

Integrated watershed and erosion modelling for conservation prioritisation in the Kreo Sub-Watershed

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Abstract: Rapid peri-urban land-use change can intensify runoff generation, strengthen sediment connectivity, and accelerate erosion and sediment delivery, thereby threatening watershed sustainability. This study integrated the Soil and Water Assessment Tool (SWAT) and the geospatial interface for the Water Erosion Prediction Project (GeoWEPP) to quantify spatiotemporal patterns of erosion and sediment transport in the Kreo Sub-Watershed (50.6 km²), Indonesia, under 2019 and 2024 land-use conditions. SWAT was calibrated and validated against observed discharge to establish hydrological reliability prior to sediment simulation, whereas GeoWEPP was used to provide physically based, hillslope-scale diagnostics under harmonised spatial and climatic inputs. Both models indicated substantial intensification by 2024. SWAT-estimated erosion increased from approximately 64,900 to 242,200 Mg·ha⁻¹·y⁻¹ and sediment yield from 254,700 to 406,900 m³·y⁻¹, whereas GeoWEPP estimated an increase in erosion from 98,600 to 162,900 Mg·ha⁻¹·y⁻¹ and sediment yield from 216,000 to 361,500 m³·y⁻¹. Independent verification using the volume error (VE) metric showed closer agreement for SWAT (VE = 9.1%, good) than for GeoWEPP (VE = 12.4%, acceptable), supporting SWAT as the more suitable outlet-referenced model for sediment assessment while retaining GeoWEPP for hotspot identification. These results provide a basis for conservation prioritisation based on erosion hotspots, particularly where intensified erosion sources coincide with efficient sediment-transfer pathways. Overall, the integrated and verification-constrained framework provides a robust basis for targeted sediment mitigation in rapidly changing watersheds.

Keywords: conservation prioritisation, geospatial interface for the Water Erosion Prediction Project (GeoWEPP), land-use change, sediment yield, Soil and Water Assessment Tool (SWAT)

INTRODUCTION

Soil erosion and sediment delivery remain major environmental concerns in rapidly transforming watersheds, particularly in peri-urban areas where land-use conversion alters hydrological responses and sediment pathways. The conversion of forests or mixed vegetation to agricultural and built-up land generally increases runoff, reduces infiltration, and intensifies soil detachment, thereby contributing to channel siltation, downstream habitat degradation, and reservoir sedimentation. Erosion-driven sedimentation is a long-standing concern. The lower course of the Yellow River (also known as the Huang He) in China provides a classic example where long-term upstream erosion, downstream

embankment construction, and channel aggradation produced a historically unstable sediment-laden river system (Yu *et al.*, 2023). Recent remote-sensing evidence also shows that suspended sediment transport in the lower Yellow River remains highly dynamic and is influenced by reservoir regulation and channel conditions (Duan *et al.*, 2024). In contemporary catchments, land-use and land-cover (LULC) change can also substantially affect streamflow regimes and sediment yield, especially in tropical basins influenced by monsoonal rainfall and rapid landscape intensification (Sadhvani *et al.*, 2022; Regasa and Nones, 2023). In this study, erosion is understood as the detachment and mobilisation of soil from hillslopes and other source areas, whereas sediment yield refers to the portion of

mobilised material that is transported through the drainage system and delivered to the watershed outlet. Sediment connectivity further describes the efficiency with which mobilised material is transferred from source areas to the outlet, highlighting the need for assessments that identify how much sediment is produced, where it originates, and how it is delivered (Cho *et al.*, 2023).

Process-based and semi-distributed models are widely used to evaluate erosion and sediment yield under changing land use and to support watershed management. The Soil and Water Assessment Tool (SWAT) is a semi-distributed watershed model that links land use, soil, slope, and climate information to runoff and sediment generation through hydrologic response units (HRUs). SWAT has been extensively applied to assess LULC-driven changes in watershed-scale erosion and sediment delivery, including in systems where sedimentation threatens reservoir sustainability (Akoko *et al.*, 2021; Regasa and Nones, 2023). Meanwhile, the geospatial interface for the Water Erosion Prediction Project (GeoWEPP) provides a GIS-based implementation of the WEPP framework and supports hillslope-oriented representation of runoff, rill and interrill erosion, and sediment movement along topographically defined flowpaths. WEPP-based approaches are therefore useful for assessing erosion control and mitigation strategies in urban and peri-urban landscapes (Guo *et al.*, 2021). Because SWAT and GeoWEPP differ in how they represent erosion generation, transport, and routing, model selection can influence decision-making outcomes, making inter-model comparison valuable for strengthening inference and reducing dependence on a single modelling structure (Andualem *et al.*, 2023).

Robust model evaluation is therefore essential, particularly when simulation outputs are intended to guide conservation planning. Reliance on a single performance metric may obscure important deficiencies, because hydrological or sediment simulations with apparently acceptable performance can still contain bias, timing errors, or other dynamic inconsistencies that are critical for sediment assessment (Cinkus *et al.*, 2023; Ziarh *et al.*, 2024). Recent diagnostic approaches emphasise the need to distinguish bias, timing, and dynamic errors to improve interpretation and avoid overconfidence in calibrated results (Schwemmler, Demand and Weiler, 2021). These concerns are particularly relevant for erosion and sediment modelling because parameter equifinality, data scarcity, model-structure sensitivity, and LULC classification uncertainty can propagate into sediment estimates and affect watershed assessments used to inform decisions (Baghel, Mishra and Trivikrama Raju, 2025; Kumar, Choudhary and Thomas, 2025; Sharma *et al.*, 2025). In addition, parameter non-stationarity and temporal variability in catchment behaviour can limit the transferability of calibrated parameter sets across different periods and conditions (Lan *et al.*, 2020; Koutsoyiannis, 2025).

The Kreo Sub-Watershed in Central Java is a rapidly changing peri-urban landscape covering 50.6 km², where land-use changes between 2019 and 2024 are likely to have altered erosion intensity, sediment yield, and sediment delivery efficiency. At the same time, studies from other regions indicate that structural and nature-based interventions, particularly check dams and vegetation-based measures, can significantly reduce sediment transfer and reshape basin-scale sediment responses (Zhang *et al.*, 2022; Fang *et al.*, 2023; Carrera-Villacrés *et al.*, 2025). However,

relatively few applied watershed studies combine a controlled assessment of LULC change, dual-model comparison across watershed- and hillslope-scale frameworks, and independent outlet-based sediment verification in a single workflow. Accordingly, this study integrates SWAT and GeoWEPP to: (i) quantify spatiotemporal changes in erosion and sediment yield between 2019 and 2024, (ii) compare model responses under harmonised inputs to distinguish land-use signals from model-structure effects, and (iii) improve the reliability of sediment estimates through diagnostic evaluation and independent verification. Formal conservation-scenario analysis, including the quantitative simulation of specific vegetative or mechanical interventions, is beyond the scope of this paper; instead, the verified model outputs are used to derive hotspot-based conservation implications from the identified erosion and sediment-delivery patterns.

MATERIALS AND METHODS

STUDY AREA AND DATA USED

The Kreo Sub-Watershed covers approximately 50.6 km² in Central Java, Indonesia, and was selected as a peri-urban basin characterised by heterogeneous topography, mixed land cover, and spatially variable soils. Geographically, the watershed extends approximately from 7°04'00" S to 7°09'00" S and from 110°16'00" E to 110°26'00" E. According to the digital elevation model (DEM) used for watershed delineation, elevation in the Kreo Sub-Watershed ranges from approximately 80 to 600 m a.s.l. The watershed has a volcanic-fluvial landscape, with hilly to steep volcanic terrain in the upper reaches and gentler fluvial and depositional terrain downstream toward the Garang River system. Representative hydrometeorological data used in this study indicate a humid tropical monsoonal climate, with mean annual precipitation of approximately 2,900 mm·y⁻¹, about 148 rainy days, a mean air temperature of approximately 28.9°C, a mean relative humidity of about 76%, and mean annual potential evapotranspiration of approximately 950 mm·y⁻¹. The geological setting is dominated by volcanic materials, including volcanic breccia, tuffaceous sand, and sandy tuff, while the mapped soil classes consist mainly of Vertic Luvisols, Chromic Luvisols, and Mollic Andosols, with Vertic Luvisols occupying the largest proportion of the watershed. Figure 1 shows the study area at multiple geographic scales, including its location within Java Island and the delineated Kreo Sub-Watershed boundary and river network used in the SWAT and GeoWEPP simulations (Fig. 1). These spatial characteristics were incorporated as the main physical inputs for erosion and sediment-yield modelling.

The modelling database consisted of a DEM, soil maps, land-use and land-cover (LULC) maps for 2019 and 2024, daily rainfall and meteorological data, observed streamflow, and field-based sediment observations. The DEM was obtained from the TanahAir Indonesia geospatial data portal with an approximate spatial resolution of 0.27 arc-second, or about 8 m. The 2019 and 2024 LULC maps were derived from supervised classification of Landsat 8 OLI/TIRS imagery at 30 m spatial resolution, whereas the soil map was obtained from the Harmonized World Soil Database (HWSD) at a resolution of 30 arc-seconds (approximately 1 km). All spatial datasets were projected to UTM-WGS

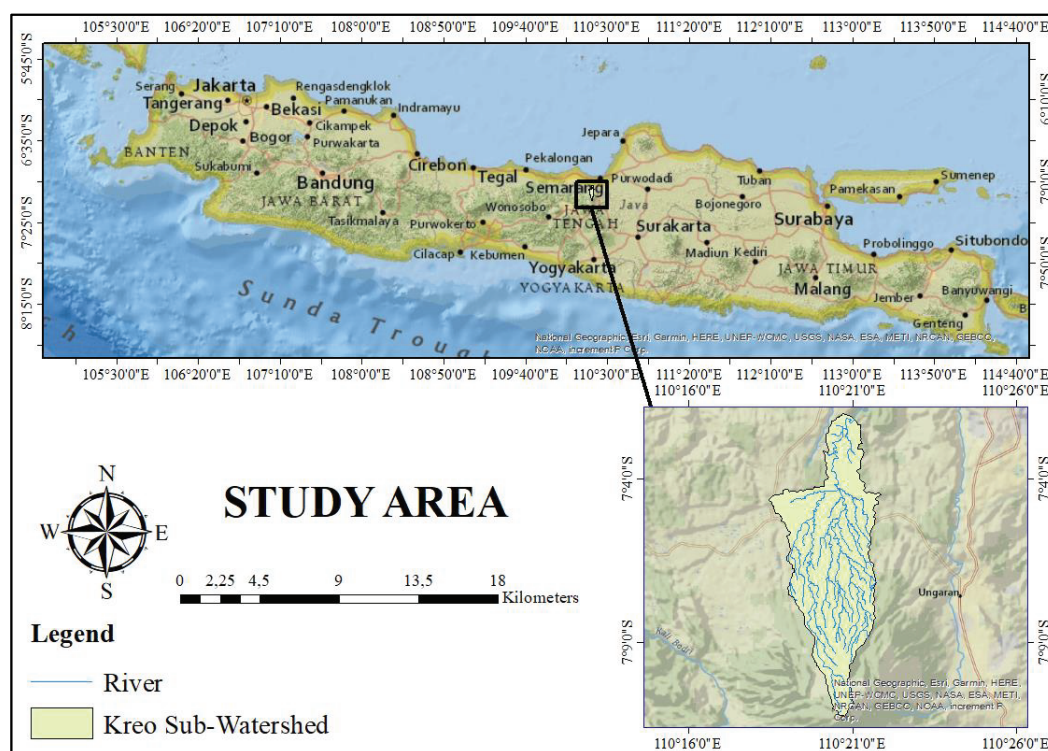


Fig. 1. Location of the Kreo Sub-Watershed within Java Island, Indonesia; source: authors' elaboration based on DEMNAS and Esri basemap data

1984 Zone 49S and harmonised for SWAT and GeoWEPP input preparation. Because the input datasets differed in their native spatial resolutions, model outputs were summarised at watershed and sub-basin scales and reported at an appropriate level of numerical precision. Training samples and cross-checking procedures were used to assess classification consistency and reduce land-cover input bias, recognising that LULC classification uncertainty may propagate into erosion estimates (Chordia *et al.*, 2022). The same DEM, soil, and climate inputs were used for both land-use conditions so that differences in simulated erosion and sediment yield primarily reflected land-use change rather than differences in supporting input data, consistent with comparative watershed modelling practice (Kumar, Choudhary and Thomas, 2025; Talebizadeh *et al.*, 2025).

Rainfall inputs for 2010–2023 were derived from two rainfall stations with complete records: Sumur Jurang, located at 07°06'25.52" S and 110°23'10.68" E, and Gunung Pati, located at 07°05'10.68" S and 110°22'03.00" E. Areal rainfall was estimated with the Thiessen polygon method, based on each station's area of influence within the Kreo Sub-Watershed. Because only two rainfall stations were available, no explicit elevation-dependent orographic correction was applied; topographic effects were instead represented through the DEM-derived terrain, slope classes, and hydrological calibration and validation. Observed streamflow data were used for hydrological calibration and validation. Field-based sediment observations were aggregated into annual sediment volumes and used as independent constraints for sediment verification, given the sensitivity of sediment simulations to runoff dynamics and parameter uncertainty (Alavez-Vargas *et al.*, 2023; Baghel, Mishra and Trivikrama Raju, 2025).

SETUP OF THE SOIL AND WATER ASSESSMENT TOOL

SWAT was applied as a semi-distributed model to simulate streamflow and sediment yield for the 2019 and 2024 land-use conditions. The watershed was delineated from the DEM, and hydrologic response units (HRUs) were generated by overlaying land use, soil type, and slope classes. During DEM-based delineation, the Kreo Sub-Watershed was further subdivided into seven SWAT sub-basins, which were used as spatial reporting units for erosion, sediment yield, and hotspot identification. The reporting categories therefore consisted of watershed-scale totals and sub-basin-scale outputs for sub-basins 1–7, rather than separate administrative or management categories. The two SWAT model runs represented comparative LULC conditions for 2019 and 2024 derived from supervised land-use classification, rather than formal management, climate, or conservation scenarios. Delineation settings and HRU thresholds were kept constant for both land-use conditions so that differences in simulated erosion and sediment yield reflected land-use change rather than model reconfiguration.

Hydrological calibration was carried out before sediment simulation to ensure a realistic representation of runoff volume, peak flow, and hydrograph timing. Calibration focused on parameters controlling surface runoff, groundwater response, and channel routing. The calibrated parameters, tested ranges, and fitted values for the 2019 and 2024 simulations are presented in Table 1. Model performance was evaluated using standard statistics, including the coefficient of determination (R^2) and Nash–Sutcliffe efficiency (NSE), alongside inspection of hydrographs and scatter plots to check the representation of flow dynamics before sediment simulation.

Following hydrological calibration, sediment yield was simulated using SWAT's internal erosion and sediment routines.

Table 1. Soil and Water Assessment Tool (SWAT) hydrological calibration parameters, tested ranges, and final fitted values for the 2019 and 2024 land-use simulations

Parameter	Description	Lower bound	Upper bound	Calibrated value	
				2019	2024
CN2	SCS curve number (dimensionless)	35	98	60	35
ALPHA_BF	baseflow alpha factor (day)	0	1	0.50	0.008
GW_DELAY	groundwater delay time (day)	0	500	37	75
GWQMN	threshold depth of water in the shallow aquifer for return flow (mm)	0	5,000	1,800	5,000
ESCO	soil evaporation compensation factor (dimensionless)	0	1	1	1
EPCO	plant uptake compensation factor (dimensionless)	0	1	0	1
GW_REVAP	groundwater revap coefficient (dimensionless)	0.02	0.20	0.04	0.05
CH_N2	Manning's n coefficient for the main channel (dimensionless)	0.01	0.30	0.05	0.25
CH_K2	effective hydraulic conductivity in main channel alluvium ($\text{mm}\cdot\text{h}^{-1}$)	0.01	500	450	20

Source: own elaboration.

Two independent simulations were performed using the 2019 and 2024 LULC maps while maintaining identical soil and climatic inputs. Outputs were summarised as annual erosion rates and sediment yields at two spatial scales: watershed totals and values for the seven delineated sub-basins, to support model inter-comparison and hotspot identification.

THE GEOSPATIAL INTERFACE FOR THE WATER EROSION PREDICTION PROJECT

GeoWEPP was used to complement SWAT by providing hillslope-oriented erosion and sediment-transport outputs. As in the SWAT simulations, the GeoWEPP model runs represented the 2019 and 2024 LULC conditions derived from supervised land-use classification, rather than formal management, climate, or conservation scenarios. In contrast to the HRU-based structure of SWAT, GeoWEPP represents rill and interrill erosion and routes sediment along topographically defined flowpaths, thereby supporting the spatial identification of localised erosion and sediment source areas (Elliot, Lewis and Cannard, 2023; Mahrukh *et al.*, 2025). GeoWEPP outputs were interpreted at the hillslope and sub-basin scales for hotspot identification, rather than as pixel-level erosion estimates, because the spatial detail of the analysis was constrained

by the input resolutions of approximately 8 m for the DEM, 30 m for the Landsat-derived LULC maps, and approximately 1 km for the HWSO soil map. GeoWEPP was implemented using the same core inputs as SWAT, including the DEM, soil maps, climate data, and the 2019 and 2024 LULC maps. The two land-use conditions were simulated separately with consistent soil and climate inputs. The GeoWEPP calibration parameters, tested ranges, and fitted values are listed in Table 2. Key soil-related parameters included interrill erodibility, rill erodibility, critical shear stress, and effective hydraulic conductivity. These parameters were assigned based on soil characteristics and adjusted within the tested ranges shown in Table 2, in view of the sensitivity of WEPP-family models to soil erodibility and hydraulic parameters (Al-Hamdan *et al.*, 2022). Model outputs were generated as spatial erosion and sediment maps for each land-use condition and were then aggregated to watershed totals for comparison with SWAT outputs.

MODEL INTERCOMPARISON AND SEDIMENT VERIFICATION

The intercomparison framework was designed to distinguish land-use effects from model-structure effects by applying SWAT and GeoWEPP under harmonised spatial inputs and identical

Table 2. Calibration parameters, tested ranges, and final fitted values for the Geospatial Interface for the Water Erosion Prediction Project (GeoWEPP) simulations

Parameter	Description	Lower bound	Upper bound	Calibrated value	Unit
Interrill erodibility	soil susceptibility to detachment by raindrop impact (splash)	2,000,000	11,000,000	7,500,000	$\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-4}$
Rill erodibility	soil susceptibility to detachment by concentrated flow in rills	0.002	0.045	0.035	$\text{s}\cdot\text{m}^{-1}$
Critical shear stress	minimum shear stress required to initiate particle detachment	1	6	2.5	$\text{N}\cdot\text{m}^{-2}$
Effective hydraulic conductivity	effective soil infiltration / percolation rate	0.3	28	0.45	$\text{mm}\cdot\text{h}^{-1}$

Source: own elaboration.

climatic forcing. Because SWAT and GeoWEPP differ in spatial discretisation and sediment-routing structure, their outputs were compared in terms of directional consistency between the 2019 and 2024 simulations, agreement on hotspot sub-basins, and differences in watershed-scale erosion and sediment totals, rather than absolute values alone (Wagner *et al.*, 2022; Kumar, Choudhary and Thomas, 2025). Outputs from both models were reported at the watershed and sub-basin scales to retain both outlet-scale sediment information and spatially distributed source-area information (Baghel, Mishra and Trivikrama Raju, 2025; Talebizadeh *et al.*, 2025). To evaluate outlet-scale sediment agreement, simulated annual sediment volume (V_2 , $\text{m}^3 \cdot \text{y}^{-1}$) was compared with field-based annual sedimentation estimates (V_1 , $\text{m}^3 \cdot \text{y}^{-1}$) using the volume error (VE) metric:

$$VE = \frac{V_2 - V_1}{V_1} \cdot 100\% \quad (1)$$

Simulation performance was classified as good for $VE < 10\%$, acceptable for $10\% \leq VE < 20\%$, and unacceptable for $VE \geq 20\%$. This verification step was included because sediment simulations may remain uncertain even after acceptable hydrological calibration, particularly under parameter-sensitive and heterogeneous catchment conditions (Alavez-Vargas *et al.*, 2023; Baghel, Mishra and Trivikrama Raju, 2025). The verified sediment outputs were then used to inform conservation priorities based on erosion hotspots. Only the observed 2019 and 2024 LULC conditions were compared under harmonised spatial and climate inputs; no additional conservation, management, or climate scenarios were simulated.

RESULTS AND DISCUSSION

MODEL PERFORMANCE EVALUATION

Hydrological evaluation was considered a prerequisite for credible estimates of erosion and sediment yield and a defensible SWAT–GeoWEPP intercomparison, because both frameworks link sediment generation to runoff dynamics despite their different structural representations (Wilk, 2022; Kumar, Choudhary and Thomas, 2025). SWAT streamflow simulations were calibrated for 2019 and validated for 2024 using standard goodness-of-fit metrics supported by hydrograph and scatter-plot diagnostics, with particular attention to the plausibility of peak-flow responses, given their importance for sediment detachment and transport. This approach is consistent with evidence that aggregated performance statistics may conceal compensating

errors that remain important for sediment realism in heterogeneous watersheds (Talebizadeh *et al.*, 2025).

The resulting statistics indicate satisfactory hydrological performance for the intended application. The model achieved $R^2 = 0.86$ and $NSE = 0.84$ during calibration, and $R^2 = 0.81$ and $NSE = 0.81$ during validation (Tab. 3), supporting the use of SWAT runoff outputs for subsequent sediment simulation and model intercomparison. Because SWAT and GeoWEPP differ in output structure, their performance was evaluated using complementary criteria. SWAT was evaluated against observed discharge using R^2 and NSE , whereas GeoWEPP was evaluated by comparing simulated sediment volume with field-based annual sedimentation estimates, as reported in the verification subsection. Nevertheless, acceptable hydrological performance was not interpreted as proof of sediment accuracy; instead, it provided the methodological basis for subsequent structural comparison and independent sediment verification (Alavez-Vargas *et al.*, 2023).

Table 3. Hydrological performance statistics of the Soil and Water Assessment Tool (SWAT) streamflow simulation for the calibration (2019) and validation (2024) periods

Evaluation period	Land-use condition	R^2	NSE
Calibration	2019 LULC	0.86	0.84
Validation	2024 LULC	0.81	0.81

Explanations: R^2 = coefficient of determination, NSE = Nash–Sutcliffe efficiency, LULC = land use and land cover.
Source: own study.

SPATIOTEMPORAL EROSION AND SEDIMENT CHANGE

With runoff dynamics adequately represented, the contrast between 2019 and 2024 can be interpreted primarily as a land-use-driven signal rather than a hydrological artefact. Under harmonised inputs, both SWAT and GeoWEPP indicated substantial intensification of erosion and sediment export in 2024, strengthening confidence that the observed directional change reflects a real shift in watershed behaviour rather than a model-specific response (Kumar, Choudhary and Thomas, 2025; Sharma *et al.*, 2025). As shown in Table 4, both models indicated a clear increase in erosion and sediment yield between 2019 and 2024. SWAT showed a stronger erosion response than GeoWEPP, whereas both models simulated substantial increases in outlet sediment yield. Table 4 reports rounded absolute values and percentage changes consistent with the spatial resolution and uncertainty of the input data. Although the magnitude of erosion

Table 4. Watershed-scale erosion rate and sediment yield simulated by Soil and Water Assessment Tool (SWAT) and geospatial interface for the Water Erosion Prediction Project (GeoWEPP) under 2019 and 2024 land-use conditions

Model	Year	Erosion ($\text{Mg} \cdot \text{ha}^{-1} \cdot \text{y}^{-1}$)	Sediment ($\text{m}^3 \cdot \text{y}^{-1}$)	Erosion change (%)	Sediment change (%)
SWAT	2019	64,900	254,700	–	–
	2024	242,200	406,900	+273.2%	+59.7%
GeoWEPP	2019	98,600	216,000	–	–
	2024	162,900	361,500	+65.1%	+67.4%

Source: own study.

response differed, both models showed comparable increases in sediment yield at the watershed outlet. This convergence suggests that land-use transition between 2019 and 2024 increased not only detachment potential but also sediment delivery efficiency, consistent with connectivity-driven behaviour in rapidly transforming peri-urban basins (Wilk, 2022).

These results are broadly consistent with previous studies showing that peri-urban and rapidly transformed catchments tend to exhibit disproportionate increases in sediment export relative to land-cover change because vegetation loss, surface disturbance, and drainage modification jointly enhance both runoff generation and sediment connectivity (Sadhvani *et al.*, 2022; Regasa and Nones, 2023). In the Kreo Sub-Watershed, the concurrent increase in simulated erosion and outlet sediment yield between 2019 and 2024 therefore suggests not only greater hillslope detachment but also a more efficient transfer of mobilised material through connected pathways. This interpretation is important because management decisions based solely on erosion source magnitude may overlook the role of intermediate storage loss and pathway efficiency in controlling exported sediment loads. These findings suggest that, in peri-urban watersheds, land use change amplifies both source activation and delivery connectivity, thereby accelerating downstream sediment hazards.

MODEL INTERCOMPARISON AND STRUCTURAL INTERPRETATION

The difference between SWAT and GeoWEPP should be interpreted as structural sensitivity rather than contradiction (Andualem *et al.*, 2023). Through its hydrologic response unit (HRU) structure and conceptual routing, SWAT tends to amplify erosion response when land-use change increases runoff energy across multiple HRUs, whereas GeoWEPP explicitly represents rill and interrill erosion, hillslope routing, and internal deposition along flowpaths (Akoko *et al.*, 2021; Guo *et al.*, 2021; Wang *et al.*, 2023). Consequently, part of the additional sediment mobilised under 2024 conditions may be redistributed or temporarily stored within hillslopes in GeoWEPP, resulting in a more moderate erosion increase despite a substantial rise in delivered sediment.

The key finding is the consistency of outlet-scale sediment trends. Despite contrasting erosion sensitivities, both models indicate that the watershed has become more efficient in transferring mobilised material to the outlet. In peri-urban systems, stronger sediment connectivity may arise from vegetation loss, slope modification, drainage expansion, and increasing surface sealing, all of which reduce intermediate storage and accelerate sediment transfer (Wilk, 2022). The intercomparison therefore provides complementary structural evidence that the 2019–2024 land-use transition shifted the Kreo Sub-Watershed toward a more delivery-efficient sediment regime, offering a stronger basis for management inference than reliance on a single model alone (Schwemmler, Demand and Weiler, 2021; Batista *et al.*, 2022; Knoben and Spieler, 2022; Boardman *et al.*, 2025).

VERIFICATION AND CONSERVATION IMPLICATIONS

Independent sediment verification was used to constrain structural uncertainty and identify the model most appropriate for outlet-referenced sediment assessment and conservation

prioritisation (Alavez-Vargas *et al.*, 2023). Based on the volume error (VE) metric, SWAT had a VE of 9.1% (good), whereas GeoWEPP had a VE of 12.4% (acceptable) – Table 5. These results indicate that both models provide credible sediment estimates, but SWAT shows closer agreement with field-based outlet sedimentation and is therefore more suitable as the primary outlet-referenced model for conservation prioritisation (Naseri, Azari and Dastorani, 2021; Wang *et al.*, 2023).

Table 5. Sediment verification results based on volume error (VE) comparing field-based sedimentation and model simulations

Model	Observed sediment ($\text{m}^3 \cdot \text{y}^{-1}$)	Simulated sediment ($\text{m}^3 \cdot \text{y}^{-1}$)	VE (%)	Performance class
SWAT	143,800	130,800	9.1	good
GeoWEPP	143,800	185,300	12.4	acceptable

Explanations: SWAT = Soil and Water Assessment Tool, GeoWEPP = geospatial interface for the Water Erosion Prediction Project. Source: own study.

This result reflects fitness for purpose and does not invalidate GeoWEPP. GeoWEPP remains valuable for mechanistic interpretation and hotspot diagnosis because its hillslope-based routing is sensitive to topographic controls and internal redistribution (Elliot, Lewis and Cannard, 2023). However, when conservation priorities are derived from an outlet-referenced sediment target, lower deviation from field observations provides a more transparent basis for prioritising SWAT outputs. The combined evidence is consistent with water-sensitive planning principles that emphasise site-specific and process-based intervention design rather than uniform watershed-wide measures (France, 2002). Accordingly, source-control measures, such as vegetative rehabilitation and increased cover, should be combined with delivery-control measures, such as strategically placed check dams to reduce both sediment detachment and sediment transfer efficiency. This interpretation is consistent with recent studies showing that check dams are most effective when coupled with upstream stabilisation and targeted to strongly connected source areas (Sun and Wu, 2023; Baghel, Mishra and Trivikrama Raju, 2025; Talebizadeh *et al.*, 2025).

Several limitations should nevertheless be acknowledged when interpreting the quantitative magnitudes. First, the analysis isolates the land-use signal by comparing 2019 and 2024 LULC conditions under harmonised supporting inputs, which strengthens attribution but may simplify some temporal variability in catchment behaviour. Second, the two models employ different structural representations of detachment, routing, and deposition, so divergence in absolute values should be interpreted as structural sensitivity rather than inconsistency. Third, the sediment verification is outlet-referenced, which makes it relevant to decisions about watershed export but does not fully resolve internal redistribution processes at finer spatial scales. Even so, the convergence of both models on the direction of change, together with independent sediment verification, provides sufficient confidence for hotspot-based conservation planning and for using SWAT as the principal outlet-referenced model in this rapidly changing peri-urban watershed.

CONCLUSIONS

This study shows that land-use transition between 2019 and 2024 substantially intensified erosion and sediment delivery in the Kreo Sub-Watershed, highlighting the vulnerability of rapidly transforming peri-urban basins to increasing sediment hazards. By integrating the Soil and Water Assessment Tool (SWAT) and the geospatial interface for the Water Erosion Prediction Project (GeoWEPP) under harmonised spatial inputs and consistent climatic forcing, the analysis provides structurally independent evidence that the increase in simulated sediment export represents a robust watershed response to landscape change rather than a model-specific artefact. The results further indicate that this intensification was driven not only by greater detachment potential associated with reduced protective cover and expanding human disturbance, but also by stronger hydrological and sediment connectivity that enhanced sediment transfer to the channel network and watershed outlet.

Hydrological calibration provided a credible basis for sediment inference, while cross-model comparison strengthened interpretation by revealing consistent directional change despite differences in erosion sensitivity related to detachment, deposition, and routing processes. Independent verification against field-based sedimentation estimates further constrained outlet-scale uncertainty and supported the use of SWAT as the primary outlet-referenced model for conservation prioritisation, with GeoWEPP serving as a complementary tool for hotspot diagnosis. These findings indicate that effective sediment mitigation should not rely on uniform watershed-wide interventions, but rather on targeted strategies that combine source-control measures to reduce detachment and improve infiltration with delivery-control measures to intercept sediment along efficient transport pathways. Beyond its local relevance, the study shows how structural model comparison and independent outlet-based verification can inform hotspot-focused sediment management in rapidly changing catchments. The verification-constrained dual-model workflow offers a transferable approach to sediment management under structural and data uncertainty.

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AUTHOR CONTRIBUTIONS

1st Author (30%): study design, data collection, manuscript preparation, and literature search. 2nd Author (19%): statistical analysis, data interpretation, and manuscript preparation.

3rd Author (19%): data collection, statistical analysis, and data interpretation. 4th Author (16%): statistical analysis, data interpretation, and literature search. 5th Author (16%): data collection, statistical analysis, and manuscript preparation.

CONFLICT OF INTEREST

All authors declare no conflict of interest.

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