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Sediment Deposition Analysis Using InfoWorks ICM for Segamat River, Muar River Basin

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Abstract

Various environment-related issues within a river system associated with urbanization will lead to urban channel and river bank erosion and sedimentation problems such as floods, water quality degradation and disruption to the ecosystem. Apart from the development, river dredging activities and sand mining will also cause instability problems to the river morphology. In view of its negative impacts to the river system, an assessment on the river morphology for Segamat River, Johor has been conducted. The study aimed to examine the processes of erosion and deposition of river morphology and propose strategic measures to minimize the effects of erosion and sedimentation along the river. Sediment transport modelling has been carried out for 10-, 50-, 100- and 1000-year Average Recurrence Interval (ARI) storm events based on the runoff hydrograph using InfoWorks Integrated Catchment Modelling (ICM) coupled with a sediment-transport module. The Ackers-White sediment transport equation was selected in the model due to its applicability across a wide range of particle sizes and flow conditions, offering reliable predictions for the study reach. The simulation results highlight the large variability in channel morphology along river reach, where the sediment transport model predicts more sediment deposition at the middle reach of Segamat River. The findings underpin an Erosion and Sedimentation Control Plan (ESCP) that spatially targets dredging moratoria, buffer-zone restoration, and adaptive sand-extraction scheduling to restore morphodynamic equilibrium and reduce flood risk.

1. Introduction

Urbanization and associated human activities have significantly impacted river systems, leading to channel and bank erosion, increased sedimentation, flooding, water quality degradation, and ecosystem disruption [1]. In addition to urban development, sand mining and river dredging have been widely reported to destabilize river morphology and degrade fluvial environments. These activities can lead to serious consequences such as land loss due to erosion, lowering of the water table, and increased suspended sediment loads, which in turn affect water quality and contribute to bed degradation. The latter may compromise critical infrastructures like bridge foundations, river embankments, and flood protection systems [2]–[3].

Excessive in-stream sand extraction disrupts the natural equilibrium of river channels, leading to degradation of aquatic habitats, and damage to both private properties and public infrastructure [2], [4]. A key concern is the disturbance of sediment balance, where the selective removal of medium to coarse sand and gravel lowers the median grain size and reduces the sediment supply available for downstream transport. This shift causing bed erosion, particularly in areas with insufficient replenishment. Additionally, the deepening of river channels caused by sand mining can increase the local channel slope, which in turn raises flow velocities and further accelerates erosion processes [5].

Without proper environmental management, sand mining poses serious long-term threats to river health, infrastructure stability, and biodiversity. In response to its adverse impacts, a comprehensive assessment of the Segamat River's morphology was conducted. This study focused on understanding sediment transport processes and morphological changes, which are crucial for evaluating flood behavior, especially during the monsoon season marked by intense and prolonged rainfall. It is well-documented that the most significant erosion and sediment transport events typically occur during floods, leading to geomorphological consequences [6]–[9].

The primary objective of this study was to analyse the erosion and deposition processes that influence the equilibrium of river morphology. By doing so, we aimed to propose strategic measures that can effectively mitigate the adverse effects of erosion and sedimentation along the river. It can be understood better with the support of some analysis tools. This assessment is deeming important to fill the gaps of the previous assessment done on flood analysis in particular on the same catchment [10]–[11] on the severity of erosion and deposition of sediments for Segamat River.

2. Study Area and Method

2.1 Study Areas

Segamat River Basin (Fig. 1) is situated in the northern part of Johor with 14 m above the mean sea level and encompasses a catchment area of 701.06 km^2. The catchment occupied roughly 70% of highland with elevation up to 1000 meters, while the remaining sub-basins comprises of hillsides with swampy area wide. Segamat River originates from Gunung Besar and joins Muar River at Kampung Tebing Tinggi [12]. Segamat River Basin was mainly occupied by agriculture (473.50 km^2), followed by forest (171.81 km^2), developed areas (24.22 km^2), transportation (16.66 km^2) and waterbody (15.39 km^2) in 2017. Several major floods have been experienced in Segamat River Basin since 1971 which caused extensive damage to the local communities.

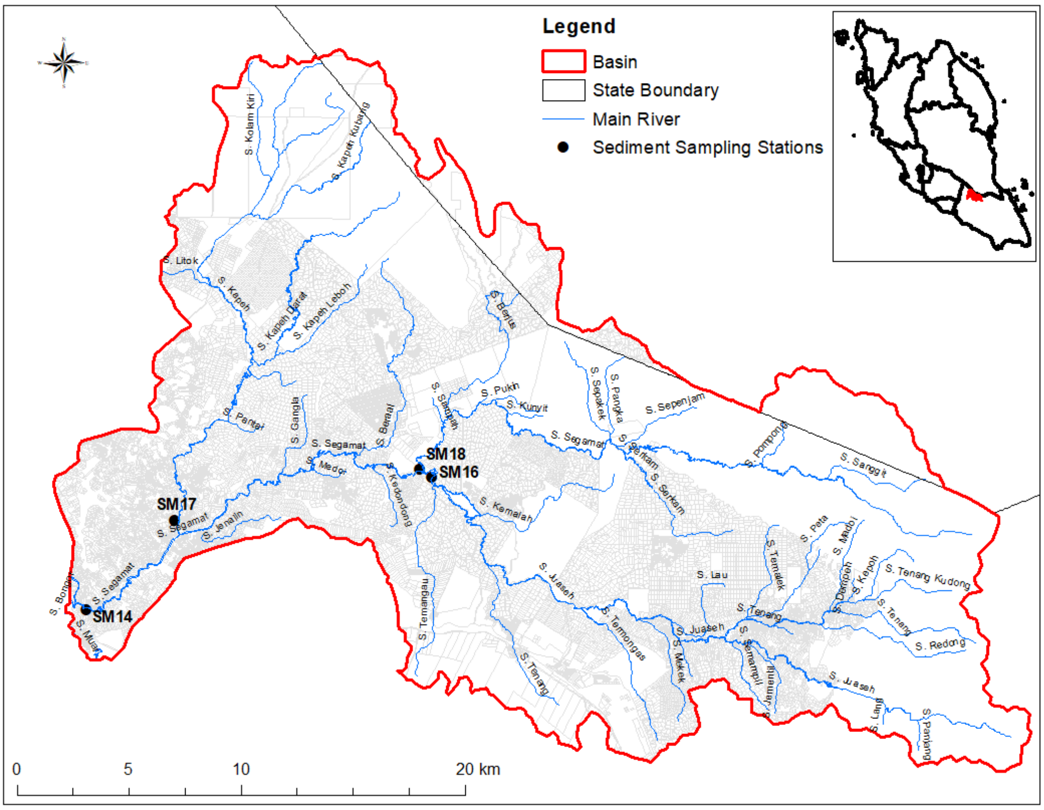


Fig. 1 *Segamat River Basin*

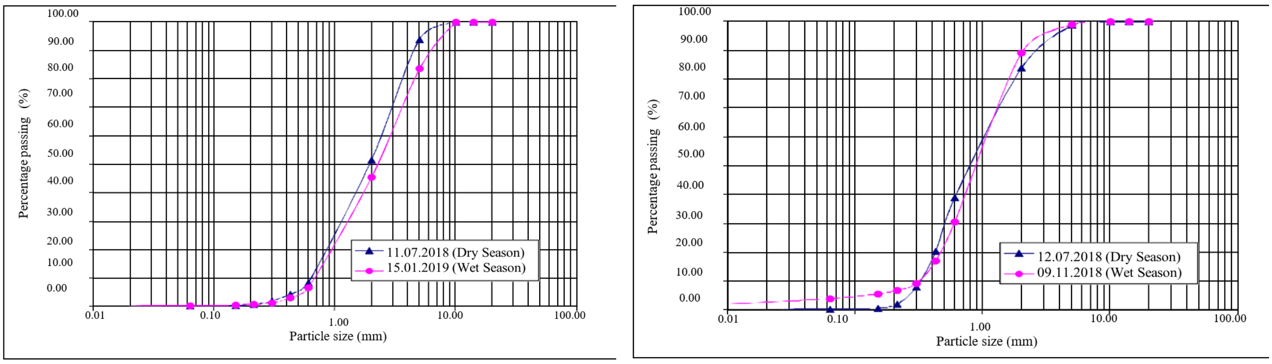
2.1.1 Data Collection Methods

Studies of sediment transport scour and fill aggradation and deposition together with flood analyses can be performed by computer model simulation. Increased runoff due to greater impervious areas and the general decline in sediment yield following urbanization resulted in urban channel erosion and deposition. Sediment transport modelling for Segamat River was carried out using InfoWorks Integrated Catchment Modelling (InfoWorks ICM) based on 1-Dimensional (1-D) hydrodynamic modelling approach as numerical modelling is known to play a vital role in simulating the scenarios of inter-related changes in channel-bed profile and changes in bed and finally to obtain the location of sedimentation or erosion [13], [14].

In addition, bed material data collected from 2017 to 2019 covering low and high flow during dry and wet seasons at four (4) sampling sites (Fig. 1) along Segamat River, Kapeh River and Juaseh River were among the prerequisite input in the sediment transport model. The results of sieved analysis were done by accredited laboratory for bed material samples. Grain size distribution and sediment concentration over time (pollutograph) were used to specify initial bed material compositions on the riverbed. The Ackers-White [15] total load equation was employed to estimate the sediment transport rate, incorporating both bedload and suspended load components, based on flow conditions and sediment characteristics.

2.1.2 Data Processing and Analysis

Based on the sieve analysis of sediment samples collected from the site (Fig. 2), the ranges of mean sediment size are between 0.40 mm and 2.30 mm which indicated that Segamat River Basin is made up of sand material (Table 1). The result portrays that the bed material for Juaseh River is coarser than Segamat River. However, bed material for Kapeh River is having finer sediment size (mean sediment size approximately 0.41 mm to 0.43 mm) as compared to Segamat River and Juaseh River.



(a) **(b)**

Fig. 2 *Sediment size distributions of the Segamat River at (a) CH 1500 (SM14); (b) CH 23000 (SM18)*

Table 1 *Mean sediment size (d_{50}) of bed material for 4 locations in Segamat River Basin*

Sampling Location	Places	Date	Mean Sediment Size, d_{50} (mm)
SM14	Segamat River at Chainage 1500	11-07-18	1.95
		15-01-19	2.30
SM18	Segamat River at Chainage 23000	12-07-18	0.80
		09-11-18	0.90
SM16	Juaseh River at Chainage 1000	11-07-18	1.75
		09-11-18	1.70
SM17	Kapeh River at Chainage 500k	11-07-18	0.43
		10-11-18	0.41

The sediment boundary was set to be the sediment rating curve (sediment versus flow) developed based on the available Segamat river geometry survey and on-site sediment sampling. As depicted in Table 1, the ranges of mean sediment size of Segamat River in between 0.80 mm and 2.30 mm illustrate that the river is made up of coarse sand material. Hence, the development of the rating curve was based on Engelund-Hansen total load equation [16], as recommended in the Department of Irrigation and Drainage (DID) study on river sand mining capacity in Malaysia [4]. The calculation for all the rating curves was found to be significant at coefficient of determination, $R^2 = 99\%$ [13].

To simulate in-stream sediment transport under various storm conditions, sediment concentration over time (pollutograph) was generated at each sub-basin outlet. Table 2 presents a sample of the geometry and sediment load input used in the model for different sub-basins. Several assumptions were made in the sediment transport modelling process. First, sediment transport was estimated only along the main channel of the Segamat River, excluding its tributaries. Second, hydraulic structures such as bridges and culverts were not incorporated in the current simulation.

Table 2 *Summary of input parameters for InfoWorks ICM*

Category	Parameter	Source
Geometry	Reach length	2016 Survey – Approximately 41.4 km
	Cross section	2016 Survey – 84 surveyed cross section
	Roughness coefficient	Riverbank – 0.035; Floodplain – 0.05 to 0.10
Sediment	Sediment samples	Sediment grab sampling in 2019 at 2 locations along Segamat River
	Sediment transport formula	Ackers-White (1973) total load equation
	Active layer depth method (1D)	d_{50}
	d_{50} of SF1 (mm)	1.50
	Density (kg/m^3)	2650
	Specific gravity	2.65
	Porosity of SF1	0.25
	Skin roughness parameter	1.25
	Angle of response (degree)	45
	Pollutograph	Derive from sediment rating curve based on hydrologic input (Q_{10}, Q_{50}, Q_{100} and Q_{1000} flood hydrograph)

2.1.3 Model Setup

The hydrodynamic and sediment transport model was developed using InfoWorks ICM, which supports both one-dimensional (1D) and coupled one- and two-dimensional (1D–2D) flow simulations. This model was selected for its ability to simulate unsteady open channel and floodplain flows, enabling a detailed analysis of hydrological, hydraulic, and sediment dynamics. The workflow for the sediment transport modeling process is illustrated in Fig. 3. It comprises four primary stages: data collection, data preprocessing and analysis, model setup, and scenario-based simulations integrating hydrological, hydraulic, and sediment transport components.

The river network for Segamat River sediment transport modelling covers a length of 41.4 km from the upstream at Chainage 41000 to the downstream at Chainage 00 was built with a total of 84 cross sections spaced approximately 500 meters apart, capturing longitudinal variations in topography and roughness. Rainfall data from within and around the Segamat River Basin were utilized to derive Intensity-Duration-Frequency (IDF) curves to estimate design rainfalls for 10-, 50- and 100- and 1000-year ARIs and storm durations from 15 minutes to 72 hours, generate sub-basin hydrographs, and determine critical storm durations based on various rainfall temporal distributions. Concurrently, water level and streamflow records were used to characterize hydraulic responses and support the calibration of river flow conditions. Hydrological analysis was conducted to establish the rainfall–runoff relationships, linking precipitation inputs to the resulting river discharge. InfoWorks ICM solves the full dynamic Saint-Venant equations, allowing for the simulation of a wide range of flow regimes and channel geometries.

The model's inflow boundary condition was defined using hydrographs derived from upstream sub-basin rainfall-runoff modeling, while the downstream boundary condition was defined using observed water level data (Fig. 4). Once the hydraulic model was calibrated and validated against observed flow and water level records, sediment transport simulations were conducted using embedded transport modules. These simulations facilitated an assessment of erosion and deposition patterns, thereby informing river basin management, sediment control strategies, and the design of mitigation measures for critical reaches within the Segamat River Basin.

As part of the study's objective to enhance integrated catchment simulation capabilities, sediment transport modeling was incorporated into the calibrated hydrodynamic model within the InfoWorks ICM platform. To simulate sediment dynamics representative of Malaysian river conditions, the Ackers-White sediment transport equation [15] was selected for implementation. This empirical model, derived from controlled flume experiments, is particularly effective for simulating bed load and suspended sediment transport in non-cohesive alluvial channels, especially under variable flow conditions typical of tropical catchments. The Ackers-White formulation accounts for key sediment transport drivers, including flow velocity, hydraulic radius, median sediment particle size (D_{50}), and sediment specific gravity. These parameters enable a detailed characterization of sediment behavior across different flow regimes, whether steady baseflows or unsteady storm-driven discharges.

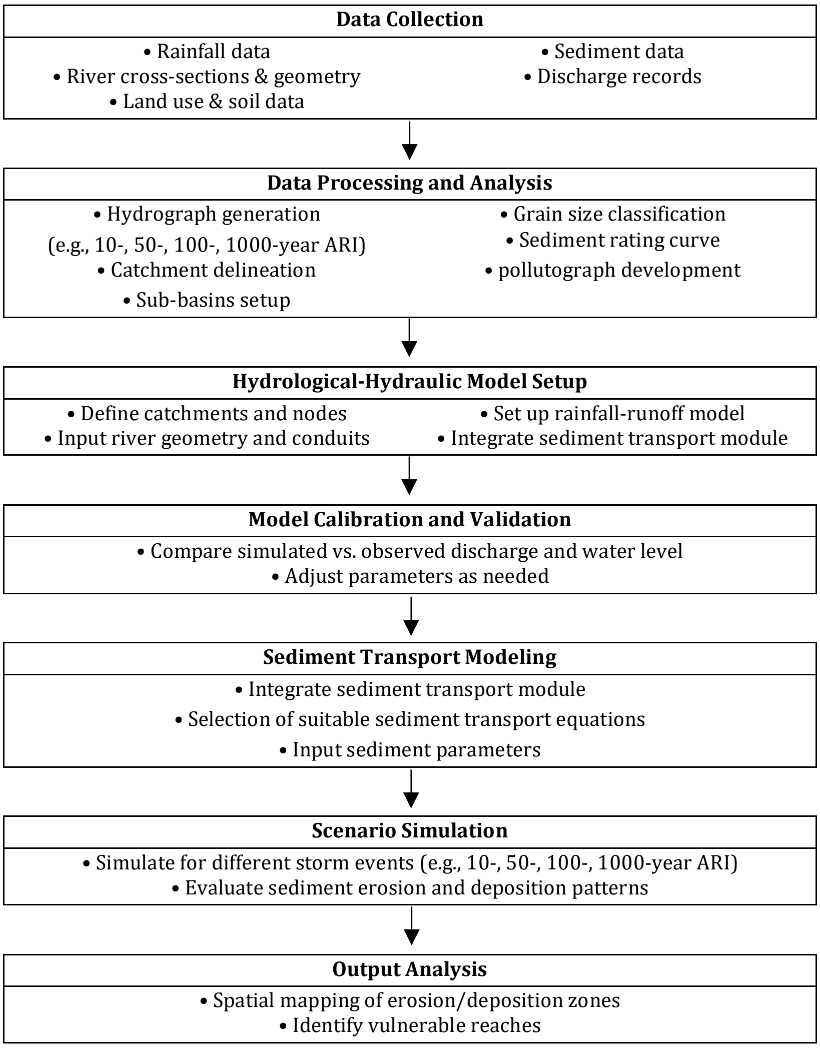


Fig. 3 *Overview of the methodology flowchart*

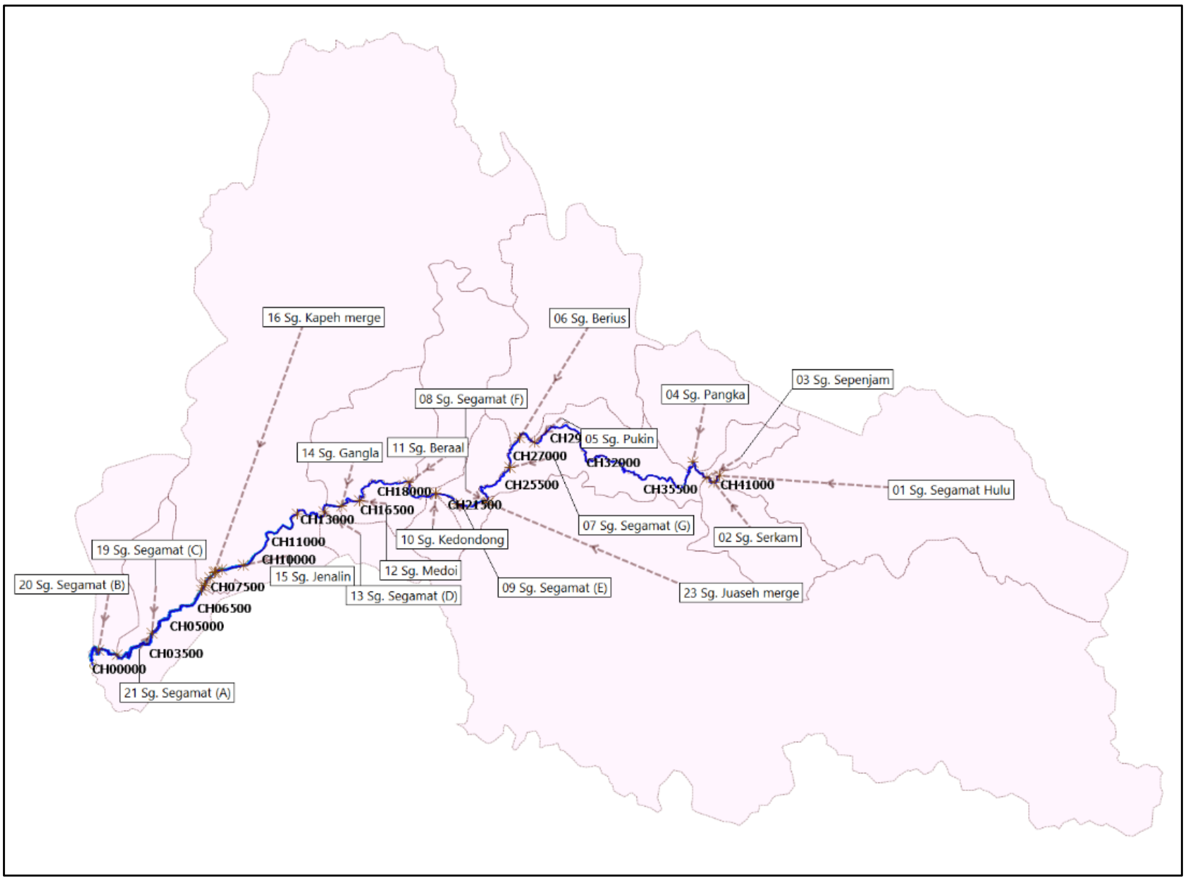


Fig. 4 *River network layout of the ICM sediment transport model. The arrows indicate inlet flows from contributing sub-catchments into the main river system*

To enhance the physical realism of sediment simulations, the InfoWorks ICM platform incorporates a layered sediment structure consisting of a passive layer and an active layer. The passive layer represents immobile channel-bed material that influences channel conveyance but remains unaffected by transport processes during the simulation. In contrast, the active layer comprises mobile sediment subject to erosion, deposition, and entrainment, governed by hydraulic conditions and sediment properties. The active layer can be further divided into two sediment fractions, allowing flexibility in representing mixed-grain sediments. This dual-layer configuration allows for a more accurate simulation of channel evolution, bed degradation, and localized aggradation, particularly in areas influenced by changing land use or hydraulic structures. By integrating this sediment transport framework into the calibrated hydrological-hydraulic model, the study provides valuable insights into sediment dynamics along the Segamat River and supports evidence-based planning for river maintenance, sediment control infrastructure, and long-term basin management.

3. Results and Discussion

3.1 Sediment Analysis

The sediment analysis was performed over a range of sediment depositions, which have been measured along the river reach by using flood events of 10-, 50-, 100- and 1000-year ARIs with the simulation of 12 hours critical storm duration. The average sediment depth was measured after the flood events (Fig. 5 to 8). In this study, the simulation results traced deposition that occurred throughout the Segamat river reach, where the sediment transport model predicts more sediment deposition at the middle reach of Segamat River, i.e. CH 8500 to CH 27500. Fig. 9 summarises possible sediment deposition for various storm ARI of the overall river reaches.

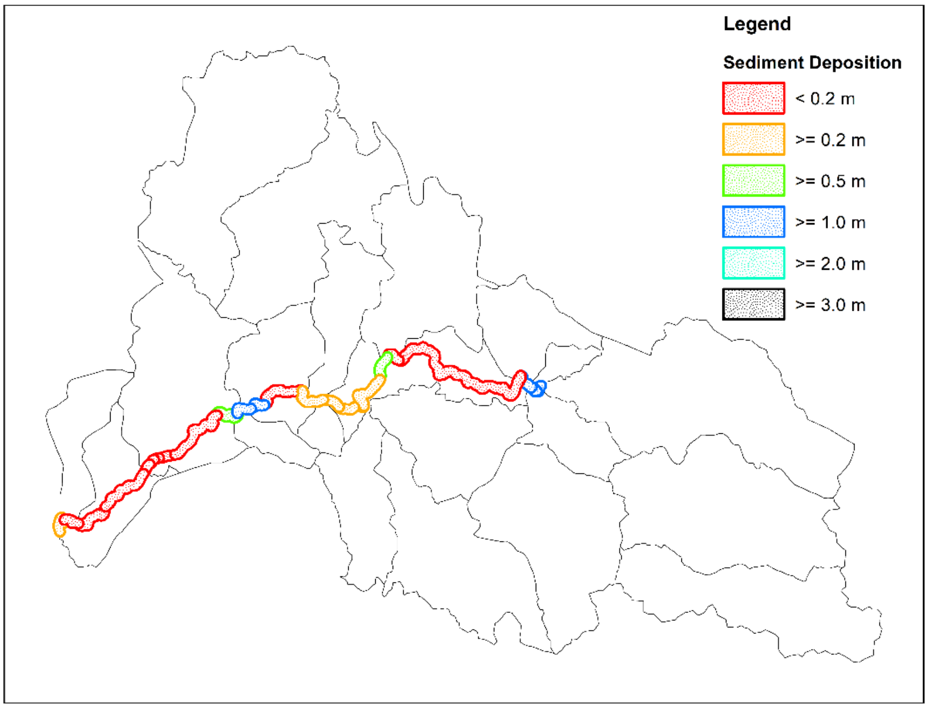


Fig. 5 *River reach with possible sediment deposition after 10-Year ARI storm*

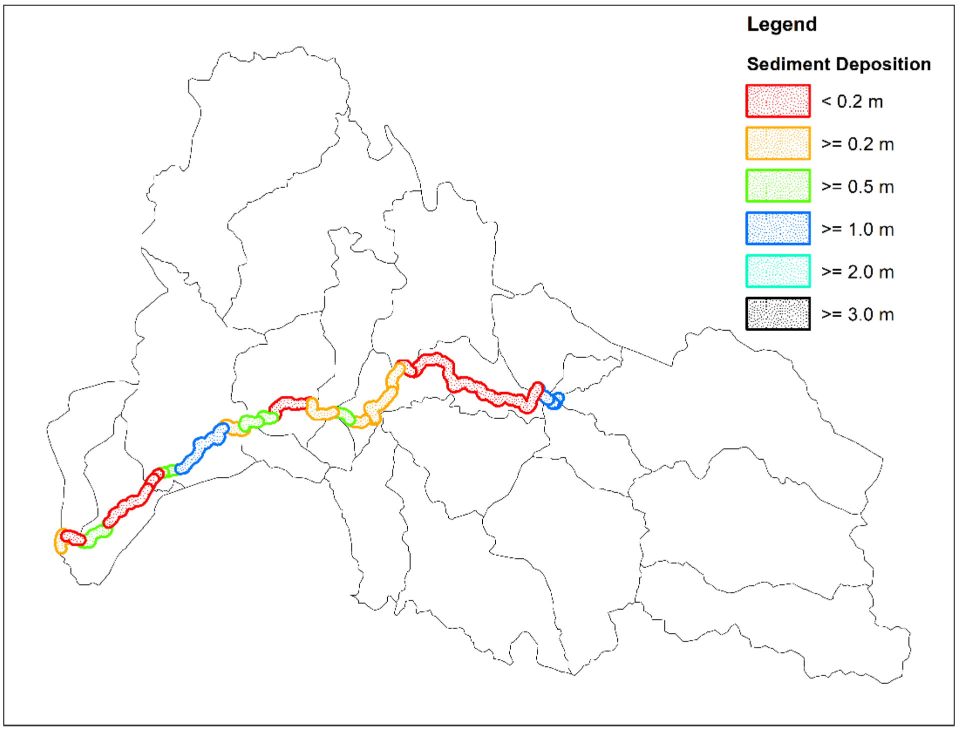


Fig. 6 *River reach with possible sediment deposition after 50-Year ARI storm*

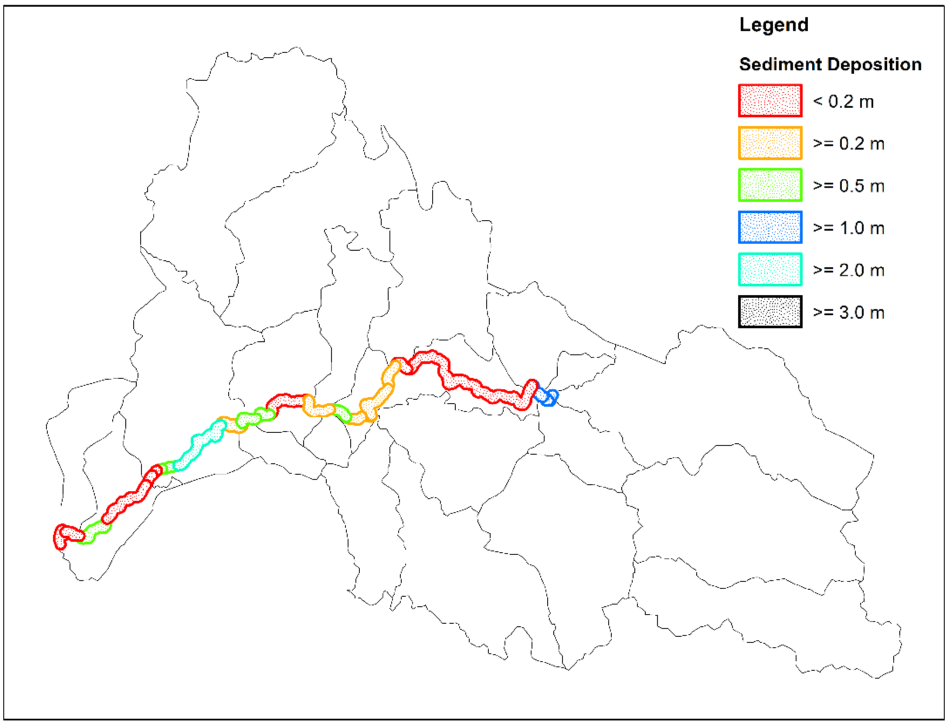


Fig. 7 *River reach with possible sediment deposition after 100-Year ARI storm*

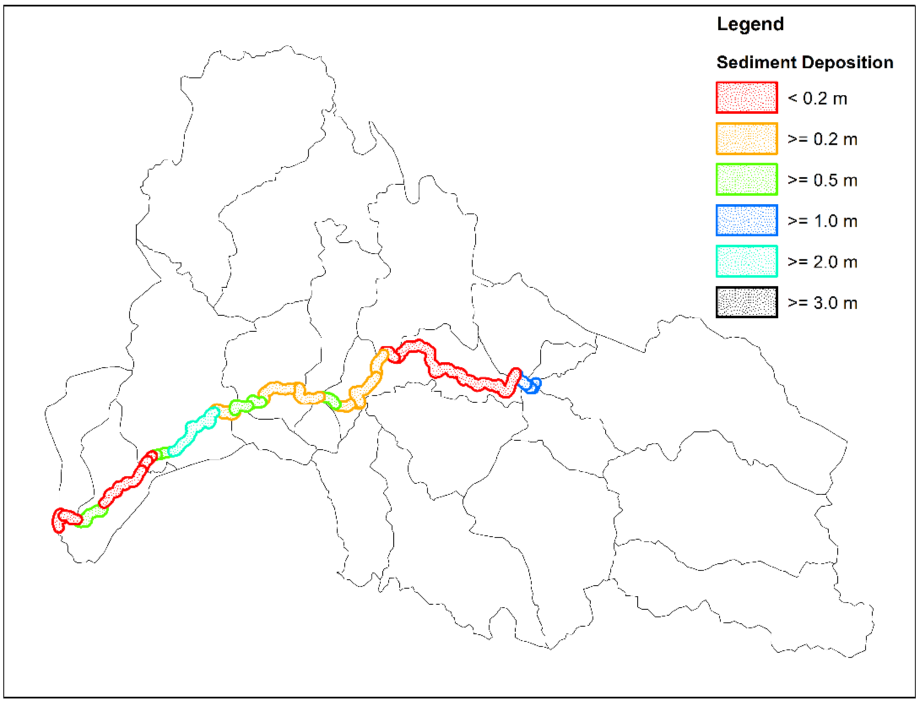
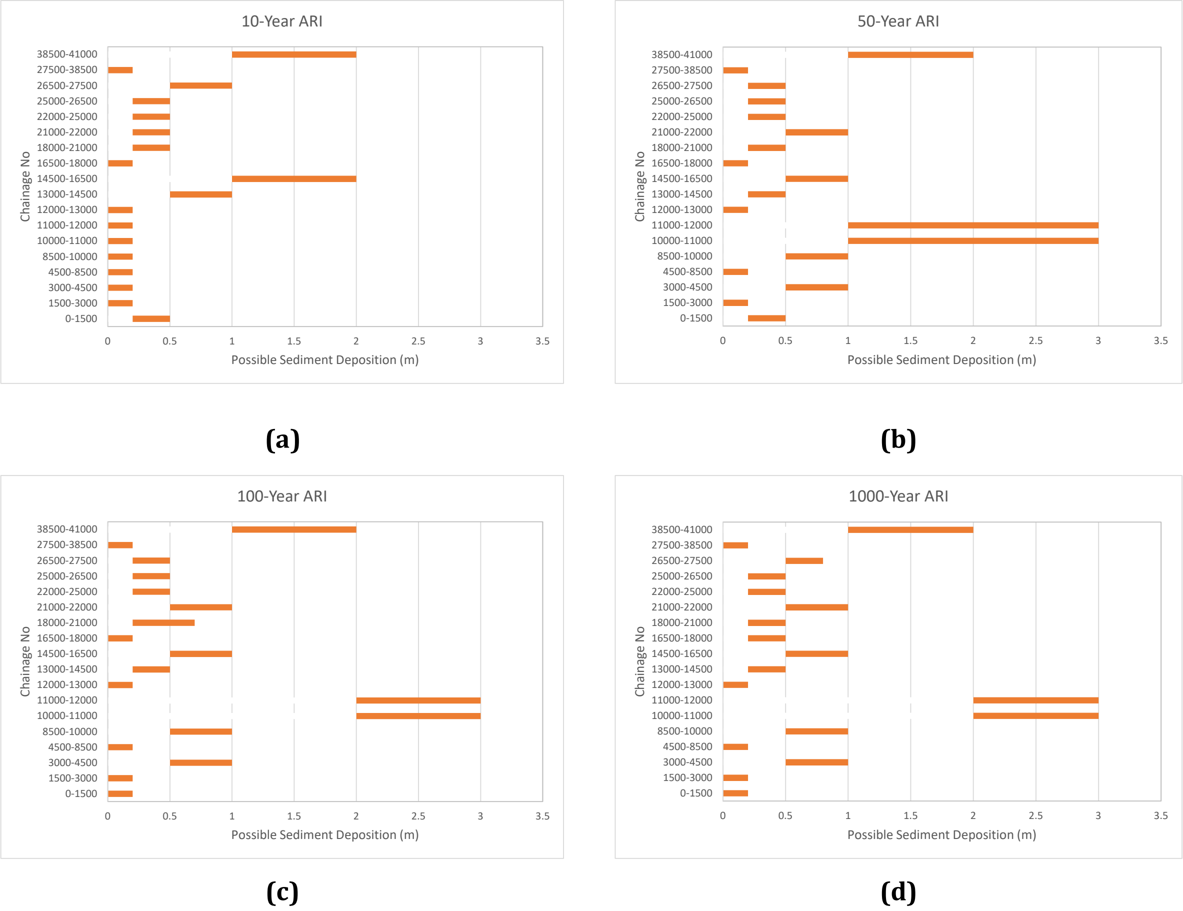


Fig. 8 *River reach with possible sediment deposition after 1000-Year ARI storm*



(a) **(b)**

(c) **(d)**

Fig. 9 *River reach with possible sediment deposition for (a)10-Year ARI; (b) 50-Year ARI; (c) 100-Year ARI; (d) 1000-Year ARI*

3.2 Action Plan

Hence, it is recommended to developing an action plan in guiding the policy makers and stakeholders, especially in sand dredging or sand extraction activities shall be well planned and maintained via systematic approach involving Erosion and Sedimentation Control Plan (ESCP) as one of the Best Management Practices (BMPs) for Segamat River. There are three (3) main strategy measures suggested as follow:

(a) Measure 1– River Improvement and Maintenance Works
River improvement and maintenance works are needed to ensure that the hydraulic capacity is always at its optimum condition. Regulating river bed is needed in Segamat River to avoid over dredging or over deposition of sediment. River bed survey is suggested to be carried out every six (6) months to assess the changes in the river bed for over deposition and scouring and river dredging has to be decided based on the latest river bed survey. Preventive measures such as sediment transport model for every river which determine the annual sand production of the river within the basin should be developed.

(b) Measure 2 – Awareness on Erosion and Sedimentation issues through Participation of Stakeholders
In minimizing river erosion and sedimentation, participation of stakeholders is crucial and important. It can be done through multi-faceted dialogues, talk and campaigns with sand mining operators, plantation owners, farmer associations pertaining to measures in managing issues of sand mining, erosion and sedimentation. Development of materials in the form of illustrations such as flyers, posters and others also can be distributed to the community to raise awareness on these issues.

(c) Measure 3– Improve Monitoring and Enforcement of Pollution Controls
The 1st Edition of Urban Stormwater Management Manual for Malaysia (MSMA) published by the Department of Irrigation and Drainage Malaysia (DID) in 2000 and the 2nd edition revised in 2012 provided detailed erosion and sediment control guideline to manage erosion and sedimentation on-site to prevent further damage to the nation's

water bodies [17], [18]. In addition, DID has enhanced the Erosion and Sediment Control Plan (ESCP) Chapter in MSMA 1st edition with new guideline for comprehensive ESCP in managing and controlling erosion and sediment processes in construction and development sites in 2009 [19].

Improve regulatory framework for smaller development projects are required to prepare and implement the ESCP for the State Authorities in ensuring that development Standard of Procedure (SOP) is adhered without prejudice by the developers or land users. DID, Department of Environment (DoE) and Segamat District Council should be responsible for tightening the requirement in approving new development based on these suggestions. In addition, it is timed that ESCPs be made as a permanent and compulsory requirement for all land conversion from forest to plantations and mining activities, as this is the critical stage when meter of precious topsoil is lost which exposed without protection to heavy rains.

In relation to sand mining activities, it is imperative that all operators adhere strictly to the recommendations outlined in the report study by the Department of Irrigation and Drainage (DID) Malaysia [4]. The guidelines emphasize that sand extraction should be prioritized in river stretches that exhibit significant sedimentation, as this helps mitigate sediment build-up and restore channel capacity. Extraction is recommended only from the central one-third portion of the river channel. Furthermore, mining activities must not be conducted within 500 meters of critical hydraulic infrastructure such as pumping stations and water intakes, or within 200 meters of smaller structures including bridges and buildings, unless explicit permission has been granted by DID. Sand and gravel extraction is strictly prohibited in locations where erosion is occurring or anticipated, particularly at concave riverbanks. The permissible depth of material removal from the riverbed should also take into account the river’s width and its natural sediment replenishment rate.

4. Conclusion

River morphological analysis is essential in helping to examine the processes of erosion and deposition in equilibrium of river morphology. Current study clearly indicated a prevalent deposition pattern along the entire length of the Segamat River. Specifically, the sediment transport model highlighted a higher tendency for sediment deposition within the middle reach of the river, specifically between CH 8500 and CH 27500. The observed trend indicated a general decline in sediment transport capacity as the flow rate and slope gradient decreased. This reduction in sediment transport capacity was particularly evident at CH 8500, where the slope gradient transitioned from steep at the hill slope to a flatter gradient downstream. As a consequence, the model predicted a higher occurrence of sedimentation when the slope gradient decreased at this specific location.

Consequently, it is recommended to developing an action plan in guiding the policy makers and stakeholders, especially sand dredging or sand extraction activities shall be well planned and maintained via systematic approach, involving Erosion and Sedimentation Control Plan (ESCP) as one of the Best Management Practices (BMPs) for Segamat River.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Yuk San Liew and Safari Mat Desa;* ***data collection:*** *Mou Leong Tan and Chun Kiat Chang;* ***analysis and interpretation of results:*** *Yuk San Liew, Safari Mat Desa, Mou Leong Tan and Chun Kiat Chang;* ***draft manuscript preparation:*** *Yuk San Liew and Chun Kiat Chang. All authors reviewed the results and approved the final version of the manuscript.*

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