

PHOSPHORUS AND CADMIUM TRANSPORT VIA SURFACE RUNOFF IN SONGKHLA LAKE  
CATCHMENT USING ANNAGNPS AND TREX MODELS

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การจำลองการเคลื่อนย้ายของฟอสฟอรัสและแคดเมียมโดยน้ำผิวดินในกลุ่มน้ำทะเลสาบสงขลา  
โดยแบบจำลอง AnnAGNPS และ แบบจำลอง TREX



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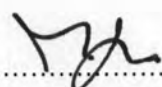
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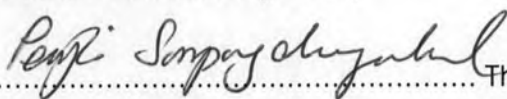
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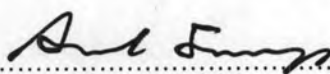
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นายกิติบัญญัติ กิจบำรุง : การจำลองการเคลื่อนย้ายของฟอสฟอรัสและแคดเมียมโดยน้ำผิวดินในลุ่มน้ำทะเลสาบสงขลาโดยแบบจำลอง AnnAGNPS และแบบจำลอง TREX (PHOSPHORUS AND CADMIUM TRANSPORT VIA SURFACE RUNOFF IN SONGKHLA LAKE CATCHMENT USING ANNAGNPS AND TREX MODELS) อ.ที่ปรึกษา: ผ.ศ. เพ็ญใจ สมพงษ์ชัยกุล, ดร. อ.ที่ปรึกษาร่วม: Prof. G. Padmanabhan, Ph.D. 182 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อจำลองการเคลื่อนย้ายของฟอสฟอรัสและแคดเมียมในลุ่มน้ำทะเลสาบสงขลาโดยน้ำผิวดิน ทะเลสาบสงขลาตั้งอยู่ทางภาคใต้ของประเทศไทย ครอบคลุมพื้นที่ 1,042 ตารางกิโลเมตร รองรับน้ำจากพื้นที่รับน้ำทั้งสิ้น 7,687 ตารางกิโลเมตร เนื่องจากเศรษฐกิจของลุ่มน้ำขึ้นอยู่กับเกษตรกรรมเป็นหลัก ปัญหามลพิษประเภทไม่สามารถระบุแหล่งกำเนิดได้จึงเป็นปัญหาที่มีความสำคัญ การไหลหลากของน้ำผิวดินเป็นกลไกหลักในการเคลื่อนย้ายมลพิษประเภทไม่สามารถระบุแหล่งกำเนิดได้ การจำลองการเคลื่อนย้ายมลพิษประเภทนี้จึงนิยมใช้แบบจำลองการกระจายเชิงพื้นที่ การศึกษาครั้งนี้ใช้ Substance Flux Analysis (SFA) ประมาณการปริมาณฟอสฟอรัสและแคดเมียมจากพื้นที่ลุ่มน้ำที่เข้าสู่ทะเลสาบและจำลองการเคลื่อนย้ายของฟอสฟอรัสและแคดเมียมโดยน้ำผิวดินด้วยแบบจำลอง AnnAGNPS และแบบจำลอง TREX โดยแบ่งพื้นที่ลุ่มน้ำออกเป็น 8 ลุ่มน้ำย่อย ตามผลการวิเคราะห์สภาพพื้นที่ด้วยเทคนิค delineation ในการสร้างแบบจำลอง ทำการปรับเทียบและตรวจสอบแยกกันในแต่ละลุ่มน้ำย่อย พารามิเตอร์ที่ใช้ในการปรับเทียบ ได้แก่ hydraulic conductivity, soil erodibility, flow resistance, crop management factor และ chemical distribution coefficient ผลจากแบบจำลองพบว่า 1 ใน 3 (34%) ของฟอสฟอรัสและแคดเมียม มาจากลุ่มน้ำย่อยอยู่ตะกาศและลุ่มน้ำย่อยฝั่งตะวันออก 4 และมาจากลุ่มน้ำย่อยคลองปาพะยอม-ท่าแนะและลุ่มน้ำย่อยพรุห่อ-รัตนภูมิ ลุ่มน้ำละประมาณ 15% จากการจำลองสถานการณ์ทั้งสิ้น 3 สถานการณ์ คือ ปรับเปลี่ยนปริมาณการใช้ปุ๋ย, ปรับเปลี่ยนสูตรปุ๋ยที่ใช้ และปรับเปลี่ยนชนิดพืชที่ปลูก ผลการจำลองโดยใช้พื้นที่ลุ่มน้ำย่อยอยู่ตะกาศและลุ่มน้ำย่อยฝั่งตะวันออก 4 ซึ่งเป็นลุ่มน้ำย่อยให้ฟอสฟอรัสและแคดเมียมมากที่สุด พบว่าเมื่อปรับเปลี่ยนสูตรปุ๋ยที่ใช้จากปุ๋ยสูตรที่มีแคดเมียมสูง (3 mg-Cd/kg) ไปเป็นสูตรที่มีแคดเมียมต่ำ (1 mg-Cd/kg) ทำให้แคดเมียมที่เคลื่อนย้ายเข้าสู่ทะเลสาบลดลงถึง 5 เท่า ผลการจำลองแสดงให้เห็นว่าการปรับเปลี่ยนสูตรปุ๋ยฟอสเฟตเป็นวิธีการลดปริมาณแคดเมียมที่เข้าสู่ทะเลสาบอย่างมีประสิทธิภาพ ให้ผู้ที่มีอำนาจตัดสินใจ และ/หรือ นักวางแผน ควรใช้ข้อมูลนี้ประกอบการพิจารณาในการวางแผนและการส่งเสริมการเกษตร

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KEY WORD: NON-POINT SOURCE POLLUTION/SONGKHLA LAKE BASIN/SUBSTANCE FLUX ANALYSIS / PHOSPHORUS CONTAMINATION /CADMIUM CONTAMINATION

KITIPAN KITBAMROONG: PHOSPHORUS AND CADMIUM TRANSPORT VIA SURFACE RUNOFF IN SONGKHLA LAKE CATCHMENT USING ANNAGNPS AND TREX MODELS THESIS ADVISOR : ASST. PROF. PENJAI SOMPONGCHAIYAKUL, PH.D. THESIS COADVISOR: PROF. G. PADMANABHAN, PH.D. 182 PP.

The objective of this research is to model transport of phosphorus and cadmium via surface runoff from its catchments to Songkhla Lake. The lake is located in southern Thailand covering an area of 1,042 km<sup>2</sup> with a drainage area of 7,687 km<sup>2</sup>. As economy in the area based on agriculture, non-point source pollution loading from the surrounding drainage area to the lake is of great concern. Surface runoff is considered as a major mechanism to transport non-point source pollutants. To model non-point source pollution transport via surface runoff, spatially distributed parameter models are commonly used. In this study, Substance Flux Analysis (SFA) was used as a tool to obtain better estimates of potential phosphorus and cadmium loadings from the catchment. AnnAGNPS and TREX models were used to simulate the transport of phosphorus and cadmium from the drainage area to the lake. The catchment was divided into 8 sub-watershed based on delineation results and individually modeled, calibrated and validated. The selected parameters for calibration include hydraulic conductivity, soil erodibility, flow resistance, crop management factor and chemical distribution coefficient. The results obtained from validation process reveal the relative loadings of phosphorus and cadmium from different parts of the watershed. Almost one third of the phosphorous and cadmium were contributed from U-Tapao and Eastern Coast #4 sub-watersheds (34%). Klong Pa Payom & Thanae and Phru Poh & Rattaphum sub-watersheds contributed at approximately 15% each. Three scenarios, comprises of change of fertilizer application rate, change of fertilizer type, and change of crop types, were conducted in the most contributed sub-watershed, U-Tapao and Eastern Coast #4. The scenarios demonstrated the changing of fertilizer type from high cadmium type (3 mg-Cd/kg) to low cadmium type (1 mg-Cd/kg) leads to 5 times declining of cadmium load to the lake. This information suggests an effective approach to minimize cadmium loadings by changing of phosphate fertilizer type. Decision makers and/or planners should take this information into account when making a consideration for crops planning or agricultural extension.

Field of study Environmental Management

Academic year 2007

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### List of Symbols

$a$	experimentally determined constant for flocculation
$A_c$	cross sectional area of flow [ $L^2$ ]
$A_s$	surface area [ $L^2$ ]
$B_e$	width of eroding surface in flow direction [L]
$B_x, B_y$	flow width in the x- or y-direction [L]
$\hat{C}$	USLE soil cover factor [dimensionless]
$C_c, C_{c1}$	total chemical concentration in the water column [ $M/L^3$ ]
$C_{cb}, C_{c2}$	total chemical concentration in the soil or sediment bed [ $M/L^3$ ]
$C_s$	concentration of sediment particles in the water column [ $M/L^3$ ]
$C_{sb}$	concentration of sediment particles in the soil or sediment bed [ $M/L^3$ ]
$C_t$	concentration of entrained sediment particles at the transport capacity [ $M/L^3$ ]
$C_w$	concentration of entrained sediment particles by weight at the transport capacity [dimensionless]
$d_f$	median floc diameter ( $\mu m$ ) [L]
$d_p$	particle diameter [L]
$d^*$	dimensionless particle diameter [dimensionless]
$D$	diffusion coefficient [ $L^2/T$ ]
$D_e$	DOC-binding effectiveness coefficient [dimensionless]
$D \frac{\partial C_s}{\partial x}$	diffusive flux the x-direction [ $M/L^2T$ ]
$D \frac{\partial C_s}{\partial y}$	diffusive flux the y-direction [ $M/L^2T$ ]
$E$	evaporation rate [L/T]
$f$	infiltration rate [L/T]
$F$	cumulative (total) infiltrated water depth [L]
$f_b$	fraction of the total chemical in the bound phase [dimensionless]
$f_{bt}$	fraction of the total chemical in bound phase in the water column

	[dimensionless]
$f_d$	fraction of the total chemical in dissolved phase [dimensionless]
$f_{d1}$	fraction of the total chemical in dissolved phase in the water column [dimensionless]
$f_{m1}$	fraction of the total chemical in the mobile phase in the water column [dimensionless] = $f_{b1} + f_{d1}$
$foc_D$	fraction organic carbon of DOC [dimensionless]
$foc_n$	fraction organic carbon of particle “n” [dimensionless]
$fp_n$	fraction of the total chemical in the particulate phase associated with particle “n” [dimensionless]
$fp1_n$	fraction of the total chemical in particulate phase associated with particle “n” in the water column [dimensionless]
$fp2_n$	fraction of the total chemical in particulate phase associated with particle “n” in the sediment column [dimensionless]
$g$	gravitation acceleration [ $L/T^2$ ]
$G$	particle specific gravity [dimensionless]
$h$	surface water depth (flow depth of water column) [L]
$H_c$	capillary pressure (suction) head at the wetting front [L]
$H_w$	hydrostatic pressure head of water (depth of water in channel) [L]
$[H^+]$	hydronium ion concentration (activity)
$i_e$	excess precipitation rate [ $L/T$ ]
$i_g$	gross precipitation rate [ $L/T$ ]
$i_n$	net (effective) rainfall rate at the surface [ $L/T$ ]
$J_c$	sediment transport capacity areal flux [ $M/L^2T$ ]
$J_d$	deposition flux [ $M/L^2T$ ]
$J_{dc}$	chemical deposition flux [ $M/L^2T$ ]
$\hat{J}_d$	sediment deposition volumetric flux [ $M/L^3T$ ]
$J_e$	erosion flux [ $M/L^2T$ ]
$J_{ec}$	chemical erosion flux [ $M/L^2T$ ]

$\hat{J}_e$	sediment erosion volumetric flux [M/L <sup>3</sup> T]
$J_{ic}$	chemical infiltration flux [M/L <sup>2</sup> T]
$\hat{J}_n$	net sediment transport volumetric flux [M/L <sup>3</sup> T]
$J_{xc}, J_{yc}$	chemical advective flux in the x- or y-direction [M/L <sup>2</sup> T]
$\hat{K}$	USLE soil erodibility factor [dimensionless]
$K_d$	chemical distribution coefficient [L <sup>3</sup> /M]
$K_h$	effective hydraulic conductivity [L/T]
$K_p$	chemical partition coefficient [L <sup>3</sup> /M]
$K_{oc}$	Koc organic carbon normalized partition coefficient [L <sup>3</sup> /M]
$L_c$	length of channel in flow direction [L]
$m$	experimentally determined constant for flocculation
$m_n$	concentration of particle "n" [M/L <sup>3</sup> ]
$n$	Manning roughness coefficient [T/L <sup>1/3</sup> ]
$P$	probability integral for the Gaussian distribution
$P_c$	wetted perimeter of channel flow [L]
$\hat{P}$	USLE soil management practice factor [dimensionless]
$P_{dep}$	probability of deposition [dimensionless]
pH	-log[H <sup>+</sup> ]
$q$	unit flow rate of water = $v_a h$ [L <sup>2</sup> /T]
$Q$	total discharge [L <sup>3</sup> /T]
$q_c$	critical unit flow for erosion (for the aggregate soil matrix) [L <sup>2</sup> /T]
$q_l$	lateral unit flow from overland plane to channel (floodplain) [L <sup>2</sup> /T]
$q_s$	total sediment transport capacity (kg/m s) [M/LT]
$q_x, q_y$	unit discharge in the x- or y-direction = $Q_x / B_x, Q_y / B_y$ [L <sup>2</sup> /T]
$Q_x, Q_y$	flow in the x- or y-direction [L <sup>3</sup> /T]
$\hat{q}_x, \hat{q}_y$	total sediment transport areal flux in the x- or y-direction [M/L <sup>2</sup> T]
$R$	Retardation factor [dimensionless]

$R_h$	hydraulic radius of flow = $A_c / P$ [L]
$R_x, R_y$	dispersion (mixing) coefficient the x- or y-direction [ $L^2/T$ ]
$R_x \frac{\partial C_s}{\partial x}$	dispersive flux the x-direction [ $M/L^2T$ ]
$R_y \frac{\partial C_s}{\partial y}$	dispersive flux the y-direction [ $M/L^2T$ ]
$S_e$	effective soil saturation [dimensionless]
$S_f$	friction slope [dimensionless]
$S_{fx}, S_{fy}$	friction slope (energy grade line) in the x- or y-direction [dimensionless]
$S_i$	interception capacity of projected canopy per unit area [ $L^3/L^2$ ]
$S_0$	ground surface slope [dimensionless]
$S_{0x}, S_{0y}$	ground surface slope in the x- or y-direction [dimensionless]
$t$	time [T]
$T$	cumulative (total) depth of water transported by transmission loss [L]
$t_l$	transmission loss rate [L/T]
$t_R$	precipitation event duration [T]
$u^*$	shear velocity [L/T]
$v_a$	advective (flow) velocity (in the x- or y-direction) [L/T]
$v_c$	critical velocity for soil or sediment erosion [L/T]
$v_f$	flow velocity between overland plane and channel (floodplain) [L/T]
$v_g$	gross precipitation water volume [ $L^3$ ]
$v_i$	infiltration rate or transmission loss velocity of water [L/T]
$V_i$	interception volume [ $L^3$ ]
$V_n$	net precipitation volume reaching the surface [ $L^3$ ]
$v_r$	resuspension (erosion) velocity [L/T]
$v_s$	quiescent settling velocity [L/T]
$v_{se}$	effective settling (deposition) velocity [L/T]



$v_{sf}$	floc settling velocity (cm/s) [L/T]
$v_r$	resuspension (erosion) velocity [L/T]
$v_x, v_y$	advective (flow) velocity in the x- or y-direction [L/T]
$v_x C_s$	advective flux in the x-direction = $J_x$ [M/L <sup>2</sup> T]
$v_y C_s$	advective flux in the y-direction = $J_y$ [M/L <sup>2</sup> T]
$V_s$	volume of sediments [L <sup>3</sup> ]
$V_w$	volume of water [L <sup>3</sup> ]
$W$	unit discharge from/to a point source/sink [L <sup>2</sup> /T]
$\hat{W}_s$	sediment point source/sink volumetric flux [M/L <sup>3</sup> T]
$W_{w,s,c}$	material point source/sink: water [L <sup>3</sup> /T], solids, or chemical [M/T]
$z$	elevation of the soil surface or sediment bed [L]
$\alpha_x, \alpha_y$	resistance coefficient for flow in the x- or y-direction [L <sup>1/3</sup> /T]
$\beta$	resistance exponent = 5/3 (assuming Manning resistance) [dimensionless]
$\nu$	kinematic viscosity of water [L <sup>2</sup> /T]
$\nu_x$	particle interaction parameter [dimensionless]
$\omega_0$	settling velocity [L/T]
$\rho_b$	bulk density of soil or bed sediments [M/L <sup>3</sup> ]
$\tau_0$	bottom shear stress (M/LT <sup>2</sup> )
$\tau_{cd,c}$	critical shear stress for deposition of cohesive particles, defined as the shear stress at which 100% of the particles deposit (M/LT <sup>2</sup> )
$\tau_{cd,n}$	critical shear stress for deposition of non-cohesive particles, defined as the shear stress at which 50% of particles deposit (M/LT <sup>2</sup> )
$\phi$	total soil porosity [dimensionless]
$\theta_e$	effective soil or sediment porosity = $(\phi - \theta_r)$ [dimensionless]
$\theta_r$	residual soil or sediment moisture content [dimensionless]
$\sigma$	experimentally determined constant for deposition
$\pi_b$	equilibrium binding coefficient [L <sup>3</sup> /M]

$\pi_{p_n}$	equilibrium partition (distribution) coefficient for particle "n" [L <sup>3</sup> /M]
$\pi_{px_n}$	particle-dependent partition coefficient [L <sup>3</sup> /M]
$s _{t+dt}$	value of model state variable at time t+dt [L] or [M/L <sup>3</sup> ]
$s _t$	value of model state variable at time t [L] or [M/L <sup>3</sup> ]
$\frac{\partial s}{\partial t} _{t+dt}$	value of model state variable derivative at time t [L/T] or [M/L <sup>3</sup> T]