GIS based Non-Point Source Pollution Assessment

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Abstract

In recent years, pollution load calculation has become a topic for research that resulted in the development of numerous GIS modeling methods. The existing pollution method for nonpoint source (NPS) can not be indentified and calculated the amount of the pollution precisely. This research shows that the association of typical pollutant concentrations with land uses in a watershed can provide a reasonably accurate characterization of nonpoint source pollution in the watershed using Expected Mean Concentrations (EMC). The GIS based pollution assessment method is performed for three pollutant constituents: BOD, TN, and TP. First, the runoff grid by means of the precipitation grid and runoff coefficient is estimated. Then, the NPS pollution loads are calculated by grid based method. Finally, the final outputs are evaluated by statistical technique. The results illustrate the merits of the approach. This model verified that GIS based method of estimating spatially distributed NPS pollution loads can lead to more accurate representation of the real world.

Keywords: pollution calculation; expected mean concentrations; nonpoint source pollution; GIS

1. Introduction

As the important indicators of water quality, BOD (Biochemical Oxygen Demand), TN (Total Nitrogen) and TP (Total Phosphorus) can be used to indicate the amount of water pollutants such as PS (point source) or NPS (non-point source) pollution. Non-point source water pollution can be recognized as pollution that is not related with sewer pipes with specific locations. Urban runoff, forestry operation, agriculture such as paddy and crop are all potential sources of NPS pollution. GIS based 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. Traditional 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. Thus, NPS models require a distributed modeling technique. Using expected mean concentration (EMC) method can overcome this problem.

The objective of this research is to develop a GIS based assessment model using EMC table for NPS pollution load calculation for the Nak-dong watershed in South Korea. EMC determines concentrations and loadings in the stream based on expected mean concentrations from land use information.

2. Related work

As NPS pollution has garnered more attention in recent years, governmental and private research institutions have designed methods of GIS based assessing nonpoint source pollution. 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". Schueler (1987) states the estimating pollutant export from urban development sites as well as USEPA (1992) as simple empirical approach. Spatially distributed models consider the basin spatial arrangement when defining values for the model factors. Lumped models exploit a single value for each factor for the whole watershed. GWLF (Haith et al., 1996) is an example of lumped factor models. Also, the event-based models simulate the rainfall or snowfall. They involve few meteorological data, but antecedent moisture conditions is necessary (Novotny and Chesters 1981). A list of required model collection criteria is accessible in NCR (2002).

3. Materials and Methodology

The study area in this research was a Nakdong watershed of Kyungsang province in east-south part of South Korea (Fig.1). This area is approximately 23,384 square kilometer. For this study, DEM with 30m resolution from Land sat 7 satellite images (1/5,000) and landuse with 30m resolution from Land sat 7 ETM (1/250,000) were used.

The method used in this study includes four steps. 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.

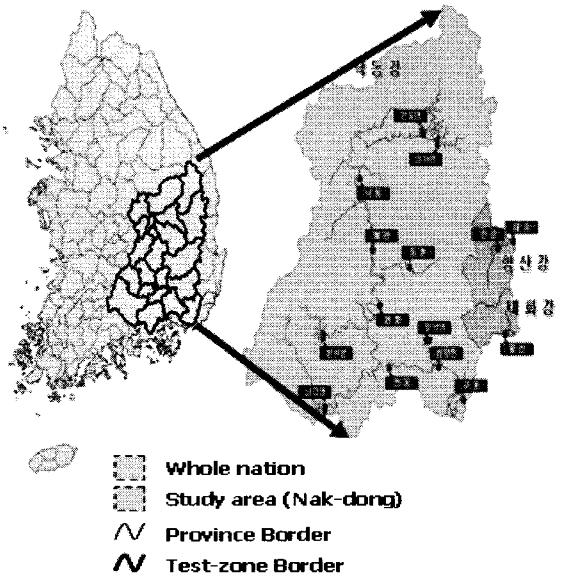

Figure 1. Nakdong watershed study area.

In the first step 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 Nakdong 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 landuse and soil type data using an empirical rainfall-runoff function, whose parameters are defined for different land uses.

In the next step, EMC table was calculated based on the following steps. In the first step, several random sample points from difference kind of landuse were gathered. Then, 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 Nakdong area.

Table 1. EMC table of Nakdong area.

EMC Factor	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

3.1 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 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. Fig. 2, 3, and 4 show the final results of EMC-DEM based NPS pollutant loads from each DEM cell or landuse polygon and summed using an accumulation function to get the total pollutant loads from the Nakdong watershed.

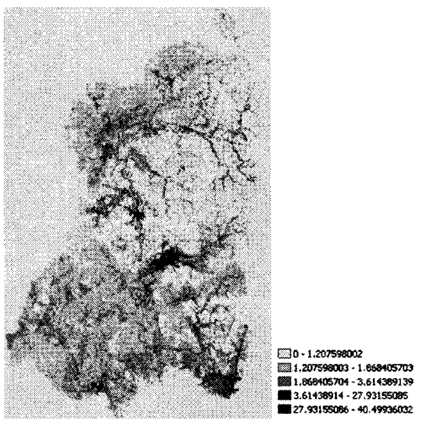

Figure2. BOD EMC loads grid.

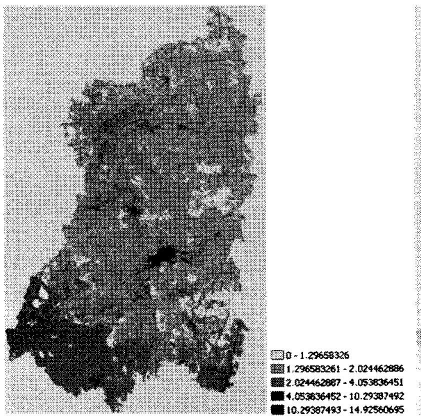

Figure3. TN EMC loads grid.

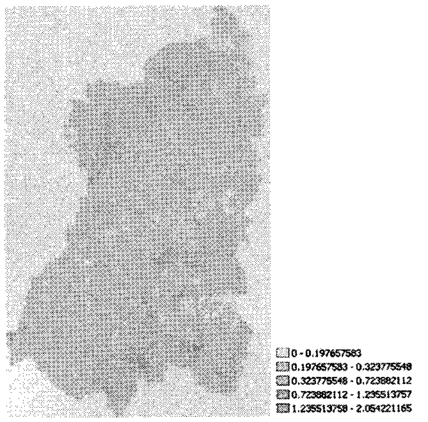

Figure4. TP EMC loads grid.

The GIS NPS pollution assessment method is performed for three important indicators of water quality (BOD, TN, and TP). EMC values for the pollutants were highly variable among landuses. This variation depends on many factors such as soil type, topography, precipitation. Advantages of the method are summarized below: First, 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. Finally, the EMC method offers an efficient way to identify specific regions with relatively higher pollutant loads.

3.2 Model evaluation

To evaluate the utility, generality, accuracy, and reliability of EMC-DEM model, comparisons are recommended between the expected concentrations and traditional technique using pollutant load unit factors. A statistical t-test analysis is run on the expected concentrations, the observed and traditional approach to determine if the model predicts the equilibrium concentration within a reasonable range.

An empirical NPS pollutant load model using pollutant load unit factors was used. The model output identified nonpoint source load from each landuse unit. The empirical NPS pollutant load discharges are calculated by multiplying the generation pollution load calculation by one practical constant number (0.25). The generations of pollution load calculations also are computed by multiplying each landuse area by the pollutant load unit factors.

An average t-test was applied in the Nakdong watershed using 31 observed sample points (n=62, α= 0.05, P=2.04). Fig. 5 illustrates the comparison between real value, EMC and traditional TN. This proves that the results of EMS table are very close to the sample data and the traditional values are very difference from sample data.

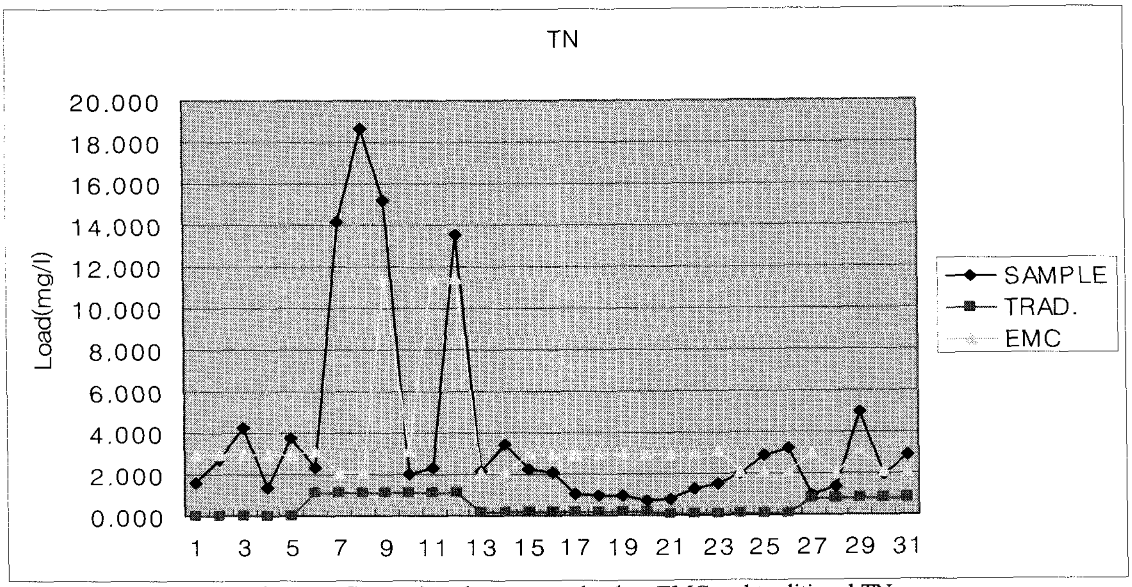

Figure 5. Comparison between real value, EMC and traditional TN

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 evaluation (n=62, α= 0.05, P=2.04), 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.

In the traditional method, pollutant concentration from runoff is assumed to be directly related to landuse in the region and is not considered other information such as geographical region, DEM, soil type, etc. In particular, a single average estimated pollutant concentration is assigned to all agricultural landuses instead of considering unique concentrations for different crops, soil types, or activities. The 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.

4. Conclusion

The used method in this research leads to an approach that determines the landuse based EMC values in a watershed properly. EMC values for the pollutant were highly variable among landuses. This variation depends on many factors such as soil type, topography, precipitation, etc. Overall, the EMC-DEM based model is seen to provide relatively accurate estimation of NPS pollutant loads and concentrations throughout the stream network than traditional concentration using pollutant load unit factors. Further studies need to be made for determining event based concentration which does not have constant pollutant for each landuse and also vary from event to event or among different landuse 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 the use of a water quality simulation model.

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References

Alves, M.A., 2005, *A Watershed Information System (WIS) for Water Quality Analyses*, PhD Thesis, Cornell University, NY, 190-200.

Aronoff, S., 1995, Geographic Information Systems: A Management Perspective, WDL Publications.

Groot, R. and J. McLaughlin, 2000, Geospatial Data Infrastructure: Concepts, Cases and Good Practice, Oxford University Press.

Haith, D.A., R. Mandel, and R.S. Wu, 1996, Generalized Watershed Loading Functions, Version 2.0. User's Manual, Cornell University, Ithaca.

NIER, 1999, Total Water Pollution Load Management Plan Establishment Methodology for Han River's watershed. National Institute of Environment Research, notification no. 1999-143, South Korea. http://www.nier.go.kr/

Novotny, V. and Chesters, G., 1981, Handbook of nonpoint pollution – sources and management, Von Nostrand Reinhold Company, New York-NY.

NRC-National Research Council., 2002, Assessing the TMDL approach to water quality management, National Academy Press. Washington, DC.

Schueler, T.R., 1987, Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs, Metropolitan Washington Council of Governments, Washington, DC.

USEPA, 1992, Guidance Manual for the Preparation of Part 2 of the NPDES Permit Application for Discharges from Municipal Separate Storm Sewer Systems. (EPA Document No. 833-B-92-002).