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UAV photogrammetry for riverine analysis: A systematic review of methodologies, accuracy, and challenges

Nabil Muhamad
Tadulako University,
INDONESIA

Yassir Arafat
Tadulako University,
INDONESIA

Alifi Yunar
Tadulako University,
INDONESIA

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Abstract

High-resolution spatial data is crucial for riverine modeling and flood mitigation. Traditional data often lacks necessary resolution or flexibility, making Unmanned Aerial Vehicles (UAVs) a transformative solution for generating precise Digital Elevation Models (DEMs). This systematic review analyzes 65 peer-reviewed studies published between 2014 and 2025. Following PRISMA guidelines, studies were selected based on specific inclusion and exclusion criteria focusing on riverine hydraulic applications to evaluate data acquisition methods, spatial accuracy, and operational challenges. The synthesis reveals a standard workflow using multirotor platforms, Structure from Motion (SfM) photogrammetry, and Ground Control Points (GCPs) to feed hydrodynamic models like HEC-RAS. While the literature consistently reports centimeter-level vertical accuracy—ideal for mapping flood inundation—critical challenges persist regarding the optical penetration of dense vegetation and submerged bathymetry. Ultimately, while UAV photogrammetry is a robust spatial analysis tool, advancing high-fidelity riverine analytics requires hybrid approaches integrating technologies like UAV-borne LiDAR and sonar. Creating these seamless topobathymetric models is essential for improving reliable flood risk management and informing effective environmental policy.

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INTRODUCTION

The capability of UAV-derived topography as an input for hydraulic modeling, particularly in riverine environments, has been the subject of increasing research and application. Studies have demonstrated the potential of UAVs to provide high-resolution and detailed topographic data that can improve flood simulations and hydraulic analyses (Annis et al., 2020), capture micro-topographic features (Mazzoleni et al., 2020), and offer advantages in terms of cost and

***Corresponding Author:**
Nabil Muhamad, Tadulako University, INDONESIA,
Email: nabillamperouge@gmail.com

time efficiency compared to traditional methods (Luppichini et al., 2019; Tauro et al., 2018). Furthermore, UAV-based data collection has been found effective for surveying channels and floodplains, especially during dry periods (Clasing et al., 2023; Javernick et al., 2014).

However, despite this demonstrated potential and the increasing adoption of UAV technology in hydrology and water management, its integration into water resource research is still considered to be in its infancy (Vélez-Nicolás et al., 2021). While some reviews exist concerning the application of UAVs in hydrology, they often emphasize single or a few selected hydrological variables or specific environmental applications. A clear, comprehensive, and one-stop review addressing different hydrological variables, sensors, and their applications in surface water and groundwater studies is noted as lacking. Specifically concerning the use of UAV-derived DEMs for hydraulic modeling of riverine environments, a comprehensive synthesis is needed to consolidate the diverse methodologies employed, evaluate the reported accuracy assessments, and identify key challenges (Acharya et al., 2021).

Significant geospatial challenges persist when using UAVs for DEM generation in riverine environments. A primary limitation is the difficulty in accurately mapping submerged areas and river bathymetry using standard photogrammetry, particularly in turbid water, which often requires integration with other sensors like sonar or relying on simplifying assumptions (Hoogendoorn, 2023). Additionally, factors such as adverse weather conditions, dense vegetation cover, proper camera calibration, point cloud classification, and Ground Control Point (GCP) availability during flood events heavily affect the quality and accuracy of UAV-derived DEMs (Mazzoleni et al., 2020). The impact of different DEM resolutions and levels of accuracy on hydraulic model performance, as well as the trade-offs between accuracy, resolution, cost, and operational feasibility, require further synthesis across various studies (Reali, Andrea, 2018). The literature also highlights the need for a robust framework for combining different data sources and assessing limitations in rivers with diverse morphologies and geographical contexts (Clasing et al., 2023; Hoogendoorn, 2023). However, a critical research gap persists: there is currently no comprehensive synthesis that explicitly consolidates the fragmented methodologies of UAV photogrammetry in riverine environments, quantitatively compares their reported spatial accuracies, and unifies the persistent operational limitations into a single framework.

Therefore, to fully leverage the potential of UAV technology and spatial analytics for riverine hydraulic modeling, a systematic review is necessary. The primary objective of this study is to provide a comprehensive synthesis of the current state of research on the use of UAV-derived DEMs for the hydraulic modeling of riverine environments. Specifically, this review aims to: (1) identify and synthesize the diverse methodologies employed for acquiring and processing UAV data; (2) assess and summarize the reported accuracy of UAV-derived DEMs, including factors influencing accuracy and methods of validation; (3) evaluate the demonstrated utility of using UAV-derived DEMs for various hydraulic modeling applications, such as flood mapping, habitat assessment, and morphological change analysis; and (4) identify and discuss the key challenges encountered when using UAV-derived DEMs across different study contexts. In fulfilling these objectives, the explicit contributions of this study are: a systematic synthesis of current UAV data acquisition and processing methodologies; a quantitative comparison of reported spatial accuracies and validation techniques; and the identification of critical research gaps and operational challenges, particularly regarding dense vegetation and submerged bathymetry.

The remainder of this paper is structured as follows. Section 2 details the research methodology, outlining the PRISMA protocol, search strategy, and eligibility criteria used to select the reviewed literature. Section 3 presents the results and discussions, providing a bibliometric overview followed by an in-depth analysis of the methodologies, accuracy assessments, and key challenges identified. Finally, Section 4 presents the conclusion and highlights avenues for future research.

METHOD

Study Design and Protocol

Systematic reviews are explicitly designed to summarize and synthesize findings from existing literature on a particular subject (Page et al., 2021a). The use of a predefined and reproducible methodology, such as the PRISMA protocol, is essential to minimize bias and ensure the quality and transparency of the review. PRISMA was initially developed by medical authors to improve reporting standards but has been broadly accepted and applied across various fields due to its clarity and reliability (Rezvani et al., 2023).

Information Sources

Academic databases are the primary sources for conducting comprehensive literature searches. Several sources highlight the use of **Scopus** as a leading platform for academic research due to its extensive coverage across disciplines, stringent quality requirements, and robust search capabilities (Odey & Cho, 2025). Other sources also mention searching additional platforms and grey literature to ensure completeness (Mensah et al., 2022).

Search Strategy and Identification

A detailed search strategy is formulated using keywords and Boolean operators to identify relevant documents (Odey & Cho, 2025). This process often begins with preliminary keyword searches to determine scope and relevance, followed by refinement based on findings (Hakim et al., 2024). Keywords are carefully chosen to align with the study's objectives and may focus on specific themes or technologies. Search fields, such as TITLE-ABS-KEY, may be employed to limit results to those most relevant (Amatebelle et al., 2025).

Table 1. Search Strategy

Search Engine/Site	Search Terms (including specific sections searched)
Scopus	TITLE-ABS-KEY (('**UAV***' OR '**drone***' OR '**UAS**' OR '**DEM**' OR '**DTM**' OR '**DSM**' OR '**Digital Elevation Model***' OR '**photogrammet***' OR '**SfM**') AND ('**Hydraulic Model***' OR '**Flood Model***' OR '**HEC-RAS**' OR '**River***' OR '**Stream***' OR '**Riverine**' OR '**accuracy**' OR '**assessment**' OR '**validation**' OR '**challenges**' OR '**utility**' OR '**methodolog***'))
DOAJ	Searching across Title, Abstract, and Keywords fields using a combination of the following terms: **UAV**, **drone**, **UAS**, **DEM**, **Digital Elevation Model**, **hydraulic modeling**, **flood modeling**, **HEC-RAS**, **river**, **stream**, **riverine**, **accuracy**, **assessment**, **validation**, **challenges**, **utility**, **methodology**.
Google Scholar	Generic search of the following terms or combination of **UAV / drone / UAS / DEM / Digital Elevation Model** combined with **hydraulic modelling / flood modelling / HEC-RAS / river / riverine**

Eligibility Criteria

Clear inclusion and exclusion criteria are established to determine which papers are eligible for the review (Odey & Cho, 2025). Common criteria include:

1. **Publication Type:** Often restricted to peer-reviewed journal articles, though some reviews may include book chapters, conference papers, or grey literature (must be peer reviewed).
2. **Publication Date:** Some reviews specify a time frame to focus on recent advancements.
3. **Relevance:** Papers must focus on the specific research topic and keywords of interest.
4. **Originality:** Original research is typically prioritized
5. **Duplicates:** Duplicate articles found across different sources are excluded.

Table 2. Eligibility Criteria

Category	Inclusion Criteria	Exclusion Criteria	Source(s)
Publication Status	Peer-reviewed journal articles and conference papers.	Grey literature (e.g., reports, dissertations, theses, abstracts, commentaries, book chapters, news).	(Page et al., 2021b)
Study Content	Studies that develop, utilize, or assess UAV-derived DEMs specifically for riverine hydraulic modeling.	Studies using UAVs for non-hydraulic purposes (e.g., general mapping, agriculture); studies using non-UAV DEMs (e.g., satellite, ground survey).	(Page et al., 2021b)
Study Type	Primary research studies presenting original data or methods.	Review articles, meta-analyses, editorials.	(Page et al., 2021b)
Time Frame	Articles published between January 2014 and December 2025.	Articles published before 2014.	(Page et al., 2021b)

Screening and Selection

The screening process involves reviewing the identified documents based on the eligibility criteria. This typically occurs in stages, starting with reviewing titles and abstracts, followed by a full-text review of potentially relevant articles (Page et al., 2021a). Documents not meeting the criteria are excluded at each stage, with reasons for exclusion often recorded (Rezvani et al., 2023). To mitigate potential bias during the study selection process, the initial screening and final inclusion decisions were reviewed and verified independently by two senior researchers (Y.A. and A.Y.). The PRISMA flow diagram visually tracks the number of records identified, screened, assessed for eligibility, and finally included in the review.

Data Extraction and analysis

Once the final set of papers is selected, data relevant to the review's objectives are extracted (Rezvani et al., 2023). For bibliometric analysis, data such as authors, affiliations, countries, publication years, keywords, and citation counts are compiled (Amatebelle et al., 2025). This data is then analyzed using specialized software tools.

Bibliometric and Content Analysis Tools

Several software tools are used for conducting bibliometric and network analysis:

1. **Biblioshiny v4.3.1 in R Studio:** Used for bibliometric techniques including co-occurrence analysis, thematic evolution, and network visualization.
2. **VOSviewer (version 1.6.20):** Utilized for science mapping, identifying thematic clusters, and network visualization of keyword co-occurrence, authors, institutions, and countries.
3. **CiteSpace:** Used for analyzing literature related to River and Lake Health Assessment (RLHA) and UAV remote sensing, including keyword aggregation, timeframe, and conceptual progression.
4. **wordclouds.com:** A free webservice to generate word cloud. Used for creating an immediate visual representation of the most prominent keywords or theme.

These tools enable quantitative analysis of research trends over time, citation patterns, research productivity by various entities, keyword frequencies, co-occurrence patterns, and collaboration networks. Network visualization maps can illustrate the frequency and significance of keywords in the literature (Amatebelle et al., 2025). Content analysis is a qualitative step involving in-depth review of the selected articles to extract information on methodologies, theoretical perspectives, findings, challenges, limitations, and advancements (Odey & Cho, 2025).

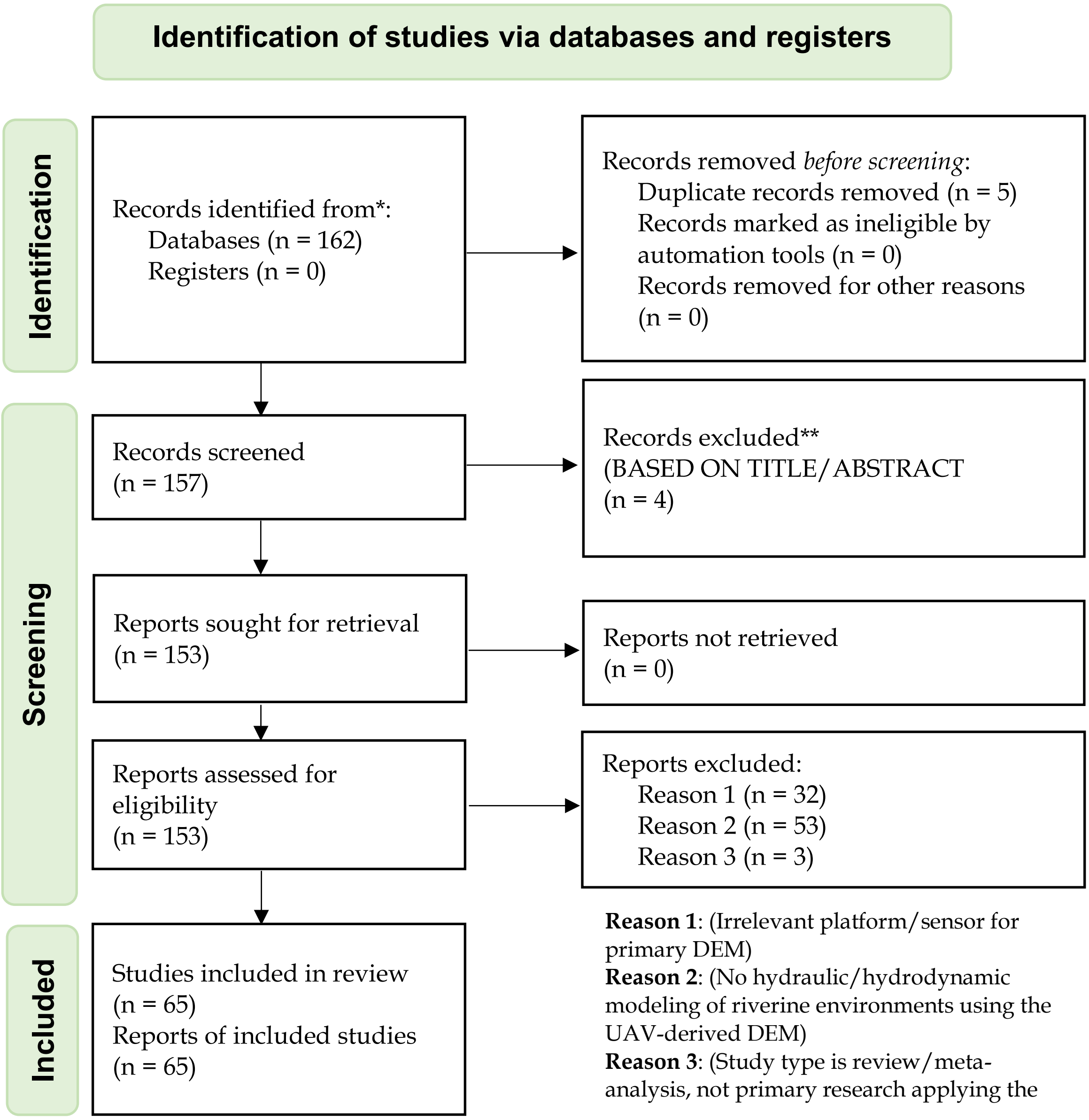

Figure 1. PRISMA Flow Diagram

RESULTS AND DISCUSSIONS

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily. The discussion can be made in several sub-sections. This systematic literature review analyzed 65 unique peer-reviewed studies to synthesize the current state of research on the utility and challenges of using UAV-derived DEMs for the hydraulic modeling of riverine environments. The findings are presented and discussed below, beginning with an overview of the literature's temporal and geographical distribution, followed by an in-depth analysis of methodologies, accuracy assessments, demonstrated applications, and persistent challenges.

Overview of the Literature

The reviewed literature, spanning from 2014 to 2025, shows a marked increase in publications, with a significant surge from 2020 onwards. As illustrated in Figure 2, over 70% of the 65 unique studies were published between 2020 and 2024. This trend indicates a rapidly growing recognition of the technology's potential in riverine science.

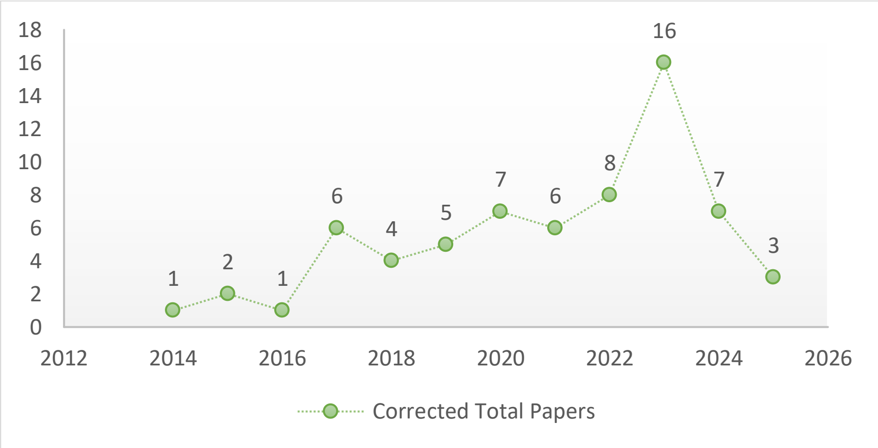

Figure 2. Publication trend of the 65 reviewed studies from 2014 to 2025, showing the number of unique articles per year

To identify the core themes and dominant concepts within this body of research, a keyword analysis was performed. **Figure 3 presents a word cloud** generated from the author-provided keywords, offering an immediate visual representation of the most prominent topics. Unsurprisingly, terms like 'UAV', 'Hydraulic Modeling', 'DEM', and 'Flood' are central.

Figure 3. Word cloud of author keywords from the 65 reviewed studies, illustrating the prominence of key research themes. Larger font size indicates higher frequency of occurrence

A more detailed quantitative analysis of the keywords, summarized in Table 3, reveals the primary focus areas. The most frequent keywords relate to the core technology ('UAV/Drone' - 65 papers; 'DEM/Topography' - 65 papers; 'SfM/Photogrammetry' - 53 papers) and its primary application ('Hydraulic/Hydrodynamic Modeling' - 65 papers; 'Flood Modeling/Hazard' - 57 papers). Furthermore, keywords concerning methodological rigor ('Accuracy Assessment/Validation' - 54 papers) and specific river characteristics ('River Morphology/Geometry' - 49 papers; 'Discharge/Flow' - 37 papers) are also highly prevalent. This confirms a strong research focus on both the practical application of UAVs for flood analysis and the critical need to validate the accuracy of the resulting data.

Table 3. Detailed keywords mentions

Keywords	Mention
UAV / Drone Technology / UAS	65 Papers
Hydraulic Modeling / Hydrodynamic Modeling	65 Papers
DEM / DTM / DSM / Topographic Data / Bathymetry	65 Papers
SfM (Structure from Motion) / Photogrammetry	53 Papers
Flood Modeling / Flood Hazard / Risk / Inundation / Analysis	57 Papers
River Morphology / Fluvial Geomorphology / Channel Geometry / River Features / River Cross-Sections / Bathymetry (morphological aspects)	49 Papers
Accuracy Assessment / Validation / Comparison / Sensitivity / Error Analysis (incl. GCPs as a method)	54 Papers
LiDAR (UAV-borne or for comparison) / Laser Scanning	16 Papers
Discharge / Stream Power / Flow Velocity / WSE / Streamflow / Rating Curve / Flow Estimation (incl. LSPIV)	37 Papers
Sediment / Grain Size / Roughness (Manning's n) / Vegetation Roughness / Scour / Debris Flow	27 Papers
Remote Sensing (General)	6 Papers
Habitat Modeling / E-flows (Environmental Flows)	2 Papers
Data Assimilation / Parameter Estimation	1 Paper

The research is geographically diverse, with studies conducted across at least 32 countries (Figure 4). The most frequent study locations were Italy (5 studies), Greece (6 studies), and China (6 studies). This global spread covers a wide array of riverine environments, from mountainous and alpine rivers in Europe and Asia to tropical systems in Southeast Asia and Africa, and arid or ephemeral streams in various regions. This diversity underscores the technology's adaptability to different geomorphological and climatic contexts.

Methodologies Employed

The reviewed studies employ a range of technologies and methods to acquire, process, and model riverine systems. The following sections elaborate on these key methodological components.

UAV platforms and sensors

The most common UAV platforms are commercially available multirotor systems, valued for their flexibility and ease of use (**Figure 5**). The DJI Phantom series was the most frequently mentioned platform (24 mentions), followed by the DJI Mavic and Inspire series. For sensors, the vast majority of studies (61 of 65) relied on standard RGB cameras coupled with photogrammetric techniques (**Figure 6**). However, to overcome the limitations of photogrammetry, a growing number of studies integrated more advanced sensors. For example, UAV-based thermal sensors are being used to map water temperature, which is a critical variable for habitat assessment (Kuhn et al., 2021). UAV-borne LiDAR was mentioned in 8 studies for its ability to penetrate vegetation, while sonar systems (5 mentions) were used to acquire bathymetric data in submerged channel sections (Bandini et al., 2017; Flener et al., 2013).

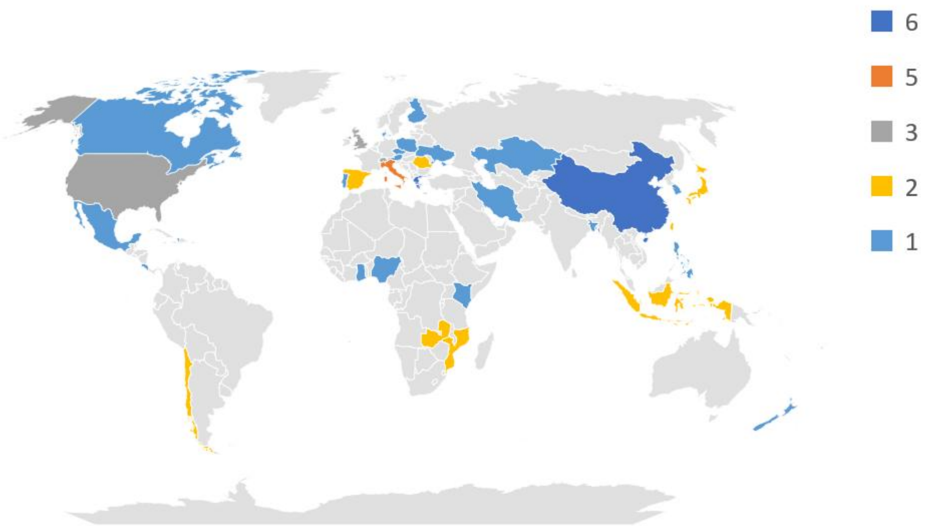

Figure 4. Geographical distribution of the 65 reviewed studies, showing the number of reviewed studies per country.

Table 4. Types of UAV used

UAV Type	Total Mentions
DJI Phantom series	24
Fixed-Wing (Specific models/Generic)	11
Generic/Unspecified Multirotor/Quadcopter/Hexacopter	9
DJI Mavic series	7
DJI Matrice series	4
DJI Inspire series	3
Vapor35 (Helicopter type for DLS)	2
ULM (Ultralight Motor)	1
MMC Ruyunlong M6 (Hexacopter)	1
Aeryon Scout (Quadcopter)	1
Parrot Anafi	1
MikroKopter Hexa XL (Hexacopter)	1

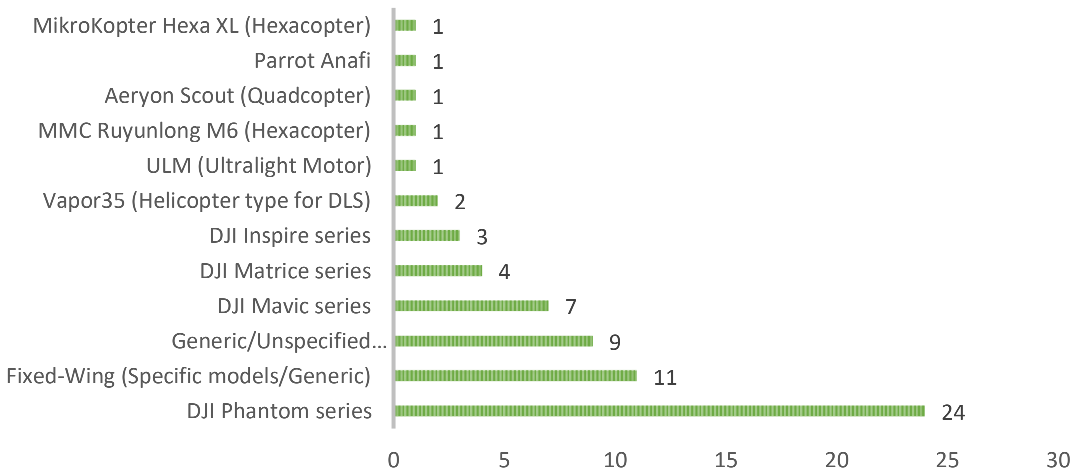

Figure 5. Types of UAV platforms mentioned in the reviewed studies

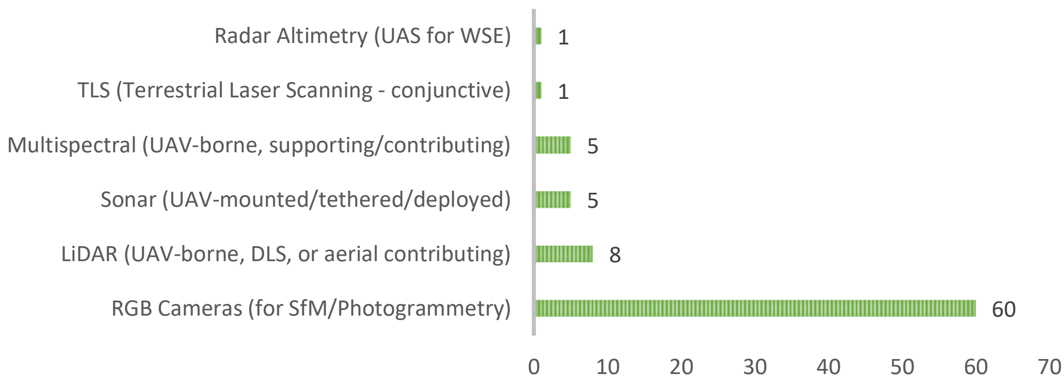

Figure 6. Types of sensors deployed in the reviewed studies

DEM generation and processing

Structure from Motion (SfM) photogrammetry is the dominant technique for generating high-resolution topographic data, utilized in 59 of the 65 studies (**Figure 7**). The critical importance of georeferencing accuracy was highlighted by the fact that 57 studies explicitly mentioned the use of Ground Control Points (GCPs) to improve the spatial accuracy of the final DEM. A key processing challenge is creating a seamless topobathymetric model. Methodologies frequently involved integrating UAV-derived topography of dry areas (banks and floodplains) with bathymetry data acquired through other means, such as sonar or traditional field surveys (e.g., RTK-GPS). Recent studies also show the high potential of GNSS Post-Processed Kinematic (PPK) workflows, which can reduce the need for extensive GCP networks, even in complex environments (Famiglietti et al., 2021).

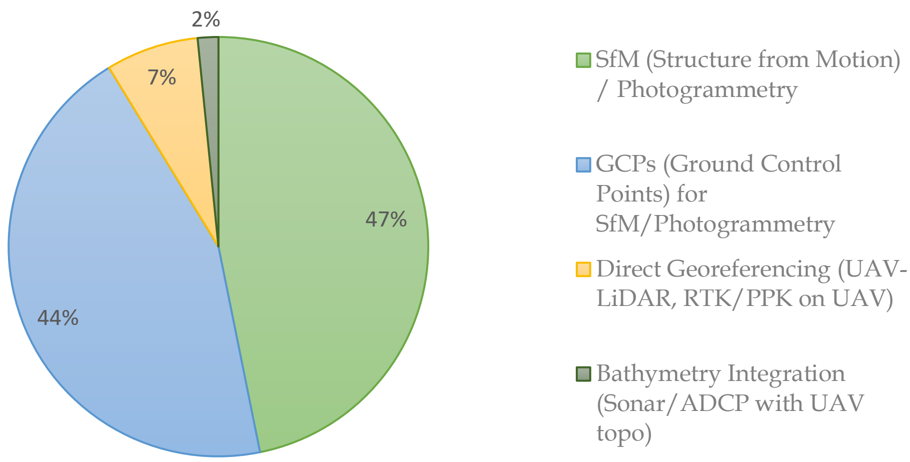

Figure 7. DEM generation and processing method

Hydraulic models employed

A wide array of hydraulic models was used, but the HEC-RAS software suite was by far the most prevalent, mentioned in 36 studies for both 1D and 2D modeling (**Figure 8**). This dominance suggests its status as an industry and research standard. Other notable models included FLO-2D (3 mentions), Delft3D / D-Flow (2 mentions), MIKE models (2 mentions), and various GIS-based or custom-built algorithms, demonstrating a diverse toolkit available to researchers.

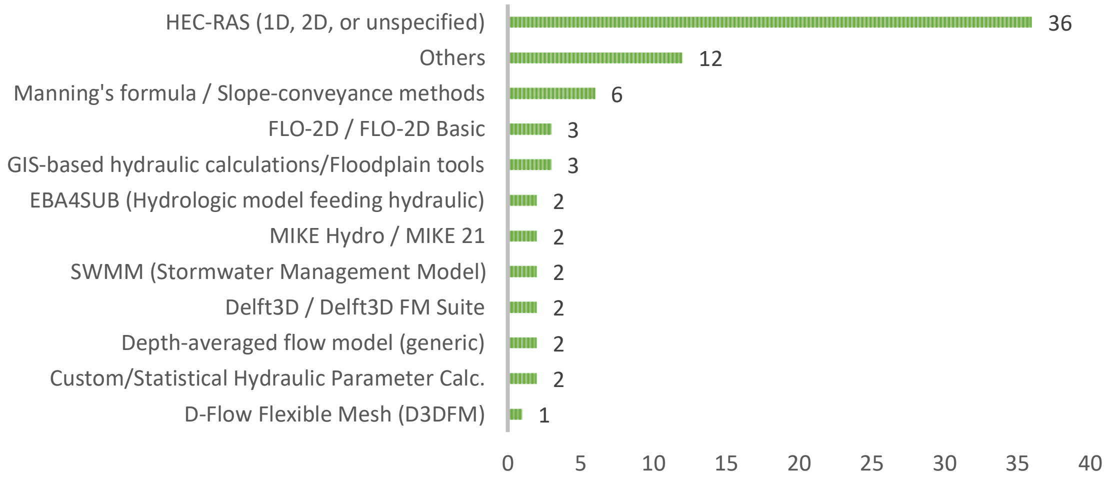

Figure 8. Hydraulic models employed (software or algorithms) in reviewed studies

River environment studied

The versatility of UAV technology is evident in the wide range of river environments studied (**Figure 9**). The most common settings were mountainous, alpine, or steep rivers (21 mentions) and gravel-bed or coarse-bed rivers (18 mentions), where high-resolution topography is crucial for capturing complex morphology. Other frequently studied environments included urban or peri-urban rivers (15 mentions), meandering systems (15 mentions), and vegetated corridors (11 mentions), each presenting unique challenges for data acquisition and modeling.

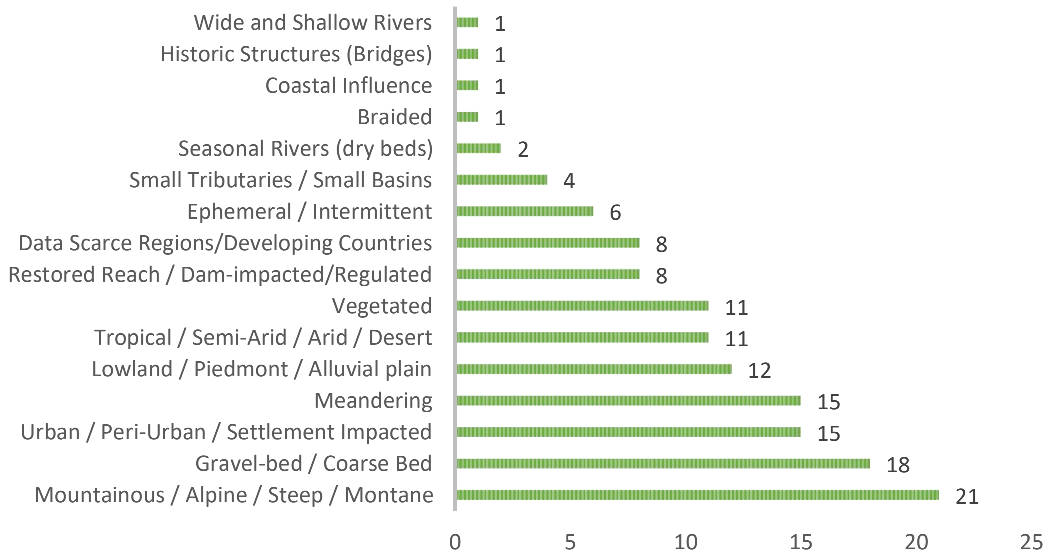

Figure 9. Type of river environtment mentioned in the reviewed studies

Accuracy of UAV-Derived and Model Validation

The accuracy of the input DEM is a cornerstone of reliable hydraulic modeling, and its assessment was a central theme across the literature.

Reported accuracy metrics

Studies consistently demonstrated that UAV-SfM, when combined with a well-distributed network of GCPs, can produce DEMs with **centimeter-level to low decimeter-level vertical accuracy** (Eltner et al., 2016; James et al., 2017). Reported Root Mean Square Error (RMSE) values for the vertical accuracy of the terrain model were often in the range of <5 cm to 15 cm. The accuracy of hydraulic model outputs, such as Water Surface Elevation (WSE), was consequently improved, though often tempered by uncertainties in other parameters like bathymetry and roughness.

Validation methods

The most common method for validating the geometric accuracy of a UAV-derived DEM was the use of independent checkpoints measured with high-precision instruments (**Figure 10**). The use of **GCPs and checkpoints** was mentioned in **57 studies**. Comparison against other high-resolution data sources, such as **Terrestrial Laser Scanning (TLS) or RTK-GPS surveys**, was the second most frequent validation approach (35 mentions). Furthermore, **33 studies** validated the final **hydraulic model outputs** by comparing simulated flood extents or water levels with field observations (e.g., wrack marks, gauged data) or results from other established models.

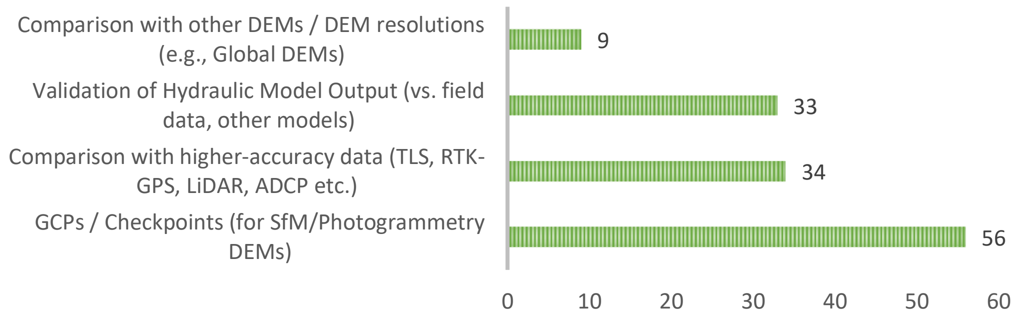

Figure 10. Validation method employed in the reviewed studies

Factor influencing accuracy

The review identified several critical factors that influence DEM accuracy (**Figure 11**). The most cited factor was **vegetation** (36 mentions), as canopy cover can obscure the ground surface from photogrammetric sensors. Other major factors included the **data processing workflow and algorithms chosen** (31 mentions), the density and **distribution of GCPs** (29 mentions), **water properties** like turbidity and surface reflection that limit bathymetric mapping (22 mentions), and **flight parameters** such as altitude and image overlap (22 mentions).

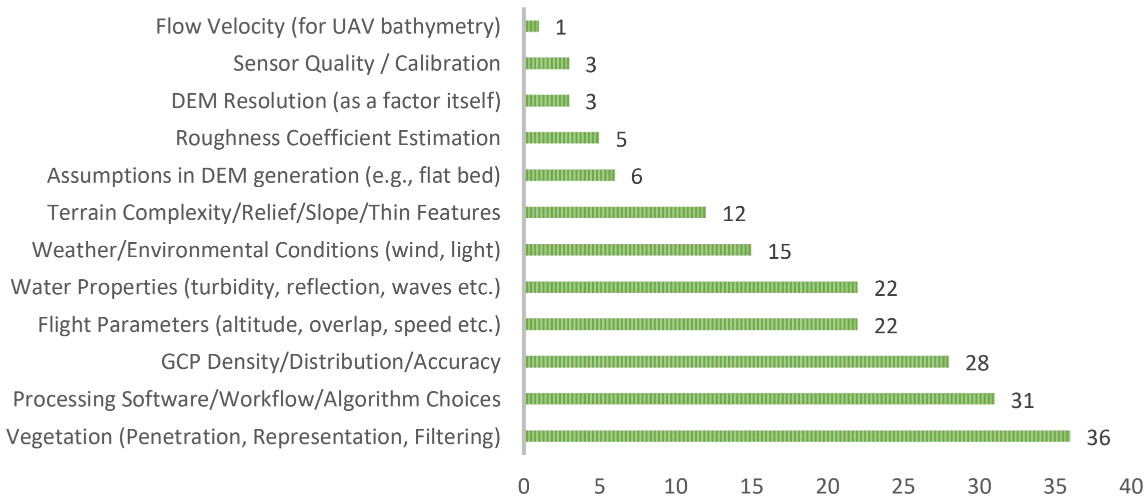

Figure 11. Factors influencing accuracy mentioned in the reviewed studies**.**

Demonstrated utility and applications

The primary utility of UAV-derived DEMs lies in their ability to provide high-resolution, current, and cost-effective topographic data for a variety of critical riverine applications (**Figure 12**).

The most dominant application, reported in **55 studies**, was **flood inundation mapping and hazard assessment**. The fine-scale topography captured by UAVs allows for more detailed and accurate delineation of flood-prone areas compared to coarser global DEMs. Other significant applications include:

1. **Hydraulic Characterization:** Estimating discharge, water surface profiles, and flow velocity (23 mentions) and measuring detailed channel cross-sections and geometry (20 mentions).
2. **Geomorphological Analysis:** Conducting morphological change detection, analyzing sediment budgets, and performing detailed geomorphological surveys (13 mentions).
3. **Model Improvement and Analysis:** Using the high-resolution data for the calibration and validation of hydraulic models (12 mentions) and for estimating hydraulic roughness from detailed vegetation or surface texture data (8 mentions).
4. **Ecohydraulics:** Assessing physical river habitats for species (5 mentions).

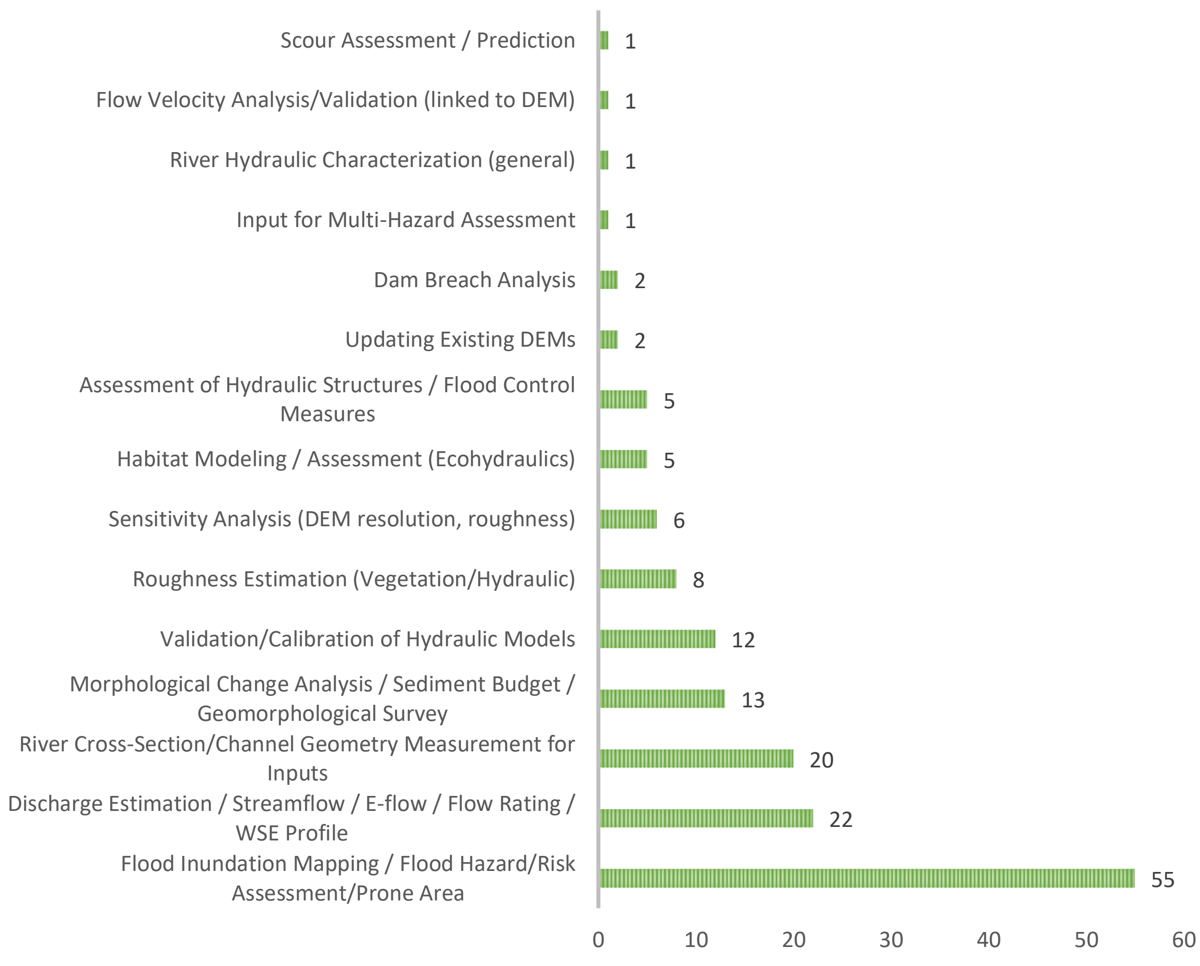

Figure 12. Demonstrated utilities and applications mentioned in the reviewed studies

Key Challenges and Limitations

Despite the clear utility, the systematic review highlighted several persistent challenges and limitations (**Figure 13**). The two most significant and frequently cited challenges were:

1. **Vegetation Penetration (42 mentions):** Standard photogrammetry cannot "see" through dense vegetation canopy, leading to inaccurate representation of the ground topography in forested or heavily vegetated riparian zones. This often necessitates integration with LiDAR or extensive manual data filtering. Various filtering algorithms have been developed to classify point clouds and attempt to remove vegetation cover, though their effectiveness varies with canopy density (Wallace et al., 2016).

2. **Bathymetry Acquisition (40 mentions):** Optical sensors are ineffective at mapping submerged topography in water that is deep, turbid, or has surface glare. This remains a major bottleneck, requiring the integration of sonar, green LiDAR, or reliance on simplifying assumptions that can reduce model accuracy. While some progress has been made in depth-retrieval from imagery in clear and shallow water through refraction correction, these methods are highly sensitive to turbidity and surface glare (Dietrich, 2017; Woodget et al., 2015).

Other notable challenges included the **time, cost, and complexity of data processing** (24 mentions); achieving georeferencing **accuracy in complex or remote terrain** (29 mentions); **data scarcity** for model calibration and validation (21 mentions); and operational constraints related to **weather and flight conditions** (20 mentions). These challenges underscore that while UAVs are powerful tools, their effective application requires careful planning, methodological integration, and an awareness of their inherent limitations.

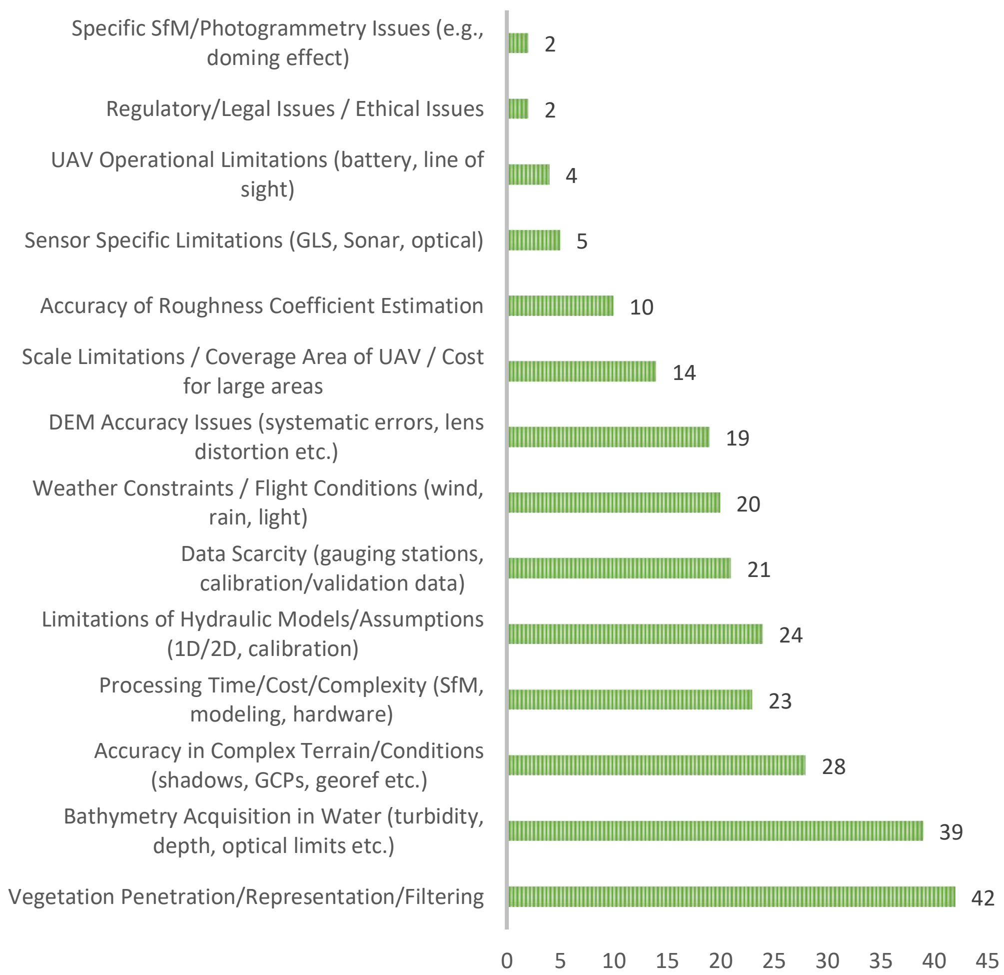

Figure 13. Key challenges and limitations mentioned in the reviewed studies

CONCLUSION

This systematic literature review, analyzing 65 peer-reviewed studies, confirms the transformative and established role of Unmanned Aerial Vehicles (UAVs) in the hydraulic modeling of riverine environments. The rapid increase in publications since 2020 underscores the technology's growing importance and adoption within the scientific community. The review's findings lead to several key conclusions that address the utility, methodologies, and persistent challenges associated with this application.

The primary utility of UAV technology lies in its proven ability to generate high-resolution Digital Elevation Models (DEMs) with centimeter- to low-decimeter-level vertical accuracy, provided that best practices, such as the use of a well-distributed network of Ground Control Points (GCPs), are followed. This level of detail offers a significant advantage over traditional and coarser datasets, enabling more precise flood inundation mapping, which was the most dominant application found in this review. The research community has largely converged on a standard methodological workflow that combines multirotor UAV platforms like the DJI Phantom series with Structure from Motion (SfM) photogrammetry and the use of the HEC-RAS modeling suite. Despite these advancements, the review highlights two critical and consistently reported challenges that significantly limit the standalone capability of UAV-based photogrammetry. The inability of optical sensors to penetrate dense vegetation canopy remains the most frequently cited obstacle. Secondly, mapping submerged riverbed topography (bathymetry), especially in turbid or deep water, is a major bottleneck that compromises the accuracy of hydraulic models. Consequently, this review concludes that while UAV-photogrammetry is an indispensable tool, its optimal application in complex riverine environments necessitates methodological integration. The challenges of vegetation and bathymetry require a shift towards hybrid approaches, combining UAV-derived topography with data from other sensors like UAV-borne LiDAR for sub-canopy ground detection and sonar systems for bathymetric mapping. The future of high-fidelity riverine modeling will depend on refining the integration of these multi-source datasets to create seamless and accurate topo bathymetric models. Addressing these challenges will be crucial for fully leveraging the potential of UAVs in critical areas such as flood risk management, geomorphological analysis, and eco-hydraulic studies. To overcome these current sensor limitations, future research directions must explicitly focus on developing AI-based bathymetry extraction methods and robust data fusion frameworks.

Finally, it is important to acknowledge the limitations of this systematic review itself. Methodologically, the search strategy was primarily restricted to peer-reviewed literature published in English across specific databases, which may introduce publication bias and exclude valuable practical insights from grey literature, such as government flood management reports or industry white papers. Furthermore, while this study synthesizes reported spatial accuracies, it provides a qualitative synthesis rather than a statistical meta-analysis of error metrics. Based on these shortcomings, future systematic reviews in this domain should aim to incorporate grey literature and non-English publications to capture a more comprehensive global perspective. Additionally, future research should transition toward formal meta-analyses to statistically quantify the exact impacts of varying UAV flight parameters and sensor combinations on hydrodynamic model performance.

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AUTHOR CONTRIBUTIONS

Nabil Muhamad: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization. Yassir Arafat: Supervision, Writing – Review & Editing. Alifi Yunar: Supervision, Review & Editing.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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