

VEGETATION BLOCKAGE ASSESSMENT FOR IRRIGATION CHANNELS USING COMPUTER VISION

ÉVALUATION DE L'OBSTRUCTION DES CANAUX D'IRRIGATION PAR LA VÉGÉTATION AU MOYEN DE LA VISION PAR ORDINATEUR

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ABSTRACT

Climate change has increased the frequency and intensity of extreme rainfall events, placing greater hydraulic pressure on agricultural irrigation and drainage channels. Although vegetation within channels provides ecological benefits, excessive vegetation growth can reduce conveyance capacity and increase flow resistance. Current maintenance practices still rely largely on visual field inspections, which are labor-intensive and lack quantitative evaluation criteria. To address this issue, this study proposes a vegetation Blockage Index (BI) based on frontal projected area (FPA) analysis and computer vision techniques. The framework integrates Depth Anything and YOLOv8-seg in three stages: monocular depth estimation for channel geometry reconstruction and distant vegetation filtering, vegetation segmentation into herbaceous, shrub, and arboreal classes, and gridded FPA analysis within the effective flow conveyance region. A resistance-weighted BI is then calculated using class-specific FPA distributions to represent vegetation-induced hydraulic blockage conditions. Results show that the proposed framework can reduce subjectivity in maintenance assessment while improving evaluation consistency and efficiency. In addition, the method provides spatial visualization of vegetation blockage conditions along channel reaches, allowing identification of sections with relatively high hydraulic resistance. Compared with conventional field inspections, the proposed approach enables continuous and high-resolution assessment along the channel length and supports more targeted vegetation maintenance. The framework provides an objective assessment tool for irrigation channel vegetation management under increasing hydraulic stress conditions.

Keywords: Irrigation and Drainage, Channel Maintenance, Blockage Index, YOLOv8-seg, Monocular Depth Estimation.

RÉSUMÉ

Le changement climatique a accru la fréquence et l'intensité des épisodes de précipitations extrêmes, ce qui soumet les canaux agricoles d'irrigation et de drainage à une pression hydraulique plus forte. Bien que la végétation présente dans les canaux procure des avantages écologiques, sa croissance excessive peut réduire la capacité de transport et augmenter la résistance à l'écoulement. Les pratiques d'entretien actuelles reposent encore largement sur des inspections visuelles de terrain, qui nécessitent beaucoup de main-d'œuvre et ne disposent pas de critères d'évaluation quantitatifs. Pour remédier à ce problème, cette étude propose un indice d'obstruction par la végétation (BI), fondé sur l'analyse de l'aire projetée frontale (FPA) et sur des techniques de vision par ordinateur. Le cadre intègre Depth Anything et YOLOv8-seg en trois étapes : l'estimation monoculaire de la profondeur pour reconstruire la géométrie du canal et filtrer la végétation éloignée ; la segmentation de la végétation en classes herbacée, arbustive et arborée ; et l'analyse maillée de la FPA dans la zone utile de transport de l'écoulement. Un BI pondéré par la résistance est ensuite calculé à partir des distributions de la FPA propres à chaque classe, afin de représenter les conditions d'obstruction

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hydraulique dues à la végétation. Les résultats montrent que le cadre proposé peut réduire la subjectivité de l'évaluation de l'entretien tout en améliorant la cohérence et l'efficacité de cette évaluation. En outre, la méthode fournit une visualisation spatiale des conditions d'obstruction par la végétation le long des tronçons de canal, ce qui permet de repérer les sections présentant une résistance hydraulique relativement élevée. Par rapport aux inspections de terrain classiques, l'approche proposée permet une évaluation continue et à haute résolution sur toute la longueur du canal, et favorise un entretien plus ciblé de la végétation. Ce cadre constitue un outil d'évaluation objectif pour gérer la végétation des canaux d'irrigation dans un contexte de contraintes hydrauliques croissantes.

Mots-clés : Irrigation et drainage; Entretien des canaux; Indice de blocage; YOLOv8-seg; Estimation de la profondeur monoculaire.

INTRODUCTION

Climate-resilient irrigation and drainage management requires channels that can convey storm runoff safely while supporting the ecological functions increasingly emphasized in Nature-based Solutions (NbS). Conventional maintenance often relies on concrete-lined geometry and repeated vegetation clearance to preserve hydraulic capacity. However, channel vegetation can also stabilize banks, filter sediment and nutrients, moderate microclimate, and provide habitat. The practical engineering question is therefore not whether vegetation should always be removed, but how managers can distinguish vegetation that meaningfully increases hydraulic resistance from vegetation that can remain without compromising conveyance (Environment Agency, 2015; European Centre for River Restoration, 2014).

In many local irrigation and drainage systems, maintenance decisions still depend on visual field inspection. These inspections are labor-intensive, uneven across sites, and difficult to translate into repeatable hydraulic indicators. Unmanned Aerial Vehicle (UAV) monitoring has improved spatial coverage, but most plan-view imagery is better suited to mapping canopy or surface cover than to evaluating structures exposed to flow. This distinction is important because hydraulic roughness is driven by flow-facing stems, branches, and near-bed vegetation rather than by green pixels alone (Barnes, 1967; Jarrett, 1985; Knehtl et al., 2018; Fiorentini et al., 2023). Frontal-view UAV imagery provides a more hydraulically meaningful perspective for maintenance screening because it records vegetation projected into the effective conveyance section. This view is not intended to replace surveyed cross sections or hydrodynamic modelling. Its value is to provide a rapid field-oriented representation of vegetation that may generate form drag within the channel.

The hydraulic interpretation follows well-established vegetation-flow concepts. Herbaceous vegetation is generally flexible and can reconfigure or bend under increasing flow, reducing its effective frontal area. Shrubs behave as semi-rigid vegetation and may retain a larger projected area under flow. Trees include rigid trunks and woody branches that can create localized high-resistance obstacles even when their areal cover is small. This flexible, semi-rigid, and rigid distinction is consistent with previous studies of vegetated-channel resistance and provides the basis for using vegetation type, rigidity, and FPA as screening variables (Petryk & Bosmajian, 1975; Kouwen, 1988; Järvelä, 2004; Nepf, 2012; Aberle & Järvelä, 2013).

Specifically, the study integrates frontal-view UAV imagery, depth-assisted filtering of the effective conveyance region, YOLOv8-seg vegetation segmentation (Jocher et al., 2023), pixel-wise FPA quantification, and resistance-weighted BI interpretation for NbS-oriented channel maintenance. The intended contribution is practical and engineering-oriented: the framework helps managers rank channel sections for inspection, selective trimming, or retention.

METHODS AND MATERIALS

The proposed method is designed for rapid screening of vegetation-related hydraulic blockage in agricultural irrigation and drainage channels. It uses frontal-view UAV images because this perspective better represents the cross-sectional obstruction encountered by flow than conventional plan-view vegetation mapping. The workflow consists of three operational phases: vegetation extraction from UAV imagery, frontal projected area (FPA) quantification within the effective conveyance region, and BI-based hydraulic screening.

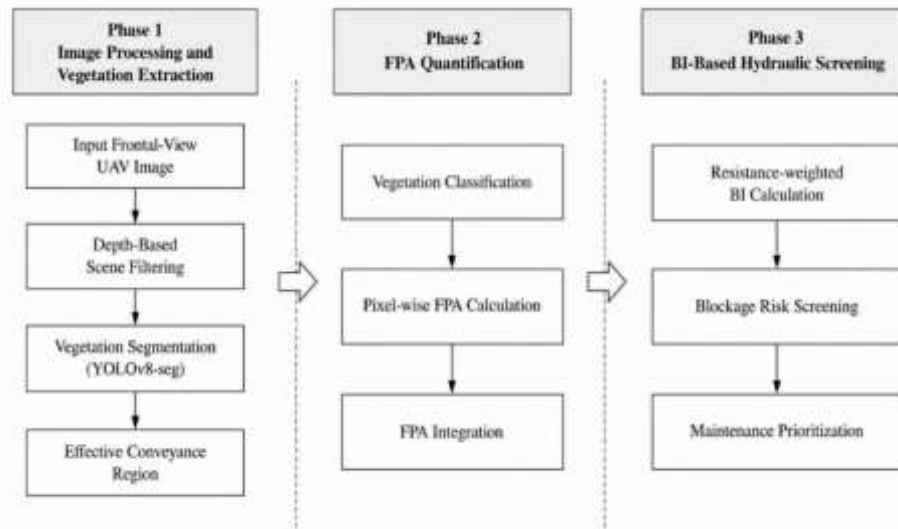


Figure 1. illustrates the overall workflow of UAV-based vegetation extraction, FPA quantification, and BI-based hydraulic screening.

As summarized in Figure 1, the workflow first identifies the hydraulically relevant portion of the scene and extracts vegetation classes. It then calculates class-specific FPA at the pixel level and integrates these areas into a resistance-weighted Blockage Index (BI). The output is not intended as an absolute discharge-capacity estimate, but rather as a relative screening indicator for comparing monitoring sections and supporting maintenance prioritization.

Hybrid AI Framework for Vegetation Extraction

The vegetation-extraction framework combines depth-based scene filtering with vegetation segmentation. A monocular depth-estimation model, Depth Anything (Yang et al., 2024), is first used to reduce the influence of distant background vegetation, side-bank clutter, and non-conveyance features that may visually overlap with the channel in a two-dimensional image. The resulting depth-informed mask supports identification of the effective conveyance region for subsequent hydraulic interpretation.

Depth-based filtering functions as a practical scene-screening step. In frontal-view channel imagery, background trees or bank vegetation may appear close to the conveyance section even when they are hydraulically irrelevant. Filtering according to relative scene depth therefore helps retain pixels associated with the effective channel region while reducing interference from visually similar background objects.

Vegetation segmentation is subsequently performed using YOLOv8-seg (Jocher et al., 2023). Vegetation objects are classified into herbaceous, shrub, and tree categories according to hydraulic behavior rather than botanical taxonomy. Herbaceous vegetation represents flexible cover with relatively low resistance under high-flow conditions; shrubs represent semi-rigid vegetation with

intermediate form drag; and trees represent rigid woody structures capable of producing stronger local hydraulic obstruction.

Compared with conventional bounding boxes, instance segmentation masks more effectively represent irregular vegetation geometry within the channel section. The segmented vegetation masks are further intersected with the effective conveyance region so that the analysis focuses on vegetation most likely to influence flow conveyance.

FPA Quantification and BI-Based Screening

Within the effective conveyance region, each pixel is assigned to herbaceous, shrub, tree, or non-vegetation classes. The FPA of each vegetation class is calculated from the accumulated vegetation pixels within the effective region. Because the imagery is intended for relative maintenance screening rather than surveyed area estimation, all FPA values are normalized by the effective conveyance area in image space.

After class-specific FPA values are obtained, the Blockage Index (BI) is calculated by applying resistance weights to the vegetation classes according to their expected hydraulic influence:

$$BI = \sum_i \left(W_i \times \frac{FPA_i}{A_c} \right)$$

where W_i represents the resistance weight assigned to vegetation class i , FPA_i represents the frontal projected area of that class, and A_c represents the effective conveyance area.

The assigned weights are herbaceous = 0.2, shrub = 0.5, and tree = 1.0. These values follow a Manning roughness and USGS-related hydraulic interpretation in which flexible herbaceous vegetation generally produces relatively small resistance effects because of bending and reconfiguration under flow, semi-rigid shrubs produce intermediate form drag, and rigid woody vegetation maintains projected area and generates stronger local obstruction. This weighting structure allows BI to reflect vegetation rigidity and hydraulic influence rather than visual vegetation abundance alone. If the effective conveyance region were dominated by rigid woody vegetation, the BI would approach its upper limit of 1.0. Conversely, even sections with high vegetation coverage may still exhibit relatively low BI values when dominated by flexible herbaceous vegetation. The normalization therefore separates hydraulic blockage from simple visual greenness and improves relative comparison among monitoring sections.

For engineering interpretation, BI values are further divided into three relative blockage classes. BI < 0.3 represents relatively low blockage conditions generally dominated by flexible herbaceous vegetation. BI values between 0.3 and 0.6 indicate moderate blockage conditions in which semi-rigid or woody vegetation begins to influence hydraulic resistance more substantially. BI > 0.6 represents relatively high blockage conditions associated with dense rigid vegetation and stronger potential conveyance obstruction. These categories are intended to support maintenance prioritization and field inspection rather than replace detailed hydraulic modelling or calibrated Manning roughness estimation. The resulting BI is therefore best interpreted as a relative hydraulic screening indicator for comparing monitoring sections within the same UAV survey framework.

APPLICATION

Study Area: Shuhu Creek Agricultural Drainage Channel

The study area is Shuhu Creek in Hualien County, eastern Taiwan, as shown in Figure 2. The monitored reach functions as part of a local agricultural drainage and irrigation system, conveying irrigation return flow, field drainage, and storm runoff. Compared with natural rivers with complex

cross-sectional variability, the monitored reach has a relatively simple channel alignment and a clearer bank boundary, making it suitable for testing image-based FPA and BI estimation.

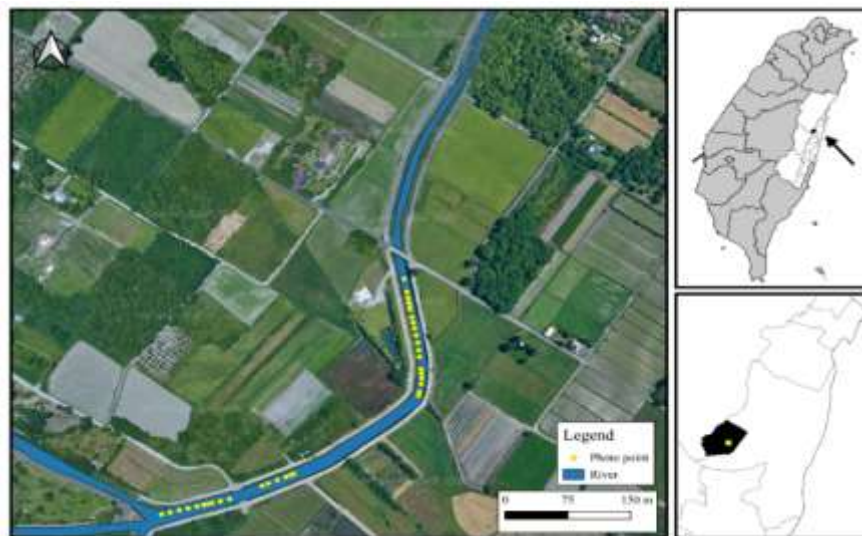


Figure 2. Location and monitoring reach of Shuhu Creek, Hualien County, Taiwan.

The site is typical of maintained agricultural channels: the geometry is regulated, the conveyance section is relatively stable, and periodic maintenance limits large-scale woody encroachment. Vegetation is dominated by herbaceous cover, while shrubs and trees occur only locally. This setting is useful for testing the central distinction between vegetation cover and hydraulic blockage. A section may look highly vegetated in the image but still present limited hydraulic blockage if the cover is flexible and herbaceous. Localized woody clusters may still form relative hotspots, but the expected BI distribution should be low-risk dominated. Field images were collected using a UAV operated as close as practicable to the channel centerline or main flow direction. This frontal-view configuration was chosen to reduce single-bank occlusion and to capture the channel bed, side-bank vegetation, and effective flow-facing structures in the same image. The resulting dataset is suitable for depth filtering, segmentation, and pixel-wise FPA integration.

Image Acquisition and Channel Geometry Criteria

Monitoring images were collected from relatively straight and hydraulically interpretable reaches of the agricultural drainage channel. Sections containing abrupt bends, severe perspective distortion, or locally discontinuous channel geometry were excluded to reduce uncertainty in frontal-view interpretation. Because the purpose of this study was screening-level hydraulic comparison rather than surveyed cross-sectional reconstruction, image selection focused on maintaining geometric consistency among monitoring sections. The UAV survey was conducted during a vegetation-rich period prior to routine flood-season maintenance in order to represent realistic channel conditions associated with vegetation obstruction. Images affected by excessive blur, severe occlusion, or incomplete channel visibility were removed during preprocessing. After quality screening, a total of 36 monitoring images were retained for subsequent BI analysis.

Vegetation Segmentation and Hydraulic Classification

Vegetation extraction was performed using YOLOv8-seg with hydraulic-oriented vegetation classes consisting of herbaceous vegetation, shrubs, and trees. Unlike ecological vegetation surveys, the classification strategy emphasized hydraulic behavior and structural resistance characteristics rather than species-level taxonomy. Herbaceous vegetation represented flexible low-resistance cover, shrubs represented semi-rigid vegetation with intermediate form drag, and trees represented rigid

woody structures capable of producing stronger local obstruction. To improve the hydraulic relevance of the segmentation results, vegetation masks were combined with the effective conveyance region derived from the depth-filtered scene. The processed outputs were subsequently used for frontal projected area (FPA) quantification and BI-based blockage assessment. For each monitoring image, the processed dataset included effective conveyance area, class-specific vegetation area, total vegetation coverage, and weighted BI values for comparative hydraulic screening.

RESULT AND DISCUSSION

Segmentation Performance and Interpretation for Hydraulic Screening

The YOLOv8m-seg model achieved an overall mask mAP@50 of 0.196. The result reflects the difficulty of vegetation extraction in agricultural drainage environments characterized by shadows, overlapping vegetation, irregular channel geometry, and visually similar bank textures. In this study, however, the segmentation model functions primarily as a supporting component within a hydraulic screening framework rather than as the central focus of computer-vision performance evaluation. Tree vegetation was generally identified more consistently than shrub vegetation because woody crowns and trunks provide clearer structural contrast in frontal-view imagery. By comparison, shrub vegetation frequently overlapped with herbaceous cover or shaded regions, increasing classification uncertainty under field conditions. These limitations indicate that the framework is more suitable for reach-scale hydraulic screening and maintenance prioritization than for detailed vegetation inventory analysis.

Depth-constrained filtering improved the hydraulic relevance of the extracted vegetation patterns by limiting the analysis to the effective conveyance region and reducing interference from visually similar background vegetation. As a result, the framework evaluates vegetation according to its potential interaction with flow conveyance rather than simple image occurrence.

At the operational scale considered in this study, local segmentation uncertainty does not directly translate into proportional hydraulic assessment error because BI is spatially aggregated over the effective conveyance section and weighted according to vegetation rigidity. Consequently, the hydraulic interpretation is controlled more strongly by the overall distribution of flexible versus rigid vegetation elements than by small local boundary differences. The proposed framework is therefore best interpreted as a practical UAV-assisted hydraulic screening tool for identifying relative vegetation blockage patterns within irrigation and drainage channels. For ICID-oriented applications, its primary value lies in converting ordinary UAV imagery into a repeatable hydraulic indicator that supports inspection planning and selective vegetation management.

Quantification of Vegetation FPA and BI-Based Hydraulic Interpretation

The 36 monitoring images revealed a clear contrast between visual vegetation abundance and weighted hydraulic blockage. The unweighted vegetation coverage ratio had a median of 55.65%, a mean of 51.83%, and a range of 14.50–85.23%, indicating that many channel sections appeared heavily vegetated in ordinary field imagery.

A representative example is Sampling Cross-section 390 (Figure 3). Although the section exhibited high raw vegetation coverage of 74.9%, its weighted BI was only 16.9%. This contrast highlights the central hydraulic interpretation of the framework: vegetation rigidity and effective conveyance obstruction are more important for maintenance assessment than visual vegetation abundance alone.

Across the representative monitoring dataset, weighted BI values remained relatively low. The weighted BI had a median of 11.87%, a mean of 11.13%, and a range of 2.90–18.22%. All monitoring sections remained below the moderate blockage threshold of $BI = 0.3$, and none approached the relatively high blockage category. The monitored reach of Shuhu Creek should therefore be interpreted as a low-risk, herbaceous-dominated agricultural drainage channel rather than a system strongly affected by rigid woody obstruction.

The vegetation composition strongly explains this result. Herbaceous vegetation dominated nearly all monitoring sections, whereas woody vegetation was spatially limited and generally concentrated near channel margins. Although woody vegetation occupied only a small proportion of the effective conveyance area, it exerted a disproportionately large influence on localized BI peaks because rigid stems and branches maintain projected area and generate stronger flow resistance.



Figure 3. FPA quantification and Weighted BI output for Sampling Cross-section 390.

This hydraulic distinction can be observed in several representative samples. The maximum BI case, image 0311, had vegetation coverage of 82.38% and a weighted BI of 18.22%, yet herbaceous vegetation still remained the dominant vegetation type. Conversely, image 0385 exhibited the highest visual vegetation coverage at 85.23% but produced a weighted BI of only 17.05% because the vegetation was primarily flexible herbaceous cover. These comparisons demonstrate that BI responds more strongly to vegetation rigidity distribution than to total vegetation abundance.

From a hydraulic perspective, flexible herbaceous vegetation may produce dense visual cover while contributing relatively limited obstruction after reconfiguration under flow. In contrast, even limited woody vegetation can generate localized conveyance resistance because rigid branches and trunks preserve frontal projected area during high-flow conditions. The BI framework therefore helps distinguish between visual greenness and effective hydraulic blockage, reducing the likelihood of unnecessary vegetation removal based solely on visual density.

A concise sensitivity analysis was conducted by perturbing herbaceous and shrub weighting values by $\pm 10\%$. Under the observed low-to-moderate blockage conditions, the relative ranking of monitoring sections remained stable, indicating that the framework is sufficiently robust for maintenance prioritization and comparative screening. This result should be interpreted as ranking stability rather than proof of absolute hydraulic accuracy.

From a practical maintenance perspective, the dataset suggests that widespread vegetation clearing is not necessary within the monitored reach. Most sections can retain herbaceous vegetation while maintaining relatively low hydraulic blockage conditions, whereas localized woody clusters or recurring BI peaks represent the locations most suitable for targeted inspection before flood seasons.

Spatial Visualization and Identification of Relative Maintenance Hotspots

The section-scale BI values were mapped along the monitored channel to convert individual image assessments into a spatial maintenance interpretation. As shown in Figure 4, the spatial distribution of BI values enables visualization of relative maintenance hotspots along the monitored reach. This reach-scale visualization is important for irrigation and drainage agencies because maintenance planning is typically conducted along continuous channel sections rather than at isolated monitoring points.

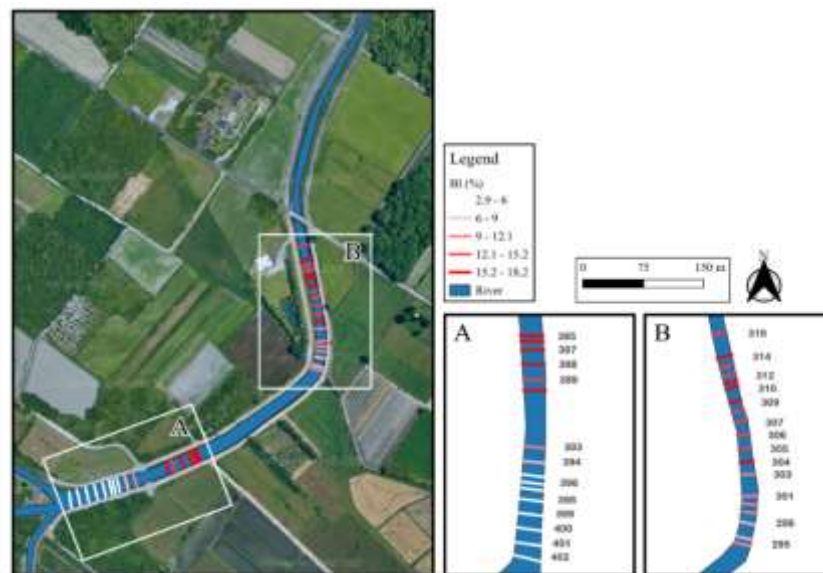


Figure 4. Spatial distribution of Vegetation Blockage Index (BI) and visualization of maintenance hotspots along Shuhu Creek channel.

Because all monitoring sections remained below $BI = 0.3$, the spatial map shown in Figure 4 should be interpreted as a relative hotspot assessment within a generally low-risk system rather than as evidence of severe hydraulic obstruction. The mapped results instead identify locations where the combined effects of vegetation amount and rigidity may justify closer inspection or selective maintenance.

The spatial pattern further reinforces the distinction between vegetation abundance and hydraulic obstruction. Long channel sections with dense herbaceous vegetation remained associated with relatively low weighted BI values, whereas localized BI peaks were typically associated with concentrated woody vegetation or locally dense vegetation structure. From a maintenance perspective, this information provides substantially greater operational value than a simple vegetation/no-vegetation interpretation.

In practical maintenance interpretation, channel sections exhibiting dense herbaceous vegetation but consistently low BI values may not require immediate vegetation removal and can instead remain under periodic monitoring. By contrast, localized sections associated with recurring BI peaks or concentrated woody vegetation may warrant closer pre-flood inspection or selective trimming to reduce potential conveyance obstruction while preserving ecological and stabilization functions. This distinction is particularly important in NbS-oriented channel management because visually dense vegetation does not necessarily correspond to severe hydraulic resistance. Under routine UAV inspection, the proposed framework can therefore support a transition from blanket vegetation clearance toward more targeted and evidence-based maintenance prioritization.

The spatial BI distribution also supports NbS-oriented management strategies. Rather than treating all vegetation as undesirable obstruction, the framework helps distinguish vegetation that can remain within the channel from vegetation more likely to influence hydraulic conveyance. This approach supports selective vegetation management while retaining ecological and stabilization functions where hydraulic risk remains limited.

CONCLUSION

This study proposed and tested a UAV-based Vegetation Blockage Index (BI) framework for vegetation blockage assessment in agricultural irrigation and drainage channels using frontal-view UAV imagery, monocular depth estimation, and YOLOv8-seg instance segmentation. By integrating depth-assisted filtering, pixel-wise frontal projected area (FPA) quantification, and resistance weighting, the framework converts ordinary field images into a practical hydraulic screening indicator for comparing vegetation blockage conditions among monitoring sections. The Shuhu Creek case demonstrated that visual vegetation coverage and hydraulic blockage should not be treated as equivalent, as weighted BI values remained relatively low despite high vegetation coverage due to the dominance of flexible herbaceous vegetation rather than rigid woody obstruction. The results further indicate that BI is more sensitive to vegetation rigidity distribution than to total vegetation abundance, allowing more effective identification of localized high-resistance vegetation. Although segmentation uncertainty remains under complex field conditions, especially for shrubs, the proposed framework remains suitable for relative hydraulic screening and vegetation blockage assessment in irrigation channels.

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