Mapping Erosion and Deposition in an Agricultural Landscape: Developing a Spatial Validation Dataset with UAV SfM-MVS

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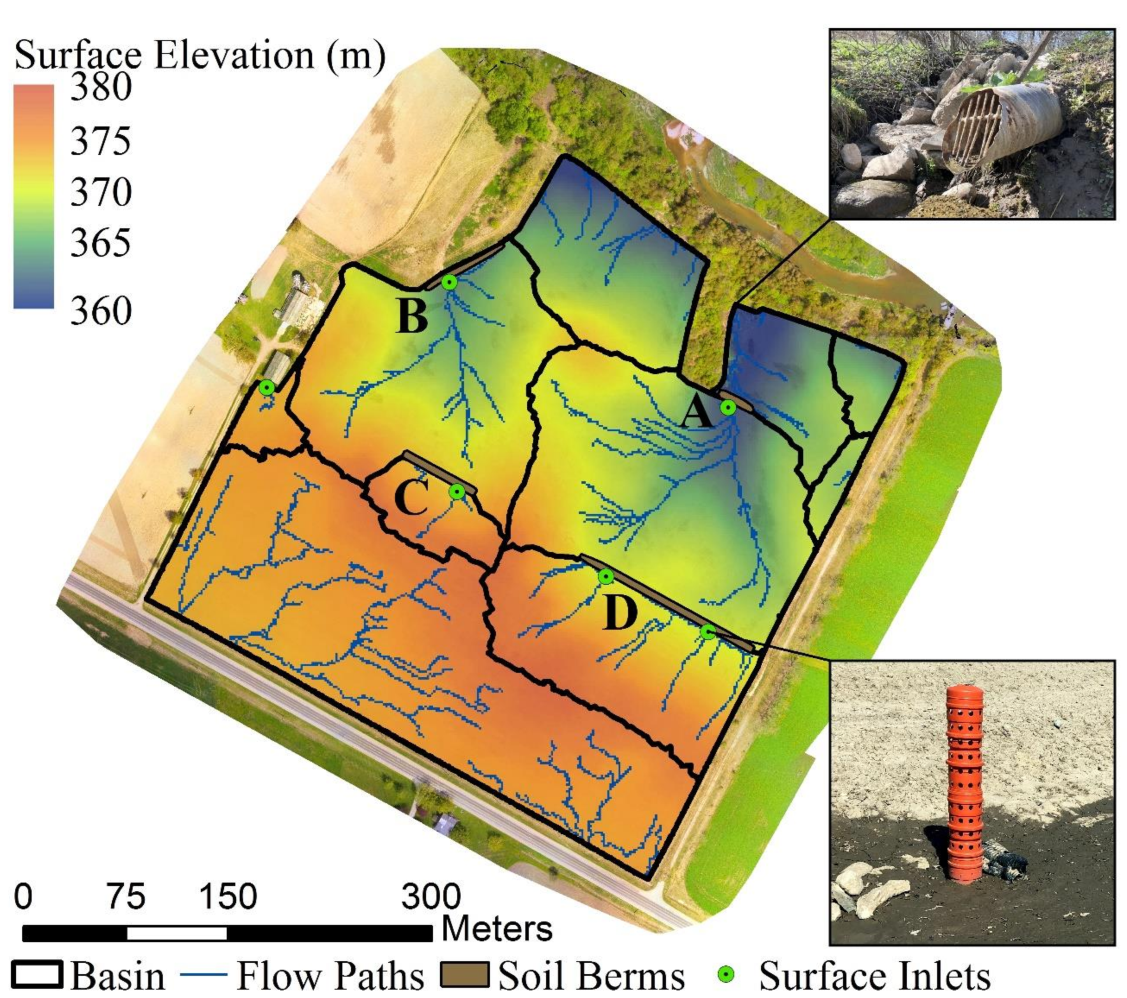
Introduction

Past decades have seen rapid advancements in the field of soil erosion modelling, with a shift away from lumped empirical models and towards fully-distributed physically-based erosion models. Distributed erosion models facilitate the spatial predictions of erosion and deposition across the landscapes by computing runoff and modelling the subsequent detachment, transport, and deposition of sediments. Despite the ability to represent the physical process of erosion spatially, distributed erosion models are validated with discharge and sediment yield at catchment outlets; spatial information on erosion and deposition rates are seldom used for validation. We demonstrate the viability of using **structure-from-motion (SfM)** and **multi-view stereo (MVS)** algorithms coupled with the use of **unmanned aerial vehicles (UAVs)** to generate novel spatial validation datasets. These spatial datasets allows us to tackle three key erosion modelling issues: spatial equifinality, model parameterization, and discretization of the landscape.

Methodology

Seven UAV surveys were conducted between May 7, 2018 and April 25, 2019 on a 15.95 hectare (~40 acre) agricultural field in Southwestern Ontario. The field had tile drainage and catch basins installed in the winter of 2017/2018 to collect surface runoff and eroded soils. An Aeryon Labs R60 Skyranger UAV system equipped with the SR-3SHD payload was used for all image acquisitions. The SR-3SHD payload captures 15 MP RBG 4608 x 3288 resolution images. The UAV was flown at 60 to 90m AGL using parallel-axis flights with a 70% image overlap. All SfM-MVS pointclouds were generated in Pix4D using a self-calibrating bundle adjustment with 27 to 54 ground control points.

Figure 1. Agricultural study site. Basins "A", "B", "C", and "D" are used for soil deposition calculations seen in Figure 3.



Results: Volumetric Deposition in Basins

Figure 2. 1 cm UAV orthomosaics of the agricultural study site from May 7, 2018 to September 19, 2018 and December 18, 2018 to April 25, 2019. The orthosaics were generated from 537 images (from 90m AGL flights) or 1280 images (from 60m AGL flights).

A total of 269.9mm of precipitation fell between May 17 and September 19. The resulting fluvial erosion transported and deposited 102.6m^3 of sediment in the four catch basins, corresponding to 135.47 tonnes of sediment (average bulk density of 1.32 g/cm^3). Over the winter months, between December 18 and April 25, a total of 242.mm of precipitation fell, which transported another 21.57 tonnes of sediment. The cumulative 157.04 tonnes of sediment corresponds to a sediment yield of 19.11 t ha^{-1}yr^{-1} (natural rates of soil production are less than 1 t ha^{-1}yr^{-1}). The majority of fluvial erosion occurred during the late spring of 2018 between May 17 and June 15 when the field was barren (see Figure 3 A_i – D_i).

Figure 3. Soil deposition calculated using UAV SfM-MVS for each basin (A – D): (i) May 17 to June 15, (ii) May 17 to July 24, (iii) May 17 to September 19, (iv) December 18 to April 25.

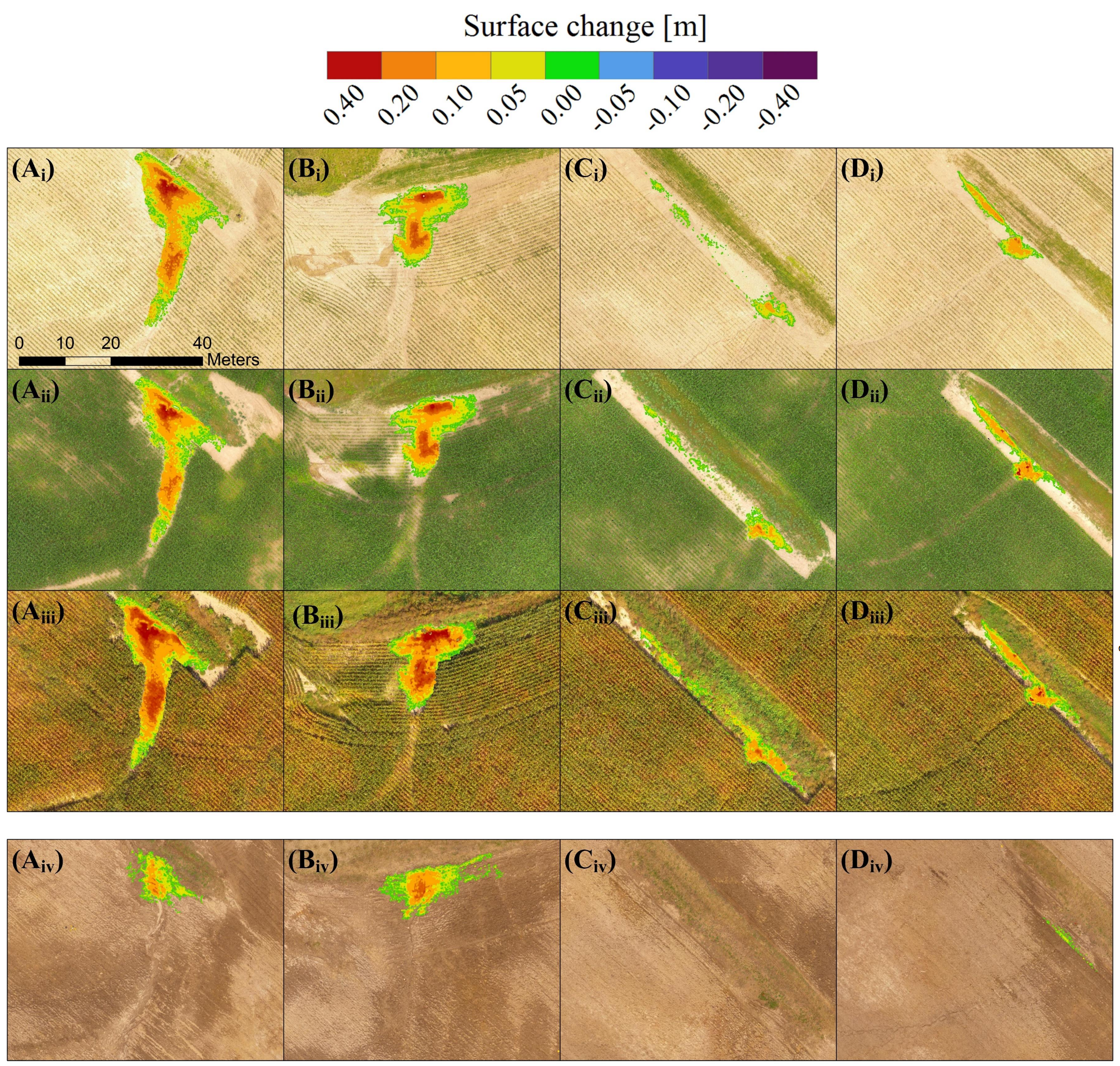
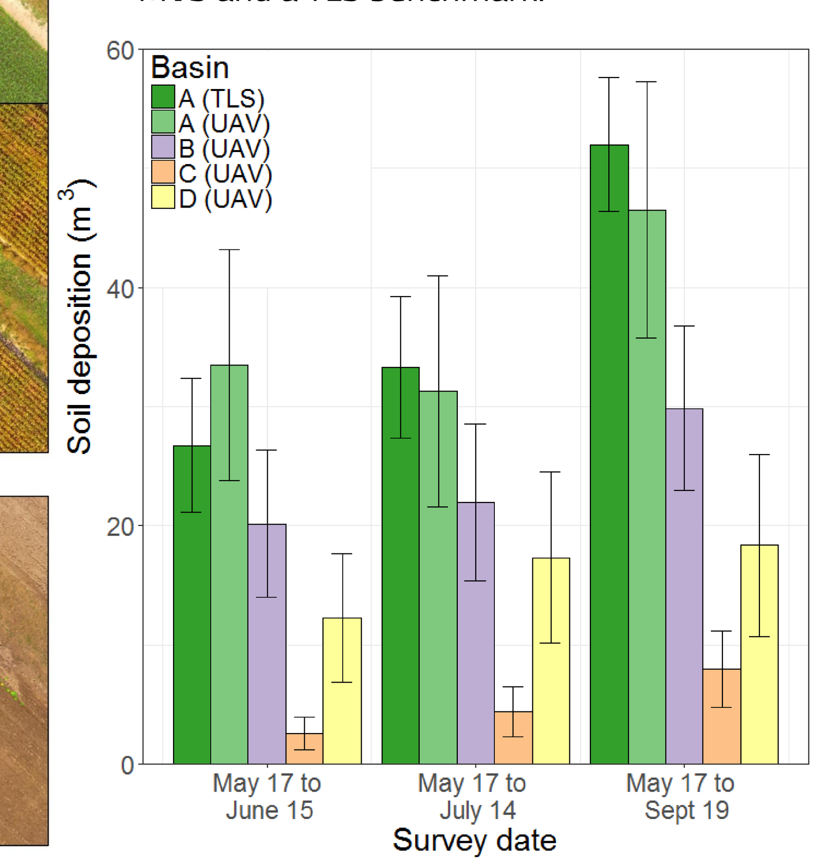


Figure 4. 6.95 tonnes of soil deposited at catch basin A from a spring storm (depicted in Figure 3 A_{iv}).

Accuracy Assessment

UAV SfM-MVS soil deposition calculations aligned well with terrestrial laser scanner (TLS) results when using a ±0.04 m UAV confidence interval (see Figure 5 below). The confidence interval is based on the vertical accuracy of RTK-GNSS which was used for measuring ground control points.

Figure 5. Soil deposition calculations with confidence intervals using both UAV SfM-MVS and a TLS benchmark.



Erosion Modelling: Process Domains

The basis of many erosion models today is the Universal Soil Loss Equation (USLE). The USLE was developed by Wischmeier and Smith with the United States Department of Agriculture and Soil Conservation Services in the 1950's as a tool to assist farmers in conservation planning. An empirical regression was calculated from 10,000 plot years of erosional data measured on standardized plots (1.8 m x 22.1m; 9% slope) with up-and-down hill tillage patterns. Most erosion models rely on the empiricisms of the USLE and only have sub-routines for sheet and rill erosion.

Ephemeral gully erosion is the most commonly neglected process domain in erosion modelling, despite it being the primary process domain in many agricultural catchments. For 3 of our 4 basins, ephemeral gully erosion contributed 85 – 95% of the total deposition in catch basins.

	Basin A	Basin B	Basin C	Basin D
Size (hectare)	3.28	2.67	0.48	1.82
Average Slope	4.97	5.18	3.81	3.77
Maximum flow length (m)	269	233	92	159
Total Deposition (tonnes)	44.14	26.60	3.38	16.14
Ephemeral Gully Erosion (% total)	95	85	0	90
Sheet and Rill Erosion (% total)	5	15	100	10

Table 1. Total erosion and deposition for each of the four measured basins from May 17 to June 15 (erosive processes are preliminary estimates based on UAV SfM-MVS change detection).

Erosion Modelling: Conclusions

With UAV SfM-MVS spatial datasets we can:

- identify erosional process domains (e.g., sheet, rill, gully)
- calculate volumetric erosion processes greater than ±0.04 m
- create detailed topographic maps (1cm pixels); 16 hectares (40 acres) can be mapped with 1-2 hours of flight time
- assess sedimentological and hydrological connectivity

For agricultural UAV applications we recommend flying at 60 m AGL (~1cm pixel resolution) with 2.5 ground control points per hectare.

Figure 6. UAV image overlooking the agricultural landscape of southwestern Ontario.