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Effects of Digital Elevation Model in Water Quality Modeling using Geogrpahic Information System

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Abstract

Aim of this research was to investigate the effects of Digital Elevation Model (DEM) for sensitivity analysis with two types of DEMs: 1 to 24,000 and 1 to 250,000 DEM. Another emphasis was given to the development of methodology for processing DEMs to create ArcGIS Pro and GRASS layers. This was done while developing water quality system modeling using DEMs which were used to model hydrological processes and SWAT model. Sensitivity analysis with DEMs resulted in different runoff volumes in the model simulation. Runoff volume was higher for the 1:24,000 DEM than 1:250,000 DEM, probably due to the finer resolution and slope which increased the estimated runoff from the watershed. Certainly the DEMs were factors in precision of the simulations and it was obvious during sensitivity analysis that DEMs had significant effect on runoff volumes. We suggest, however, that additional comparative research could be conducted involving more parameters such as soil and hydrologic parameters to provide insight into the overall physical system which the SWAT model represents.

Key Words: *DEM, Runoff Volumes, SWAT Model, ArcGIS, Water Quality System Modeling*

1. INTRODUCTION

A sensitivity analysis of a quantitative model is used to examine the effect of variations in model inputs and parameter values upon model behavior and output [1]. Sensitivity analysis assists in answering questions concerning the relative importance of the various model components and the accuracy needed in estimating model parameters [2]. While sensitivity analysis can identify their importance of a single variable or more to the mechanism of the model, it can not consider the effect of interactions between variables. Sensitivity analyses are used to indicate where care should be taken with parameter estimation or where the principal data collection efforts should be concentrated. A digital elevation model (DEM) is a numerical representation of surface elevations over a region of terrain. DEMs provide the same sort of information as contour maps, but in a digital format suitable for processing by computer-based systems rather than in an analog format. With the increasing availability of DEM and water quality modeling application with them, it is worthwhile to call attention for sensitivity analysis as GIS-based water quality modeling result depends on the priori established spatial data. In order to investigate sensitivity analysis, different factors or evaluation criteria are used based

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on the purpose of research and those evaluation variables include topographic, geological, climatic, and socioeconomic characteristics. As DEMs are increasingly used to model hydrological processes, the manner in which the model respond to the choice of raster cell size (scales) was investigated in this research. As the distribution of slopes can be most clearly identified with DEM, DEMs were used to investigate the results of runoff volumes which was affected by the sensitivity of runoff parameters, watershed surface area, and elevations changed under different DEM resolutions. Furthermore, amounts of runoff are mostly affected by when DEMs with finer resolutions were implemented. The purpose of this study was to investigate the effects of DEM for sensitivity analysis with water quality model and two types of DEMs: 1 to 24,000 and 1 to 250,000 DEM. Another emphasis was given to the development of methodology for processing DEMs to create GIS layers. This was done while developing water quality system modeling using DEMs which were used to model hydrological processes.

2. MATERIALS and METHODS

The watershed, located in Gwangju, was chosen as a study area. This study was accomplished by using DEM, ArcGIS Pro, Geographic Resource Analysis Support System (GRASS, 1994), and SWAT model which was used to measure runoff volumes [3] . In addition, Arc Macro Language and AWK were used for writing several programs. DEMs at a scale of 1:24,000 and 1:250,000 were purchased from National Geogrpahic Information Institute as ANSI-standard ASCII characters in fixed length blocked record format. The 7.5-minute Digital Elevation Model (DEM) data files are digital representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. Each 7.5-minute DEM is based on 30- by 30-meter data spacing with the Universal Transverse Mercator UTM projection. The 1-degree DEM (3- by 3-arc-second data spacing) provides coverage in 1- by 1-degree blocks and 1-degree DEM's are also referred to as "3-arc second" or "1:250,000 scale" DEM data. These DEMs later were imported to ArcGIS and changed to UTM coordinate system from State Plane coordinate system. The Soil & Water Assessment Tool (SWAT) is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change [4]. SWAT was used to assess soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

2.1. Processing of DEMs using GIS

As DEMs were acquired in ASCII format, it was necessary to generate spatial coverage in ArcGIS and then convert them into a GRASS layer as SWAT used GRASS layers to create model input parameters [5]. This process was also used to compare two different tools for DEM generation. To permit conversion of ArcGIS coverages to GRASS, several alternative methods were used. DEMs were converted into ArcGIS Pro grid by using ASCIIGRID command. After creating a single DEM , LATTICECLIP in ArcGIS was used to delineate the DEM covering only the watershed area. LATTICECLIP creates a lattice defined by the overlap between a grid and a polygon coverage. An existing watershed boundary was used as a clipping coverage and the outgrid was used as the grid to be clipped. GRIDASCII command in Arc was used to create a simple ASCII text file from a grid. Table 1 shows the ASCII file of DEM generated by GRIDASCII and -9999 is NODATA and 548 is real value. Raster cell values can be either positive or negative, integer, or floating point. Cells can also have a NODATA value to represent the absence of data. Sometimes there are homogeneous areas in a raster dataset that the you do not want to display. These can include borders, backgrounds, or other data considered to not have valid values and these are expressed as NODATA values, although other times they may have real values. In this paper, NODATA was stored as -9999 a common value for storing NODATA that was part of the raster dataset and these values was computed using neighboring available values. The file consisted of header information containing key words and values, followed by cell values in run-length order.

Table 1. ASCII header file and digital elevation values generated by GRIDASCII

nclos	332
nrows	349
xllcorner	464592.18115985
yllcorner	4535474.0035082
cellsize	92.9200241022554
NODATA_value	
-9999 -9999 -9999 -9999-9999 -9999 -9999 -9999 -9999 -9999 -9999 - 9999 -9999 -9999	
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 - 9999 -9999 -9999	
548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548	
548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548 548	

Header information reorganized by GRIDASCII must be modified to an appropriate format followed by a stream of grid-cell values. For this purpose, an awk program, fixgridascii.awk, was written to reformat the header file. The fixgridascii.awk program modified the header file so that R.IN.ASCII command in GRASS could recognize its header format to generate a GRASS layer. R.IN.ASCII converted an ASCII raster text file created by GRIDASCII into a binary raster map layer. To fulfill this process the input file must have a header section which describes the location and size of the data. The header information consists of the origin, the number of rows and columns, and the values used to represent NODATA mesh points. This information was followed by a space-delimited list of grid-cell values. The north, south, east, and west field values entered are the coordinates of the edges of the geographic region. The rows and columns field values describe the dimensions of the matrix of data to follow. The procedure used in sensitivity analysis was to run a set of SWAT input parameters which were generated by using two different DEMs. Two DEMs were used to delineate subbasins on a portion of the watershed, and those two subbasins were used as a basis for generating input parameters. Figure 1 shows the study area in 3D image created in GRASS. The GRASS r.watershed program, which uses an eight-cell search, was applied to the two DEMs for automatic subbasin delineation. Model simulation with SWAT using the two different DEMs resulted in hydrography at the outlet that reflected differences introduced by DEMs and calculated runoff volumes derived from DEMs.

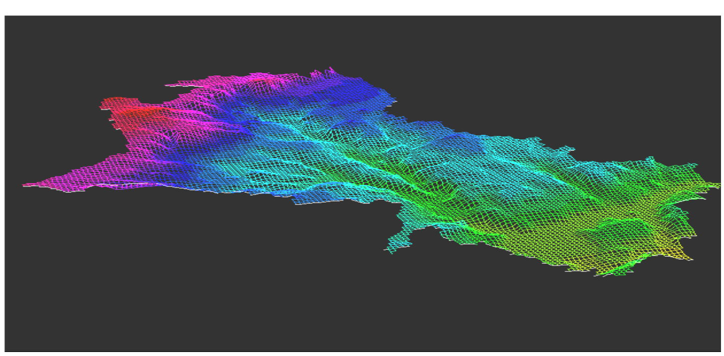

Figure 1. 3-D image of the watershed.

2.2. Sensitivity Analysis with DEM and SWAT

Two broad types of DEMs can be distinguished: gridded DEM and feature DEM. Gridded DEMs record a surface elevation for every intersection in a two-dimensional coordinate grid covering the region under investigation. Feature DEMs record only a random distribution of elevations across the region, especially those elevations along the boundaries of the Earth's surface features, such as roads and rivers [5]. Sensitivity analysis was carried out by investigating the sensitivity of two types of DEMs on runoff volume. The two DEM formats used were 1:250,000-scale (1-degree) data and 1:24,000-scale (7.5-minute) DEM data. The 7.5-minute DEM data (30m x 30m per cell) are more highly resolved than the 1-degree DEM data (90m x 90m), at three arc-seconds. A comparison was made of these two data sets on a portion of the watershed which was delineated based on 1:24,000 DEM data availability. A comparison of images of 7.5-minute and 1-degree digital elevation models for the variable of elevation for the watershed was presented. The images were displayed as a level-sliced color image, with red colors as higher elevations and yellow for lower elevations (Figure 2).

a) 1:24,000 DEM **b) 1:250,000 DEM**

Figure 2. Two DEM images which were used for sensitivity analysis of runoff volumes to model hydrological processes to the choice of cell size; a) is 1:24,000 DEM (7.5-minute) with higher resolution image and b) is 1:250,000 DEM (1-degree) with lower resolution image.

3. RESULTS

SWAT calculated runoff volumes during two years (2019-2020) for the watershed. As the model generated runoff volume in cubic feet per second, the conversion to cubic meters from feet was achieved by dividing the conversion factor (0.03719) by the total direct runoff (cfs). A linear regression, depicting measured runoff versus SWAT simulated runoff was generated for two years using S-plus. A satisfactory calibration was considered to be the set of curve number parameter values that minimized the difference between the simulated and observed runoff, and at the same time, yielded a least square regression equation of simulated versus observed monthly runoff that most nearly coincided with the equal value line [6]. Runoff volume was higher for the 7.5 minute data, probably due to the finer resolution and slope which increased the estimated runoff from the watershed (Table 2).

Table 2. Comparison of runoff volumes with two different types of DEMs

YEARS	1:24,000 DEM	1:250,000 DEM
2019	1.2^10^7	.7^10^7
2020	1.4^10^7	1.3^10^7
TOTAL	2.6^10^7	2.0^10^7

That is, as the slope of the watershed flattens (1:250,000 DEM), the response of stream flow was delayed and resulted in reduced runoff volume. The 7.5 minute DEM resulted in higher runoff discharges, whereas a flatter

DEM resulted in lower rise and lower runoff discharge. These results were somewhat consistent with findings made by Chaplot et al. in which the best SWAT cell size was the finer cell sizes [7]. Larger grid sizes (1:250,000) were found to underestimate runoff and erosion when compared to smaller size. From these results, it was concluded that the detail of hydrologic information that can be automatically extracted from a DEM was directly related to the quality and resolution of the DEM itself. In addition, it was concluded that, in application of water quality modeling analyses, 1 degree DEM data might be more preferable for water quality modeling. Figure 3 shows the compared results of runoff volumes produced by the DEMs.

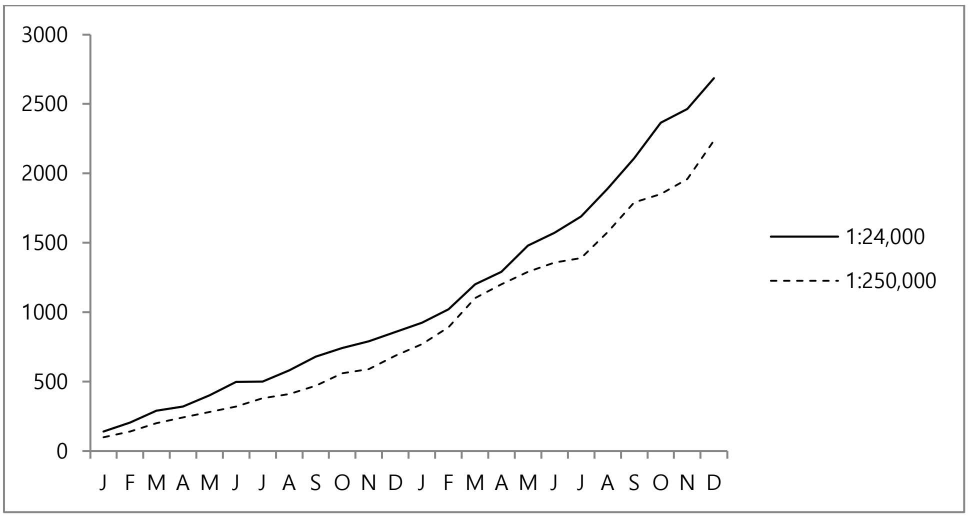

Figure 3. Comparison of total runoff volumes produced by two DEMs. X-axis is months and Y-axis is runoff volumes(10^4 m^3).

4. CONCLUSIONS

Through this research, pre-processing and post-processing procedures of DEMs to generate ArcGIS Pro and GRASS layers were developed to simplify the use of integrated GIS. Sensitivity analysis with DEMs resulted in different runoff volumes in the model simulation. Runoff volume was higher for the 1:24,000 DEM data, probably due to the finer resolution and slope which increased the estimated runoff from the watershed. Certainly the DEMs were factors in precision of the simulations. It was obvious during sensitivity analysis that DEMs had significant effect on runoff volumes. Adjusting the SCS Curve Number also resulted in a significant changes in runoff yield. We suggest, however, that additional comparative research could be conducted involving more parameters such as soil and hydrologic parameters to provide insight into the overall physical system which the SWAT model represents. Further applications of the model with higher resolution of DEM and various land use types are recommended. Comparison of DEMs revealed that 1:24,000 DEM might be more preferable for water quality modeling. SWAT model underestimated total runoff volumes with 1:250,000 DEM, but use of 1:24,000 DEM increased runoff volumes. We have concluded that, in our application in water quality modeling analyses, 1-degree DEM data are preferable to our applying DEM with water quality model. We suggest, however, that additional comparative research be conducted involving both types of DEMs for a variety of terrain types.

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