APPLICATION OF AnnAGNPS MODEL FOR SOIL LOSS ESTIMATION AND NUTRIENTS LOADING FOR MALAYSIAN CONDITIONS

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ABSTRACT

Non-point source (NPS) pollution is one of the major sources of contribution of pollutants to watersheds and stream water. Although awareness has increased in Malaysia over the last few decade, there is still no unified system that can continuously monitor and evaluate watersheds in the country. Most studies are limited to short-term evaluation and do not provide long-term monitoring. This study aims to apply AnnAGNPS watershed modelling to assess NPS pollution in three selected watersheds. Rainfall data of 2004 and 2005 are used to calibrate and validate the model. The results of simulation are generally satisfying. Runoff estimation could reach a coefficient of determinacy of 0.73, and event based sediment yield produced R^2 of 0.57. The average annual erosion rate of studied area is 62 Mg/ha/yr for 2004 and 123Mg/ha/yr for 2005. The distribution erosion is in agreement with the National Erosion Risk Map. N and P predictions are slightly inconsistent with R^2=0.69 and 0.64 respectively but with high standard deviation. The study is able to detect rubber estate and urban land as major contributor to soil erosion. Rubber estate is also the main contributor for nitrogen loading. The study also identifies LS factor to be the most sensitive parameter in influencing erosion and sediment yield. Error and inconsistency can be caused by reference data that may be not suitable for local condition. The average result shows that AnnAGNPS is able to perform well under Malaysian condition and can do even better if proper improvements are made. A database should be set up to aid local research in improving watershed study, particularly AnnAGNPS.

ABSTRAK

Pencemaran *NPS (Non-point Source)* merupakan penyumbang terbesar kepada pencemaran kualiti air sungai. Walaupun kesedaran tentang pencemaran ini semakin meningkat pada dekad yang lalu, Malaysia masih lagi kekurangan dari segi sistem pemantauan dan pengajian yang bersatu dalam menangani pencemaran ini. Kajian ini bertujuan untuk mengaplikasikan model AnnAGNPS ke atas tiga kawasan kajian untuk mengkaji kesesuaian penggunaan model ini di Malaysia dalam memantau pencemaran NPS. Kajian mendapati keputusan simulasi model adalah memberangsangkan. Simulasi air larian hujan memberi keputusan R^2 sebanyak 0.73, simulasi hakisan dan pemendapan pula memberikan R^2 sebanyak 57. Purata hakisan tahunan kawasan kajian didapati sebanyak 62 Mg/ha/yr untuk tahun 2004 dan 123 Mg/ha/yr untuk tahun 2005. Perbandingan pengangkutan nitrogen (N) and fosforus (P) simulasi dengan sampel air adalah sebanyak R^2 =0.69 dan 0.64 masing-masing. Ladang Getah dan kawasan perbandaran dikenalpasti sebagai guna tanah yang paling banyak menyumbang kepada hakisan. Selain itu, lading getah juga merupakan punca pencemaran nitrogen yang paling besar. Kajian juga mendapati factor LS mempunyai kepekaan yang tertinggi dalam mempengaruhi amaun hakisan di kawasan kajian. Ketidakjituan dan kesalahan dalam keputusan simulasi berkemungkinan besar disebabkan oleh ketidaksesuaian data yang dirujuk untuk digunakan dalam keadaan Malaysia. Keputusan yang memuaskan menunjukkan AnnAGNPS sesuai digunakan di Malaysia dan kecekapannya boleh dipertingkatkan lagi. Satu database yang sistematik dan menyeluruh perlu diwujudkan untuk menggalakkan pembangunan kajian pencemaran NPS terutamanya dengan aplikasi AnnAGNPS.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement: Non-point Source Pollution In Malaysia

Non-point Source (NPS) is pollution that refers to contamination by pollutant, which the sources of pollution is hard to be pinpoint or identified. The source of NPS is normally associated with an area rather than a location or point, i.e. agricultural land, golf courses and parking lots (Ritter et al., 2001). NPS pollutants include sediment, nutrients, pathogens, toxic materials, heavy metals and many more.

Computer modelling provides perfect aid in simulating, analyzing, and comparing data to help in decision-making. Many models are developed and modified to reach greater performance in watershed simulation. One of the more popular and renowned model is the Agricultural Non-point Source Pollution Loading Model (AGNPS) (Young et al., 1987). AGNPS was introduced by the Agricultural Research Service (ARS), United States Department of Agriculture (USDA) in the late 1980's (AnnAGNPS, 2005). The model is an event-based watershed simulation programme that could predict sediment yield, runoff, peak discharge, nutrients prediction, and other chemical properties. Over the years, AGNPS has developed into a powerful simulation tool for non-point source pollution continuous research and studies all around the world.

Upon its release, AGNPS instantly gain popularity in the United States. After proven by research for its efficiency, AGNPS was tested in various corner of the world, including Germany (Grunwald & Norton, 1999; Rode & Frede, 1998), Ethiopia (Mohammed et al, 2004; Heregeweyn & Yohannes, 2002), Italy (Lenzi & Di Luzio, 1995), India (Dayawansa, 1997) and Thailand (Chowdary et al., 2001). Most of these studies found that GIS integration is an essential part of modelling which will significantly reduce the effort and time of researchers in processing and storing of data. All the research above agreed that AGNPS predicts non point source pollution with generally good accuracy.

Realising the need, ARS revised the model and in 1998, they released AnnAGNPS, which is the Annual Agricultural Non-point Source Pollutant Loading Model (AnnAGNPS). AnnAGNPS (Bingner & Theurer, 2005) is similar to AGNPS but includes a continuous routing process that allows the model to simulate data of more than one day. The model is also bundled with other useful utility programmes including a GIS based interface. Application of AnnAGNPS shows better prediction of long-term non-point source pollution effect than previous versions of the model (Shrestha, 2005; Suttle et al, 2002).

In Malaysia, NPS pollution is at high level of concentration especially in urban areas during the wet (monsoon) season (MSMA, 2000). Although there are efforts of studying soil loss and nutrient transport using GIS (Shanker Kumar et al, 1998; Roslinah & Norizan, 1997), these studies are of short term and do not provide long term monitoring and prediction. Fortunately, though, Malaysia is heading towards the direction of environmental conservation. The government commitment in this aspect is shown by the release of Urban Stormwater Management Manual for Malaysia (MSMA, 2000). Implementation of guideline will only be successful if there is a uniform system used nationwide to monitor and analyze non point source pollution, as AGNPS is in United States.

1.2 Objectives

Realising the need to control non-point source pollution, and after thorough reading on this topic, a set of appropriate objectives have been underlined to define the scope of work and limit of this study. Upon completion, the study should be able to:

- Examine and validate the performance of AnnAGNPS model under local climate and condition.
- Estimate the amount of non-point source pollution namely sediment, nitrogen and phosphorus content.
- Identify areas or locations where severe pollution occurs and eventually provide useful information to help decision making in soil management and conservation.
- Create a database or a set of example work procedure to aid further study and development of the AnnAGNPS model in Malaysia.

1.3 Model Description

AGNPS (Young et al, 1987) and AnnAGNPS (Bingner & Theurer, 2005) are actually almost the same. Both models adopt the same basic principles with the major difference being, AnnAGNPS support continuous simulation while AGNPS only support single event simulation. The major difference between the models are summarised as below:

Table 1.1: Major Differences between AGNPS and AnnAGNPS

AGNPS	AnnAGNPS
Event Based Simulation	Continuous Simulation
Adopt USLE for Sediment Yield	Adopt RUSLE for Sediment Yield
MS-DOS based	Windows based (more user friendly)

As long-term evaluation is needed in this study, AnnAGNPS is chosen as the simulation model. Thus, following discussion will concentrate solely on AnnAGNPS model. As AnnAGNPS is developed based on AGNPS, the model retain strength of its predecessor and significant improvements are noticeable from previous versions. An obvious improvement is the adoption of Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). RUSLE is similar to Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) with only the technique and technology of obtaining the erosion factors being improved. The basic components of AnnAGNPS process are listed below (Borah & Bera, 2003; Bosch et al., 1998)) while further details are mentioned in Chapter 3: Methodology.

Table 1.2: Component of AnnAGNPS with corresponding theory and reference

Model Components	Adaptation	Reference
Runoff generation	SCS Curve Number Method	TR-55,1986
Channel Runoff	Modified Manning's Equation	Bingner & Theurer, 2005
Sediment Generation	RUSLE	Renard et al, 1997 Bingner & Theurer, 2005
Sediment overland Transport	HUSLE (Hydro-geomorphic Universal Soil Loss Equation)	Bingner & Theurer, 2005
Sediment channel transport	Einstein Deposition Equation Bagnold's Transport Capasity	Bingner & Theurer, 2005
Chemmical Routing	Conservation of Mass	Bingner & Theurer, 2003

For this study, AnnAGNPS model will be applied on three watersheds in Seberang Perai Selatan, Pulau Pinang Malaysia. Simulation period of 2 years (2004 and 2005) is chosen as the period of study. Simulation data will then be compared with field sampling data and available results from other similar studies in the region to determine the accuracy of AnnAGNPS.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With population growth, men are doing more damage to the environment. Water pollution is one of current major concerns. Generally, source of water pollution can be divided into 2 groups, the point source pollution, and the non-point source pollution. Point source pollution refers to pollution, which its source is easily located and identified such as the outlet of a wastewater or a factory disposal outlet. Non-point source however refers pollution, which its source is too general and is hard to trace down to a specific point of pollution. These pollutants include fertilizer application, domestic drain water, urban storm water runoff and pesticides application (Ritter et al., 2001). Of all these categories, sediment is the most significant NPS contaminant (greatest volume, by weight) according to Thornton et al. (1999). Both Thorton et al. (1999) and Ritter et al. (2001) agreed that rainfall runoff has the major influence of NPS in watershed. As watershed pollution becomes increasingly alarming in recent decades, study on this issue to find solution and control method has hastened the development of watershed computer modelling. Among some popular models includes ANSWERS, AGNPS and SWAT.

The Agricultural Non-Point Source (AGNPS) Pollution Modelling System is developed by joint effort of U.S. Department of agriculture, Agriculture Research Service (USDA-ARS) and Natural Resources Conservation Service (AnnAGNPS, 2005). AGNPS is a cell-base modelling programme capable of analysing both single event and continuous (only after certain modification) data input. AGNPS modelling has been rapidly developed in recent years and the current model (AGNPS 5.0) incorporates several modules and utility tools. However, the core of AGNPS consists of hydrology module, sediment yield module, and nutrient and pesticide transport module (AnnAGNPS, 2005).

AGNPS input data can be divided into watershed data and cell data. Watershed data includes all data applicable to the whole watershed while cell data differs from each individual cell. Since the model is cell-based, size and quantity of selected cell will affect labour involved, as well as accuracy and precision of simulation result (Wilson J.P., 2001). There are all together 22 parameters to be inserted in order to run the complete model. These parameters includes, land use, slope angle, soil properties, use of fertilizers, hydrology data and many more (Yoon, 1996; Phothong et al., 2004)

The main output of the model includes run-off estimation, peak flow estimation, sediment yield, phosphorus loading, and nitrate loading. The model uses exist mathematical and empirical method to yield all these output based on the 22 parameter inserted. The basic method for each output is presented in table below.

Table 2.1: Modules and Corresponding Basic Methodology *(Ma & Batholic, 2003)*

MODULES	BASIC METHODOLOGY
Hydrology Runoff	Curve Number (CN) Method by USDA-Soil Conservation Service
Hydrology- Runoff Velocity	Manning's Equation
Soil Erosion	Universal Soil Loss Equation (USLE)
Nutrients Loading (N & P)	Pollution Loading (PL) Computer Model

Responding to users demand, a team of scientists from ARS (USDA) and NRCS (USDA) joined up again to review AGNPS. In early 1998, AnnAGNPS is released. Also known as, AGNPS 2001, AnnAGNPS is viewed as the evolution of AGNPS. The new model not only inherits the flexibility and easy-to-use features of its predecessors, it has made significant improvements on weaknesses of previous models. Borah & Bera (2003) wrote on the review of watershed models and commented that AnnAGNPS is an excellent model for long-term assessment of watershed to support management practice especially in agricultural aspect.

Unlike the single-event simulation of AGNPS, AnnAGNPS includes a routing system that allows continuous simulation over long period (AnnAGNPS, 2005). Other major improvements from previous versions includes a built-in GIS/AGNPS interface, application of better processing methods (RUSLE, HUSLE, simulation of daily soil moisture) and incorporation of several useful programmes (TOPAZ, TOPAGNPS, AGFLOW).

There are over 400 input parameters for AnnAGNPS. These inputs can be categorized in five major categories, namely, climate, land characterization, field operation, feedlot operation, and chemical characterization (Bosch et al., 1998). Although some parameters are optional, many are essential for better simulation results.

Bosch et al. (1998) commented on the advantages and limitations of AnnAGNPS model. Some obvious advantages of the model include:

- The ability of model to self-modify the value of curve number, soil moisture, reach geometry features over time. This will create a simulation condition, which is similar to actual situation.

- Model includes user-friendly interface, which incorporates various useful models. These models (GEM, TOPAZ, AGFLOW), previously needed to be executed separately, can be executed in a convenient interface. The interface supports GIS, which improves spatial data management and storage.

However, Bosch et al. (1998) also mentioned a few limitation of the model as listed below.

- The routing system is fixed to a complete cycle of a day regardless how long it takes in actual situation.
- There is no spatial variation of rainfall. (will effect large watersheds)
- There is no tracking of nutrients deposition from a day to another (between routing periods).
- There is no consideration of mass conservation for water cycle.
- Point source loading rate is assumed constant.

Despite the limitation, AnnAGNPS has proved to be the preferred watershed modelling in the United States because of the support data provided by ARS and NRCS for this model (Bosch et al., 1998). The USDA server provides information and data for registered user in the country. The availability of data reduces the tediousness time consumption of data preparation.

2.2 Previous Studies on AGNPS and AnnAGNPS

AGNPS was first presented in 1985 and have since been tested and modified by hundreds of researchers and users all around the world. Rode and Frede (1998) tested the AGNPS model for soil erosion and water quality for agricultural catchment in Hesse, Germany. This was the first validation test carried out outside of the United States. The result was very encouraging with runoff estimation being labelled as 'generally satisfactory' and the sediment yield estimation presented good result with coefficient of efficiency (E) 0.85 and 0.93 for 2 tested watersheds.

Grunwald and Norton (1999) carried out calibration and validation of the model on two watersheds in Munich (Bavaria), Germany. They tested the models with 52 rainfall-runoff events (22 for calibration and 30 for validation). AGNPS is also tested on Augucho Catchment, Western Hararghe, Ethiopia. AGNPS is collaborated and tested with data record of 8-10 years on two different cell sizes. From this study, peak runoff rate and sediment yield are well predicted with runoff event being the only non-significant result (Heregeweyn & Yohannes, 2002).

Unlike AGNPS, AnnAGNPS application is less due to its relatively new release. Besides, AnnAGNPS requires 400 over input parameters, which may be a barrier to less developed nations, as complete data is not available. In 2002, Suttles et al. (2002) applied AnnAGNPS to assess sediment and nutrient loadings in Georgia Coastal Plain Streams in The United States. The result of simulation is compared to 7 year observed data. It is found that AnnAGNPS performs excellently in predicting runoff, except for forests areas. Suttles et al. (2002) suggests that AnnAGNPS should consider riparian condition to improve its applicability on coastal watersheds. As for sediment loading, the result has a similar trend of runoff. Suttles et al. (2002) commented that runoff is related to sedimentation by influencing the carrying capacity of sediment loads.

Shrestha et al. (2005) calibrated and validated AnnAGNPS according to highland condition. The study was performed on a watershed in Siwalik Hills of Nepal. Shrestha et al. (2005) aims to evaluate surface runoff, peak flow, and sediment yield of the area using AnnAGNPS. The required data were taken from MSEC project. The output of simulation shows that AnnAGNPS can perform rather well in highland area. The model underestimates runoff by 15% during calibration and 22% during validation. Peak flow prediction is somewhat poor with overestimation of 2.5-4 times of actual peak flow. Sediment yield is over predicted by 120% and 153%. Shrestha et al. (2005) pointed out that while TR-55 Curve Number Method (TR-55, 1986) excels in predicting runoff, it is not suitable to estimate peak flow. The method of calculating ranfall-runoff erosivity factor, R for soil loss estimation should be improved, according to Shrestha et al. (2005).

2.3 Developments on AGNPS with GIS or Other Interface

From research and study, many users of AGNPS find the major drawback with early versions of AGNPS models is the handling of massive amount of input and output data (Lenzi & Di Luzio, 1995; Leon et al., 2000). He (2000) commented that although some modules can automate input data processing, most of AGNPS modules are not integrated with Geography Information System (GIS) to allow editing, displaying and updating of data. It is clear that AGNPS model lacks versatility without GIS interface software, as the data management of AGNPS model alone appears to be too tedious and time consuming.

As stated in previously, AGNPS has its weakness especially in estimating runoff (Heregeweyn & Yohannes, 2002; Rode & Frede, 1999). Other shortcomings of AGNPS includes it does not have a subsurface flow component (Borah & Bera, 2002). The model does not include subsurface flow simulation, which is also a source of NPS. However, subsurface water contribution of NPS is far less compared to surface runoff. Another complaint on AGNPS is the size of study area and cell size is limited to a certain size. The size of study area ranges from few hectares to about 20,000ha (Wilson J.P., 2001)

To tackle some of these problems in using AGNPS, some innovative measures have been taken. Many users incorporate or link AGNPS with GIS tools to increase its versatility and capability. In Padova (Italy), Lenzi and Di Luzio (1995) developed an integrated AGNPS/GIS Software to deal with large amount of data effectively. The software creates an environment that simplifies data entry and presentation. In pre-processing phase, the software permits data combination, reclassification, and editing with ease. In post-processing unit, the software loads the output data in graphical mode to allow easy evaluation and reference of the large amount of simulated results. The study yield result similar to previous validations as the only non-significant outcome was the runoff while the other results are largely satisfying.

In a research of directly linking AGNPS with GIS and a Relational Database Management System (RDBMS), Yoon (1996) emphasize that such integration can facilitate better data storage, manipulation, and analysis. The direct linkage provides direct data entry to AGNPS model from GIS software, while having to do this manually previously. The direct linkage allows instant modification on data and having an instantaneous result will help in decision making such as Best Management Practices (BMP) for watershed.

Dayawansa (1997) put remote sensing into use in the effort of applying AGNPS model to an important sub catchment, Nilambe, Sri Lanka. In the process of obtaining all the 22 input parameters of AGNPS, 5 parameters were found directly dependant on land use and cover, thus, a method was suggested for using remote sensing to develop required digital maps through Indian Remote Sensing Satellite (IRS LISS II). From the maps, data are then extracted using programmes and can be directly included in AGNPS model. Although Dayawansa (1997) did not develop a thorough system to extract all data from maps and digital images, her effort of using remote sensing in acquiring up-to-date data provide inspiration to many later developers and researchers. In her findings, Dayawansa noted that AGNPS generates acceptable estimation of soil erosion, sediment yield, and production of nitrogen, phosphorus, and chemical oxygen demand (COD). She also acknowledged the efficiency of applying remote sensing and GIS to AGNPS in the aspect of obtaining up-to-date and detail results.

In year 2000, Leon et al. presented the idea of creating a diffuse pollution model included in a decision support system. The system consists of pre-processing and post-processing tools, model control and sensitivity analysis. The chosen model is AGNPS and the base system is the Regional Analysis Information System (RAISON). Leon et al. pointed out that though similar to normal GIS, RAISON emphasizes decision support and expert system. Though the research is still under study, the paper has shown encouraging results of how new technologies improve data manipulation, input file creation, simulation control and result interpretation.

It is known that most input data of AGNPS model are interpreted from digital maps. However, map information are only updated at set intervals, making the use of GIS limited in monitoring environmental phenomena such as critical area and rapid growing urban land. Satellite Remote Sensing on the other hand provide excellent data source for environmental study and monitoring. By integrating remote sensing with GIS and watershed model, a powerful tool to manage the environment is created. A case study on 2,700ha Damodar River valley using this system shows significant result (Chowdary et al., 2001). The study successfully constructs a framework in environmental monitoring. The framework (integration of AGNPS model, Arcinfo GIS and Remote Sensing) provide excellent service in creating AGNPS input data, prioritizing watershed by severity of pollution, and pinpointing critical areas that are crucial for any decision making.

During a study of land use impact on water quality on Dowagiac River, Michigan (USA), ArcView NonPoint Source Pollution Modelling (AVNPSM) was developed. The programme integrates ArcView Spatial Analyst with AGNPS in a Windows-based environment using Avenue (programming language for ArcView). The programme covers data generation from digital maps to visualizing output results. By applying AVNPSM to the study area, the author finds it to be very user friendly and significantly improves the efficiency of NPS modelling process (He, 2002).

In the same year, Finn et al. (2002) carried out a comprehensive study of applying GIS to AGNPS. Four watersheds; two in Georgia, 1 in Indiana and the other in Washington, were studied. Finn et al. (2002) emphasized on the importance of directly extracting data from sources. Therefore, a programme capable of generating input parameters, executing the AGNPS model, and analysing the output is developed.

Part of the model, known as AGNPS Data Generator provides user-friendly interface between GIS database and AGNPS model to allow direct extract of input from EDRAS Image. In this study, Finn et al (2002) demonstrated the development of AGNPS/GIS interface and validated it using the data collected from the four watersheds.

Ma and Bartholic (2003) carried out study in Marrow Lake sub-watershed, Michigan (USA). The study uses GIS to access input data then analyze the data using AGNPS. However, instead of manually entering the interpreted data (by GIS ArcView or Arc Info), Ma and Bartholic (2003) developed a data input model, AGDAT to aid this cause. The model is programmed to utilize AGNPS formatted data directly from GIS generated database. Using the developed link programme, the study area is assessed to analyse how watershed NPS changes under different situations and conditions in a watershed.

A more recent study sees AGNPS being integrated with GRASS carried out by Phothong and Corner (2004). The AGNPS-GRASS interface was developed in 1992. Phothong and Corner tried to refine and correct some difficulties in the programme. In this study, methods of generating all 22 parameters of AGNPS input using AGNPS-GRASS are shown. The programme produces all 22 parameters in 13 layers of digital maps. The study also refines some mathematical methods of generating data to obtain results that are more accurate. Though the integration of AGNPS-GRASS still contains a few flaws, the study still succeed in proving that a GIS aided AGNPS model is more user friendly and more efficient in studying NPS in watershed.

2.4 Watershed Studies in Malaysia

In Malaysia, GIS has been blooming. Its application in watershed study however, is still at an infant stage. In an effort to apply GIS to watershed study, Shanker Kumar et al. (1998) has developed a distributed NPS simulation model in a GIS-base environment. ArcView GIS Spatial Analyst has been chosen as the core programme. The NPP model was written into the programme using Avenue (Programming language for Arc View GIS). The study was divided into 3 stages: Conceptual stage, Implementation Stage and Validation Stage. Shanker Kumar et al. (1998) commented that the model provide good platform to study annual or monthly soil loss by altering input data. However, the programme is claimed to be somewhat short in predicting detailed events such as soil loss in a single rainfall runoff.

The Malaysian Government has also been active in implementing GIS in developing environmental mitigation methods. In the nation’s effort to conserve soil and water, Erosion Risk Map is developed by integrating USLE with GIS. Watershed maps, Agroclimatic maps, terrain class maps, and database for soil physical properties are all generated from the application of GIS (Mohd Zulkifli Mohammad, 2000). These efforts although do not involve direct watershed study, still provide vital information for any research on watershed studies.

2.5 Summary

Non-Point Source (NPS) Pollution appears to be one of the major concerns of environmental study. Rainfall runoff events are believed to be major contributor to watershed pollution (Thorton et al., 1999; Ritter et al., 2001). AGricultural Non-Point Source (AGNPS) Pollution model is developed by USDA-ARS and NRCS to simulate watershed pollution (AnnAGNPS, 2005). AGNPS consists of three major modules, which are Hydrology, Erosion and Sediment, and Nutrients Transport. After being introduced in 1985, AGNPS has been tested and validated all around the world (Rode and Frede, 1999; Grunwald and Norton, 1999; Heregeweyn & Yohannes, 2002). Among some common finding of validation is that the runoff estimation is rather poor while sedimentation and nutrient loading estimation proved to be excellent. Another common comment of AGNPS is the complication in data entry and management (Lenzi & Di Luzio, 1995; Leon et al., 2000). In recent years, users tried to simplify data handling of AGNPS by associating it with other spatial database software such as RDBMS (Yoon, 1996), RAISON (Leon et al., 2000), ArcView or ArcInfo (Heregeweyn & Yohannes, 2002; Ma and Bartholic, 2003), and GRASS (Phothong and Corner, 2004). In Malaysia, effort of applying GIS in environmental study has been growing steadily. Mohd Zulkifli Mohammad (2000) showed that the government are using GIS-base software to develop environmental data such as erosion risk map and watershed map. Shanker Kumar et al. (1998) develop NPS model within GIS Arc View Spatial Analyst environment in effort to study Sungai Kulim River Catchment.

CHAPTER 3

METHODOLOGY

3.1 Area of Study

Three watersheds are selected in this study. All the watersheds are located in the district of Seberang Perai Selatan, Pulau Pinang, Malaysia. Figure 3.1 shows the location of Pulau Pinang and Figure 4.2 shows the area of study (Seberang Perai Selatan District). Both figures are satellite image obtained from http://maps.google.com.

Figure 3.1 Location of Pulau Pinang in Peninsular Malaysia

Figure 3.2: Area of Study in Pulau Pinang

Two of the watershed, namely Sungai Bukit Teh Watershed (Figure 3.3) and Sungai Tasik Chempedak Watershed (Figure 3.4) are next to each other while the third, Sungai Kuala Tasek Watershed (Figure 3.5) is a larger watershed that overlaps the previous 2 watersheds, as it is located further down stream.

These watersheds have almost the same characteristic and experience almost the same climate. The largest activity in watershed area is agricultural (rubber estate). The quality of the rivers in the area is in jeopardy, as the effect of such extensive agricultural activity has never been studied. The related river, Sungai Junjung is one of the largest rivers in the state. Its water quality should be properly assessed to monitor environmental pollution and to help the state government to draft effective environment quality plan and management system.

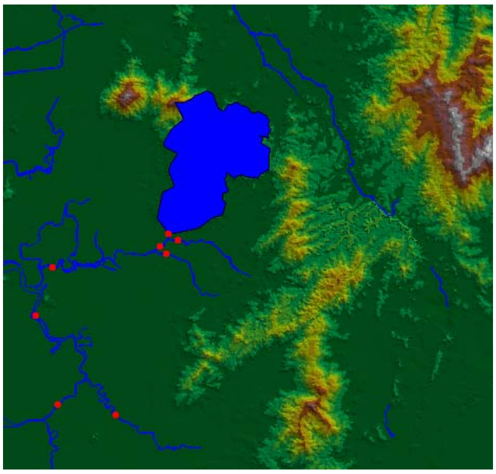

Figure 3.3: Sungai Bukit Teh Watershed

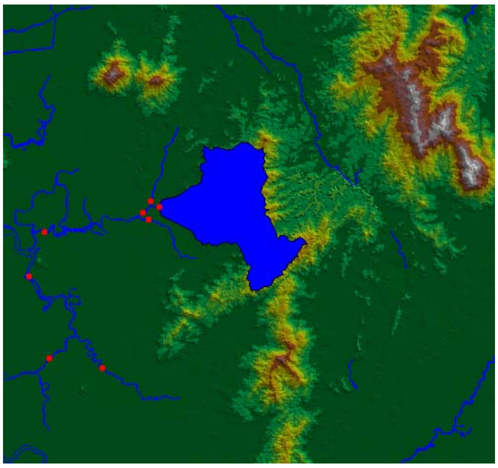

Figure 3.4: Sungai Tasik Chempedak Watershed

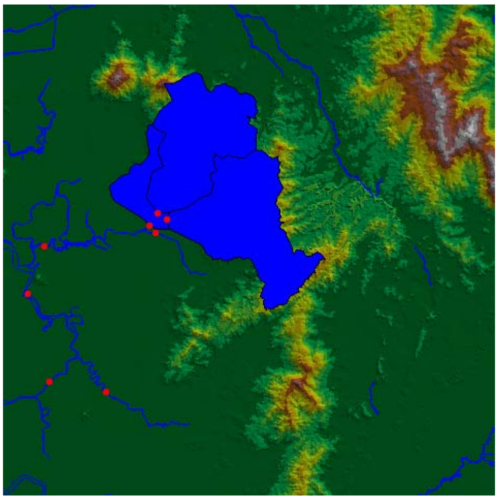

Figure 3.5: Sungai Kuala Tasek Watershed

3.2 AnnAGNPS: Annual Agricultural Non-Point Source pollutant loading model

The AnnAGNPS (Version.3.5) is used for this study. The software is developed by Agricultural Research Service, United States Department of Agriculture (USDA) and National Resources Conservation Service, USDA (USDA, 2005). Apart of providing watershed simulations, the programme also support pre and post modelling data processing, spatial data support and other utility extension software. The whole process of analyzing a watershed is shown in the flowchart below:

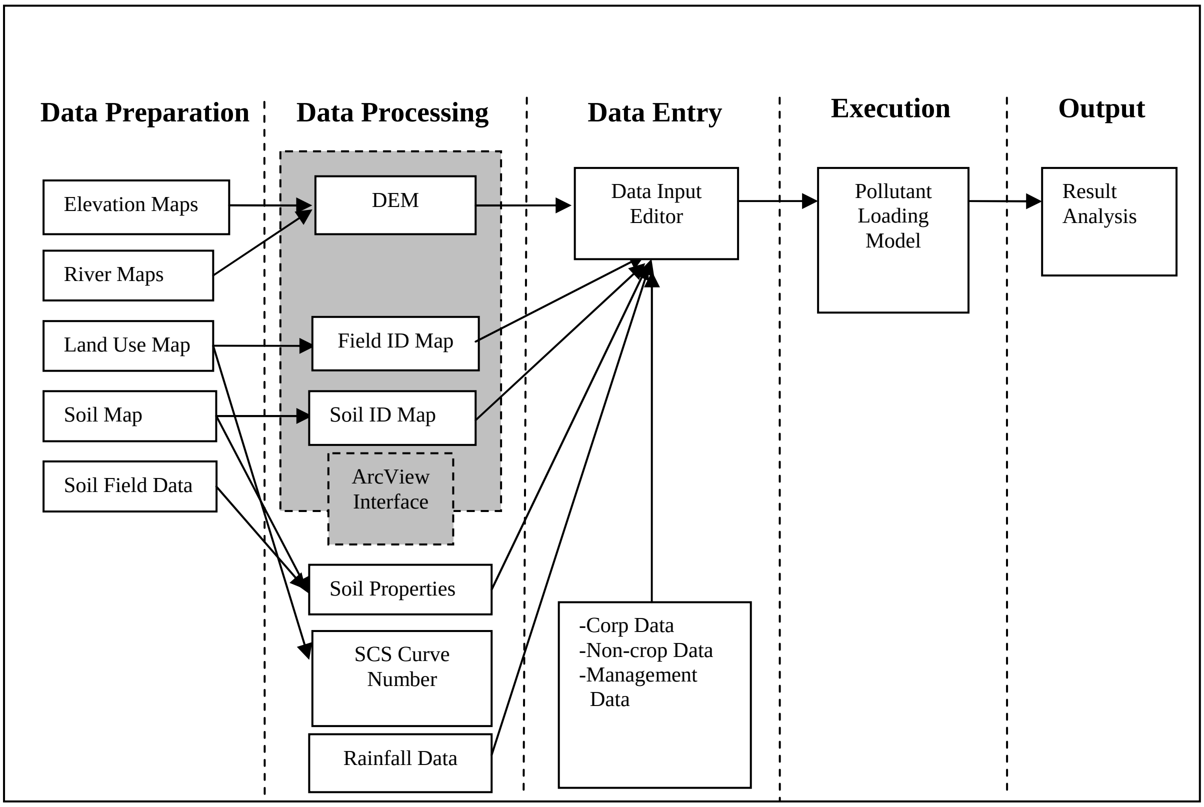

Figure 3.6: Flowchart of Data Processing

The ArcView/AnnAGNPS interface provides a good working environment to link all sub programmes together. The interface has the ability to process spatial data and transform it to data format required by the pollutant-loading model. Then from the pollutant-loading model, output data can be visualized using the interface.

The pollutant-loading model is the core of AnnAGNPS where all simulations and data processing is done. The pollutant model consists of three main simulations. First, the model will calculate hydrology results using the SCS Curve Number. Then, erosion modelling is executed based on the Revised Universal Soil Loss Equation (RUSLE). Finally, pollutant chemical loadings are computed using normal conservation of mass equilibrium calculation (Bingner & Theurer, 2005). Then, these results are routed for every cell in the model and based on the irrigation and drainage system generated; transportation of sediment is simulated, generating results of runoff, sediment, and pollutants at the outlet of watershed. As these calculations and concepts are the most fundamental part of the watershed simulation, these are discussed as below.

3.3 Runoff Estimation: SCS Curve Method

The runoff estimation method used to estimate surface runoff due to a rainfall event is the Soil Conservation Service Curve Number Method (TR-55, 1986). The method is thoroughly described in Technical Release-55 1986 issued by NRCS, USDA. In this part, only the application of SCS Curve Number method in AnnAGNPS is discussed.

Runoff is affected by several parameters such as soil type, soil moisture content, and ground cover. As these parameters are not constant throughout the watershed, the curve numbers need to be adjusted to this situation as well. To achieve this, the soil is split into two layers at the depth of 203.2mm (Bingner & Theurer, 2005). The parameters and properties of the first layer will change according to agricultural activity, climate, and so on; the second layer remains constant throughout the simulation.

Before the programme can carry out modification, a reference curve number should be provided. These values of curve number differ from every soil hydrological group and land use type. In this study, the reference are made to Technical Release-55 1986 (TR-55, 1986) issued by NRCS, USDA.

From these reference values, the curve numbers are modified according to localized (cell) soil properties, agricultural activity, and climate effect. Among the adjusted parameter due to such changes are soil moisture content, hydraulic conductivity, curve number for both dry and wet condition (CN_1, CN_3), and effect of wet and dry condition to retention time (S). The curve number modifications for dry and wet condition are given as below (Bingner & Theurer, 2005):

$$CN_1 = CN_2 - \frac{20(100 - CN_2)}{100 - CN_2 + \exp\left[2.533 - 0.0636(100 - CN_2)\right]} \tag{3.1}$$

Or

$$CN_1 = 0.4CN_2 \tag{3.2}$$

The greater value is taken. The modification for wet condition is given as below:

$$CN_3 = CN_2 \exp\left[0.00673(100 - CN_2)\right] \tag{3.3}$$

After the curve number is calculated, it is not directly used. Instead, the retention time (S) is extracted from it. The retention time, S is given as,

$$S_i = 254\left(\frac{100}{CN_i} - 1\right) \quad (3.4)$$

When the value of S is known, the S value is then modified to the daily condition using empirical formula developed by USDA-NRCS. Only the actual value of S is used to calculate the quantity of runoff using the following equation:

$$Q = \frac{(WI - 0.2S)^2}{WI + 0.8S} \quad (3.5)$$

Where

Q= Runoff quantity (mm)

WI= Water Input (mm)

After runoff is calculated using the SCS Curve Number Method, other processes that may affect the runoff volume is taken into consideration. These conditions include the effect of evapotranspiration, and subsurface flow. The flow chart of typical runoff estimation is illustrated in figure 3.7.