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High-Resolution Waterlogging Mapping along Ghazipur Drain in Delhi: A UAV-Based Bathymetric Analysis Approach

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Abstract: Environmental, economic, and public health problems are made worse by urban waterlogging especially post monsoon, in areas that are quickly urbanizing. This study employs UAV-based orthophotography and bathymetric data to examine waterlogging risks along the Ghazipur Drain in Delhi, India. High-resolution Digital Elevation Models (DEMs) with 5 cm ground sampling distance and bathymetric profiles reveal considerable drainage losses and sedimentation that reduce channel capacity by 25%. This key finding quantifies the extent of hydraulic degradation and the vital for informing the infrastructural needs. A map from the study highlights about 1,120 settlements in the low-lying areas, including Kalyan Puri, Jafrabad, Seelampur and Karawal Nagar, at the highest flood risk during monsoon months due to poor drain and high degree of urbanisation. This highlights the scale of precarious urban living and demand for actions. When combined with bathymetry, UAV data is highly beneficial for acquiring the path, elevation, and bottom features of these outflows, revealing issues such as sedimentation, obstacles, and so forth. Orthophotos (pixel resolution = 0.05 meter) deliver detailed urban infrastructure visualizations, including drainage systems, to enable site-specific interventions such as dredging and channel widening. These high resolution datasets give a strong evidence base for operational planning's and resource allocation. This method emphasizes the social and economic implications of waterlogging, such as property damage, transport disruption, and growing health hazards from waterborne diseases, which profoundly impact low- to middle-income communities. As described in this work, the influence of UAV-bathymetry in urban drainage research can be considerable. This has integrated accurately data from UAVs in flood risk management activities, and leads to urban systems planning with higher resilience level. This will translate into actionable insights to improve drainage infrastructure, reduce flood hazards, and increase urban resilience — useful information to planners and policymakers. This result confirms that UAV-bathymetry is a scalable, precise, and low-cost solution of urban waterlogging in the fast-developed cities around the world

1. INTRODUCTION

Urban waterlogging has brought seriously environment, economic and public health problems to cities around the whole world (Apel et al. 2004; Fleischmann, Paiva, & Collischonn, 2019). Too-fast development, unsatisfactory drainage systems and extreme weather cycles that are increasingly frequent are aggravating the mess - and rising global temperatures (such as from too heavy rain) also contribute (Berghuijs et al. 2014). Over one hundred million urban residents worldwide are annually affected by waterlogging (Diwate et al. 2025). This causes economic losses of $40 billion estimated not (Zhi et al. 2020). The economies of developing countries are affected even more severely. In developing countries, with their rapid urbanization far outstripping infrastructural provision, there is a great dependence that urban expansion can bring harmonious living to the countryside if only they can restrain population growth and curb the wastelands of marginal farming areas into rich fields (Annis et al. 2020). In India, cities such as Delhi, Mumbai, and Kolkata frequently see waterlogging during monsoon seasons, resulting in disrupted transportation networks, considerable economic losses, and increased risks of waterborne infection (Tomar et al. 2021). During the 2021 monsoon season, waterlogging in Delhi resulted in direct losses of ₹300 crore owing to property damage and interruptions to everyday trade (Darji et al. 2024).

The Ghazipur Drain in Delhi exemplifies the pressures faced by urban drainage systems. The drain, functioning as a primary channel for rainwater, is sometimes inundated by sediment build-up, solid waste accumulation, and intense rainfall occurrences (Bates et al. 2010). This underscores the pressing necessity for novel, scalable, and precise methods to evaluate, monitor, and alleviate waterlogging. Conventional techniques for evaluating waterlogging predominantly depend on satellite remote sensing, terrestrial surveys, and GIS-based studies (Meshram et al., 2024; Shau et al., 2024; Brakenridge et al. 2007). Satellite imagery from platforms such as Sentinel-1 and Landsat has been essential in mapping extensive inundations, offering significant spatial data. Nevertheless, these methodologies frequently encounter constraints in metropolitan environments. The course spatial resolution of satellite imagery, often 10 meters or more, renders it inadequate for detecting fine-scale urban waterlogging patterns.

Moreover, cloud cover during monsoons substantially diminishes the availability and precision of satellite data. Ground-based surveys are precise but require a lot of resources and time to deploy, and become very challenging to conduct in densely populated areas or areas experiencing flooding. found that manual geodetic surveys in urban India often encounter delays because of logistical factors, which limits its utility for real-time flood management. Digital elevation model (DEM) is other tools for waterlogging studies, and the accuracy about 1 meter or more. While these models improve the prediction of waterlogging hotspots based on building density, road networks and drainage systems, they do not provide dynamic accuracy that is essential for on-demand urban waterlogging management (Wienhold et al. 2023; Parizi et al. 2022). This leads to a lack of our ability to respond to rapidly evolving urban waterlogging scenarios. Despite their widespread usage and normalization, such standard methods are limited by the low spatial resolution, temporal rigidity, and cost-effective deployment they can provide for real-time urban flood assessment. Especially, since new projects based entirely on existing knowledge would have little chance of change, we introduce UAV-bathymetry as a new solution to these limitations and significant methodological improvement over satellite and ground-based surveys. The application of Unmanned Aerial Vehicles (UAVs) equipped with advanced sensors such as LiDAR, multispectral cameras, and bathymetric instruments is making a significant impact on waterlogging research (Li et al. 2021; Yalcin 2018). UAVs can acquire sub-metre spatial resolution and generate high-definition topographic maps as well as bathymetric maps, and thus provide unique insights into the urban drainage of water systems and inundated areas (Darji et al. 2024). Striking and precinct-based methods are unable to comfortably provide a feasible answer however, UAVs can outperform others in terms of traveling through complex and dangerous urban environments, which enables rapid and precise data acquisition (Karamuz et al. 2020). Bathymetric mapping using UAV capable of collecting underwater topography for the analysis of submerged structures like sediment deposition, obstacles, and flow disturbances (Bates et al. 2010). Such characteristics are key to understand urban drainage systems dynamics yet often overlooked in traditional assessments. Research by (Zhi et al. 2020) has demonstrated the relevance of UAV-bathymetry in the assessment of urban water-logging. Mapping of UAV-bathymetric in urban China showed that in mine-enclosed areas, 40% of the drainage capacity was lost due to sediment deposition, highlighting the urgent need for focused intervention.

There are many practical advantages of UAV-bathymetry. The UAV systems allow rapid, cost-effective data capture over wide and complex areas (Quamar et al. 2023). Firstly, UAVs can operate quickly and economically across large and complex sites and their application to derive digital elevation models (DEMs) has demonstrated an unprecedented level of detail for mapping waterlogged areas in Nanjing, China, with a 0.3-metreresolution that satellite images cannot provide (Yao et al. 2019). Second, UAVs are particularly beneficial in time-critical applications. UAV-bathymetric data was utilized in 2020 Jakarta, Indonesia monsoon floods to identify critical drainage bottlenecks within the next 24 h in order to enable rapid mitigation measures that reduced inundation levels in affected areas by 30% (Sihombing et al. 2023). In densely populated areas, such as Delhi, UAVs enable mapping of drainage systems as well as flooded areas, avoiding the logistical and safety challenges that manual surveys can pose (Uwaechia and Mahyuddin 2020). The Ghazipur Drain has a prolonged record of deposition of sediments and solid waste instigation flooding risks. Lai et al. (2018) conducted a comparative analysis of different mapping approaches and found that UAV-bathymetry reached a mapping accuracy of 95% where the satellite-based and ground-based methods reached mapping accuracies of 78% and 87% respectively. UAVs equipped with LiDAR sensors are capable of identifying system drainage inefficiencies with 92% sensitivity, making them particularly reliable for urban applications. The results of pilot experiments with UAVs conducted in India have been promising. In 2022, a project in the Indian city of Chennai employed UAV-bathymetry to assess the city's storm water drainage systems, revealing that 60% of the network was rendered non-permeable by sediment or debris (Glendenning et al. 2012). This information aided in the improvement of maintenance practices that resulted in a 35 percent reduction in waterlogging incidences in the coming monsoon season (Diwate et al. 2025).

The innovation of UAV-bathymetry revolves around its ability to build precise, high quality bathymetric maps with deep understanding of urban drainage systems (OECD 2024). Unlike the standard satellite or terrestrial methods, UAV-bathymetry is capable of recognizing submerged features that are vital for determining waterlogging extent. This competence enables researchers and city networks to identify the reasons and locations of active waterlogging, as well as assess and develop effective control measures. Moreover, UAV-bathymetry represents a huge leap forward in the time and space resolution of urban waterlogging studies. Old methods mostly rely on static information, but UAVs are able to collect and update their information in almost real time, making them very useful in dynamic waterlogging control situations. During the monsoon floods 2021 in Mumbai, UAVs monitored water levels in critical drainage systems in order to better manage pumps and other solutions during the flooding (Raj et al. 2022; Rawat et al., 2019; Wawrzyniak et al. 2016). Urban drainage systems such as Ghazipur Drain are important for storm water disposal, but are often ineffective due to sediment and other debris clogging them. UAV-bathymetry solves these problems in a more effective way. This technology provides underwater topography of the drainage at high resolutions, thus helping with locating significant areas that are vulnerable to blockage or loss of capacity. Initial UAV measurements suggest that sediment accumulation in the Ghazipur Drain reduces its effective discharge by 25% during periods of heavy rainfall (OECD 2024). The information acquired through UAV-bathymetry can direct particular activities such as silt removal and channel widening, which are very important for improving the efficiency of the draining. This technique also increases accuracy UAV-bathymetry innovation is in its ability to quickly and truthfully generate detailed maps of Urban Drainage Systems. Unlike, traditional satellite or land based methods, UAV bathymetry has the ability of revealing underwater features important for understanding waterlogging patterns. Such capability will enable researchers and planners to identify the areas affected by waterlogging, know the causes, and devise solutions to address the menace. In addition, UAV-bathymetry indicates a great progress for enabling urban waterlogging studies of space-time resolution monitoring.

Moreover, UAV-bathymetry represents a dramatic improvement of the temporal and spatial scope of urban waterlogging studies. Static data is used most frequently by conventional methods, but UAVs are able to collect and update data almost in real time, making them indispensable for active management of waterlogging situations. From monitoring the water levels of critical drainage systems so that pumps can be deployed and other mitigating actions put into place more effectively during the 2021 monsoon floods in Mumbai, UAVs were put to great use (Banolia et al. 2023). Drains in the city like the Ghazipur Drain are important for managing storm water, but are often inefficient because of sedimentation and garbage build up. UAV-bathymetry proposes an adequate solution to these problems. It provides a means to accurately map underwater topography of the drain and identifies key areas where obstruction or loss of capacity is likely to occur. Preliminary survey measurements taken with UAVs suggest that sedimentation in the Ghazipur Drain reduces its effective capacity by about 25% during the peak rainfall periods (Gautam et al. 2020; Rawat and Panwar 2024; Raj and Rawat 2024; Mahanta et al., 2023). The UAV-bathymetric data tend to inform the procedures that need to be done like silt dredging and channel widening which are important for optimizing drainage processes. This technique reduces the risk of water logging and increases the serving life of the city's constructions. This development addresses important gaps in research respond to rapidly evolving urban waterlogging scenarios. on urban flooding by demonstrating the application of UAV-bathymetry to urban drainage. Modern studies often conduct surface investigations of the water logging problem using an average geographical approach which misses crucial submerged components of the drainage mechanisms. This study applies UAV-bathymetric data to show how structural and morphologic components contribute to water logging and thus offers a new approach to management of urban drainage. In contrast to previous works, however, UAV-bathymetry is a new approach to studying and managing urban flooding. This approach uses UAV-bathymetry on the Ghazipur drain in Delhi while addressing an important local issue and forming a replicable study for urban drainage systems worldwide. It can collect real-time data which allows it to operate with precision in urban spaces. The specific results of the research are crucial for civil engineers and scientists for the creation of better methods of combating waterlogging.

2. LITERATURE REVIEW

The use of UAV-Bathymetry has great advantages in solving and addressing the limitations of current methods of monitoring the degree of waterlogging as it offers more accurate, faster, and more suited to a global urban environment (Rakha and Gorodetsky 2018). This penetration depth enables high-resolution wide area mapping to sub-meter accuracy, allowing for the identification of subtle sub-seafloor features that are typically missed by other techniques such as satellite or ground surveys (Del Savio et al. 2023). Model accuracy is higher using such models, which has shown to be beneficial in many regions across the world (Fewtrell et al. 2010). UAV-Bathymetry, can identify silt deposition, blockage to drainage system, and so on, which is one of the maintenance issues to be done to minimize urban water logging demonstrated how UAV-Bathymetry was able to detect silt deposition and blockages in a drainage system, which is a critical area for maintenance in order to reduce urban waterlogging (Rossi et al. 2020). Likewise, (Brown, 2022) pointed out its usefulness in more rural areas where precise underwater topography is necessary for flood control. These instances demonstrate the immense potential UAV-Bathymetry has for solving the multitude of topographic challenges that arise from urban waterlogging (Bilașco et al. 2022).

UAV Bathymetry has the added benefit of acquiring data over extensive regions over a short period of time. It makes UAVs useful in carrying out preventative and mitigate assessments of waterlogging in real-time during and after a flood incident. In a study conducted on waterlogging disaster events in Nanjing, China, Rossi et al. (2020) detailed the importance of timely disaster information for environmental planning and mitigation actions, and how UAV – Bathymetry made it possible to use critical data just hours after the disaster flooding. These capabilities are essential in urban areas with short time to flood regions, where traditional methodologies will take weeks or days to formulate actionable data. Similarly, Bilașco et al. (2022) in the Philippines put UAV-Bathymetry to use because of flooding that occurred frequently during the monsoon seasons and required urgent data for disaster relief and enhanced long term drainage management. Apart from the timeliness, UAV-Bathymetry allows access to remote places that are not safe or easily reachable through the traditional surveying techniques. These areas are severely flooded, have thick vegetation, or have very complex urban drainage systems. In Oregon, USA, UAV Bathymetry use was showcased by Medvedev et al. (2020).

In Oregon, USA, UAV Bathymetry use was showcased by (Sott et al. 2020) employed UAV Bathymetry to overcome ground-based crew limitations caused by urban floods. Using UAVs enabled the acquisition of invaluable data without placing survey personnel at jeopardy of harsh weather conditions. Another important benefit of UAV-Bathymetry is that it is cost-effective in terms of labour and time, as well as equipment compared to conventional topographic surveying. UAVs equipped with state-of-the-art sensors facilitate large-scale aerial data collection without the logistical burden of large field parties or specialized equipment (Del Savio et al. 2023). Del Savio et al. (2023) identified the cost benefits of UAV-Bathymetry for urban drainage infrastructure management, suggesting that if accurate enough, they could more effectively target maintenance and construction activities. In fast growing metropolitan areas like India, UAV-Bathymetry has been adopted along water courses to mitigate persistent water logging problems at a fraction of the cost of conventional survey techniques.

UAV-Bathymetry, both regionally and internationally has demonstrated its ease of adaptability and functionality in different contexts. In Southeast Asia, parts of the world prone to seasonal flooding have employed UAVs for mapping submerged geomorphological features high in urban accuracy to aid planners in designing and implementing effective drainage systems. In the Middle Eastern region, UAV-Bathymetry has been important in evaluating the drainage systems of dry cities where sudden flash floods lead to severe water logging (Fewtrell et al. 2010). UAV bathymetric technology can be fit to different climatic and geographical conditions, which makes it universally applicable. Its application in community based projects has also improved its performance. Sufficient examples can be mentioned for the use of UAV bathymetric in Africa that was intended to map flood risk zones in urban centres, enabling local authorities and communities to synergize towards feasible mitigating strategies. With this common action approach, not only is adaptive capacity increased, but there is also better understanding of the waterlogging phenomenon among different groups. Among its many benefits, UAV bathymetry comes with certain challenges. The range of adoption has been slower due to limits of sensor technology, data processing requirements, and policies that govern the deployment of UAVs. However, these limits have been slowly changing due to improvements in sensing and higher access to efficient data processing applications. In addition, more international regulations on the use of UAVs are likely to increase the operational barriers in urban settings. This is likely to make UAV bathymetry more possible and useful than ever before.

In short, UAV-Bathymetry has become a major technique in addressing urban waterlogging issues across the world. Unlike other approaches and methods that came before, this breaks new ground due to its ability to provide high perspective data quickly while being cost effective. That makes it an invaluable tool to urban planners, and also to politicians and disaster-response teams. Due to emerging technical innovations, UAV-Bathymetry will be at the forefront of the global battle against urban flooding and resilience, this innovative solution will help mitigate, what many believe is the greatest threat to cities in current times (Fewtrell et al. 2010).

3. DATA AND METHODS

3.1 Study Area

Ghazipur Drain is an important but polluted drainage line of East Delhi, also called pentamerous drain because it runs along National Highway 24 (NH-9). However, urban encroachment, leachate from landfills and untreated sewage have made it one of the most contaminated water bodies in the region. The drain excretes not only rain but also wastewater, which is ultimately drained into the polluted river Yamuna. Ghazipur Drain lies between 28.620° N to 28.640° N latitude and 77.290° E to 77.320° E longitude (Fig 1) as such it represents a considerable drainage network in East Delhi. The beginning point lies near Patparganj Industrial Area, known for the dense manufacturing units and the industrial waste that they add to the drainage system. The drain runs southeast and passes through diverse residential, commercial and landfill areas, before meeting the Yamuna River. Its total length is estimated to be between 12 to 15 kilometers. The drain traverses several densely populated areas, including Ghazipur, Mayur Vihar, and nearby settlements, which further increase the pollution levels due to uncontrolled solid waste disposal.

Regarding the altitude, the highest level of the drain is situated close to the Ghazipur, where the adjacent area attains an altitude of approximately 215-220 meters above the sea level. The gradient towards the Yamuna River floodplain is also relatively shallow with its lowest point being approximately 198–200 masl, which in principle should facilitate continuous drainage. Nonetheless, during the monsoon season. severe waterlogging and urban flooding occurs due to water stagnation caused by sediment accumulation, excessive siltation, and solid waste blockage. The Ghazipur Drain is well-known for one of the major environmental issues namely the direct escape of toxic landfill leachate from the neighboring Ghazipur landfill. Research has indicated that elevated levels of heavy metals, organic pollutants, and microplastics have been found in water samples from the drain, making it one of the most ecologically dangerous drainage systems in Delhi. In addition, its slow speed of flow and lack of proper dredging processes reduce its conveyance, exacerbating local flood and health threats for communities downstream. Using Unmanned Aerial Vehicles (UAVs) release high-resolution bathymetric mapping has been able to provide essential information regarding the depth profile, sedimentation, and obstruction points in the drain. By utilizing LiDAR technology, multispectral imaging, and drone-assisted remote sensing, researchers can create hydrological models to evaluate water flow dynamics and pinpoint areas susceptible to excessive sediment accumulation and blockages. This approach will support improved drainage planning, flood risk reduction, and water quality enhancement efforts in East Delhi.

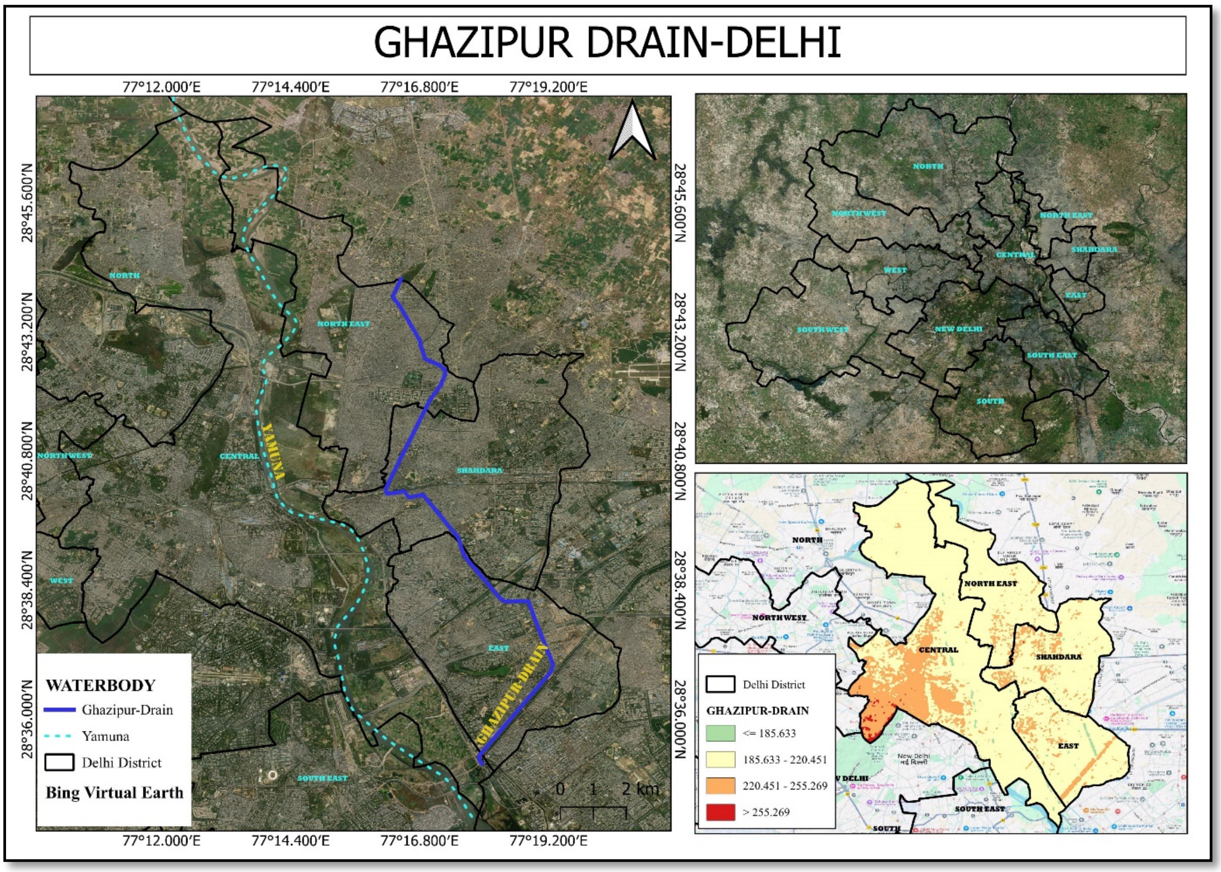

Fig. 1: The Ghazipur Drain and surrounding areas in Delhi, India

3.2 Data Used and Methods

A robust methodology was employed that combined UAV based aerial imagery, DGPS ground survey and bathymetric data for a high-resolution mapping and analysis of waterlogging in the Ghazipur Drain. These methods resulted in a high value, high density data set necessary for successful hydrodynamic and topographic models in the study area. The flowchart in Fig 2. breaks down each component of the process.

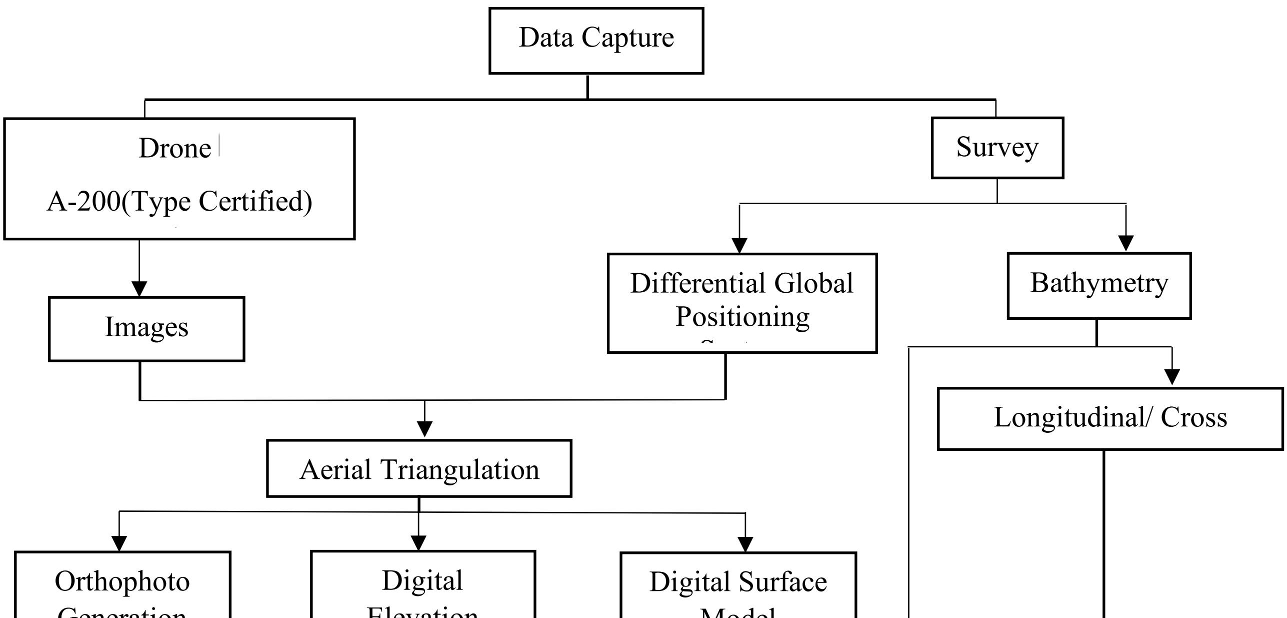

Fig. 2: Methodology

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This process involves collecting geographical data using UAVs and advanced surveying methods to deliver a comprehensive analysis (Suzuki 2020). The internal parameters of the drone camera, were calibrated before the flights, and additionally in the pre-processing phase in the agisoft metashape software. With overlapping RTK correction windows (static base station logs) providing temporal alignment; the photogrammatic was made consistent by methodology using a differential gobal navigation system approach. DGPS involves a stationary base station which compares its known coordinates to the satellite signals, measuring the difference between them to transmit corrections to a mobile unit known as a rover, and then applying the corrections to the GPS signals received by the rover, achieving positional accuracy below one meter. Both RTK and Static methods employ carrier-phase corrections, with RTK achieving real-time centimeter accuracy and Static surveying providing even greater precision through longer observation times and post-processing.

A certified A-200 drone captures high-resolution JPEG images (illustrated in Figure 2) equipped with RTK-enabled GPS, ensuring precise geotagging and a ground sampling distance (GSD) of 2–5 cm for detailed surface examination (Nielsen et al. 2022). Aerial surveys are conducted with a side overlap and forward overlap to ensure data redundancy and seamless image stitching. GCPs use DGPS technology to provide geospatial precision. The use of Static reference GCPs and Real-Time Kinematic (RTK) points makes it possible for the UAV images to georeferenced with other geographical datasets (Fig 3) (Suzuki 2020). An echo sounder records bathymetric depth profiles with a vertical precision of ±2 cm. Although combining these depth measurements with Differential Global Positioning System (DGPS) coordinates produces a high-resolution bathymetric map. UAV imagery and GCP data are used to produce Digital Elevation Models (DEMs), with vertical resolution of 5–10 cm (Saponaro et al. 2020). This reveals low-lying areas and small elevation changes. Additionally, using the bathymetric data, DEMs are processed into Digital Terrain Models (DTMs). The DTMs provide high spatial resolution of both terrestrial and submerged landscapes (Table 1) (Zhu et al. 2019). A standardized bar check was performed to field-calibrate the echo sounder at the beginning of each survey to adjust for signal lag and environmental variability. A bar check was used to calibrate the echo sounder, where a reference plate was raised and lowered to known depths, which allowed for correction adjustments associated with signal lag, transducer draft, and environmental variability. The speed of sound in water was also configured from in-situ temperature and salinity of each section, so the acquired data was overcome with the consideration of the depth of the detect section under field conditions. GPS timestamps were used to time-synchronize the recorded depth values with DGPS and UAV logs, which facilitates spatial alignment and minimizes error propagation in the resulting DTMs.

Table 1: An Assessment of Techniques for Capturing Waterlogging Extents along the Ghazipur Drain

Data Type	Description	Methodology	Purpose
Drone Imagery	Asteria A200 drone-captured high-resolution JPEG photos with RTK-enabled GPS geotagging	Aerial survey is scheduled with a 70% side lap and 80% overlap to guarantee comprehensive coverage and facilitate seamless image stitching.	To obtain intricate surface pictures of the subject region for topographical examination
Ground Control Points (GCPs)	Control points based on DGPS are established at intervals of 1 km using static observations, while RTK points are positioned every 250 meters.	Accurate GNSS location to guarantee high absolute precision and facilitate the synchronization of bathymetric and UAV data.	To accurately align UAV imagery with bathymetric data and ensure consistency in mapping.
Bathymetric Data	Depth profiles collected using an echo sounder along the waterlogged areas	Integration of bathymetric data with DGPS coordinates for comprehensive underwater topography mapping	To ascertain underwater topography, silt deposition, and depth fluctuations in drainage systems
Digital Elevation Model (DEM)	Depth profiles obtained through the use of an echo sounder in the waterlogged regions	Generation of a Digital Elevation Model (DEM) utilizing UAV data and Ground Control Points (GCPs) to construct a surface elevation model for topographical study.	To identify low-lying regions and probable waterlogging sites based on elevation variances.
Digital Terrain Model (DTM)	Enhanced Digital Elevation Model integrating bathymetric data for seamless terrain mapping	Integration of bathymetric data with Digital Elevation Models to produce an accurate depiction of both terrestrial and subaqueous terrain.	To examine the dynamics of waterlogging in regions with intricate drainage systems
Orthophoto	Aerial image that has undergone geometric correction, depicting the specified area of interest.	Generation of orthophotos through the application of geometric adjustments to UAV imagery	To illustrate surface characteristics and offer context for recognizing potential waterlogging areas.
Topographical Mapping	Evaluation of elevation, depressions, and slopes through the application of Digital Elevation Models (DEM) and Digital Terrain Models (DTM).	Utilize GIS technologies to detect depressions, inclines, and additional topographical characteristics linked to waterlogging.	To produce maps and visualizations for the identification of locations susceptible to waterlogging

Orthophotos are created by geometrically correcting UAV images, achieving pixel-level precision with a ground sample distance (GSD) of 2–5 cm. Such orthophotos are accurate, georeferenced representations of surface features, forming the basis of waterlogging vulnerability mapping.

Topographical maps are extremely useful for analyzing elevation, depressions and slopes from DEMs or DTMs by utilizing GIS technology to map high-resolution maps that contain valuable information about the topography of the area (Zhu et al. 2019). These outputs can assist in spatializing waterlogging vulnerability and inform mitigation strategies (Chai and Draxler 2014). The methodology serves as a leap mechanism for effective waterlogging mapping and management by supplementing UAV high-resolution data, GCP placement, and GIS analysis.

Table 2: UAV specifications

Specification	Details
Drone Model	Asteria A200
Type	Multi-rotor UAV
Max Flight Time	Up to 40 minutes (depending on payload)
Max Flight Speed	15 m/s
Operating Range	Up to 5 km
GPS Mode	Real-Time Kinematic (RTK) and GNSS
Camera Resolution	Up to 20 MP
Camera Type	Frame camera
Image Format	JPEG, RAW
Ground Sample Distance (GSD)	As low as 3 cm (depending on altitude)
Max Wind Resistance	10 m/s
Stabilization	3-axis gimbal
Payload Capacity	Approximately 2 kg
Battery Type	Li-Po (Lithium Polymer)
Battery Capacity	6,000 mAh
Charging Time	Approximately 60–90 minutes
RTK Accuracy	Horizontal: ±1 cm, Vertical: ±2 cm
Operating Temperature	-10°C to 40°C
Dimensions	Folded: 350 x 200 x 150 mm
Weight	2.2 kg (including battery and camera)

Table 2 illustrates how the A200 can provide a GSD down to 3 centimeters, depending on altitude, allowing for detailed surface mapping. This drone effectively captures topographical features that lead to water pooling, including slope variations, fissures, and dips, even at a low GSD. When mapping extensive waterlogged areas, the 3-axis gimbal stabilization ensures the camera remains steady during flight, resulting in clear, motion-free images. This adds stabilization, allowing for consistent image quality for accurate surface models, even with moderate wind. The A200 has a 40min flight time allowing the user to cover larger areas in one flight, making waterlogging studies less cumbersome with no need to change batteries frequently. Based on the above specifications, Asteria A200 is a powerful tool for the land analysis, mapping and monitoring for waterlogged areas for water logging risk analysis and water management planning.

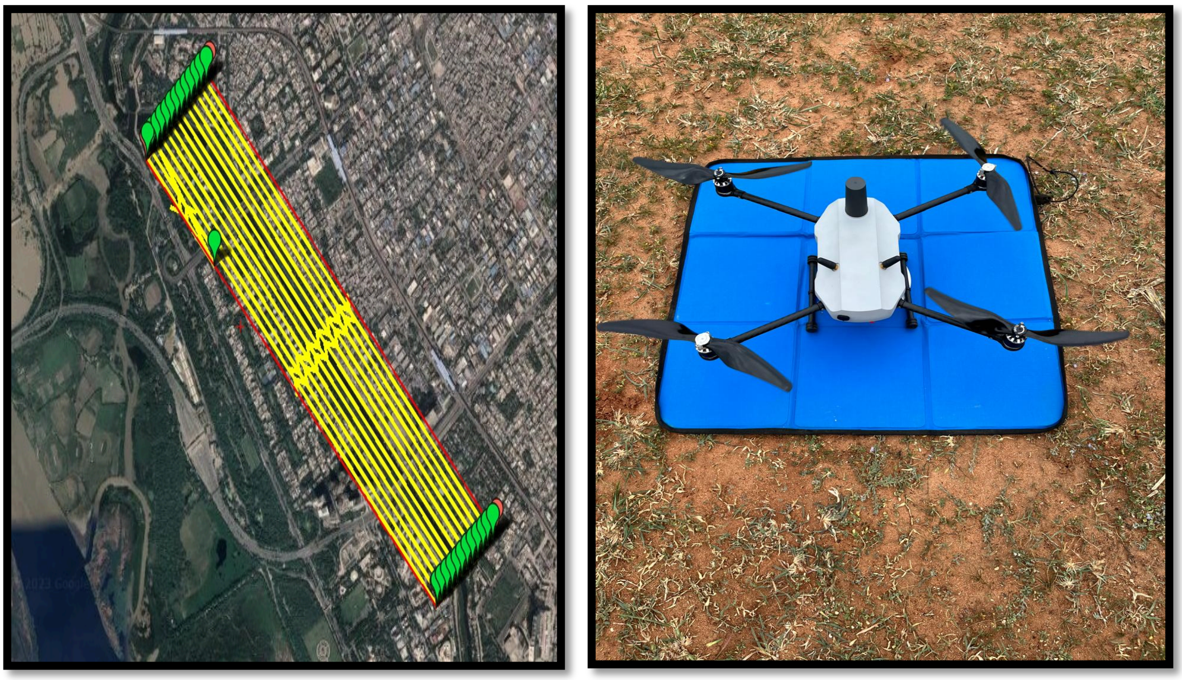

Fig. 3: Flight strategies and unmanned aerial vehicles for surveying the site

The flight plan had a 70% side lap and an 80% overlap between all images taken, resulting in a good and complete collection with almost no gaps (see Fig 3.). The area covered was 100 meters wide, with a distance of 35.25 meters between flight lines as shown in Fig 4. The Ground Control Points (GCPs) used for georeferencing were sized at 1.5 × 1.5 meters to improve visibility from the UAV's altitude, thereby enhancing overall accuracy by providing clearly identifiable spots in the landscape, as shown in Fig 4. In addition to spatial control, redundancy was introduced by surveying each GCP three times with the mean of the points being used as coordinate values in order to eliminate any outliers. Together, these steps led to an improvement in the overall model georeferencing accuracy.

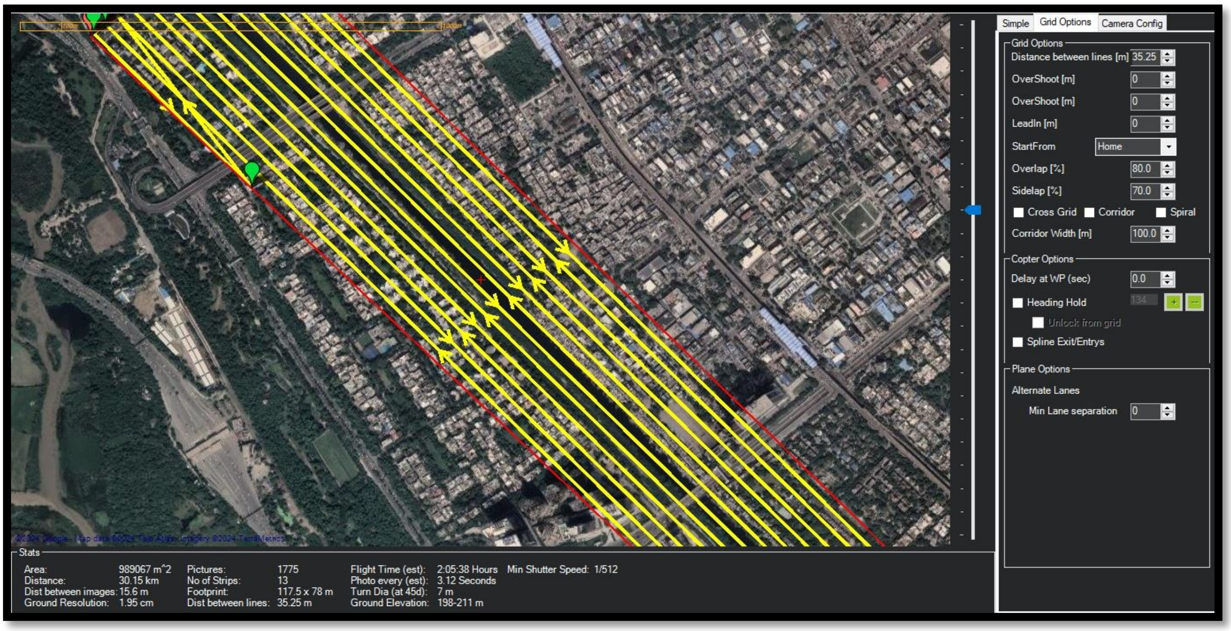

Fig. 4: Details of Flight Plan

A Differential Global Positioning System (DGPS) survey was conducted to enhance the positional accuracy of aerial photography and provide vital data for water level rise that leads to waterlogging. This DGPS survey utilized Global Navigation Satellite System (GNSS) constellations to achieve high-precision location tracking (Saponaro et al. 2020). Primary Ground Control Points (GCPs) were established at 1 km intervals for measuring Ghazipur Drain (3 × 30 min static observations at each site). Moreover, Real-Time Kinematic (RTK) points were collected at every 250 meters distance to verify the accuracy of data remained consistent across the extent of the study area (see Fig 5). The horizontal accuracy was ±3 cm and the vertical accuracy ±5 cm which can be achieved through the integration of DGPS and RTK. Over vegetated or canopied areas, there were minor deviations due to GNSS signal attenuation. Bathymetric data were collected using an echo sounder simultaneously with the DGPS survey to acquire depth profiles of the Ghazipur Drain. The echo sounder data played a key role in establishing a holistic understanding of the morphology and hydrodynamic processes of the drain spoil.

Fig. 5: depicts the Ground Control Points taken within the study area.

Once the data was captured, processing with the aerial triangulation of the UAV images begins. In this case builds from the DGPS ground control points that can be used to match from the geotagged images, thus leading to a composite image that is very precise (Acharya et al. 2021). It improves both absolute accuracy, which refers to alignment with real-world coordinates, and relative accuracy, ensuring consistency among the images. This guarantees that every part of the collected data aligns perfectly with its neighboring sections. This approach was augmented for vertical consistency within the digital terrain models by considering parallax distortions and terrain shifts in dense point-cloud generation with multi-view stereo algorithms. In Agisoft Metashape, we imported the ground control points (GCPs) that were collected using DGPS technology. To serve as real-world imaging reference points, all the GCP coordinates were keyed into the software. The GCPs acted as control sites during alignment, and this allowed Agisoft Metashape to properly align the drone photos (Li et al. 2021). By placing the GCPs, aerial images are aligned to the ground position thus providing a model that is spatially accurate and improves the absolute accuracy of the model. After importing the photos and GCPs, Agisoft Metashape detects features in photos. The software identifies key features in overlapping photos to establish tie points, matching characteristics like corners and textures (Bates et al. 2010). The matching determines the relative positions between the photos, which is required for triangulation. The photogrammetric bundle block adjustment algorithms in Agisoft Metashape optimize the alignment of images by correcting discrepancies (Darji et al. 2024). This adjustment modifies the locations and orientations of the images to best fit them with the GCPs. Each image is treated as a "block," and the software calculates the spatial relationships between these blocks and the GCPs to enhance alignment. The Root Mean Square Error (RMSE) across the three spatial dimensions resulted in 4.2 cm (X), 3.6 cm (Y), and 5.1

cm (Z), manifesting a high level of spatial accuracy between UAV images and control points after the bundle block adjustment process.

3.2.1 Photogrammetric Processing

The bundle blocks are adjusted by a camera using camera information, such as focal length (f), offsets of the principal point (cx, cy), and distortion coefficients (K1, K2, K3, K4, P1, P2) in Agisoft Metashape (Zhu et al. 2019). These parameters help reduce lens distortion, like radial and tangential distortions, which can also create errors in the model.

3.2.2 Lens Distortion Correction and Normalization

By minimizing positioning errors between adjacent photos, bundle adjustment enhances relative accuracy and ensures seamless alignment of the dataset.

$$x = x/z \quad \dots (1)$$

In this context, X represents the horizontal position and Z indicates the depth, which helps in normalizing the point's position on the image plane. Photogrammetry and aerial triangulation involve the conversion of 3D points from the camera's local coordinate system into 2D coordinates on what is referred to as a "normalized image plane," as illustrated in Eq. 1. The local coordinate system of the camera assigns coordinates (X, Y, Z) to any point in 3D space, where X and Y denote the horizontal and vertical distances from the optical center, while Z signifies the depth. To achieve normalized coordinates that are independent of depth, you divide X by Z and Y by Z.

$$y=Y/z \quad \dots (2)$$

In this context, Y represents the vertical position and Z indicates the depth, which helps in normalizing the point's position on the image plane. According to Eq. 2, the normalized coordinates are given by $(x, y) = (X, Y)$ or (x,y) = (Z X, Z Y). This transformation effectively scales all points as if they were being projected onto a unit-distance plane from the camera, thereby removing the depth factor. The normalized coordinate system makes manipulating these points during computation easier, as the intrinsic properties of the camera (focal length, distortion coefficients, etc.) can be applied seamlessly when projecting a point to an image. Working with normalized coordinates allows for more intuitive lens distortion correction uniformly which makes the alignment of 3D points to their 2D projections better. It is a technique that has been used in photogrammetry as it makes the transformation of 3D points to a 2D image plane as accurate as possible.

$$r = \sqrt{(\varkappa^2+y^2)} \quad \dots (3)$$

In this case X2 and Y2 are simply the Euclidean square distance from origin to a given point. Radial distance from Equation 3 is needed for correcting radial lens distortion, which an optical artefact occurs when our lens curvature causes points located outside of the image to shift. To get r, you take the square root of the x value squared + the y value squared. This gives us the Euclidean distance from the image centre (the origin, in normalised coordinates) to the point we selected. The radial distance r is important to find out how near a point is to the centre of the image, which is further required to carry out distortion correction. Calculating r allows us to better align positions closer the edges of the image (that have the highest distortion) with their more accurate representation on the image plane. Such an improvement will enable spatial data to more accurately reflect real world coordinates and distances, useful in applications such as 3D cartography.

"x^'=x.(1+k_1 r^2+k_2 r^4+k_3 r^6+k_4 r^8)+(P_1 (r^2+2x^2)+2P_2 xy)" … (4)

Here, X'= Asymmetry of the image

K1, K2, K3, K4 are radial distortions coefficients

P1, P2 are tangential distortion coefficients

y^'=y.(1+k_1 r^2+k_2 r^4+k_3 r^6+k_4 r^8)+(P_1 (r^2+2x^2)+2P_2 xy) … (5)

Here, y'= Asymmetry in the image

K1, K2, K3, K4 are radial distortions coefficients

P1, P2 are tangential distortion coefficients

All the equations shown in Eq. 4 and 5 take care of radial and tangential distortion, respectively, and the output coordinates (x', y') impose the position of the point correctly on the image plane. So, correcting this is a key part of photogrammetry for high accuracy, as minimizing the effects of displacement and distortion together leads to better alignment of the measurements, and, ultimately, better root mean square error (RMSE) in mapping and 3D applications.

3.2.3 Image Projection to Pixel Coordinates

The last transformation from normalized coordinates into image pixel coordinates taking the camera's intrinsic parameters and sensor geometry into consideration is:

u=w.0.5+Cx+x^'·f+x^'·B+y:B_2 … (6)

Where, F = Focal length

Cx, cy are the principal point offsets

B1 and B2 are the skew coefficients

W and h are the width and heights of the image in pixels

Eq. 6 correctly projects a normalized coordinate point (x', y') onto the pixel grid of the image, while considering the camera's characteristics. Focal length and skew coefficients are major parameters that play a pivotal role in placing point u in a plane, which helps in mapping 3D points to a 2D plane. This changes photograph mapping more prominent precision for 3D rebuilding and mapping.

v=h·0.5+Cy+y^'·f … (7)

Where, F = Focal length

Cx, cy are the principal point offsets

B1 and B2 are the skew coefficients

W and h are the width and heights of the image in pixels

Eq. 7 similarly is a function that converts a point with normalized, corrected coordinates y' into the vertical pixel coordinate v considering the internal parameters of the camera. The focal length of scales the normalized coordinate y to match the distance of the camera to the scene and the principal-point offset cy centers the optical axis aligned to the sensor when the center of the optical axis does not coincide with the sensor center. It correctly projects 3D points to the 2D image plane in photogrammetry, which is the image formation model that should yield consistent images which are indeed aligned for more accurate reconstruction and mapping. After triangulation, an orthophoto was generated, where the rectified composite image was transformed geometrically to create an orthophoto. This orthophoto acts as a base layer for the topographical mapping of Ghazipur Drain. Numerous models were developed from the triangulated images that had been captured via aerial imagery into forms representative of the landscape including Digital Terrain Models (DTM) and Digital Surface Models (DSM). A digital elevation model (DEM) was first created showing surface heights for both natural features and human-made structures in the area. The DEM was then processed further to yield a Digital surface model (DSM) and finally a Digital Terrain Model (DTM). It is a digital representation of the ground surface without any objects like buildings and vegetation that is ideal for all terrain viewing.

3.2.4 Bathymetric Integration and Topographic Modeling

Bathymetric data from the echo sounder was integrated into the Digital Terrain Model (DTM), resulting in a detailed representation of the topography, including the underwater profile of the Ghazipur Drain.

Fig. 6: Survey of the bathymetry of the Ghazipur Drain.

Bathymetry data is important in waterlogging analysis, particularly in urban areas as it provides the instruments to assess the underwater land surface area of the drains/rivers/reservoirs (depicted in fig 6). By adding bathymetric data, UAV surveys provide complementary surface and underwater landscape data (Stark and Oskoui 1989). Such surveys allow recognition of the depth and shape diversity of water bodies, sedimentation, and possible areas where water stagnation occurs (Babbar et al. 2017). This is important for assessing the behaviour of water in relation to urban areas, particularly in areas at risk of drainage problems or flooding (Del Savio et al. 2023). By accurately mapping underwater topography, bathymetric data can pinpoint problematic areas that may exacerbate waterlogging following heavy rainfall or rising water levels. The images depict a bathymetric survey being conducted on the Ghazipur Drain, which is essential for determining underwater depth and mapping the drain bed's topography A modest wooden skiff functions as a staging point, highlighting its applicability for shallow inland waterways. Manual depth-gauging devices and echo sounders pinging underwater were employed in tandem by the assessment party to chart floor elevations via echo return intervals. Concurrently, a Differential Global Positioning System gadget geotagged soundings, ensuring high spatial precision. Supplementary geospatial metadata including latitude, longitude, altitude and measurement dependability furnished important contextual framing for integrating these figures with other pre-existing datasets such as Digital Elevation Models. Occasionally deeper pools amid intermittent sandy shallows challenged the draught of the shallow-draft vessel yet the crew persevered in cataloguing the assorted depths. This survey maps the underwater topography of the drain, evaluating siltation levels, potential water stagnation areas, and flow blockages. The data is then used to create detailed maps and is combined with information gathered from UAVs.

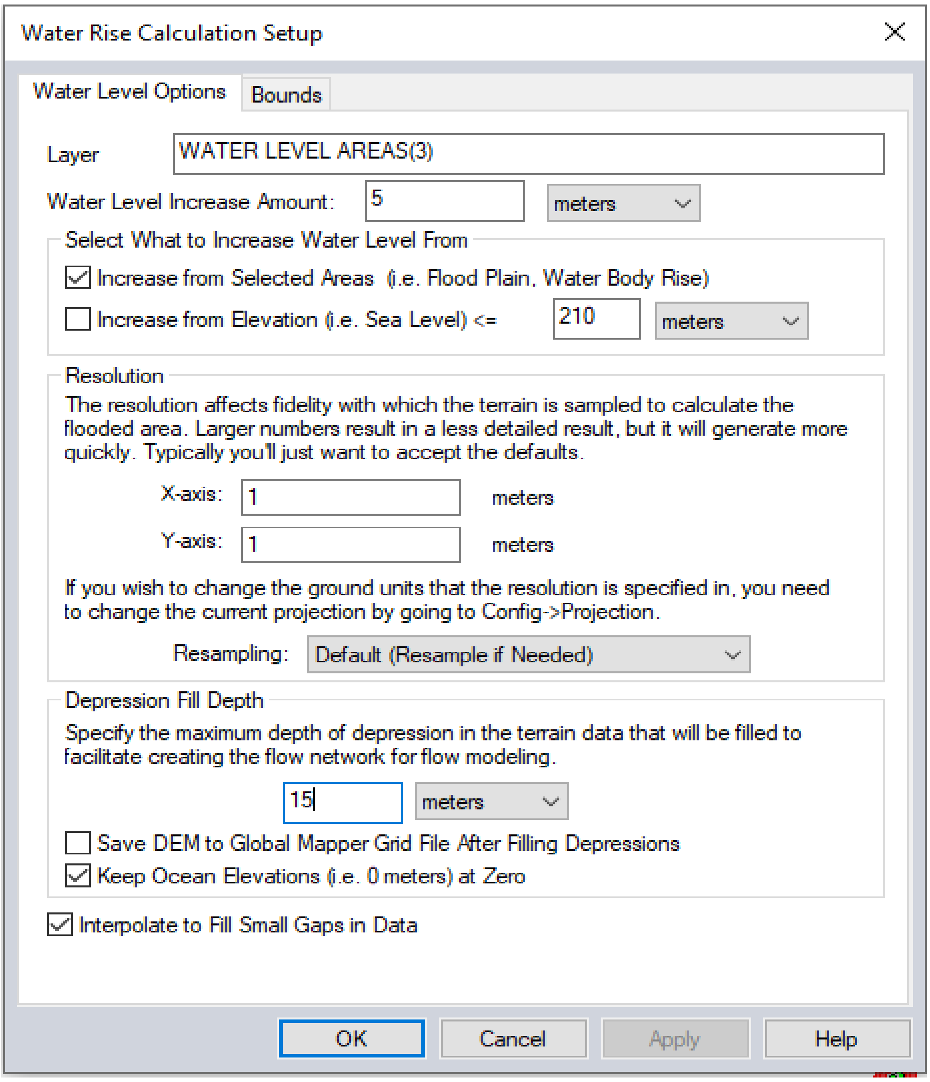

Fig. 7: Configuration settings for Water Rise in Global Mapper.

Configuration of UAV and bathymetric data for waterlogging analysis The Resolution field indicates that 1 meter for both X-axis and Y-axis samples with a high-resolution terrain model. This resolution improves precision by enabling an accurate delineation of terrain elements, making it critical for UAV data integration. Under the Resampling option, it defaults to Default (Resample if Needed) making data adjust automatically to resolution needs to hold consistency between datasets. This layer is used to fill depressions so that their areas and arrangement in relation to water accumulation and movement across the terrain is understood, and the DEPTH which would take preference is set to 15 Meters. This also prevents isolated water mass and ensures the continuity of surface water flow model. Save the floored DEM as a Global Mapper Grid File after depression filling We keep the Ocean Elevations at Zero meter to prevent any unintentional alterations into coastal or oceanic environments while concentrating the analysis on inland waterlogging. In order to fill small holes in the point cloud, we have turned on the interpolation option (Fig 7), which helps to fill in the gaps, and to integrate UAV and bathymetric data, as our UAV data can have a lot of gaps due to coverage limitations or obstacles when data collection is happening. This improves the dataset and makes it more suitable for conducting research on waterlogging. High-resolution digital elevation models and bathymetric data derived from UAVs provide a near-complete picture of land and water topography. To complement the UAV data, bathymetric measurements and depth profiles (from echo sounding) represent a first-of-its-kind data layer that identifies topographical features under the water surface that impact the dynamics of waterlogging.

This method plays a key role in urban waterlogging research, as having detailed topographical data is essential for analyzing drainage patterns and identifying areas that are at risk (Kumar et al. 2021). It enables the identification of low-lying regions and possible obstructions in urban drains, like the Ghazipur Drain, through careful mapping of the terrain, including underwater features Integration of UAV and bathymetric data used as a baseline to identifier land susceptible to wetness, that can be used and integrated into urban planning and maintenance plan to enhance drainage systems to reduce flooding risks in urban areas (Zhu et al. 2019).

4. RESULTS

The current study provides a detailed insight into the flooding hazards associated with Ghazipur Drain in Delhi. A high-resolution Digital Elevation Model (DEM) at 5 cm ground sample distance (GSD) was generated using UAV-based orthophotography and bathymetric data. The orthophoto (in UTM Zone 43/WGS84) gave us a very well detailed visual aerial image of Ghazipur Drain and the existing urban surface. Due to the RGB spectral channels, the visualisation of surface objects such as roads, buildings and vegetation is evident, hence the exact margins of the drain are precisely identifiable. Such visuals became necessary to ascertain areas vulnerable to waterlogging and also look at proximity of urban sprawls to the drainage network along with essential infrastructure like roads and metro stations. Bathymetric data from the drain were also incorporated to refine the DEM. Such an improvement gave us a more complete view of the subsurface terrain and surface, reducing ambiguities and enabling better quality control on elevation assessments. Based on the refined DEM, hydro-logical simulations were carried out to simulate different scenarios of rising water levels and detect the highly potentially waterlogging areas under rainfall events. These hydrology simulations were performed using the “Simulate Water Level Rise” module in Global Mapper (v24), which enabled the discretization of the enhanced DEM into controlled inundation based on incremental elevation thresholds. This was done by implementing a surface of water across the grid defined on the terrain, and then checking for those cells in the raster that were below the defined water elevation, effectively emulating ponding or flood propagation over the landscape in reality. Simulated rise scenarios were created at 0.5-meter intervals from 0.5 m to 5 m, resulting in inundation extents under various severity levels. Flood fill algorithms and raster reclassification helped to identify connected flood zones, allowing the calculation of their spatial extents.

The UAV-derived topographic data is assessed and provided new insights on the spatial distribution and intensity of waterlogging in urbanized regions worldwide. It made possible to find out close areas to the drain which can be flooded because of the poor slope and insufficient drainage ability. Furthermore, the enhanced DEM used in this study allows for accurate volume estimation of potential water accumulation in these areas, providing insights for targeted post-flooding interventions. A quantitative sensitivity analysis was done to assess model robustness by perturbing the input DEM with synthetic elevation noise of ±0.1 m (for low-lying areas) and ±0.2 m (for mountainous areas). These perturbations simulate real-world vertical uncertainty on UAV photogrammetric products and sensor-derived bathymetry. Sensitivity test results showed that an elevation difference of ±10 cm could produce a 12–18% change in estimated inundation area and water volumetric accumulation estimates differences of up to 15%. Furthermore, spatial analyses illuminated that the most significant discrepancies in flood extents manifested along transition zones between built-up edges and depressions with topographically ambiguous flow accumulation paths. This explains how localized errors in the terrain elevation, particularly in the vicinity of bathymetric discontinuities, play an essential role in the correctness of hydrological predictions and about areas with flood risk. An UAV orthophoto was used as a digital reference to delineate the drain boundary and those infrastructures surrounding it, showing where the drainage system interacts with the urban fabric. Combined high-resolution topography and bathymetry further improved realization of waterlogging threats and mitigation needs. These results highlight the importance of using UAV-based imagery for proper urban waterlogging management. This study gives the insight on the risks associated with water logging, which serves as an important baseline for urban planners and policy makers to identify the appropriate drainage improvements and risk management strategies to reduce flooding in certain areas or communities.

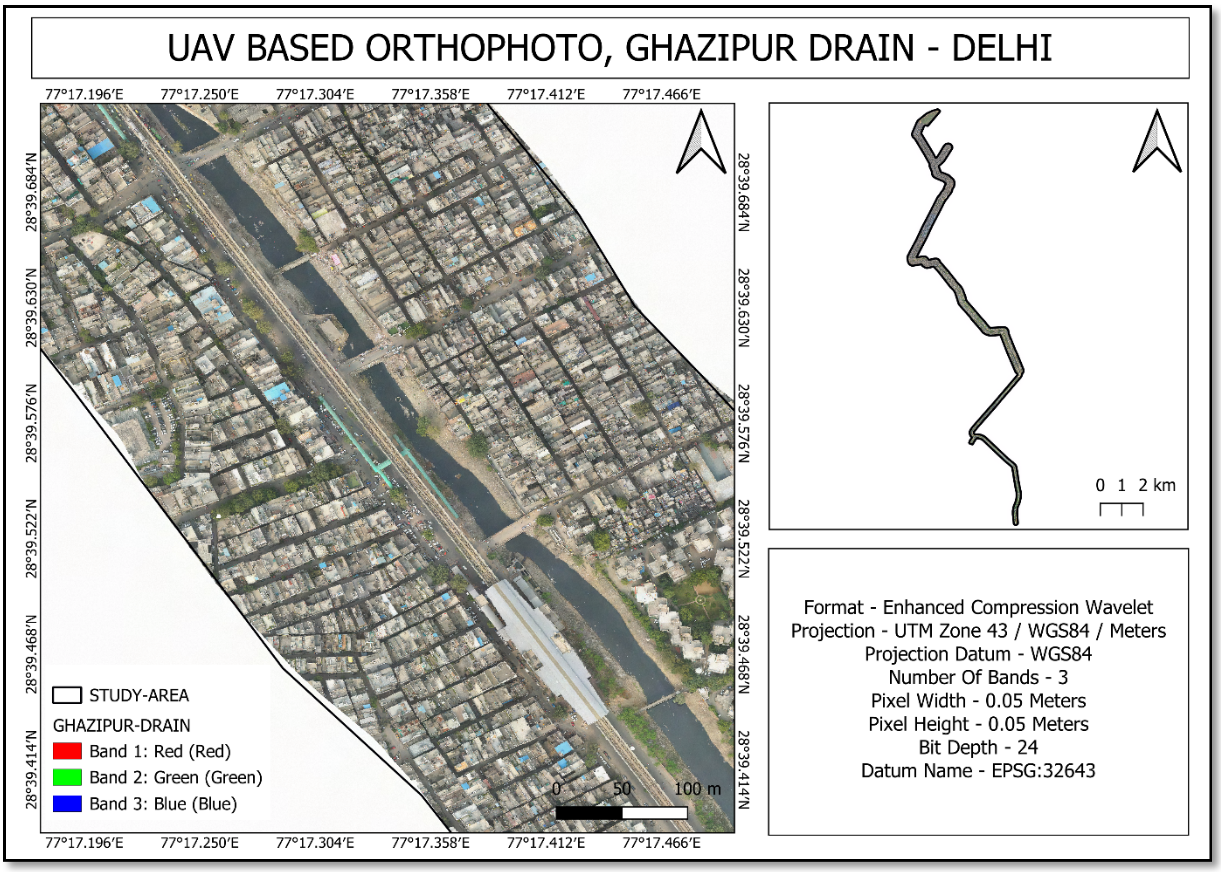

Fig. 8: A drone-based high-resolution georeferenced aerial photograph of Ghazipur Drain in Delhi.

Drone based images are referenced using ground control points in georeferencing ensures high-definition aerial image of Ghazipur Drain in Delhi showing land cover classification outcomes (Fig 8). With a pixel resolution of only 0.05 meters, the resulting aerial image is so detailed it shows even roads, neighborhoods, vegetation, and bodies of water in the surrounding area. Using WGS84 datum in UTM Zone 43 allows integration with geospatial analysis tools and corresponds with real world coordinates. The vector overlay designates the study area, where the analysis more directly highlights drainage details, detailing where urban infrastructure interfaces with the Ghazipur Drain. The detailed visual analysis obtained from the true-color RGB bands also aids in identifying potential waterlogging areas and determining the proximity of urban infrastructure to drainage systems. Other characteristics like the scale bar and north arrow help in interpreting the aerial photograph by providing a clear spatial context. A high-resolution Digital Elevation Model created from drone images and depth data from an eco-sounder provides detailed surface and subsurface information. Figure 9 shows that the DEM shows changes in elevation of the study area from 101.979 m to 240.959 m. A color gradient is used to represent low-lying areas at risk for flooding (blue, green) and the falling elevation (orange, red). With the incorporation of depth data, the DEM was able to accurately represent the underwater topography, enhancing the visualization of drainage and elevation disparities along the Ghazipur Drain.

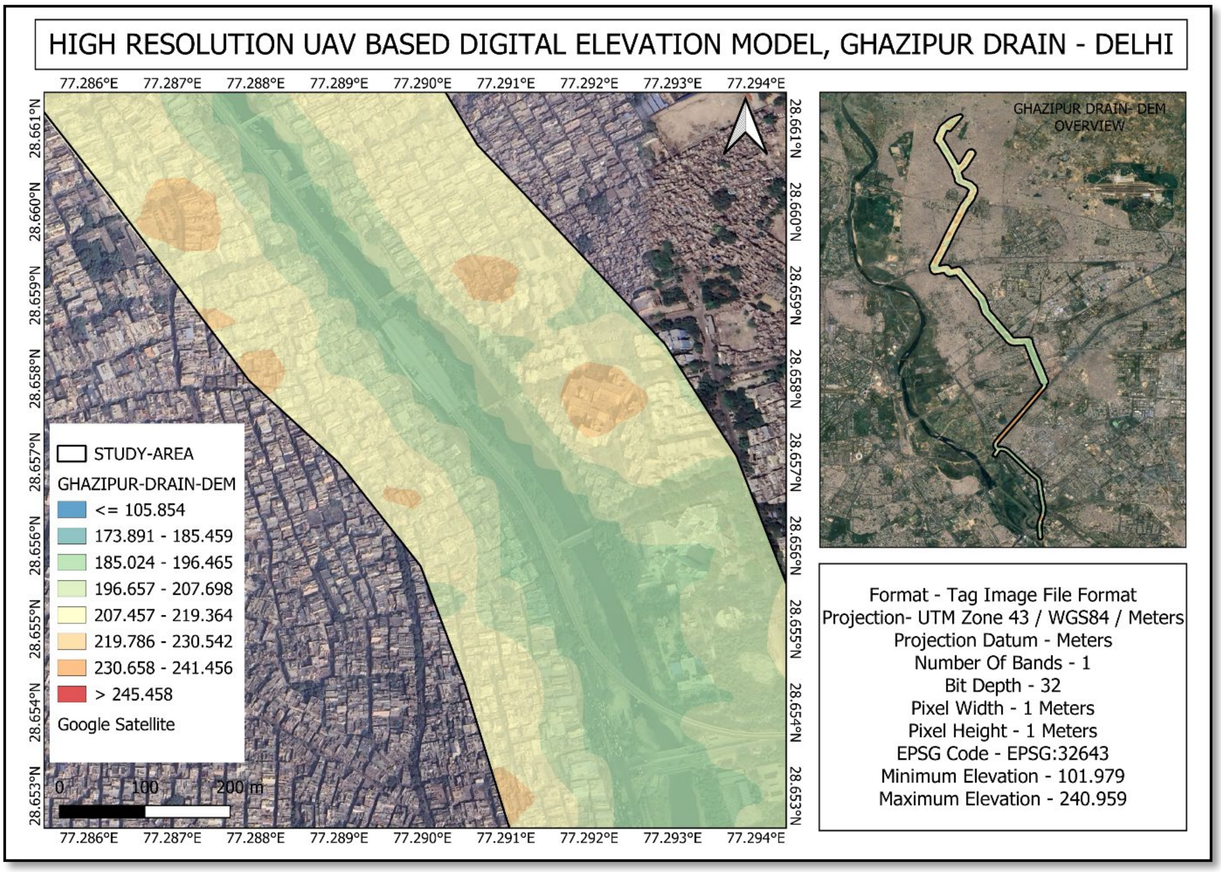

Fig. 9: High-resolution Digital Elevation Model of Ghazipur Drain, Delhi using UAV

The well-defined Fig 9 of the vector overlay facilitates targeted analysis. Ground Control Points (GCPs) minimize these differences so that the DEM and orthophoto have real-world coordinates and correspond to the same pixel. The DEM, with its 1 meter resolution, provides insight into elevation modifications and their interaction with hydrological processes in the area. To put the drainage system in context to the nearby urban infrastructure, such as roads and settlements, the following overlay on Google Satellite imagery was created.The integration of UAV imagery and bathymetric data aids in pinpointing waterlogging hotspots in low-lying areas adjacent to the Ghazipur Drain. This study investigates elevation and drainage patterns through high-resolution data, offering insights into areas that need intervention to boost drainage efficiency. The orthophoto and DEM are strengths and provide a basic dataset to explore the interfacing urban environment of Ghazipur Drain which is necessary for flooding mitigation and drainage planning.

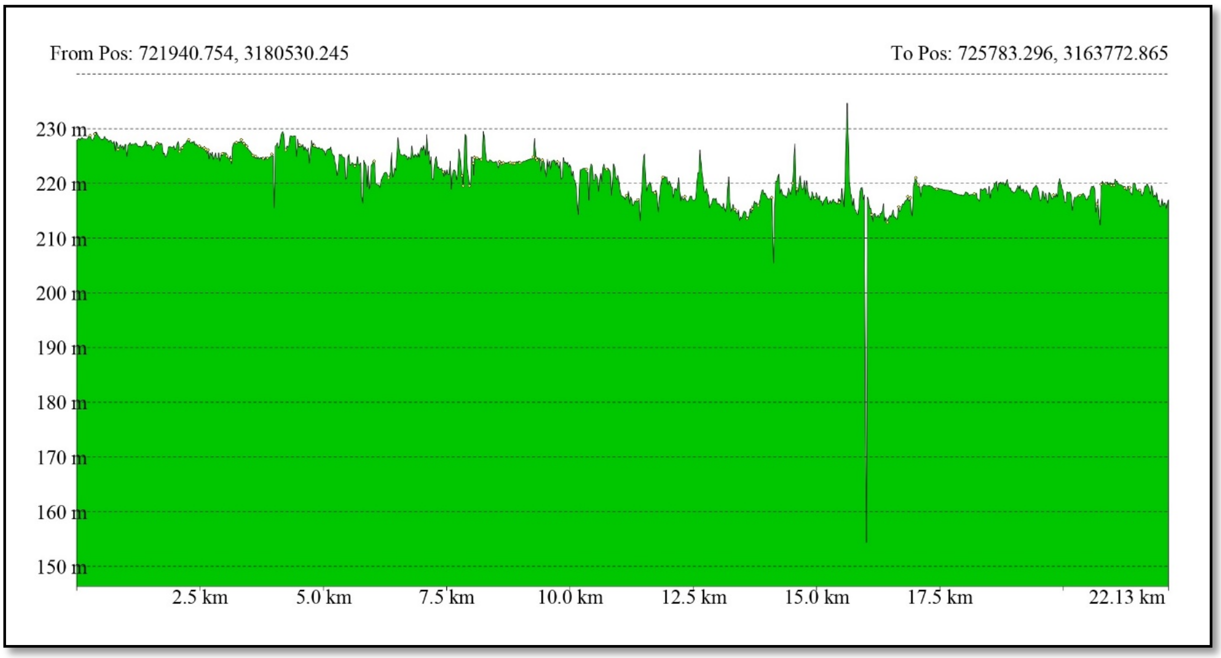

Fig. 10: Longitudinal section to track the water flow direction of Ghazipur Drain using Bathymetry and UAV based DEM

Longitudinal profile of the Ghazipur Drain based on UAV-based DEM and on bathymetric data (Fig 10). This profile shows the flow of the drain from north to south into the Yamuna River, while also demonstrating variation in elevation. The drain begins at 230 meters in the north and slopes gradually downward to less than 150 meters in the south. The ever-same gradient suggests a natural slope that can allow the natural flow of water towards the Yamuna. Combined UAV and bathymetric data facilitates effective and accurate monitoring of both surface and sub-surface elevation changes, as showcased in the longitudinal profile. The flow direction, from north to south, demonstrates the action of the drainage system and indicates stagnant and capacity-deficient areas). Elevation analysis helps to understand runoff and assist in the drainage positively as well as negative drainage assists in better drainage management and prevention of waterlogging in the Ghazipur Drain.

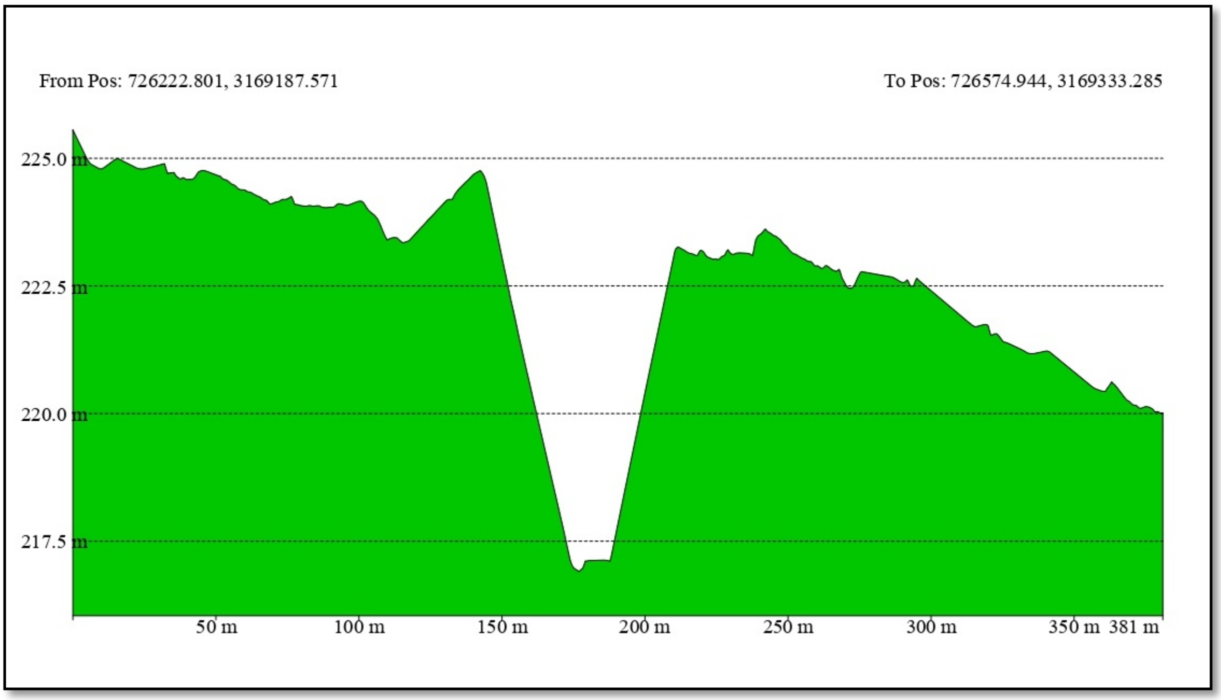

Fig. 11: Cross section to study the topography of Ghazipur Drain using Bathymetry and UAV based DEM

Time series Ghazipur Drain DEM and bathymetric data plotted in cross-sectional profile in Fig 11.This profile illustrates both the surface and underwater terrain, highlighting elevation changes across the drain's width that clarify flow dynamics and identify waterlogging hotspots. The cross-section features a concave shape with steep slopes on either side and a flat or gently sloping channel bed in the center. The edges are around 225m wide, and the lowest part of the channel bed is below 217.5m. Underwater changes in topography can influence the water flowing in the drain, helping identify areas where silt build up or obstructions can occur to inhibit flow.

Cross-sectional profiles highlight areas where drain depth or narrow sections may inhibit drainage function, and identify waterlogging hotspots. After a splash of rain, steep slopes or a lumpy channel bed can hold up water, increasing the chance of localized flooding. This profile also identifies potential erosion sites and sediment transport processes, which are important for the longevity of the drain. Understanding these topographical features is vital for planning interventions: dredging silt deposits, repairing eroded banks and widening constricted sections. This UAV and bathymetric data fusion provides urban planners and engineers access to targeted improvement measures to increase the capacity of the drainage system, which will mitigate waterlogging in adjacent urban areas. The longitudinal and cross-sectional profiles highlight the need for integration of UAV and bathymetric data to better evaluate and manage access to the Ghazipur Drain.

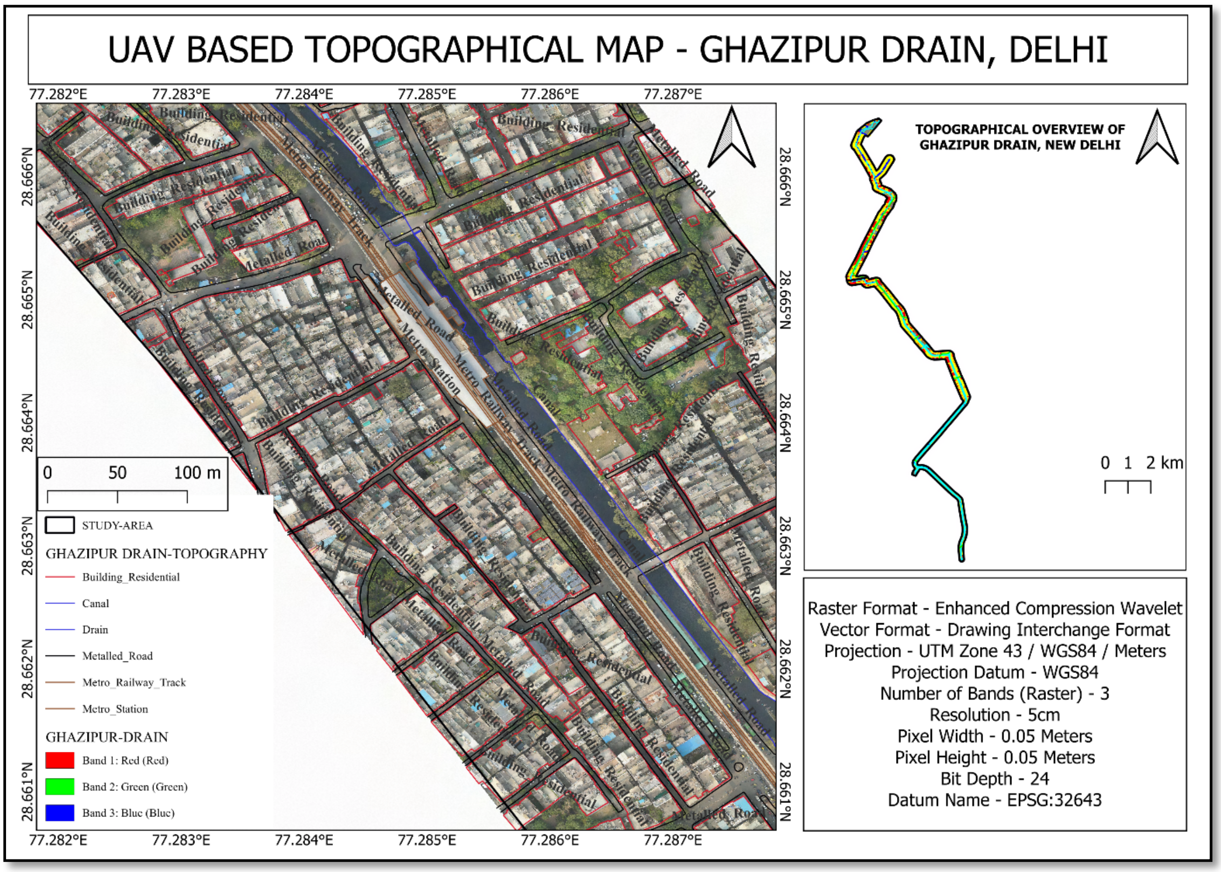

Fig. 12: High-resolution UAV based Topographical map of Ghazipur Drain in Delhi

Fig 12 displays a highly detailed topographical map of Ghazipur Drain in Delhi constructed using imagery collected by unmanned aerial vehicles and organized within a Keyhole Markup Language file for precise topological analysis. The mapping pinpoints noteworthy elements such as the metro line running parallel to the drain. It shows eight metro stations—Gokulpuri, Maujpur, Jafrabad, Welcome, and East Azad Nagar Metro Stations—located along the 30 km corridor. The infrastructure, along with the identified 2,954 residential and commercial buildings near the drain, indicates a considerable risk of waterlogging during the monsoon season. The map particularizes 237 drainage pathways, subway tracks, metal roadways, culverts, overpasses, retaining walls, and canals, critical facets for comprehending the drainage scheme and its means to manage heavy precipitation. Amassing these layers permits a thorough assessment of the drainage framework and its interplay with urban constituents.

With metro tracks, residential areas and commercial properties surrounding the metro drainage system, the need for specific strategies against waterlogging is reinforced. UAV aerial mapping in higher resolution makes it easy to pinpoint trouble spots like brooks, culverts or areas where sediment build up may restrict water flow. This mapping provides fundamental spatial information to identify the areas susceptible to flooding and the waterlogging prone areas for urban planners to make better drainage improvement plans. This visualization highlights the significance of incorporating UAV mapping along with infrastructure mapping to enable QUICK action to prevent the repercussion of waterlogging in such densely populated, infrastructure dense region during the monsoon season.

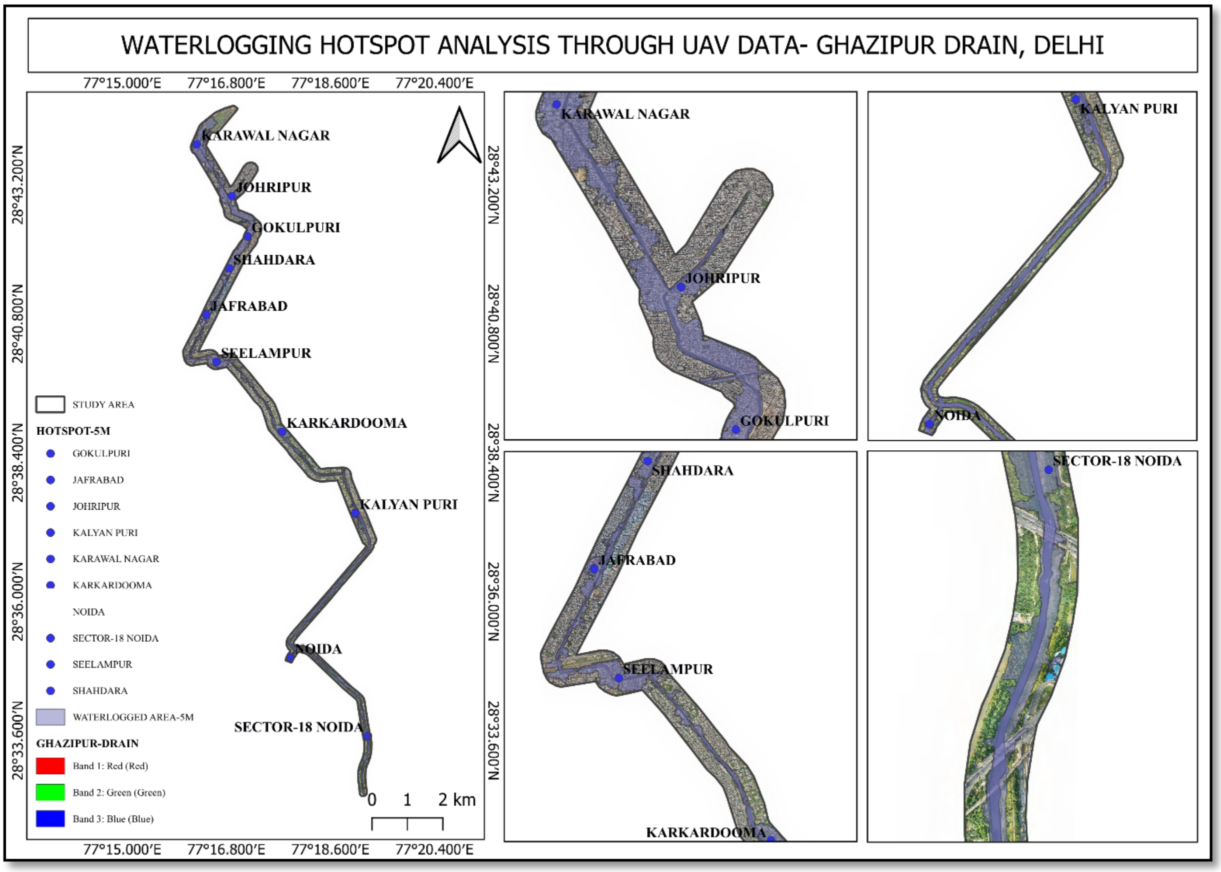

Fig. 13: Identifying Hotspot through high resolution UAV based dataset

The analysis of waterlogging hotspots along the Ghazipur Drain, based on UAV-based DEM, orthophoto and bathymetric data indicates areas prone to extreme water level rises (fig 13). The analysis also suggests that 5-meter rise at the water level can result in extensive waterlogging problem in places including Kalyan Puri, Jafrabad, Seelampur, Karawal Nagar and parts of Noida, with about 1,120 settlements found vulnerable. These settlements, with closely-knit residential and commercial structures, are in low-lying pockets without adequate drainage systems, making them vulnerable to urban waterlogging. Leveraging elevation data with surface mapping and sub-surface profile data, to identify critical intersection hotspots of urban infrastructure with natural drainage pathways that can be a catalyst for overflow drenching during precipitation events or significant rises in water levels. The DEM illustrates these changes in elevation, with lower lying areas near the Yamuna River — like Kalindi Kunj at approximately 196 meters — and higher elevations in Himarpur and Trilokpuri, which rise to around 225 meters. These distinctions influence how water accumulates — particularly low-lying regions, where water lingers for longer. High-resolution, true-color orthophoto gives the full picture of the area around the study site highlighting important urban elements such as the road infrastructure, metro stations, residential neighbourhoods etc. Moreover, detailed bathymetric data on the underwater profiles of the drain, helps in determining drainage capacity and identifies sediment build-up, or a bottleneck, that can impede smooth water flow.

The findings also highlight the critical need for specific intervention in informal settlements and densely populated places, where natural drainage routes are usually blocked. Metro stations like Gokulpuri, Maujpur and Karkardooma Court, Karawal Nagar and Seelampur are at high risk, underlining the need for better drainage and urban planning. The findings also stress on the importance of regulatory measures to tackle waterlogging, highlighting the need for effective drainage designs and minimizing construction activities in vulnerable areas. Additionally, while the UAV data provides high-resolution mapping, its accuracy may be affected in areas with dense vegetation or poor visibility. The analysis uses a generalized rise in water levels over the entire study area, which may not capture localized differences. Moreover, it fails to consider the effects of future urban development or climate change, such as increased rainfall intensity and frequency, which may increase the risk of waterlogging. The lack of complete ground validation also injects some uncertainty to the findings.

A combination of UAV and bathymetric data can provide the scenic diversity of surface and subsurface information that is extremely valuable for waterlogging studies. UAVs produce high-resolution images for image classification, accuracy assessment and modelling, enabling the precise detection of low-lying features, urban features, and drainage paths. A bathymetric map of the seabed provides more detailed insight into drainage capacity and flow based on local conditions. All in all, these technologies represent a powerful tool for identifying areas at risk of waterlogging, prioritizing where prevention work is needed, and directing their urban planning efforts. When incorporated together, these tools can help urban planners design their cities to increase flood resilience and mitigate waterlogging problems in rapidly urbanizing regions.

5. DISCUSSION

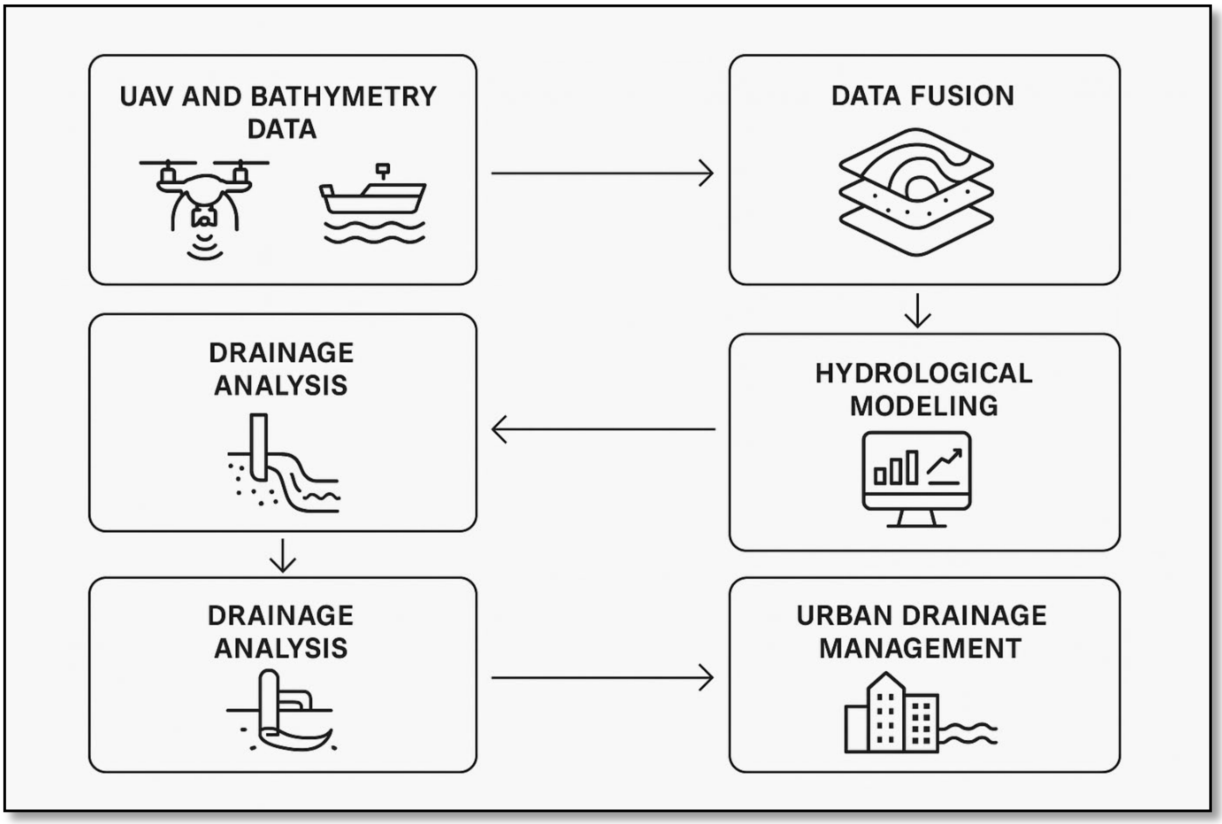

Fig. 14: Connectivity of UAV-based photogrammetry and bathymetric data with urban drainage assessments and decision-making processes.

To contextualize the findings, Figure 14 illustrates the end-to-end workflow that was utilized - from UAV and bathymetric data acquisition to finally addressing critical drainage planning outcomes through policy recommendations. Here, both orthophotography captured via UAVs as well as bathymetric data helped uncover waterlogging near the intersections of Ghazipur Drain - an important urban drainage system situated in Delhi. High-resolution digital elevation models, orthophotos, and underwater topological information collectively facilitated the examination of local topography, subsurface drainage pathways, and the vulnerability to waterlogging. Lengthier sentences were peered at alongside shorter ones to reveal a nuanced understanding of the environment's challenges and how technical insights can inform practical solutions. According to these findings, 1,120 settlements would face the risk of a 5-metre rise in water levels in Kalyan Puri, Jafrabad, Seelampur, Karawal Nagar and parts of Noida. Because monsoons in these areas are characterized by both intense rain and also by long periods without rain, low elevations, dense infrastructure, and poor drainage mean these areas are very prone to flooding. When this DEM is integrated with the bathymetric data, a precise representation of topographic alterations along with the under-water profile is obtained, which enables recognition of waterlogging hotspots and development of specific mitigation measures like dredging and channel widening. The orthophoto shows the relationship between man-made infrastructure and natural drainage systems, with surface features such as streets, metro stations and houses. Future analyses should complement these findings with socio-economic datasets, including population density, household income levels, housing typology, and access to infrastructure services, to enhance the policy relevance of these findings. This will allow for the identification of critically exposed communities, especially informal settlements and economically disadvantaged neighborhoods, where hydro meteorological risks are exacerbated by socio-economic vulnerability. This data fusion can help policymakers identify areas for potential intervention and prioritize where social risk and hydrological exposure converge, allowing for an equitable distribution of drainage upgrades and emergency services.

Waterlogging causes socio-economic drawbacks, especially for economically disadvantaged families in highly populated localities, where the immediate impacts include damages to their properties, disruption of daily lives, and increased vulnerability to water-borne diseases. The economic impact is aggravated by disruptions to metro stations and road networks. These results point to the urgency of targeted mitigation measures, such as upgrading drainage infrastructure, tighter urban planning standards, and community-led water management programs. UAV, bathymetric data helps provide a more spatial context and to explore runoff one otherwise may miss using traditional methods especially as related to silt accumulation and drainage pathways appear to improve relative to, in most cases, existing works. While the study has strengths, it also has some limitations. Particularly, the changing waterlogging situations in regions require dynamic hydrological modeling that can better simulate the real-time effective interactions of water flow and rainfall-runoff, thereby providing more comprehensive information on water information to better assist in the construction of collection and treatment systems. Future work should aim for integration with such distributed or semi-distributed hydrological models (e.g., HEC-HMS9,7, SWMM10,14, or LISFLOOD-FP12,13) to simulate the temporal dynamics of surface runoff, infiltration and urban drainage network performance for varying precipitation intensity. Dynamic models are able to integrate spatially variable precipitation, drainage connectivity, surface permeability, and land use change to produce outputs of flood depth and velocity in time-series. Additionally, integrating real-time rainfall forecasts and future climate projections from satellite measurements (e.g., CMIP6 datasets) within these models will lead to better estimates of flood recurrence intervals, long-term risks, and the consequences of climate-induced extremes. However, it is assumed that water levels rise evenly across the study area, resulting in several major assumptions, and UAV data accuracy can be affected by vegetation cover or inadequate visibility. Moreover, new urban developments and climate change may lead to worsening waterlogging risks, which are not tackled in this study. UAV operations may also be limited by legal and operational obstacles, such as the existence of restricted airspace and the range of sensors. To overcome these limitations, future UAV missions should adopt multispectral or LiDAR payloads that can penetrate vegetated canopies and enhance terrain accuracy. Moreover, drone surveys can be planned after the monsoon season, when vegetation is minimal, or supplemented with terrestrial laser scanning or GNSS rover ground surveying to enhance calibration and decrease vertical uncertainty. Legal and regulatory issues can be tackled by designing pre-approved flight corridors and working with local civil aviation authorities to obtain flight permission in emergency sites.

The findings also affect the urban planning and waterlog mitigation strategies. Immediate dredging and channel expansion should be prioritized in at-risk areas. Rules must change to limit development in flood-prone areas and enable water to flow naturally. Using real time UAV monitoring at different levels in monsoon seasons can better relations to flood response and remote periphery with decision making levels. For a forward-looking perspective, the need for Early Warning Systems (EWS) that encompass UAV-derived topography combined with Internet-of-Things (IoT) sensor networks for real-time collection of the rainfall, flow, and water level data needs to be considered. When incorporated into decision-support frameworks, these systems can enable early evacuation planning, drainage gate management, and crisis coordination. Future research should combine climate change projections to improve understanding of long-term waterlogging trends. This study has shown that UAV-based data and bathymetric analysis can provide a considerable improvement in flood resilience in urban areas. Info on quality surface/subsurface topography helps with effective water management practices Adopting this scalable and replicable approach is an effective solution to reduce risk and guarantee that urban drainage infrastructure can keep up with growing urbanization and climate change facing cities.

6. CONCLUSION

The findings of this study greatly highlight the success of high-tech integration of UAV-based orthophotography and bathymetric dataset in identifying the urban waterlogging problems, especially in examining Ghazipur Drain in Delhi. The research produces high-resolution Digital Elevation Models (DEMs) and merges them with sub-surface bathymetric profiles to provide a comprehensive understanding of both surface and underwater drainage dynamics. The findings identify critical waterlogging hotspots, indicating that nearly 1,120 communities in low-lying areas, such as Kalyan Puri, Jafrabad, Seelampur, Karawal Nagar, and parts of Noida, are especially vulnerable to flooding after heavy rainfall or significant water level rises

These data underline the critical need for targeted interventions in the form of dredging, extracting sediments, widening channels, and also improving urban planning to prevent overflooding. This combination of UAV and bathymetric data affords unprecedented spatial and temporal precision, allowing scientists to identify water-shed inefficiencies in drainage and sedimentation that previous methods may have missed. Orthophotos capture fine details of the surface, and give planners a unique opportunity to evaluate the current situation to see if there are a risk management strategy is viable for sustainable urban growth regarding drainage. They also bring out the socio-economic impact of waterlogging on vulnerable communities, infrastructure, public health and the local economy. The study has limitations, including that it does not include dynamic hydrological modeling, localized water level changes, urban development or climate change considerations. Filling in these gaps with future research will improve projected efficacy and relevance of these strategies. The adoption of this technology will also rely heavily on overcoming operational issues associated with UAV deployment and sharpening the regulatory frameworks surrounding it.

This work shows that UAV-bathymetry can be used to develop a scalable, accurate, low-cost response to urban waterlogging. The findings provide valuable insights for policymakers, urban planners and engineers to prioritize initiatives to improve drainage systems and increase flood resilience in fast-growing urban areas. By combining high resolution and real time data, this formulation builds the basic for preventing the risk of waterlogging, which would be a challenge capability of the drainage system in the future due to the urbanization and climate change.

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