NITROGEN YIELD ESTIMATION USING GRID-BASED NUTRIENT YIELD MODEL

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KEY WORDS: Nitrogen, Grid-based, Nutrient yield model, AGNPS model.

ABSTRACT: This study employed grid-based model for estimation of nitrogen yield in the Upper Lam Phra Phloeng watershed, Thailand. Nitrogen yield portion exists in soluble form and sediment-attachment form. The algorithm used in AGNPS model is selected to simulate the nitrogen processes. The nutrient yield algorithm integrated with grid-based model was developed. Eight events were used for the model calibration with nitrogen yield data observed at two stations (M.171 and M.145). Other eights were for the model validation. The calibration was performed by adjusting nitrogen extraction coefficient. The calibration results showed that nitrogen yields in runoff and in sediment simulations were obtained with E = 0.82, R^2 = 0.91 and E = 0.90, R^2 = 0.93, respectively. The validation results showed that nitrogen yields in runoff simulation produced result with E = 0.63, R^2 = 0.89 and nitrogen yield in sediment produced result with E = 0.70 and R^2 = 0.93. This indicates that the calibrated grid-based nutrient yield model working under GIS can be applied to the nitrogen yield estimation with satisfactory accuracy.

1. INTRODUCTION

Rainfall-runoff event is a phenomenon that impacts nonpoint source (NPS) pollution on surface water quality. It produced both excessive runoff and sediment. Nutrient yield loss associated with rainfall-runoff events is due to surface flow, erosion, and leaching processes. Soluble nutrients are transported by surface flow. Nutrient adsorbed to sediment particles are transported by erosion. Nitrogen in this study is plants nutrient which is most frequently associated with water quality.

Data on nutrient yield with runoff and sediment are essential for accurate evaluating impact of NPS pollution, and for assessing the environmental impact including deterioration on surface water quality (Hussein et al., 1999). The *in situ* measurement of nitrogen yield loss is considered more accurate but cannot be operated anytime and anywhere as required. Therefore, the accurate nitrogen yield modeling developed can serve this purpose with more convenient and less time and budget consuming.

The objective of this study is to estimate nitrogen yield in both soluble and sediment-attached forms by using grid-based nutrient yield model in which heterogeneous watershed characteristics were considered. Finally, the output from the model was evaluated by comparing with observed nutrient yield.

2. MATERIALS AND METHODS

2.1 Study area

The 786.26 km^2 of Upper Lam Phra Phloeng watershed was selected for this study (Fig. 1). The topography of the area is characterized by generally hilly-rolling terrain, with less undulating and flat areas. Elevation ranges from 260 m above msl. in the northeastern part to about 1,307 m above msl. in the southwestern part of the watershed. This watershed is upstream area of the Lam Phra Phloeng reservoir. The climate is influenced by both the northeast and southwest monsoons, with an average annual rainfall of 1,117 mm. The soils in the area vary to be 15 soil series with different soil textures as clay, clay loam, loam, loamy sand, sandy clay loam, sandy loam, and silty clay. The land use of the watershed consists of dense and disturbed evergreen forests, dense and disturbed deciduous forests, forest plantation, field crops, and orchards. More than 41.52% of the watershed is classified as field crop area. The dominant crops are maize, sugarcane, and cassava. Amount of fertilizer usage tends to be increased considerably. The more the fertilizers are used, the higher the potential of surface water contamination is.

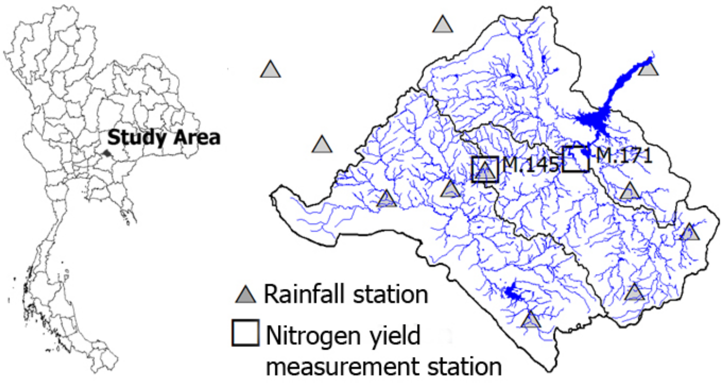


Figure 1 Location map of study area with rain stations and nutrient yield measurement stations.

2.2 Data collection

The Royal Irrigation Department (RID) provided rainfall data with 11 manual rain gauges, located within and near the watershed. Topographic maps of the Royal Thai Survey Department (RTSD) at the scale of 1:50,000 were used to generate Digital Elevation Model (DEM). Observed nitrogen yield data of the RID runoff station, M.145 with 335 km^2 drainage area at the upstream outlet and M.171 with 556 km^2 drainage area at the downstream outlet of the study area, are used for model evaluation. The soil properties, soil map, and land use data (updated to the year 2007) at scale 1:25,000 were obtained from Land Development Department (LDD). The fertilizer application rates were obtained from field investigation.

2.3 Nitrogen yield estimation method

The grid-based model selected to simulate the nitrogen processes is based on Agricultural Non-Point Source Pollution Model (AGNPS) (Young et al., 1986). The model considers soluble and sediment-attached nutrient separately. The details of algorithm can be found in the technical documentation on nutrient information from AGNPS model.

2.3.1 Nitrogen yield in runoff simulation model

The soluble nitrogen concentration in the runoff is calculated with (Young et al., 1986):

$$C_{RON} = \frac{(N_{AVS} - N_{AVR})}{F_{POR}}[e^{(-N_{DMV} I_{EFF})} - e^{(-N_{DMV} I_{EFF} - N_{RMV} R_{OFF})}] + \frac{N_{RNC} R_{OFF}}{P_{EFF}} \quad (1)$$

where C_{RON} is the soluble nitrogen concentration in runoff (kg/cell), N_{AVS} is the available nitrogen content in the surface (kg/cell), N_{AVR} is the available nitrogen in rainfall (kg/cell), N_{DMV} is the rate for the downward movement of nitrogen into the soil, N_{RMV} is the rate for nitrogen movement into the runoff, I_{EFF} is the effective or total infiltration (mm), R_{OFF} is the total runoff (mm), F_{POR} is a porosity factor, N_{RNC} is the nitrogen contribute due to rain (kg/cell), and P_{EFF} is the effective precipitation (mm). The flow diagram of the nitrogen yield in runoff estimation for this study is shown in Figure 2(a).

2.3.2 Nitrogen yield in sediment simulation model

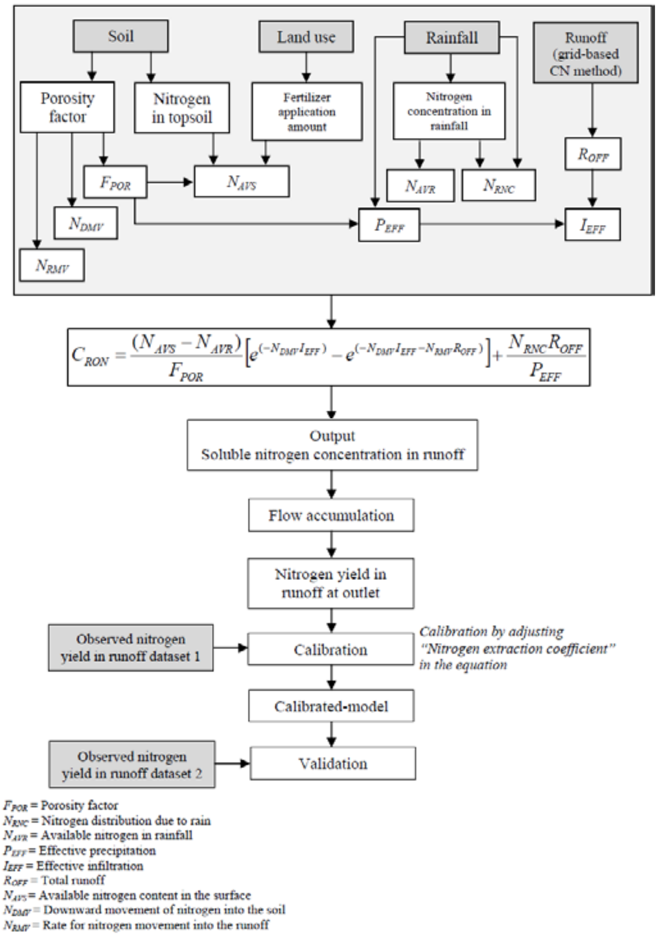
The nitrogen yield in the sediment was calculated using total sediment yield from a cell as expressed in the following equation (Young et al., 1986):

$$N_{SED} = N_{SCN} Y_{SED} ER \quad (2)$$

where N_{SED} is the overland nitrogen transported by the sediment (kg/cell), N_{SCN} is the soil nitrogen concentration (g N/g soil), Y_{SED} is the total sediment yield (kg/cell), and ER is the nutrient enrichment ratio calculated by:

$$ER = aY_{SED}^{b} T_f \quad (3)$$

where a and b are experiment constants with values of 7.4 and -0.20 respectively. T_f is a correction factor for soil texture and has values of 0.85 for sand, 1.0 for silt, 1.15 for clay and 1.50 for peat. The flow diagram of the nitrogen yield in sediment estimation for this study is shown in Figure 2(b).



$$C_{RON} = \frac{(N_{AVS} - N_{AVR})}{F_{POR}}\left[e^{(-N_{DMV}I_{EFF})} - e^{(-N_{DMV}I_{EFF} - N_{RMV}R_{OFF})}\right] + \frac{N_{RNC}R_{OFF}}{P_{EFF}}$$

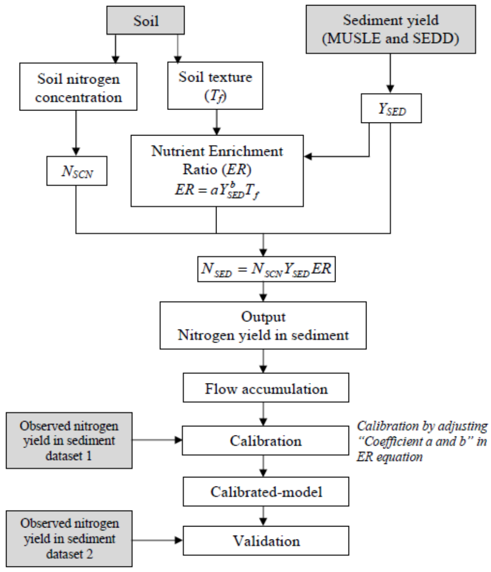


Figure 2(b) Flow diagram of nitrogen yield in sediment estimation.

Figure 2(a) Flow diagrams of nitrogen yield in runoff estimation.
Grid-based Curve Number (CN) Method (Tharapong et al., 2009), Modified Universal Soil Loss Equation: MUSLE (William, 1975), Sediment Delivery Distributed Model: SEDD (Ferro and Porto, 2000).

2.4 Nitrogen yield observation

The field observation was conducted on rainstorm events during July-October 2008. The purpose of the field observation was collecting soluble nitrogen and sediment-attached nitrogen. Water samples were collected in glass bottles and kept frozen until analyzing. The methods of water sampling and analysis procedures were followed the Standard Method for the Examination of Water and Wastewater (American Public Health Association, 1998).

2.5 Computational processes in grid-based approach

Each GIS layer of relevant parameters was prepared in raster format with grid cell size of 30 × 30 m. Each cell homogeneously represents characteristics of the nutrient relevant factors. The algorithms and equations were coded in ModelBuilder™ of ArcGIS™ with required sets of spatial analyses. The nitrogen yield in each grid cell was computed using the AGNPS model, and then routed through the watershed based on flow accumulation process. The simulated nitrogen yield values were picked up from cells located at M.171 and M.145 stations. The outputs of the model simulations and field observation of all events at these two cells were tabulated in an Excel™ spreadsheet to estimate the statistical parameters for model evaluation.

2.6 Model evaluation

The model evaluation procedures include both calibration and validation processes. Statistical parameters, namely Nash and Sutcliff's coefficient of efficiency (E) (Nash and Sutcliffe, 1970), coefficient of determination (R^2), percent deviation (Dv%) were used to test the model simulation results.

3. RESULTS AND DISCUSSION

3.1 Results of nitrogen yield in runoff

The calibration was carried out by adjusting nitrogen leaching extraction coefficient and nitrogen runoff extraction coefficient in such a manner that the calculated coefficient of efficiency (E) for all calibration events would be highest. Eight selected events were used for model calibration. Other eight events were for the model validation.

The calibration and validation results of nitrogen yields in runoff show that the model produced results with E = 0.82, R^2 = 0.91 and E = 0.63, R2 = 0.89, respectively. These statistical values suggested that the model was applicable for the study area. The calibration and validation results for simulated nitrogen yield in runoff are presented in Table 1.

Table 1 Calibration and validation results of nitrogen yield in runoff simulation and observation.

Events	Nitrogen yield in runoff (kg)		
	Observed	**Simulated**	**Dv(%)**
Calibration events			
20081030M171	44,538.72	52,748.56	-18.43
20080930M171	44,898.58	29,344.30	34.64
20080910M171	343,149.84	226,478.00	34.00
20080818M171	220.33	12,559.89	-5,599.13
20081030M145	7,791.24	33,575.20	-330.94
20080930M145	5,610.20	19,533.54	-248.18
20080910M145	87,076.85	129,036.00	-48.19
20080818M145	1,538.34	7,832.65	-409.16
Total	534,824.11	511,105.14	
Validation events			
20081025M171	40,051.52	25,138.04	37.24
20080928M171	17,151.25	16,202.50	5.53
20080915M171	95,464.03	51,764.95	45.78
20080907M171	11,545.62	24,388.05	-111.23
20081025M145	9,701.39	18,097.76	-86.55
20080928M145	3,719.58	10,521.50	-182.87
20080915M145	13,025.25	20,626.98	-58.36
20080907M145	6,513.70	8,498.21	-30.47
Total	197,172.33	175,237.99	

The regression lines of observed and simulated nitrogen yields in runoff for calibration events and validation events are plot against 1:1 lines and shown in Figure 3(a) and Figure 3(b), respectively. For calibration events, it is observable that the simulated values are slightly above 1:1 line, indicating that the model performs slightly underestimation. For validation event, the regression line is above the 1:1 line when the nitrogen yield is approximately higher than 20,000 kg, indicating that the calibrated-model is underestimation in heavier events.

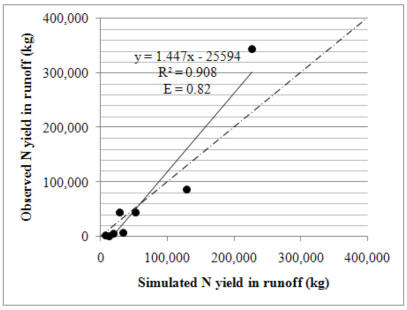


Figure 3(a) Calibration results of observed and simulated nitrogen yield in runoff.

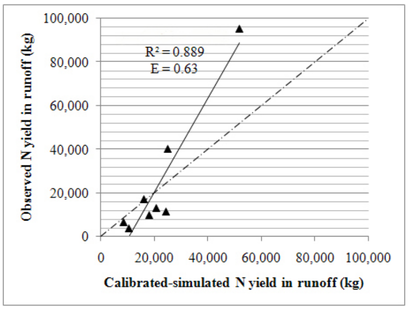


Figure 3(b) Validation results of observed and simulated nitrogen yield in runoff.

The results of nitrogen yield in runoff are displayed in Figure 4.

3.2 Results of nitrogen yield in sediment

The calibration was carried out by adjusting *a* and *b* coefficient in the Eq. 3 in such manner that the coefficient of efficient (E) for all calibration events would be highest. Eight selected events were used for model calibration. Other eight events were for the model validation.

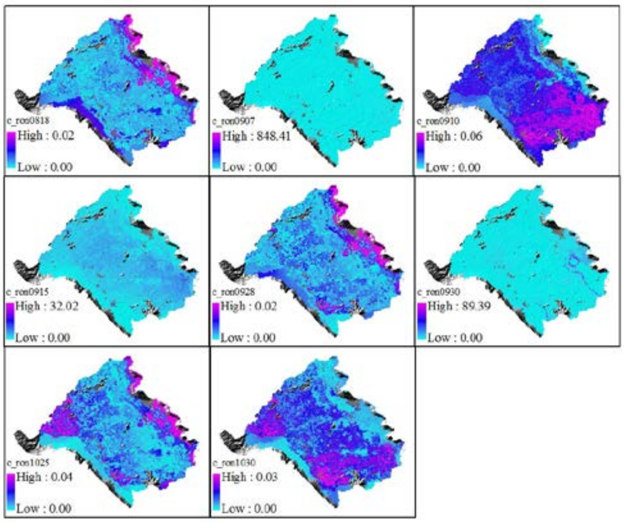


Figure 4 Spatial variation of event-based simulated nitrogen yield in runoff.

The calibration and validation results of nitrogen yields in sediment show that the model produced results with E = 0.90, R^2 = 0.93 and E = 0.70, R^2 = 0.93, respectively. These statistical values suggested the model was applicable for the study area. However, the result may change if more data events were involved in the analysis. The calibration and validation results for simulated nitrogen yield in sediment are presented in Table 2.

Table 2 Calibration and validation results of nitrogen yield in sediment simulation and observation.

Events	Nitrogen yield in sediment (kg)		
	Observed	**Simulated**	**Dv(%)**
Calibration events			
20080818M171	343.09	1,120.24	-26.51
20080910M171	45,357.58	36,105.19	20.40
20080928M171	254.83	1,310.07	-414.10
20081025M171	695.27	1,778.99	-155.87
20080818M145	299.77	409.86	-36.72
20080910M145	4,510.20	13,766.85	-205.24
20080928M145	178.18	638.86	-258.55
20081025M145	678.10	1,144.92	-68.84
Total	52,317.02	56,274.98	
Validation events			
20080907M171	2,256.50	2,767.11	-22.63
20080915M171	11,860.58	13,717.04	-15.65
20080930M171	5,030.19	8,642.38	-71.81
20081030M171	564.07	2,579.97	-357.39
20080907M145	645.67	319.59	50.50
20080915M145	1,960.81	3,845.78	-96.13
20080930M145	2,329.02	4,794.49	-5.86
20081030M145	369.83	1,103.87	-198.48
Total	25,016.67	37,770.23	

The regression lines of observed and simulated nitrogen yields in sediment for calibration events and validation events are plot against 1:1 lines and shown in Figure 5(a) and Figure 5(b), respectively. For calibration events, it is observable that the simulated values are slightly above 1:1 line when nitrogen yield in sediment is approximately higher than 10,000 kg, indicating that the model is slightly underestimation in heavier events. For validation events, the simulated values are slightly below the 1:1 line, indicating that the calibrated-model is slightly overestimation.

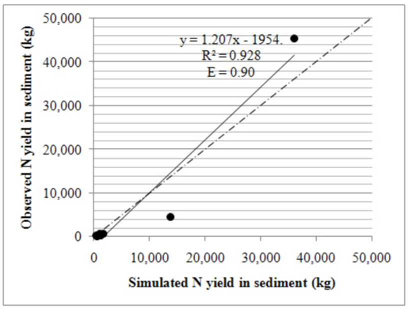


Figure 5(a) Calibration results of observed and simulated nitrogen yield in sediment.

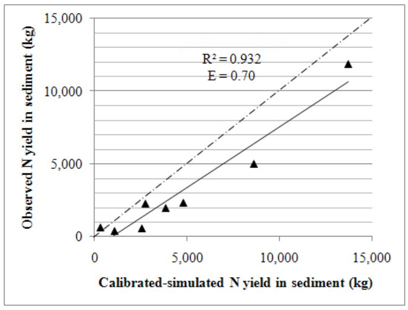


Figure 5(b) Validation results of observed and simulated nitrogen yield in sediment.

The results of nitrogen yield in sediment are displayed in Figure 6.

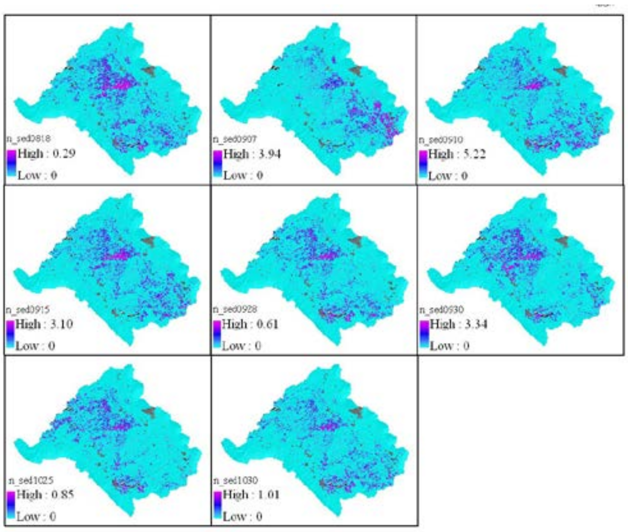


Figure 6 Spatial variation of event-based simulated nitrogen yield in sediment.

4. CONCLUSION

The calibrated results of nutrient yield method using geospatial modeling can be applied to nitrogen yield simulations with acceptable accuracy. Not only the satisfied quantitative results provided but the models are also able to estimate varying nitrogen yield over the watershed spatially. As the results of case study at the Upper Lam Phra Phloeng watershed, Thailand, it can be confirmed that grid-based nutrient yield model is applicable to nitrogen yield estimation effectively.

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