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MODELING OF SEDIMENT TRANSPORT IN MAE TAO CREEK, TAK PROVINCE, THAILAND
โมเดลการเคลื่อนที่ของตะกอนท้องน้ำในห้วยแม่ตาว จังหวัดตาก ประเทศไทย

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Abstract

This research focused on the bed sediment transport during wet season in Mae Tao Creek, Mae Sot district, Tak Province. Sediment was the main source of cadmium transport in Mae Tao Creek. MIKE 11 was used to model the channel flow and bed sediment transport. The model was run in hydrodynamic (HD) and sediment transport module (ST). Time series of water depth from May to October were used to calibrate the hydrodynamics of the creek. The reliability of hydrodynamic results was evaluated based on the correlation coefficient (CC) and Root Mean Square Error (RMSE). The CC and RMSE obtained during this study were 0.85 and 0.06 respectively. The hydrodynamic results were input into the ST module to obtain the rate of bed sediment transport. The results showed that at the downstream part of the creek, the accumulated bed sediment transport during wet season was equal to 13.32×10^4 kg.

Keywords: bed sediment, MIKE 11, Mae Tao Creek

บทคัดย่อ

งานวิจัยนี้เป็นการศึกษาการเคลื่อนที่ของตะกอนท้องน้ำที่เกิดขึ้นในช่วงฤดูฝนในห้วยแม่ตาว อำเภอแม่สอด จังหวัดตาก ตะกอนท้องน้ำเป็นตัวการสำคัญในการเคลื่อนที่ของแคดเมียมที่ปนเปื้อนในห้วยแม่ตาว แบบจำลอง MIKE 11 นำมาใช้เพื่อจำลองการไหลในลำน้ำและการเคลื่อนที่ของตะกอนท้องน้ำ แบบจำลองนี้คำนวณโดยใช้โปรแกรมทางอุทกศาสตร์และโปรแกรมการเคลื่อนที่ของตะกอน ระดับน้ำที่บันทึกรายวันในช่วง

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เดือนพฤษภาคมถึงตุลาคมถูกใช้ในการปรับเทียบชลศาสตร์ของลำห้วย ความน่าเชื่อถือของผลจากแบบจำลองการไหลถูกประเมินโดยใช้ค่าสัมประสิทธิ์สหสัมพันธ์ (the correlation coefficient) และรากที่สองของความคลาดเคลื่อนเฉลี่ยกำลังสอง (Root Mean Square Error) จากการคำนวณค่าทั้งสองมีค่าเท่ากับ 0.85 และ 0.06 ตามลำดับ ผลที่ได้จากโปรแกรมชลศาสตร์ถูกใช้เป็นข้อมูลสำหรับโปรแกรมการเคลื่อนที่ของตะกอนเพื่อหาอัตราการเคลื่อนที่ของตะกอนท้องน้ำ ผลการศึกษาพบว่าที่ขอบเขตล่างของลำห้วยนั้น การเคลื่อนที่ของตะกอนท้องน้ำโดยรวมที่เกิดขึ้นในช่วงฤดูฝนมีค่าเท่ากับ 13.32×10^4 กก.

คำสำคัญ: ตะกอนท้องน้ำ, MIKE 11, ห้วยแม่ตาว

Introduction

Sediment plays a significant role in the transportation of heavy metal pollutants through the river system. It can be used to assess the metal contamination in natural waters. This is because the sediment accumulate more heavy metals than the water. Sediment itself acts as a transporter and a possible source of pollution because heavy metals are not permanently fixed in the sediment. Sediment allows the metals to be released back into the water body whenever water chemical properties have changed, such as salinity, redox conditions, pH and organic chelators [(1)].

In Thailand, Mae Sot district was reported as the biggest source of zinc ore and many mining activities were performed by several companies[(2)]. Cadmium usually occurs in association with zinc ore and is released as by-product of zinc mining[(3)]. Mae Tao Creek was selected as the study area to demonstrate the bed sediment transport during wet season. The Mae Tao Creek is approximately 25 km long. It directly receives overland flow from the zinc deposit. The creek moves westward and supplies the Mae Moei River[(4)].

In addressing the transport of bed sediment, the channel flow of Mae Tao Creek was modeled by MIKE 11. MIKE 11 is also capable to simulate the processes of bed sediment transport, which is expected to be the main mechanism of cadmium transport in the area. The main objective of the study is to demonstrate the bed sediment transport during wet season in Mae Tao Creek, Mae Sot district, Tak province.

Materials and Methods

Ten observing stations presented in Figure 1, were selected along the creek. Station 1 was located at the downstream. Station 3 received converged water from Station 4, which was located downstream from the second mine (abandoned mine), and Station 5, which received water from Mae Tao Left. Station 6 was located between two zinc mines. Station 7 was located before entering zinc deposit area. Station 8 received water from Stations 9 -

10. Stations 9 - 10 represented Mae Tao Right and upstream of the main Mae Tao Creek.

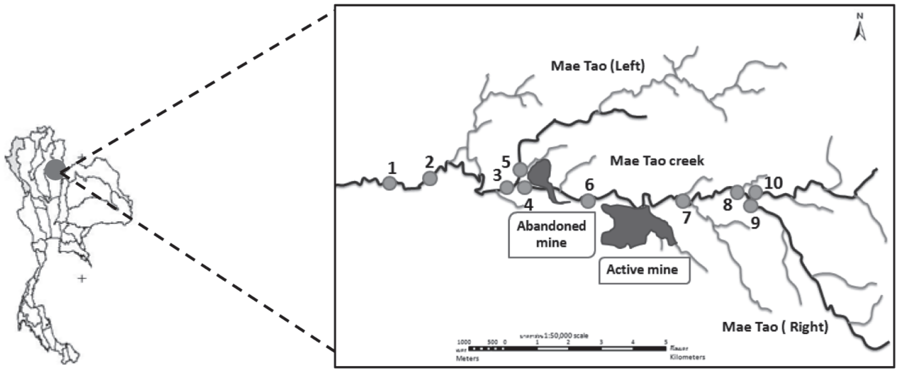

Figure 1 The ten stations along Mae Tao Creek and the two zinc mines.

Field obsevations were performed in October 2010 during wet season. At each station, approximately 1 kg of bed load sediment was sampled for determining the particle size distribution by sieve analysis following the Unified Soil Classification (USCS) method (ASTM D2487) [(5),(6)]. The geometry of cross-sections was obtained from field-surveyed. Moreover, water depth was daily recorded at two stations. Station 4 represented water that passed through the zinc mines, while Station 1 represented water at the downstream. The daily meteorological data were collected from the Thai Meteorological Department (TMD).

MIKE 11 performs one-dimensional dynamic modeling. MIKE 11 sloved the Saint Venant equations (using kinematic, diffusive or fully dynamic, vertically integrated mass and momentum equations), which can be computed numerically between all grid points at specific time intervals for a given boundary condition[(7)]. The hydrodynamic module (HD), which is the core of MIKE 11, employs an implicit, finite difference computation of unsteady flows in rivers. While the sediment transport module (ST) is utilized for simulate sediment transport within the creek by inputting the hydrodynamic results[(8)].

The bed sediment transport presented by the Meyer-Peter & Müller model[(9)], relates the transport rate to the dimensionless shear stress acting on the grains. The rate of bed sediment transport was implied by the total sediment transport rate ($S \approx Q_b$)[(10),(11)].

$$\frac{\partial S}{\partial x} + (1-\varepsilon) w \cdot \frac{\partial z}{\partial t} = 0 \qquad (1)$$

$$Q_b = q_b w \qquad (2)$$

$$q_b = \Phi_b \sqrt{(s-1) g d^3} \qquad (3)$$

$$\Phi_b = 8(\theta_{eff} - 0.047)^{1,5}; \text{ when } \theta_{eff} > 0.047 \qquad (4a)$$

$$\Phi_b = 0; \text{ when } \theta_{eff} \le 0.047 \qquad (4b)$$

$$\theta_{eff} = \frac{u_{eff}^{\ 2}}{(s-1) g d} \qquad (5)$$

$$u_{eff} = u'_f \left(\frac{n_b}{n} \right)^{0,75} \qquad (6)$$

$$n_b = 0.0192 \left(d_{90}^{\frac{1}{6}} \right) \qquad (7)$$

Where S is sediment transport rate (m^3/s); t, time (s); w, channel width (m); x, longitudinal co-ordinate (m); z, bed level (m); ε, sediment porosity; Q_b, bed load transport rate (m^3/s); d, diameter of the grain (m) ; q_b, absolute bed load transport per unit river width (m^3/s) ;φ_b, dimensionless bed load transports; s, relative density of sediment; g, acceleration due to gravity (m^3/s); u'_f, friction velocity (m/s); n, resistance number ($m^{1/6}$);d_{90}, diameter of which 90% were finer (m).

Results and discussion

Hydrodynamic simulation results

The simulated results as shown below were from May 1 to October 31, 2010. Precipitation and evaporation rates are presented in Figures 2a and 2b.

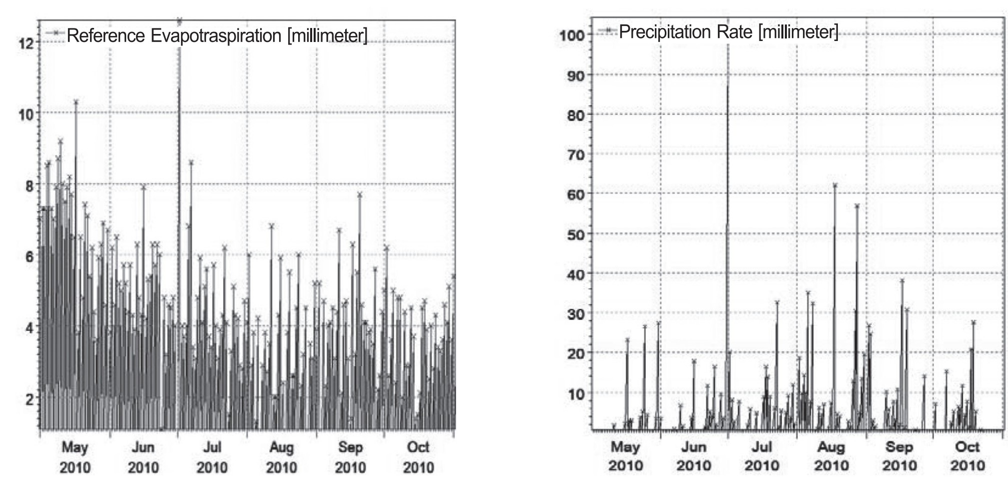

Figure 2 (a) Rainfall rate during simulation time (mm/d), (b) Evaporation rate during simulation time(mm/d)

Most precipitation in Mae Tao basin occurred from May to October. During the simulated time, the average daily precipitation was 6.2 mm, and the maximum was 104.8 mm on 1st July. The average daily evaporation was 4.7 mm, and the maximum was 12.6 mm on 2nd July. Daily time series of the water depth at Station 1 were used as downstream boundary condition, while another depth data at Station 4 were used for model calibration.

Comparison between the observed and predicted water depth at Station 4 is presented in Figure 3. The good calibration between observed and simulated water depth was confirmed, as represented by correlation coefficient (CC) of determination was 0.85. The modeling errors were low: the Root Mean Square Errors (RMSE) value obtained during this study was 0.06. The calibration results showed good agreement, except the model slightly underestimated.

The underestimation may be caused by the existing weirs in the study area which was not included in the model. Moreover, the characteristic of each part of the creek were different due to bed material composition, anthropogenic water used and water structure, while, in the calibration, all parameters were assumed to be uniform along the creek. The time series at downstream of discharge and water velocity, are displayed in Figures 4a and 4b.

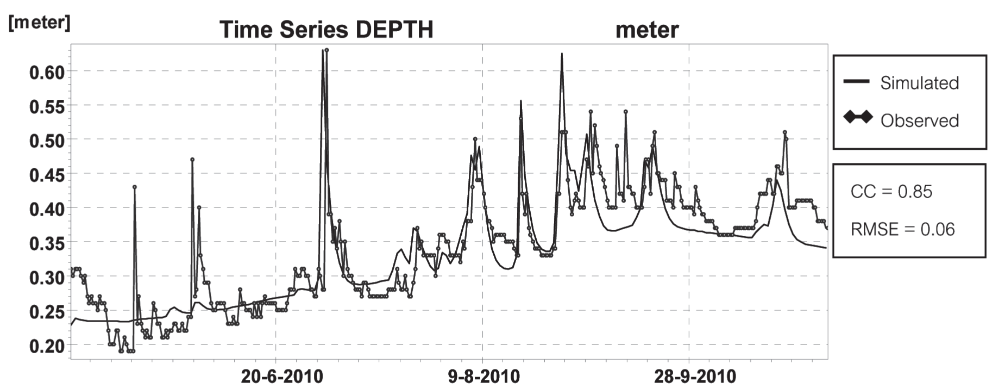

Figure 3 Observed and simulated water depths at Station 4 (m)

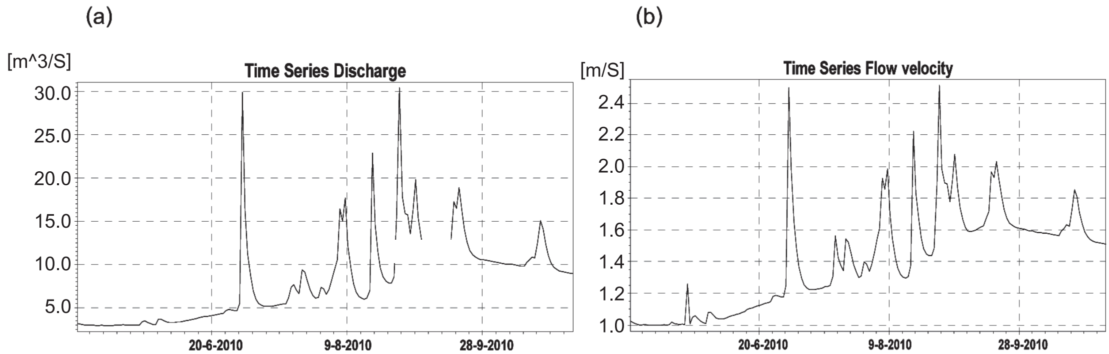

Figure 4 (a) Discharge of downstream (m^3/s), (b) Flow velocity downstream (m/s)

Sediment transport results

After simulating the water discharge along Mae Tao Creek, the hydrodynamic results were applied in the ST module for computing time series results including sediment transport, as displayed in Figure 5. Size distribution of the bed surface material at all stations shown that Mae Tao Creek was substantially covered with sand. Therefore, the Meyer-Peter & Müller model, one of the world's most widely used bedload transport equations, was selected to present the bed sediment transport.

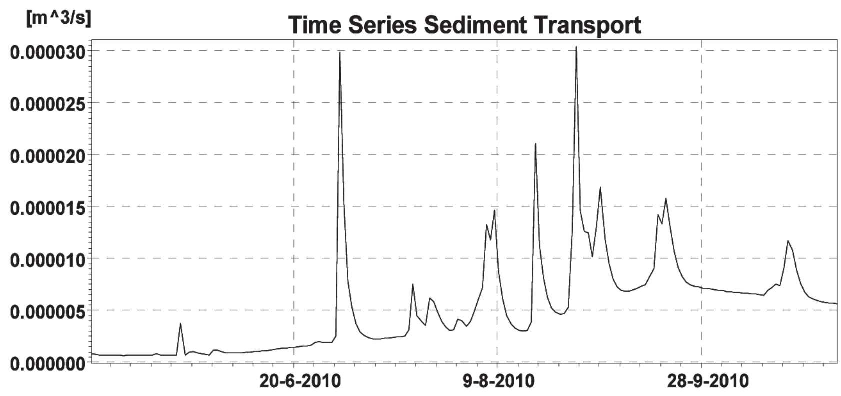

Figure 5 The rate of bed load transport at downstream (m^3/s)

Figure 5 shows the rate of bed load transport at downstream stations increased with flow discharge. The transport rate increased from 1.28×10^{-5} to 3.03×10^{-5} m^3/s with increase in discharge from 15.69 to 30.39 m^3 /s. The highest bedload transport rate was occurred during August.

At the downstream of the Mae Tao Creek, the accumulated bed sediment transport during wet season was equal to 13.32×10^4 kg. The later value was computed from the following: 83.15 m^3 of accumulated sediment transport and a density of dry sediment assumed to be 1602 kg/m^3. From Figure 4 should be mentioned that the modeled high values of bed sediment transport were due to high discharge of the creek, which occurred after storm periods.

Conclusion

The hydrodynamics and bed sediment transport during wet season of Mae Tao Creek, Mae Sot district have been studied using a1-D MIKE 11 model. First, the HD model was calibrated by comparing simulated water depth and observed depth. The agreement between field measurement and computed values were represented by CC (0.85) and RMSE (0.06). Nevertheless, the simulated results were not matched completely. This is because the data sources were inaccurate or incomplete. Finally, the rate of bed sediment transport was estimated by ST module. The accumulated bed sediment transport during wet season at the downstream part of the creek was equal to 13.32×10^4 kg of which, the peaks of bed sediment transport occurred after the heavy storms period.

Acknowledgment

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