Journal of Landscape Research 2023, 15(5): 85-88

Applications of AnnAGNPS Model for Sediment and Nutrient Loadings for Funiu Mountain Area, China

TIAN Yaowu[1*], **LIU Yali**[2], **ZHANG Chulei**[1], **ZHANG Zizheng**[1], **LI Xiaolin**[1]

(1. College of Forestry, Henan University of Science and Technology, Luoyang 471003, Henan, China; 2. Henan Forestry Ecological Construction Development Center, Zhengzhou 451000, Henan, China)

Abstract The main goal of this study was to evaluate the performance of AnnAGNPS (Annualized AGricultural NonPoint Source) pollution model, in calculating runoff, sediment loading and nutrient loadings for Funiu Mountain area. Most of the model input parameters were sourced from Luanchuan Forest Ecology Station (LFES) in Funiu Mountain area. The data on 23 storms in 2018 was used to calibrate the model and the data on 33 storms in 2019 for validation. The whole evaluation consisted of determining the coefficient of determination (R^2), Nash-Sutcliffe coefficient of efficiency (E), and the percentage volume error (VE). Results showed that the runoff volumes were underpredicted by 5.0% with R^2 of 0.93 (P<0.05) during calibration and underpredicted by 5.3% with R^2 of 0.90 (P < 0.05) during validation. But sediment loading was able to produce a moderate result. The model underpredicted the daily sediment loading by 15.1% with R^2 of 0.63 (P < 0.05) during calibration and 13.5% with R^2 of 0.66 (P < 0.05) during validation. Nitrogen loading was overpredicted by 20.3% with R^2 = 0.68 (P < 0.05), and phosphorus loading performance was slightly poor with R^2 = 0.65 (P < 0.05) during validation. In general, the model performed well in simulating runoff compared to sediment loading and nutrient loadings.

Keywords AnnAGNPS model, Runoff, Sediment loading, Nutrient loadings, Funiu Mountain area, Performance

DOI 10.16785/j.issn 1943-989x.2023.5.019

Due to the overexploitation of the watershed resources in Funiu Mountain area in China, nonpoint source (NPS) pollution has grown into a serious environmental issue. It is generally thought that this is caused by land use changes of converting forest resources to agriculture in watersheds and it had significantly impacted water yield, runoff volume and sediment loading to stream reaches[1]. Event-based AGNPS has been widely used for sediment and nutrient loadings calculations. The model was tested over a wide range of environments in Europe, North America, Australia and Africa[2-3]. AnnAGNPS is a distributed-parameter, physically-based, continuous-simulation model developed jointly by USDA-ARS and NRCS[4]. As a new model, AnnAGNPS was chosen because it is a much-improved version of its event-based predecessor AGNPS, only few studies have applied it in studying the effect of watersheds on surface water quality[3, 5-8], and it has not yet been fairly extensively validated. This paper was (1) to reveal predictive trends of AnnAGNPS in pollutant generations between the predicted and the measured data for different storm sizes and (2) to test the model capabilities in predicting the measured runoff and soil erosion for hilly watershed conditions.

1 Methodology

1.1 Study watershed

The study area chosen is Hehanhe watershed in Funiu Mountain area located in Luanchuan County, Henan province, China. The total watershed area is about 2.5 km^2 with the elevation ranges from 395 to 1,400 m. The mean annual temperature is about 20 ℃ with a maximum of 35 ℃ in July and a minimum of 2 ℃ in January. The watershed average value of slope is 33.7°, and majority of land has extreme slope (about 77%). The soils of the watershed are, in general, sandy loam in texture, with gravels and acidic in reaction. Approximately 30% of the watershed was tea plantation with the remaining area under mixed cultivation that included 15% of land area for forest, 5% for agriculture, 20% for agro-forests, 15% for rangeland and 15% for other uses.

1.2 Development of the database for Hehanhe watershed

The basic database for the Hehanhe watershed mainly includes DEM, soil and land-use maps, as well as climate and land management data (Table 1). A 5-m resolution DEM got from a contour map (1 : 10,000) of the watershed was used to delineate AnnAGNPS cells and generate network. The study area was divided into 66 cells using a CSA (critical source area) value of 2 ha and a MSCL (minimal source channel length) value of 30 m. Soil types were classified according to USDA classification[9]. Soil properties such as field capacity, bulk density and chemical properties were obtained from LFES and other sources. Field operation, field management, crop and non-crop data and other data were obtained through field survey.

1.3 Evaluation of model output

Performance and simulation accuracy of the AnnAGNPS were assessed based on the ability of the model to predict runoff, sediment loading and nutrient loadings. Statistical values such as percentage volume error (VE), coefficient of determination (R^2), and Nash-Suttcliffe efficiency (E)[10] were used to evaluate model performance. The equations to calculate VE, R^2 and E are shown below:

$$VE = \frac{\sum_{i=1}^{N}(M_i - P_i)}{\sum_{i=1}^{N} M_i} \tag{1}$$

$$R^2 = \left\{ \frac{\sum_{i=1}^{N}(M_i - \overline{M})(M_i - P_i)}{\left[\sum_{i=1}^{N}(M_i - \overline{M})^2\right]^{0.5}\left[\sum_{i=1}^{N}(P_i - P)^2\right]^{0.5}} \right\} \tag{2}$$

$$E = \frac{\sum_{i=1}^{N}(M_i - P_i)^2}{\sum_{i=1}^{N}(M_i - \overline{M})} \tag{3}$$

where N is total number of daily events, M_i is the measured value; P_i is the predicted value and $\overline{M}$ and $\overline{P}$ are the average of all measured and predicted values, respectively.

Index VE expresses the reliability of the calculation of the total amount of runoff or sediment loading transport for a longer

Received: September 20, 2023 Accepted: October 4, 2023
Supported by the National Natural Science Foundation of China (32271848).

* Correspondent author.

period of time; The R^2 value is an indicator of the strength of the relationship between the measured and predicted values. E indicates how well the plot of the measured value versus the predicted value fits the 1∶1 line. Low values of E represent high deviations between measured and predicted values. Index E is sensitive to the size of deviations of measured and predicted values for flood events with high runoff and sediment loading transport[11]; if the R^2 and E values were less than or very close to zero, the model performance is considered "unacceptable or poor". If the values were equal to one, then the model prediction is considered "perfect"[1].

1.4 Model calibration

Calibration was done manually in order to select values for the parameters so that the model closely predicted runoff and sediment yield. At first calibration focused on daily event flow volumes. Here 23 rainfall-runoff events (2018) were selected. The SCS curve number is the most important factor for accurate calculation of runoff and sediment yields[3, 4]. Its values were adjusted by trial and error with the graphical comparison[8] as well as the comparison of statistical parameters of measured and predicted runoff volume (Fig.1). Initial CN values were selected based on *National Engineering Handbook*[12].

The recent version of AnnAGNPS uses RUSLE to estimate the erosion and HUSLE for sediment loading. It is very difficult to adjust all those parameters for the calibration process. Sediment loading displayed more complex and often contradictory responses to changing input variables. The root mass, canopy cover and Manning's roughness coefficient values in each subwatershed were adjusted here by trial and error with the graphical comparison[8] as well as the comparison of statistical parameters of measured and predicted sediment yields (Fig.2).

1.5 Model validation

In the validation process, the model was operated with input parameters obtained in the calibration process and the other watershed data in 2019. The same statistical techniques were used to assess the model performance.

2 Results and discussion

2.1 Calibration of AnnAGNPS

Daily measured and predicted values of runoff and sediment loading was plotted and their distribution along with 1∶1 line presented in Fig.3, 4. The model slightly underpredicted the mean runoff volume by 5.0% as compared to the measured values (R^2 = 0.93 P < 0.05; E = 0.87). This was a satisfactory result attributed to the maximum possible calibration. But the model prediction for runoff was a little worse than in the study made by Shrestha[8] in a catchment of Nepal, who reported R^2 of 0.93 and E of 0.89.

Although some of the erosion events have very high deviations from measured values, the total sediment loading predicted by AnnAGNPS for the period of 2018 correlated well with the measured values and the VE value was only −15.1%. However, due to the large variance in data, a moderate R^2 value of 0.63 (P < 0.05) and E of 0.77 (Fig.5) were obtained. The result obtained confirmed that the model was a good simulation of the watershed in terms of runoff calculation.

2.2 Validation of AnnAGNPS

2.2.1 Runoff volume. A summary of result component and its corresponding evaluation were presented in Table 1.

The measured and predicted runoffs were plotted together with a 1∶1 line as shown in Fig.5. AnnAGNPS was validated using climatic and watershed management data of 2019. According to Chiew[13], the flow estimates can be classified as acceptable if they have E greater than 0.6 and mean predicted flow in always 15% of mean recorded flow. The model has slightly underestimated the runoff volume (5.3%). Correlation between daily measured and predicted runoff had higher correlation (R^2 = 0.90, P < 0.05) (Fig.3) and the E was found to be 0.79, which showed a little deterioration to that in model calibration.

It was found that for low rainfall volumes, AnnAGNPS overpredicted the runoff generation. while for higher rainfall volumes, the model underestimated the runoff generation. Similar results were reported in a recent study carried out by Polyakov[3]. In AnnAGNPS peak discharge is estimated using TR-55 synthetic rainfall distribution and the model allows for only a single storm type to be used across the simulated area. The climate of study area is characterized by large spatial variation of rainfall where windward uplands receive extremely heavy but intermittent rainfalls. In these topographic conditions, a single hyetograph might not be applicable for the entire watershed. Prolonged rainfalls with relatively low intensity allow water to infiltrate, effecting the timing and magnitude of peak flows. This can cause a mismatch between the amounts of measured and predicted runoff for a single day, especially during smaller events.

This result shows that the deviation is within the reasonable range and AnnAGNPS is suitable for calculating the runoff volumes. The SCS curve number technique used for the runoff calculation thus can be used successfully in predicting the runoff volume for a hilly watershed conditions.

2.2.2 Sediment yield. The measured and

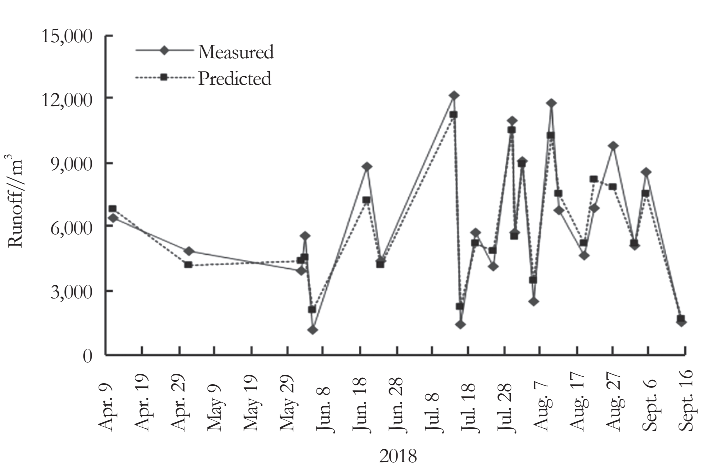

Fig.1 Measured and predicted daily runoff volumes (2018)

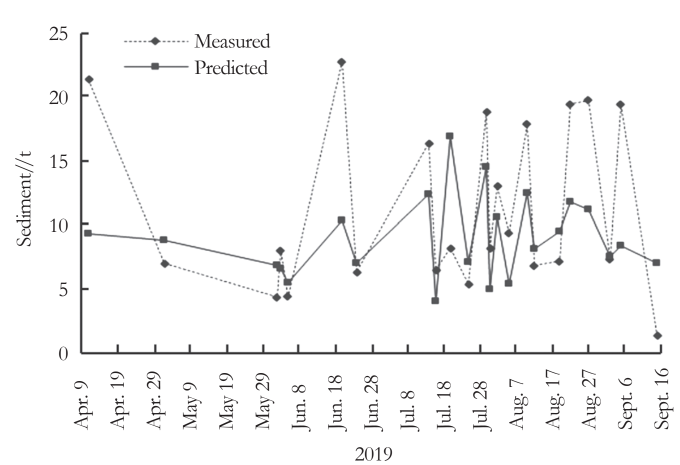

Fig.2 Measured and predicted daily sediment loadings (2019)

predicted sediment loadings were plotted together with a 1:1 line as shown in Fig.6. The regression line was below the 1∶1 line indicating underprediction of the sediment loading data. The model underpredicted the sediment yield by 13.5% during the validation phase in 2019. It showed a little improvement to that in model calibration. Correlation between measured and predicted sediment yield showed a low correlation ($R^2 = 0.66$, $P < 0.05$), which is considered moderate. The low value for E (0.69) was probably due to the model rounding up small or nearly negligible amounts of sediment loading as zero during low rainfall events.

Due to the USLE neglected storms less than 13 mm unless the storm includes excessive rainfall intensities, sediment loading predictive trend was the same as runoff generation, where the model overpredicted sediment loading in low volume rainfall and underpredicted in higher volume rainfall. Such a tendency was certain for RUSLE upon which the erosion component of AnnAGNPS was built[2-3]. So applicability of RUSLE for steep slope conditions area might be questionable. In addition, the watershed was prone to landslides, soil slips, and stream bank collapses for the larger storms. AnnAGNPS did not account for such mass wasting events, thus underpredicted sediment loading. The coefficient of efficiency, E, was 0.69 indicating poor performance of the model. Similar low value of E for daily calculation by AnnAGNPS was measured elsewhere[2-3, 14].

These show that the model performs well in simulating runoff volumes compared to sediment yields. There is a need to modify the calculation methods of sediment yield to increase the performance of the model which can aid watershed management.

2.2.3 Nutrient loadings. Notwithstanding the uncertainty in absolute calculations of nutrient loadings, the model successfully simulated the trends in nutrient generations between the predicted and the measured data. Fig.7 showed the plot of predicted versus measured nitrogen loading with regression and 1∶1 lines. The regression line was above but close to the 1∶1 line indicating over calculation (VE = 20.3%; E = 0.53). Despite noticeable inaccuracies in nitrogen predictions (R^2=0.68, P < 0.05), the results demonstrated a degree of stability. For the events of smaller magnitude the model underpredicted nitrogen loading while the opposite occurred for bigger events.

The phosphorus coefficient of determination, R^2 was found to be 0.65 (P <0.05) (Fig.8), which meant that the model was only able to explain about 65% of the variability in the measured data. The results for VE and E were poor at 23.5% and 0.43, respectively. Lack of reliable information and data regarding nutrients may be the cause for low model performance. Further studies are needed to calibrate the data and to detect the sensitivity of parameters in this aspect. Low performance of AnnAGNPS in prediction of nutrient loadings was also reported by Suttles[6], Baginska[7] and Polyakov[3].

The low quality of the model predictive capacity may result from a combination of factors. Internal model deficiencies may be related to the representation of watershed processes and the selection of relevant assessment methods, while external problems may be related to the watershed conditions and the recorded data quality[7]. The fact, for example, that the nutrient loadings were based on mass conservation, any missing input or output information of nutrients in watershed would

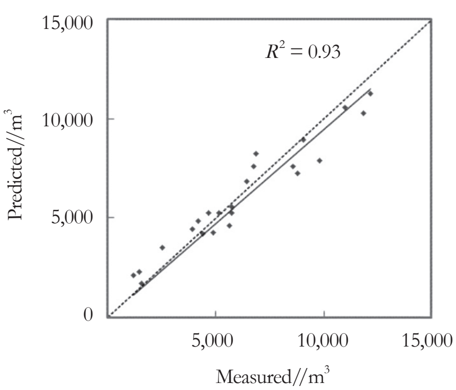

Fig.3　Measured vs. predicted daily runoff from Hehanhe watershed during calibration (2018)

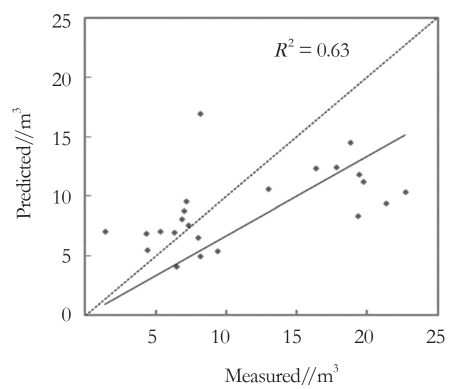

Fig.4　Measured vs. predicted daily sediment export from Hehanhe watershed during calibration (2018)

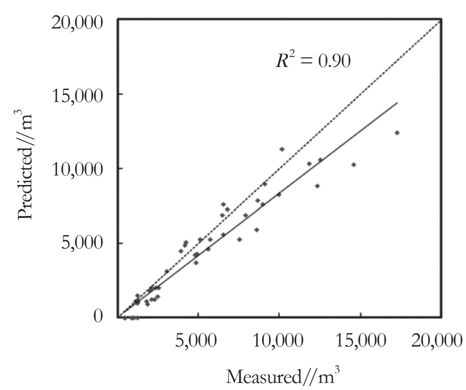

Fig.5　Measured vs. predicted runoff from Hehanhe Watershed (2019)

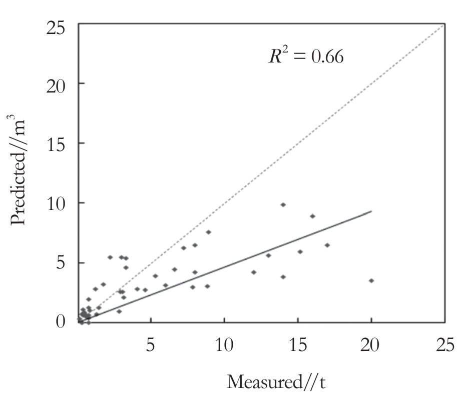

Fig.6　Measured vs. predicted sediment export from Hehanhe watershed (2019)

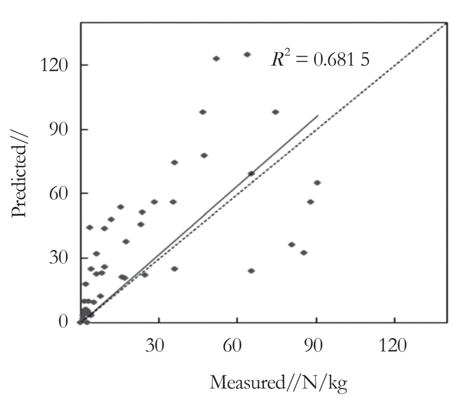

Fig.7　Measured vs. predicted nitrogen export from Hehanhe watershed (2019)

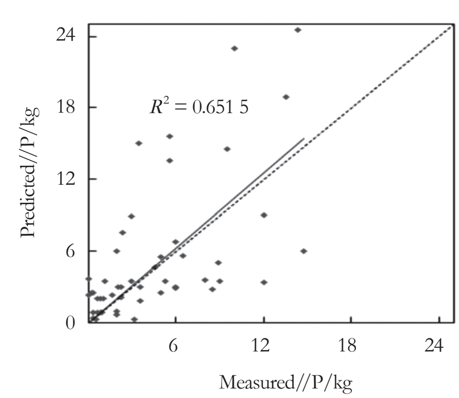

Fig.8　Measured vs. predicted phosphorus export from Hehanhe watershed (2019)

Table 1 Evaluation of AnnAGNPS performance

Evaluation method	AnnAGNPS output component			
	Runoff	Sediment loading	Nitrogen loading	Phosphorus loading
Percentage volume error, *VE* (%)	−5.30	−13.50	20.30	23.50
Coefficient of determination, R^2	0.90	0.66	0.68	0.65
Coefficient of efficiency, *E*	0.79	0.69	0.53	0.43

affect the results considerably. Bingner and Theurer[4] pointed out that the model assumed that there was no tracking of nutrient from one day to the next, which means that there will definitely be loss of mass. In other words, $R^2 = 1$ for nutrient loadings is largely impossible. The ability of the model to adequately simulate nutrient loadings in watershed is also questionable.

3 Conclusions

The study opted for reliable watershed measured data, instead of referring to foreign or model reference data when options were available. Evaluation of the model predictions demonstrates that AnnAGNPS produces results of satisfactory quality when simulating daily runoff. The runoff on a daily basis was underpredicted by 5.0% with R^2 of 0.93 ($P < 0.05$) during calibration and underpredicted by 5.3% with R^2 of 0.90 ($P < 0.05$) during validation. But a high degree of uncertainties are associated with predictions of sediment loading and nutrient loadings. The model underpredicted the daily sediment loading by 15.1% with R^2 of 0.63 ($P < 0.05$) during calibration and 13.5% with R^2 of 0.66 ($P < 0.05$) during validation. Nitrogen loading prediction was slightly better with $R^2 = 0.68$ ($P < 0.05$) than phosphorus loading performance with an $R^2 = 0.65$ ($P < 0.05$). In general, the model performs well in simulating runoff compared to sediment loading and nutrient loadings. For the smaller events, the model generally overpredicted sediment and nitrogen loadings, while underpredicted for larger events. The prediction of total phosphorus showed obvious uncertainties. As a watershed management tool, AnnAGNPS can be used for hilly conditions of Funiu Mountain area with mixed types of land uses and steep slopes that can aid in the formulation of different management strategies for the soil and water conservation.

References

[1] Hao, F. H., Zhang, X. S. & Yang, Z. F. (2019). A distributed non-point pollution model: calibration and validation in the Yellow River Basin. *J Environ Sci-China*, *16*(4), 646-650.

[2] Bingner, R. C., Mutchler, C. K. & Murphee, C. E. (1992). Predictive capabilities of erosion models for different storm sizes. *Trans ASAE*, *35*(2), 505-513.

[3] Polyakov, V., Fares, A. & Kubo, D. et al. (2007). Evaluation of a non-point source pollution model, AnnAGNPS, in a tropical watershed. *Environ Modell Software*, (22), 1617-1627.

[4] Bingner, R. L., Theurer, F. D. (2005). *AnnAGNPS Technical Processes documentation* (version 3.3 of USDA-ARS). Washington DC, USA.

[5] Yuan, Y., Bingner, R. L. (2001). Evaluation of AnnAGNPS on Mississippi Delta MSEA watersheds. *Trans ASAE*, *44*(5), 1183-1190.

[6] Suttles, J. B., Validis, G. & Bosch, D. D. (2002). Watershed-scale simulation of sediment and nutrient loads in Georgia Coastal Plain Streams using the annualized AGNPS model. *Proceedings of ASAE Annual Meeting 2002*, Paper No. 022092.

[7] Baginska, B., Milne-Home, W. & Cornish, P. S. (2018). Modeling nutrient transport in Currency Creek, NSW with AnnAGNPS and PEST. *Environ Modell Softw*, *18*(8), 801-808.

[8] Shrestha, S., Babel, M. S. & Gupta, A. D. (2006) Evaluation of annualized agricultural nonpoint source model for a watershed in the Siwalik Hills of Nepal. *Environ Modell Softw*, (21), 961-975

[9] Brown, R. B. (1999). *Fact Sheet SL-29*. Soil Texture, Soil and Water Science Department, Institute of Food and Agricultural Science, University of Florida, USA.

[10] Nash, J. E., Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I-A discussion of principles. *J Hydrol*, (10), 282-290.

[11] Krause, P., Boyle, D. P. & Bäse, F. (2005). Comparison of different efficiency criteria for hydrological model assessment. *Advances in Geosciences*, (5), 83-87.

[12] Bingner, R. L, Theurer, F. D. (2018). *AnnAGNPS technical processes documentation* (version 3.2 of USDA-ARS). Washington DC, USA.

[13] TR-55. (1986). Technical release 55: urban hydrology for small watershed. *USDA-SCS*. Washington DC, USA.

[14] Kliment, Z., Kadlec, J. & Langhammer, J. (2008). Evaluation of suspended load changes using AnnAGNPS and SWAT semi-empirical erosion models. *Catena*, *73*(3), 286-299.

****

(Continued from P84)

strengthening and improving aesthetic education in schools in the new era. Retrieved from https://www.gov.cn/zhengce/2020-10/15/content_5551609.htm.

[9] Wang, X. X. (2012). An analysis of the aesthetic value of world heritage education: The necessity of world heritage education becoming an aesthetic education course. *Journal of Hebei University (Philosophy and Social Sciences Edition)*, *37*(1), 1-5.

[10] UNESCO. (1992). *Decision 16 COM X.A: Inscription*: *Wulingyuan Scenic and Historic Interest Area* (People's Republic of China). Retrieved from https://whc.unesco.org/en/list/640.

[11] Feng, L. W. (2012). Creation analysis of the piano piece "impression of Wulingyuan · stream · cave". *Music Education and Creation*, *10*, 51-55.