Grid Based Nonpoint Source Pollution Load Modelling

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Abstract

The purpose of this study is to develop a grid based model for calculating the critical nonpoint source (NPS) pollution load (BOD, TN, TP) in Nak-dong area in South Korea. In the last two decades, NPS pollution has become a topic for research that resulted in the development of numerous modeling techniques. Watershed researchers need to be able to emphasis on the characterization of water quality, including NPS pollution loads estimates. Geographic Information System (GIS) has been designed for the assessment of NPS pollution in a watershed. It uses different data such as DEM, precipitation, stream network, discharge, and land use data sets and utilizes a grid representation of a watershed for the approximation of average annual pollution loads and concentrations. The difficulty in traditional NPS modeling is the problem of identifying sources and quantifying the loads. This research is intended to investigate the correlation of NPS pollution concentrations with land uses in a watershed by calculating Expected Mean Concentrations (EMC). This work was accomplished using a grid based modelling technique that encompasses three stages. The first step includes estimating runoff grid by means of the precipitation grid and runoff coefficient. The second step is deriving the gird based model for calculating NPS pollution loads. The last step is validating the gird based model with traditional pollution loads calculation by applying statistical t-test method. The results on real data, illustrate the merits of the grid based modelling approach. Therefore, this model investigates a method of estimating and simulating point loads along with the spatially distributed NPS pollution loads. The pollutant concentration from local runoff is supposed to be directly related to land use in the region and is not considered to vary from event to event or within areas of similar land uses. By consideration of this point, it is anticipated that a single mean estimated pollutant concentration is assigned to all land uses rather than taking into account unique concentrations for different soil types, crops, and so on.

Keywords: grid based model; nonpoint source pollution load; GIS; watershed; BOD; TN; TP; expected mean concentrations; runoff

1. Introduction

In the past few years, many efforts have been placed on the description of water quality. Normally, there are two types of water pollution sources, PS (point source) and NPS (non-point source) pollution. As the important indicators of water quality, BOD (Biochemical Oxygen Demand), TN (Total Nitrogen) and TP (Total Phosphorus) can be also used to indicate the amount of water pollutants from PS or NPS. NPS pollution load calculation has been associated with water quality contamination. NPS water pollution can be identified as pollution that is not related with a specific location, pipe sewage discharge. Urban runoff, forestry operation, agriculture such as paddy and crop are all potential sources of NPS pollution. A watershed is a district of land which includes both the streams and rivers that transport the water as well as the land surfaces from which water drains into those channels. Watershed researchers need to be able to estimate NPS pollution loads if they are to design effective water pollution management approach.

The GIS based method is an influential tool for discovering environmentally aware areas in terms of NPS pollution potential and evaluate alternative land use scenarios to calculate NPS pollution load. The GIS NPS pollution assessment method is performed by different data such as DEM, precipitation, stream network, discharge, and land use data sets and utilizes a grid representation of a watershed for the approximation of average annual pollution loads and concentrations.

Conventional NPS pollution load calculation approaches are inadequate. The difficulty in modeling NPS is the problem of identifying sources and quantifying the loads. In contradiction of a point source, where an identified volume of contaminant is discharged from a single certain source, disperse pollution is an aggregate of small contaminant inputs distributed through a watershed. Therefore, NPS models require a distributed modeling method. Many problems of the traditional method will cover using expected mean concentration (EMC) approach. EMC determines concentrations and loadings in the stream based on expected mean concentrations from land use information.

The purpose of this study is to develop a grid based model for NPS pollution load calculation using EMC table for the Nak-dong watershed in South Korea. This method using several pixel based information can trace the flow of water from cell to cell, the movement of pollution over the landscape and through a stream network is simulated.

2. Related work

Recent new techniques such as the use of GIS models have provided watershed planners with access to more information for making management decisions (Miller et al 2004). In the past few years, the extensive paper reports the development of computational tools to support decisions in water resources management (Loucks et al. 1995; Dai and Labadie 2001; Jamieson and Fedra 1996; Andreu et al. 1996; Bouraoui and Dillaha 1996). As NPS pollution has garnered more attention in recent years, governmental and private research institutions have designed methods of assessing pollution from nonpoint sources. More recently, some of these methods have been related to GIS in term of data management and processing tasks. This section provides a review of some of the more well-known NPS pollution models. There are several types of models which relate to one of the following groups (Alves 2005): "empirical, physics-based and conceptual models", "spatially distributed and lumped models", and "event and continuous time based models". First, empirical models are derived from the analysis of data and relations that describe the catchment comeback for the processes being simulated. Schueler (1987) showed the estimating pollutant export from urban development sites as well as USEPA (1992) as simple empirical approach. Additionally, USEPA (2001) provided export coefficient empirical approach to offer total loads based upon parameters containing mass pollutant per unit area, per year. Then, physically based models depend on the solution of equations to describe the physical processes in the watershed and the conceptual models are derived from the general description of the catchment processes by representing the flow paths. Second, spatially distributed models consider the basin spatial arrangement when defining values for the model factors. Further, lumped models exploit a single value for each factor for the whole watershed. CREAMS (Knisel 1980), GWLF (Haith et al., 1996), ARM/HSPF (Donigian and Davis 1985) are examples of lumped factor models. Finally, the event-based models simulate the rainfall or snowfall. They involve few meteorological data, but antecedent moisture conditions is necessary (Novotny and Chesters 1981). Moreover, continuous models sequentially simulate the processes on the watershed.

A list of required model collection criteria is accessible in NCR (2002). As a matter of fact, there is no the most excellent model for all purposes. In general, the most appropriate model will rely on the availability of data to validate and calibrate the model, on the characters of the watershed, on the final purpose and even on the understanding of the assumptions behind the model and to exploit it appropriately.

3. Materials and Methodology

This research has been experimented to calculate NPS pollution load using an EMC grid based that encompasses four stages. First, runoff grid by means of the precipitation grid and runoff coefficient was estimated. Second, after calculating EMC table via gathering and measuring water quality indicators by several sample points from different land use area, EMC grids were derived by associating the EMC table with the land use information. Third, EMC based NPS pollution load models were determined using EMC grid and landuse information. Finally, EMC grid based model were validated by comparing with traditional pollution loads calculation by applying statistical t-test method.

3.1 Study area

In this research, the study area was selected a watershed from Kyungsang province in east-south part of South Korea named as the Nak-dong watershed (Figure 1). This area is approximately 23,384 square kilometers including Nak-dong river basin which pass from three provinces and 19 cities. For this study, DEM with 30m resolution from Land sat 7 satellite images (1/5000) and Land-use Cover with 30m resolution from Land sat 7 ETM (1/250,000) were exploited.

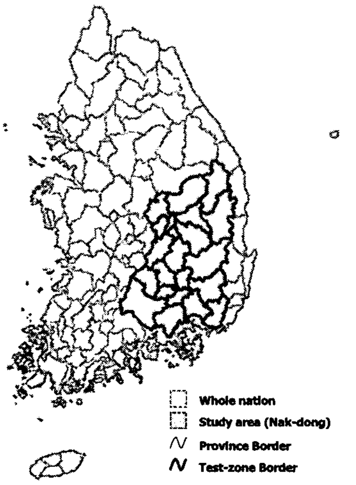

Figure 1. Nak-Dong watershed study area.

3.2 Runoff grid

The runoff grid shown in Figure 2 represents an as a total annual potential runoff across the Nak-Dong basin. The runoff grid is calculated by multiplying the precipitation grid by the runoff coefficient grid. Then, this relationship would be applied to every cell in the precipitation grid. Further, in order to select the portion of the precipitation grid applicable to the Nak-dong Basin, the average annual precipitation grid (1966-2001) contains spatial values for precipitation over the area of interest were determined. Additionally, the runoff coefficients were calculated by applying land use and soil type data using an empirical rainfall-runoff function, whose parameters are defined for different land uses. For instance, urban land has more runoff than forest land or agricultural.


Figure 2. The runoff grid of Nak-Dong area.

3.3 Expected mean concentration table

Calculating expected mean concentration (EMC) table includes the following steps. In the first step, several random sample points from difference kind of land use were gathered. In the next step, by using runoff grid value of all sample points were calculated as well as measuring the pollution load (BOD, TN, and TP) of each sample point. In the last step, Expected mean concentration table were determined by dividing pollution load of each sample point in runoff grid value of that point. Table 1 shows the estimated EMC table of Nak-dong area.

Table 1. EMC table of Nak-Dong area.

EMC Factors	BOD	TN	TP
Water	2.478	3.00	0.093
Urban Area	31.15	11.48	1.104
Grass	2.37	2.60	0.84
Forest Area	1.403	2.00	0.374
Field	31.15	11.48	1.104
Paddy	1.95	2.085	1.58
Crop	2.78	3.118	0.104

3.4 NPS pollution load model

EMC grid based NPS pollution load models with respect to three water quality indicators (BOD, TN, and TP) were calculated by associating the EMC grids with the runoff grid. In this regard, for determining EMC grids are combined the EMC table calculated in previous section with the landuse grid based on difference land cover type. Figures 3, 4, and 5 show the final results of EMC-DEM based NPS pollutant loads from each DEM cell or land use polygon and summed using an accumulation function to get the total pollutant load from the Nak-Dong watershed.

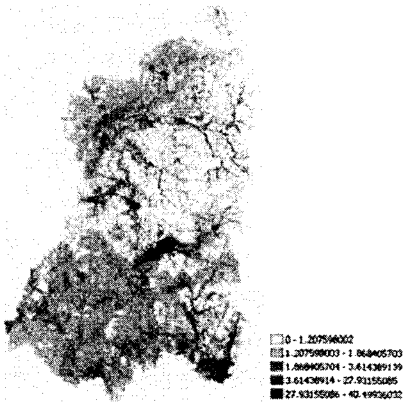

Figure3. BOD EMC loads grid.

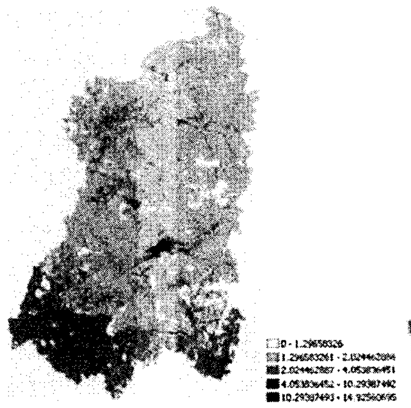

Figure4. TN EMC loads grid.

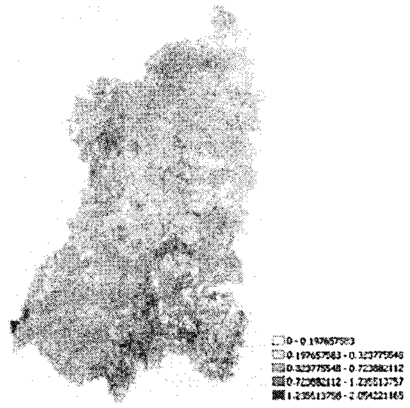

Figure5. TP EMC loads grid.

4. Discussions

The results demonstrate that grid based NPS technique has been successfully modeled in this work. The GIS NPS pollution assessment method is performed for three important indicators of water quality (BOD, TN, and TP). EMC values for the pollutant were highly variable between land uses. This variation depends on many factors such as soil type, topography, precipitation. The distribution of TN EMC in the Nak-dong area basin is shown in Figure 4. This map shows that most of the TN contribution comes from the southern portions of the basin, where agricultural land uses are predominant. However, the contributions of TN from range forest land uses are not negligible. Besides, the dissemination of TP and BOD EMC in the study area are illustrated in Figure 3 and 5. This figure shows that most of the TP and BOD contribution originates from the southern, western, and northern sections of the watershed, where urban area and agricultural land uses are prevalent.

Advantages of the method are summarized below: Firstly, grid based NPS assessment method is seen to provide relatively accurate estimates of NPS pollution loads and concentrations throughout the stream network of a hydrologic unit. Principally along smaller streams, where few or no sample point sources exist, EMC method predicted via the assessment method match quite well with average observed concentration values. Secondly, the EMC method offers an efficient way to identify specific regions where elevated levels of pollutant concentrations may be expected. Finally, this technique allow to simulate the moving of NPS contaminant in a watershed in addition to land use information using extra information of reality of around the pollutant source such as topography layer ,soil type.

While the advantages of the EMC technique are obviously evident, there are also a number of limitations with this research that should be addressed for future assessments: The use of mean annual estimation considers the flow and loads to be stable condition parameters from year to year. The results of flushing of pollutants via the method in considerable floods are not determined. Then, the EMC does not offer information on the time varying changes in pollutant concentration and are not determined to vary from event to event or between different land use subcategories. The event mean concentration is useful in estimating the loadings to receiving water bodies.

5. Model verification

After EMC NPS pollutant load calculation, the expected concentrations are compared to the observed concentrations and traditional process using pollutant load unit parameters. The t-test is used to compare the expected concentrations calculated using the water quality model, the observed concentrations and traditional calculated pollutant using pollutant load unit factors.

5.1 Traditional pollution modelling

An empirical NPS pollutant load model using pollutant load unit factors was exploited. The model output identified nonpoint source load from each land use unit. Table5 shows a NPS unit loading coefficients (NIER 1999) for the basin was applied for this empirical model. The empirical NPS pollutant load discharges are calculated by multiplying the generation Pollution load calculation by one practical constant number (0.25). The generation Pollution load calculations also are computed by multiplying each land use area by the pollutant load unit factors.

5.2 Statistical t-test method

For model validation, the t-test is used to compare the expected concentrations, the observed concentrations and traditional calculated pollutant method. A t-test is an inferential test that determines if there is a significant difference between the means of two data sets. In other words, a t-test decides if the two data sets come from the same population and expressed as the standard deviation of the difference between the means.

5.3 Verification process

In this research, an average t-test was applied in the Nak-Dong watershed using 31 observed sample points (n=62, α= 0.05, P=2.04). Table 6 illustrates the expected concentration, the observed concentration, the standard deviation, the number of samples, and the average t–test result for each of the Nak-Dong watershed.

Table 2: T-test results of samples point measurement from three approaches (observed, traditional, and EMC).

n=31	Observed sample points			Traditional method			EMC method		
	BOD	TN	TP	BOD Tradi	TN Tradi	TP Tradi	BOD EMC	TN EMC	TP EMC
Mean Value	7.345	3.850	0.263	1.685	0.442	0.055	5.104	3.538	0.633
Standard Deviation	3.169	0.841	0.091	0.529	0.081	0.012	1.558	0.481	0.123
T-test				-10.689	-42.103	-17.451	-1.438	-0.648	3.015

Once estimated traditional average pollutant loads and concentrations have been calculated, to validate the results as well as EMC method both group of data were compared with sampled data. Due to t-test rules and the situation of EMC model verification (n=62, α= 0.05, P=2.04) with respect to table 2, the t value of EMC method is more near than other methods to P values, therefore, the results of EMC grid based proves the validation of this technique. If the t-test result is larger than P, the expected value is not statistically the same as the observed values.

A negative t-test result indicates the observed concentrations are less than the expected and traditional concentrations whereas a positive t-test result indicates the observed concentrations are greater than the expected and traditional concentrations which are probably due to a missing load source in the calculations. For the expected concentration in table 6, the t values of BOD, TN, and TP are very near to p value which indicates a reasonable estimation of the EMC grid based method in the Nak-Dong area.

In the traditional method, pollutant concentration from runoff is assumed to be directly related to land use in the region and is not considered other information such as geographical region, DEM, soil type. In particular, a single average estimated pollutant concentration is assigned to all agricultural land uses instead of considering unique concentrations for different crops, soil types, or activities. Estimation of pollutant inputs using pollutant load unit factors in traditional approach has limitations in identifying seasonal variations of pollutant loadings. Seasonal changes of runoffs should be considered in the modelling of pollutant loadings form catchment into reservoirs. Evaluation of pollutant loading inputs using runoff-coefficient and EMC can overcome these disadvantages.

6. Conclusion

This research presents an EMC-DEM model designed to calculate NPS constituent loads by a viable GIS based technique within a watershed. Further, this method makes use of DEM with 30 m cell size laid over the landscape, representing the pollutant loading and runoff derived from each cell. Through tracking the flow of water from cell to cell, the movement of pollution over the area and via watershed is simulated. As the t-test evaluation in the previous section showed, the GIS based modelling can provide a reasonably accurate characterization of NPS pollution in the watershed. Moreover, this model leads to approach that determines the land use-based EMC values in a watershed properly. EMC values for the pollutant were highly variable between land uses. This variation depends on many factors such as soil type, topography, precipitation. Overall, the EMC-DEM based model is seen to provide relatively accurate estimates of NPS pollutant loads and concentrations throughout the stream network than traditional concentration using pollutant load unit factors. As further work, determining event based concentration which does not constant values cooperate with each land use and also vary from event to event or between different land use subclasses. Moreover, transport of pollutants is considered to be conservative throughout this study, i.e. no decay of pollutants is considered. For future nonpoint source pollution assessments, this limitation may be addressed via use of a water quality simulation model. Additionally, point sources are not primarily estimated as part of the regional pollution assessment. A separate research, investigates a method of estimating and simulating point loads along with the spatially distributed nonpoint loads.

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