverts, walls, and channel inverts. Hydrologically conditioned DTMs should therefore combine photogrammetry or LiDAR with field-measured breaklines and drainage assets.

8.5 Urban Greenery and Environmental Management

RGB and multispectral imagery can support tree-canopy inventories, green-space monitoring, erosion detection, riverbank assessment, and heat or vegetation analysis. Three-dimensional canopy models estimate height and volume, while repeated surveys identify removal or growth. These applications can be linked to urban green-growth indicators. Accuracy requirements may be less stringent than engineering surveys, allowing broader coverage, but consistent radiometric acquisition becomes important.

8.6 Solid Waste, Earthwork, and Environmental Compliance

Dense surfaces enable volume calculations for landfills, stockpiles, excavation, and filling. GIS overlays can assess slope, access, proximity, and environmental buffers. Repeat mapping can document unauthorized dumping or changes in disposal sites. The Trai Son experience indicates both accuracy and field-efficiency potential. For legal or payment disputes, the surface-generation method and uncertainty must be documented.

8.7 Heritage, Public Space, and Urban Design

Oblique UAV imagery and terrestrial scanning can create detailed 3D models of heritage sites, streetscapes, public squares, and architectural ensembles. These models support conservation documentation, visual-impact assessment, shadow analysis, and design communication. Flight and privacy restrictions may be more stringent in central urban and heritage areas, making coordinated multi-sensor capture important.

8.8 Emergency Response and Recovery

After floods, landslides, storms, fires, or construction incidents, UAVs can rapidly acquire current imagery and surface models. Products can map affected buildings, blocked roads, debris, erosion, and temporary water extent. Emergency products prioritize speed and broad situational awareness, but should still use available control and metadata. Once immediate response ends, a more rigorous survey may be required for reconstruction design and compensation.

9. Challenges and Risk Management

Table 3: Principal risks and mitigation measures for municipal UAV–GNSS mapping

Risk	Failure mechanism	Consequence	Primary mitigation
Regulatory / airspace	Unapproved flight, restricted zone, or changed operating conditions	Project delay, enforcement action, safety exposure	Early permit screening; approved operator; documented flight authority; contingency dates
GNSS and reference frame	Multipath, weak correction link, wrong antenna height, datum mismatch	Systematic horizontal or vertical displacement	Redundant observations; coordinate/height audit; independent checkpoints; transformation report
Image geometry	Insufficient overlap, motion blur, repetitive texture, tall-building occlusion	Holes, doming, unstable bundle adjustment	Cross-grid or oblique imagery; conservative speed; exposure checks; targeted infill
Vegetation and water	Canopy blocks terrain; water lacks stable texture	Biased DTM and incomplete shoreline/drainage features	Seasonal acquisition; LiDAR or ground survey; manual breaklines; uncertainty flags
Processing and AI automation	Over-filtering, misclassification, undetected blunders	Plausible but wrong products	Human review; validation samples; versioned workflow; error logs and acceptance tests
Data governance	Unclear ownership, weak metadata, uncontrolled copies	Stale or unauditable municipal datasets	Authoritative repository; metadata standard; role-based access; revision history

9.1 Technical Risks

Urban canyons obstruct GNSS and produce multipath. Tall buildings and cranes create turbulence and occlusion. Glass, metal roofs, water, repetitive façades, and moving traffic cause image-matching errors. Nadir images produce building lean and limited façade data. Vegetation prevents direct terrain observation. These problems are mitigated through hybrid control, cross-grid and oblique imagery, lower or terrain-following flights where safe, LiDAR, terrestrial scanning, field completion, and independent checking.

9.2 Geodetic and Datum Risks

A common hidden failure is coordinate inconsistency. GNSS results may be precise in a global frame but incorrectly transformed into VN-2000 or a local engineering system. Vertical errors can arise from confusing ellipsoidal and orthometric heights. Municipal standards should require transformation reports, common-point residuals, geoid information, control descriptions, and explicit units. Legacy datasets should be assessed before overlay rather than assumed correct.

9.3 Regulatory and Safety Risks

Urban UAV operations require compliance with registration, authorization, operator requirements, prohibited and restricted zones, and local coordination. Project schedules should include permit lead time. Safety management should be documented and audited. Contractors should provide pilot qualifications, aircraft records, maintenance logs, risk assessments, and incident procedures. Procurement should not reward unsafe low bids that omit traffic control or public exclusion measures.

9.4 Privacy, Security, and Sensitive Geospatial Data

Very high-resolution imagery can reveal individuals, private property, security features, and sensitive infrastructure. Raw data should be classified according to access need. Public web maps may require resolution reduction, masking, or controlled viewing. Data transfer and cloud processing should comply with applicable Vietnamese requirements concerning state secrets, cybersecurity, and organizational security. Contracts should define ownership, hosting location, subcontractor access, retention, deletion, and breach response.

9.5 Human Capacity and Professional Accountability

UAV operation is not equivalent to professional mapping. Pilots need air-safety competence; surveyors need geodesy and control-network competence; photogrammetrists need calibration and adjustment competence; GIS specialists need database and interoperability competence; planners need fitness-for-purpose understanding. Organizations should use multidisciplinary teams and assign professional responsibility for the final map, not only for the flight.

Training should include failure cases. Staff who only learn a standard software workflow may accept outputs with doming, poor control, or incomplete terrain. Certification and continuing professional development should cover flight operations, GNSS, photogrammetry, LiDAR, quality statistics, legal compliance, and data governance.

9.6 Institutional Fragmentation

Urban geospatial data are often commissioned by separate departments and projects. Without a shared specification and catalog, the same area may be flown repeatedly while datasets remain inaccessible to other users. A city geospatial steering mechanism should coordinate priorities, control networks, naming, metadata, update cycles, and access. National agencies should provide standards and reference services; local agencies should define operational needs and maintain authoritative local layers.

10. Governance Model and Implementation Roadmap

Table 4: Four-phase roadmap for institutionalizing UAV–GNSS mapping in Vietnamese cities

Implementation phase	Main actions	Institutional output	Key success indicator
Phase 1: readiness and standards	Inventory existing data; define use cases; establish accuracy classes and legal workflow	Municipal UAV–GNSS technical specification and governance charter	Procurements use measurable acceptance criteria
Phase 2: pilots	Select representative dense urban, peri-urban and flood-prone sites; run independent QA	Validated pilot datasets, unit costs and lessons learned	Products pass independent checkpoints and user acceptance
Phase 3: operational integration	Connect outputs to GIS, planning, construction and asset-management systems	Authoritative update workflow and shared spatial database	Update cycle becomes faster and traceable
Phase 4: scaling and maintenance	Framework contracts, training, CORS use, automated change detection and periodic audit	Sustainable citywide production capacity	Coverage, currency and re-use increase while unit cost declines

10.1 Proposed Governance Architecture

A national-local governance architecture should assign clear roles. The national survey and mapping authority maintains reference systems, fundamental geographic standards, national databases, and quality guidance. The Ministry of National Defence and relevant authorities manage airspace and UAV operational permissions. Provincial and municipal governments define urban-data priorities, fund acquisition, and maintain local databases. Licensed survey organizations conduct production and certify quality. Planning, construction, transport, natural-resources, environment, and emergency agencies act as data owners or users. Universities and research institutes support method development, training, and independent evaluation.

A municipal geospatial council or technical working group should approve an annual acquisition plan. Projects are prioritized based on urban growth, infrastructure investment, hazard exposure, data age, and cross-department demand. The council maintains a catalog of existing imagery, point clouds, DTMs, vector maps, and control. Before commissioning a new flight, departments check whether suitable data already exist.

10.2 Standard Procurement Requirements

A procurement document should include:

- Project purpose and approved use class;
- Boundary, terrain, land cover, and airspace information;
- Coordinate reference and height system;
- Target GSD or point density;
- Required horizontal and vertical accuracy;
- Minimum checkpoint design and reporting;
- Required features, contours, breaklines, and attributes;
- Field-completion requirements;
- Raw, intermediate, and final deliverables;
- Metadata and processing report;
- Software-neutral exchange formats;
- Privacy, security, and data-ownership clauses;
- Validation, correction, and warranty procedures.

The contract should avoid specifying only a drone model. Equivalent systems should be accepted if performance and safety requirements are met. Payment milestones should include acceptance of control, preliminary quality, final database, and knowledge transfer.

10.3 Phased Roadmap

Phase 1: Standards and pilots (0-18 months): Cities identify two to four pilot applications, such as peri-urban planning updates, construction monitoring, drainage mapping, and earthwork volume. A common specification and checkpoint protocol are tested. Existing VNGEONET performance and local control are assessed. Staff receive multidisciplinary training. Pilot results are independently reviewed and documented, including costs and person-days.

Phase 2: Shared municipal production (18-36 months): Successful workflows are converted into standard operating procedures. A central data catalog, tiled storage, and web GIS are established. Control monuments and reusable targets are improved in priority areas. Departments submit annual update needs through a common program. Repeat flights generate change layers linked to inspection workflows.

Phase 3: 3D city and BIM-GIS integration (3-5 years): Selected districts receive semantic 3D building, terrain, transport, vegetation, and infrastructure models. UAV data support updates, while BIM and as-built information add object detail. Open standards and APIs enable simulations for flooding, energy, mobility, views, and emergency response. Data-quality classes remain visible to users.

Phase 4: Continuous geospatial updating (beyond 5 years): The municipality operates a risk-based multi-sensor update system combining satellite monitoring, periodic aircraft or UAV surveys, mobile mapping, terrestrial scanning, IoT observations, and field verification. Automated change detection proposes updates; authorized staff validate them. Performance indicators include update latency, data reuse, inspection efficiency, design conflicts avoided, and user satisfaction—not only hectares flown.

10.4 Recommended Performance Indicators

A national or municipal program should monitor technical and institutional indicators. Technical indicators include tested RMSE, completeness, percentage of obscured area, rework rate, processing time, and product age. Operational indicators include permit lead time, field person-days per square kilometer, safety incidents, data volume, and system availability. Governance indicators include percentage of datasets with complete metadata, reuse by multiple departments, standardized formats, and validated transformations. Outcome indicators include faster planning review, reduced field inspection, improved flood or construction decisions, and lower duplication of surveys.

11. Discussion

The evidence indicates that UAV-GNSS topographic mapping has moved beyond experimental novelty in Vietnam. Multiple projects have produced large-scale maps, sub-decimeter accuracy, construction-change information, volume calculations, 3D models, and web-based information systems. The strongest results occur where the surface is visible, control is reliable, flight geometry is appropriate, and quality is independently tested. The technology is therefore ready for structured institutional adoption.

At the same time, the evidence cautions against a simplistic replacement narrative. UAV photogrammetry does not eliminate ground surveying. It changes the allocation of work. Ground control, checkpoints, obscured features, legal boundaries, critical elevations, and engineering verification still require survey expertise. LiDAR improves some vegetation and geometry problems but introduces calibration, trajectory, classification, and cost issues. A hybrid method is not a sign of technological failure; it is the professional response to different observation conditions.

Vietnam's policy environment is broadly supportive. Survey and mapping law recognizes quality and national geospatial infrastructure; the national geographic database and digital-transformation programs emphasize data integration; VNGEONET supports precise positioning; and the updated UAV regulatory framework clarifies management and operational responsibilities. The remaining gap is implementation coherence. UAV acquisition is frequently project-based, while urban information needs are continuous. Cities need programs, not isolated flights.

The empirical cases also show why accuracy reporting must improve. The Thanh Son study provides specific directional and vertical errors, area, image count, and GSD. The Ho Chi Minh City study provides multi-epoch design, control count, pixel resolutions, and sub-decimeter RMSE. The Trai Son study provides map scale, horizontal and vertical thresholds, volumes, and field-time reduction. These are useful, but future publications and contracts should consistently report checkpoint independence, spatial distribution, reference accuracy, confidence measures, datum, surface classes, processing settings, and error maps. A national reporting template would make evidence comparable and support realistic procurement.

Urban planning value arises when measurement products are connected to decision processes. An orthomosaic stored on a workstation has limited institutional impact. The same orthomosaic, when linked to parcels, building permits, plan boundaries, inspection records, and a time series, becomes a management instrument. A DTM becomes more valuable when used in drainage analysis and updated after major earthworks. A 3D mesh becomes more valuable when converted into semantic objects and linked with BIM, asset, energy, or emergency information.

The relationship between UAV data and authoritative legal data requires governance. Physical reality and legal status are different but complementary. UAVs can detect occupation, construction, and change; cadastral and planning systems define rights and approvals. Automated overlay can prioritize discrepancies, but legal decisions require validated evidence and due process. The same principle applies to building heights, boundaries, and encroachments.

A differentiated accuracy policy is preferable to a universal specification. Reconnaissance and public visualization may accept lower accuracy. Change screening may need repeatability more than absolute centimeter performance. Planning-base mapping requires documented decimeter or better performance depending on scale and use. Detailed engineering and construction require stronger vertical control, breaklines, and field verification. Legal boundary re-establishment requires authorized cadastral methods. Assigning use classes prevents both over-engineering and unsafe reuse.

Sustainability is another important dimension. UAV mapping can reduce field travel and improve targeting, but frequent flights and large computing workloads have environmental and resource costs. Data reuse, coordinated acquisition, efficient processing, and risk-based update frequency help maximize benefits. The ability to support climate resilience—through flood modeling, green-space monitoring, and post-disaster assessment—can be a major public value, provided that terrain quality is adequate.

Future research in Vietnam should focus on five areas. First, controlled comparisons of conventional, RGB-RTK, PPK, and UAV-LiDAR methods across urban morphologies are needed. Second, long-term accuracy and repeatability studies should evaluate seasonal, lighting, and calibration effects. Third, cost and productivity datasets should be standardized and published. Fourth, automated change detection and AI feature extraction should be tested against authoritative manual interpretation, with false-positive and false-negative rates reported. Fifth, interoperable BIM-GIS-CityGML workflows should be evaluated in real municipal decision settings rather than only as visualization demonstrations.

12. Conclusions

UAV and GNSS technologies offer Vietnam a practical means of producing high-resolution, current, and three-dimensional topographic information for urban management and planning. Empirical studies in Vietnam have demonstrated centimeter- to decimeter-level performance for visible surfaces, meaningful reductions in field effort, effective multi-epoch construction monitoring, accurate volume estimation, and successful integration with GIS and 3D information systems. These results are sufficiently strong to support broader institutional use.

The technology's value depends on disciplined implementation. UAV imagery must be tied to authoritative geodetic control, tested with independent checkpoints, completed for hidden features, documented through metadata, and integrated with cadastral, planning, infrastructure, BIM, and national geographic databases. Accuracy must be specified by use, not inferred from GSD or hardware advertising. Vegetation, urban occlusion, multipath, datum transformation, privacy, cybersecurity, and flight regulation must be managed explicitly.

Vietnam should adopt a phased national-local approach: standardized pilot projects, shared municipal production, semantic 3D and BIM-GIS integration, and ultimately continuous multi-sensor geospatial updating. UAV-GNSS mapping should complement rather than replace conventional survey methods. Its most important contribution is not the drone itself, but the creation of a faster and more evidence-based urban information cycle in which physical change can be observed, validated, shared, and translated into timely planning and management decisions.

13. References

1. American Society for Photogrammetry and Remote Sensing (ASPRS). ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2. Photogrammetric Engineering & Remote Sensing, 2023.
2. Atik ME, *et al*. Comparative assessment of the effect of positioning techniques and ground control point distribution models on the accuracy of UAV-based photogrammetric production. Drones. 2025; 9(1):15. Doi: https://doi.org/10.3390/drones9010015
3. Bennett RM, *et al*. Review of remote sensing for land administration. Remote Sensing. 2021; 13(21):4198. Doi: https://doi.org/10.3390/rs13214198
4. Chen C, *et al*. UAV photogrammetry in intertidal mudflats: Accuracy, efficiency, and environmental considerations. Remote Sensing. 2023; 15(7):1814. Doi: https://doi.org/10.3390/rs15071814
5. Crommelinck S, Bennett R, Gerke M, Nex F, Yang MY, Vosselman G. Review of automatic feature extraction from high-resolution optical sensor data for UAV-based cadastral mapping. Remote Sensing. 2016; 8(8):689. Doi: https://doi.org/10.3390/rs8080689
6. Duka A, *et al*. Application and accuracy of unmanned aerial survey for forest and terrain mapping. Forests. 2022; 13(12):2054. Doi: https://doi.org/10.3390/f13122054
7. Government of Vietnam. Law No. 27/2018/QH14 on Survey and Mapping, dated 14 June 2018, 2018.
8. Government of Vietnam. Decision No. 40/QD-TTg approving the project on building and completing the national fundamental geographic database, dated 9 January 2020, 2020a.
9. Government of Vietnam. Decision No. 749/QD-TTg approving the National Digital Transformation Program through 2025, with orientations toward 2030, dated 3 June 2020, 2020b.
10. Government of Vietnam. Decree No. 288/2025/ND-CP on management of unmanned aircraft and other aerial vehicles, dated 5 November 2025, 2025.
11. Hoang TT, *et al*. Improving digital elevation models in vegetated areas by integrating UAV photogrammetry, GNSS-RTK and polynomial surface modeling: A case study in Mai Pha, Vietnam. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 2026; 1.
12. James MR, Robson S, d'Oleire-Oltmanns S, Niethammer U. Optimising UAV topographic surveys processed with structure-from-motion: Ground control quality, quantity and bundle adjustment. Geomorphology. 2017; 280:51-66. Doi: https://doi.org/10.1016/j.geomorph.2016.11.021
13. Liu X, Lian X, Yang W, Wang F, Han Y, Zhang Y. Accuracy assessment of a UAV direct georeferencing method and impact of the configuration of ground control points. Drones. 2022; 6(2):30. Doi: https://doi.org/10.3390/drones6020030
14. Luong ND, Tran DT, Duong CH. Applying GIS and geospatial measurement technologies in construction data management in Vietnam: A case study of Hanoi University of Civil Engineering's campus. International Journal of Geoinformatics. 2023; 19(10):40-50. Doi: https://doi.org/10.52939/ijg.v19i9.2879
15. Meng X, *et al*. Photogrammetric UAV mapping of terrain under dense coastal vegetation: An object-oriented classification ensemble algorithm for classification and terrain correction. Remote Sensing. 2017; 9(11):1187. Doi: https://doi.org/10.3390/rs9111187
16. Ministry of Construction of Vietnam. Vietnam-Belgium cooperation in creating sustainable urban areas: Urbanization rate information for 2024, 2025.
17. Nguyen QL, *et al*. Influence of flight height on the accuracy of UAV-derived digital elevation models of complex terrain. Inzynieria Mineralna. 2020; 45(1):179-187. Doi: https://doi.org/10.29227/IM-2020-01-27
18. Nguyen VC, Le VH. Investigation of the impact of flight altitude on the accuracy of terrain maps generated using UAV-LiDAR technology. In Proceedings of the 5th International Conference on Sustainability in Civil Engineering - Volume 2. Springer, 2025, 345-353. Doi: https://doi.org/10.1007/978-981-96-5206-8_33
19. Niu Z, Xia H, Tao P, Ke T. Accuracy assessment of UAV photogrammetry system with RTK measurements for direct georeferencing. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-1-2024, 2024, 169-176. Doi: https://doi.org/10.5194/isprs-annals-X-1-2024-169-2024
20. Open Geospatial Consortium. OGC City Geography Markup Language (CityGML) 3.0 Conceptual Model Standard, 2021.
21. Phung NA, Chung MQ, Tran AT, Vo TTV, Nguyen TD, Le TP. The application of unmanned aircraft vehicle (UAV) to monitor construction area changes. Science & Technology Development Journal. 2022; 25(1):2264-2272. Doi: https://doi.org/10.32508/stdj.v25i1.3828
22. Sanz-Ablanedo E, Chandler JH, Rodriguez-Perez JR, Ordonez C. Accuracy of unmanned aerial vehicle photogrammetry surveys as a function of the number and location of ground control points used. Remote Sensing. 2018; 10(10):1606. Doi: https://doi.org/10.3390/rs10101606
23. Shakhatreh H, *et al*. Unmanned aerial vehicles: A survey on civil applications and key research challenges. IEEE Access. 2019; 7:48572-48634. Doi: https://doi.org/10.1109/ACCESS.2019.2909530
24. Szypula B. Accuracy of UAV-based digital elevation models without ground control points. GeoInformatica. 2024; 28:1-28. Doi: https://doi.org/10.1007/s10707-023-00498-1
25. Thanh PT, Elshewy MA, Long NB, Thom TT. Creation and assessment of a topographic map from unmanned aerial vehicle data in Thanh Son District, Vietnam. International Journal of Geoinformatics. 2023; 19(3):57-66. Doi: https://doi.org/10.52939/ijg.v19i3.2605
26. Tran HH, Luu TTT. UAV-based 1/500 topographic mapping for estimating limestone volume at Trai Son Quarry, Vietnam. International Journal of GEOMATE, 2026.
27. United Nations Global Geospatial Information Management - Asia Pacific. Geodetic Network of Vietnam. Department of Survey and Mapping of Vietnam, 2016.
28. Van CL, *et al*. Building 3D CityGML models of mining industrial structures using integrated UAV and TLS point clouds. International Journal of Coal Science &

Technology, 2023. Doi: https://doi.org/10.1007/s40789-023-00645-x
29. Vietnam National Geographic Information Portal. Introduction to VNGEONET (CORS), 2026.
30. Vietnam News. No-fly and restricted zones for unmanned aircraft announced; online flight-permit procedures made available, 2025.
31. World Bank. Vietnam's Urbanization at a Crossroads: Embarking on an Efficient, Inclusive, and Resilient Pathway. World Bank, 2020.
32. World Bank. Viet Nam country overview and development indicators. World Bank Group, 2026.
33. Yao H, Qin R, Chen X. Unmanned aerial vehicle for remote sensing applications - A review. Remote Sensing. 2019; 11(12):1443. Doi: https://doi.org/10.3390/rs11121443