WATERSHED MANAGEMENT USING GIS IN EAST JAVA PROVINCE OF INDONESIA

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
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in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE DECLARATION

I here by certify that the work which being presented in the dissertation entitled : **"WATERSHED MANAGEMENT USING GIS IN EAST JAVA PROVINCE OF INDONESIA,"** in partial fulfillment of the requirement for the award of the degree of the Master of Technology in Water Resources development Training Center (WRDTC) Department, Indian Institute of Technology Roorkee, in authentic record of my own work carried out during period from July 2003 to June 2004, under the supervision and guidance of Dr. Deepak Khare and Dr. Sanjay Kumar Jain.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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ABTRACT

A watershed is made up of the natural resources in a basin, especially the water, soil and the vegetation factor. The comprehensive development of a basin so as to make productive use of all its natural resources and also protect them is term watershed management. Watershed management particularly refers to the development of land water resources. This requires a reliable information on various characteristic of a watershed such as topography, land cover, rainfall, drainage, soil, geology etc. The information normally acquired from different sources for watershed management is large in volume and needs an efficient system wich stores, handles, manipulate and analyzes this information.

Geographic Information System (GIS) is a computer based system design to store, process and analyzes spatial data and their corresponding attribute information. Due to their capabilities and wide application the GISs are becoming important in natural resources management.

This work present in this study is runoff potential assessment from existing watershed management and the erosion hazard level under existing and proposed condition of watershed management using Integrated Land and Water Information System (ILWIS). ILWIS is a GIS developed by International Institute for Aerospace Survey and Eart Sciences (ITC), Enschede The Netherlands. ILWIS has both raster and vector based capabilities some basic principles of GIS are also reviewed for general conceptual understanding.

Jati watershed and Singgahan watershed, which locate in Trenggalek District, East Java Province Indonesia, are selected . Government of Eat Java Province through The Brantas River Basin Development has planned to construct a rain water structure, likely small dam in the outlet of two watersheds. This study is to assess runoff availability, runoff requirement for development plan and water balance in the watersheds, however assessment of soil loss hazard with existing watershed management which will become a problem in erosion and sedimentation in the small dam, and proposed watershed management that is soil conservation practices which will expected to reduce soil loss hazard.

The potential runoff from watershed under current management conditions was assessed and estimated using SCS- direct runoff model based on the availability rainfall data. The model parameters are CN and S were evaluated under different management conditions. Universal Soil Loss Equation (USLE) and SCS runoff model parameter were analyzed and their attribute map were generated from the common spatial data base created by ILWIS

Soil erosion due to sheet and rill form the watershed under consideration has assessed and estimated using the USLE empirical model. USLE has six factors : rainfall erosivity factor (R) , Soil erodibility factor (K), topographic factor (LS), Crop Management factor (C), and conservation support (erosion control) practices (P). The values of these factors were analyze depending on the data available for different management conditions.

Finally the result (along with brief discussion) of the estimates of runoff. avaibility, water balance, and soil loss in the watershed model under existing and proposed condition are given in the form of figure and table.

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CHAPTER I
INTRODUCTION

1.1. GENERAL

Planning and management of rainwater resources requires access and used of large amount of data. Depending on the availability of data, the planning process may require data collection, storage, processing, retrieval and presentation. The particular is the high capability to access , handle and manage information. This, together with the fact that most of data required planning for rainwater resources is geographic, point to priority need for access to computerized Geo-referenced Information System (GIS). (Hatibu,N 2000; O.B.Mzirai and J. Rockstrom 2000)

Planning constitute decision-making and requires easy access to information. GIS is the best way of handling this information for the following reason :

- Nearly all of the information for watershed management planning has some geographical facts,
- The data that is available for planning is of different types (spatial and none spatial) and from different sources,
- The visualization capability of GIS makes understanding data easier,
- Sharing of information is made easier and efficient.

GIS is defined as any system of procedures for assembling, storing, manipulating and displaying geo-referenced data and information. A computer-based system has four main capabilities. These are: input, management, manipulation and analysis, and presentation and reporting (Aronoft 1989)

The computer-based GIS needs data, data acquisition should therefore be considered an important aspect of GIS. This requires that GIS managers should be clear on the following two issues (Tamlinson et al., 1976):

- Identification of all sources of required data (spatial and attribute), their location, accessibility and collection procedures.
- Development of links and collaboration with agencies and institutions involved in gathering the different types of data to be used as an input to the system.

1.2. NEED OF GIS IN WATERSHED MANAGEMENT

Estimation of the expected amount of runoff in a given area is important in planning of any watershed management-program. Unless agood assessment of the available runoff that can be harvested or conserved is made, it is difficult to even start considering watershed management. The availability of runoff is determined by factor such as land surface, soil type and rainfall characteristic.

With others remaining the same, the characteristic of land surface can indicate the extend of runoff that can be expected. A good watershed management plan make use of naturally occurring runoff. However it is not possible to find this kind of runoff in every location or for every type of watershed management-project. The non-availability of naturally occurring runoff will increase the extend of manipulation necessary on catchment's and hence, cost of the scheme. The main factors affecting runoff generation are slope, length, vegetation cover and surface roughness of the catchment. Risk of erosion is also an important factor to be considered in choosing catchment's area.

Employing manual techniques to integrate the vast amount of data from a variety of sources for the purpose of obtaining the desired logical results for use in the watershed management aspects is both time consuming and expensive. On the other hand the present advancement of technology made it possible to easily handle and analyze large volume of data using computer based systems. A GIS in particular provides enormous potential for effectively storing, handling, manipulating, and analyzing multiple spatial data sets in a single analysis at high speed unmatched by any other method.

1.3. OBJECTIVES OF THE STUDY

The emergent geographic information system technology has been gaining popularity in its wide range of application and its capability of organizing, storing, editing, analyzing and displaying large volume of information which is referenced to geographic location and its attributes. The recent effort trying to integrate GISs and resource models into tight-coupled system in a way where both can interact directly, laid a ground for better resource planning and management decision-making. To attain the desired benefit from this new technology, therefore, requires the conceptual understanding of the system.

The principal objective of this study lies in demonstrating the application of GIS in watershed management. For present study watershed from East Java Province of Indonesia is considered. The details of the objectives of this study are: -

i) To show the potential capabilities of GIS in general, for watershed management problem.

ii) To show how predictive runoff and soil loss models can be modeled in GIS.

iii) To assess the runoff producing potential and accumulation of runoff for different land use/land cover.

iv) To assess the erosion hazard from Watershed using Universal Soil Loss Equation (USLE) GIS model.

v) To obtain the appropriate techniques of Engineering measures for catchments protection on prevailing condition in the target area through GIS modeling.

1.4. ORGANIZATION OF THESIS

The scope of this study is limited to runoff calculation and soil assessment and prediction. A review on rainfall-runoff model by SCS methods and Mogglen approach to create runoff accumulation model, soil erosion, USLE parameters, and some engineering measures for catchments protection are made in Chapter Two. For conceptual understanding some of the basic principles of GIS are reviewed and the basic components are briefly discussed. A highlight of present trend of GIS as a management tool and the possibilities of integrating resource models with GIS are also discussed in Chapter Three.

A summary of information on Jati and Singgahan watersheds in Trengggalek East Java Province Indonesia is presented in Chapter Four, which are considered in the present study. The report served as the main data input for the present study. The discussion on these data includes the existing condition and proposed development plan of the watersheds including assessment of runoff volume, water balance in the watershed and expected runoff volume to meet the demand of water requirement in the beneficiary area. The assessment of soil loss hazard in the watershed includes before and after the proposed soil conservation practices will applied in order to reduce soil loss.

Considering the existing condition and proposed development, soil erosion hazard and runoff producing potential and accumulation of various land use/land cover units were assessed. The final results of the analysis are presented in the form of images and tables along with concluding remarks. At last, an attempt was made to compile at the useful earlier works in the field of study and are listed e the end in the reference section.

CHAPTER II
LITERATURE REVIEW

In the present chapter some of the related papers are discussed for watershed management, important components like runoff, soil erosion and engineering measures are described.

2.1. GIS APPLICATION FOR WATERSHED MANAGEMENT

Gupta and Tamhane (2004), applied GIS as toll for watershed analysis. The work has been carried out are in the following manner:

- District level resource mapping creation was done using 1: 50,000 Survey of India Topo sheets keeping in view the project objectives.
- IRS–1D, LISS-III digital satellite data of 23.5 meter resolution were procured from NRSA, Hyderabad for two seasons (i.e. Rabi and Kharif cropping seasons) for land cover mapping and updating the information/data gathered from the base maps generated from 1:50,000 Survey of India Topo sheets.
- Digital Image processing of satellite data using standard software packages was done for data merging, enhancement of relevant features, digital classification and conversion to thematic maps bringing the processed data into GIS environment for water resource mapping from satellite imagery.
- By combining the remote sensing information with adequate field data, based on the status of water resources development and irrigated areas (through remote sensing), artificial recharge structures such as check dams, nala bunds etc were recommended upstream of irrigated areas to recharge downstream areas so as to augment groundwater resources.

Sarangi et, al (2004) developed User Interface in ArcGIS for Watershed Management, the developed interface is a useful tool for integrated watershed management. This also endorses the use of advanced computer assisted technology applied to the management of natural resources on a watershed basis. The interface provides the inexperienced or new user with an entry point to a powerful GIS without any detailed training in hydrological modeling. The interface command buttons perform a series of inherent GIS instructions and displays the results in a user-friendly format. The link of the developed interface with Watershed and Stream Delineation Tool (WSDT) for watershed delineation and stream network generation assists the user to start watershed management activities from a DEM, without looking for digitization of topological information. The intent of this paper is to link the geospatial database with the interpretive routines for estimation of morphological parameterson watersheds.

The Visual Basics for Applications (VBA) programming language and the ArcObjects technology used in this interface is an emerging field in GIS based applications. The flexibility of the interface for further modification and updation is an added advantage with the interface. This technique will further assist the linkage of hydrologic simulation models for prediction of real time sediment and runoff estimations on watersheds. This interface on watershed morphology estimation within ArcGIS environment is first of its kind and is a useful tool for watershed prioritization and prediction of hydrologic responses.

Adhikari,(2003) developed GIS - Remote Sensing compatible rainfall-surface runoff model for regional level planning. In the broad sense, the term hydrological modeling implies rainfall-runoff modeling, which helps in simulating and forecasting the flow from a catchment and in determining the inflow series for the ungauged catchments. Efforts have been made for the spatial distributed nature of the watershed properties by introducing GIS for spatial discretisation of watershed into interlinked systems of triangles and development of a physically based rainfall-surface runoff model for simulating flood hydrographs in a user-friendly interface (GUI). The model is compatible with both the GIS database and the Remote Sensing (RS) data, although interactive option is provided to the user for modifying the database, if necessary. GIS has also been used to describe the various thematic layers such as physiography, landuse, soil etc. in the study. Terrain modeling is a pre-requisite to hydrologic simulation of the rainfall-runoff process. Algorithms have been used in the present study to extract watershed features such as overland flow cascades, channel network, confluence points, ridges etc. for a given digital elevation data using

Triangulated Irregular Network (TIN). The overland flow is modelled as one-dimensional sheet flow over cascades of overland "flow planes" contributing as lateral inflow to the channels flowing in the valley. Both the overland and channel flows are simulated using the kinematic wave approximation of fluid flow and solved through explicit finite difference routines. The main input to the watershed is taken as the rainfall. The usage of the model for regional level planners is demonstrated for tasks such as determination of waterways for small bridges and culverts, design of spillways of small dams, construction of flood protection levees, agriculture, site planning for micro hydels etc

Hadi and Hamid (2003) worked for the Sediment yield potential estimation of Kashmar urban watershed using MPSIAC model in the GIS framework, with due attention to the relatively suitable compatibility of MPSIAC model with the arid and semiarid conditions of Iran and lack of hydrometric station in region, in order to estimating of sediment yield and providing sediment yield and erosion intensity map in this watershed, we used modified PSIAC model. At first to enter the available raw data into the GIS framework we digitized topography, geology, geomorphology, land capability, soil hydrologic groups and plant cover maps using on-screen method. In the second stage digitized maps were encoded based on the values of geology, soil erodibility, climate, land cover, land use, present status of erosion and channel erosion and sediment transport factors. Using the DEM layer, slope and rain (using the rain gradient equation) maps were provided and consequently topographic and runoff (using the logical method) factors maps were prepared. Then these factors maps were summed together and finally sedimentation score map was provided.

Pandey and Sahu (2002), worked for Generation of curve number using Remote Sensing and Geographic Information System. For ungauged watersheds accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. But this information is essential in dealing with watershed development and management problems. Conventional methods of runoff measurements are not easy for inaccessible terrain of Arunachal Pradesh. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. Many researchers (Ragan and Jackson, 1980; Slack and Welch, 1980, Tiwari et al., 1991) have been utilized the satellite data to estimate the USDA soil conservation Services (SCS) Runoff Curve Number (CN). In this study SCS Curve Number technique modified for Indian condition has been used for generation of CN for Remi Watershed, which is located in the East Siang district of Arunachal Pradesh under Pasighat circle. The area of watershed is 210.00 Km2. The watershed area lies in the Survey of India (SOI) topo-sheet No. 82 P/4, 82P/8, 83M/1 and 83M/5 .It is located between 27o 50'to 28o 05' N latitude and 950 05' to 950 25' E longitude.

Sharma et. al.(1999), developed micro-watershed plans using Remote Sensing and GIS for a part of Shetrunji river basin, Bhavnagar district, Gujarat. Micro-watershed level planning requires a host of inter-related information to be generated and studied in relation to each other. Remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. Geographical Information System (GIS) with its capability of integration and analysis of spatial, aspatial, multi-layered information obtained in a wide variety of formats both from remote sensing and other conventional sources has proved to be an effective tool in planning for micro-watershed development. In this study an approach using remote sensing and GIS has been applied to identify the natural resources problems and to generate locale specific micro-watershed development plans for a part of Shetrunji river basin in Bhavnagar district, Gujarat. Study of multi-date satellite data has reveled that the main land use /land cover in the area is rain fed agriculture, wasteland with/without scrubs in the plains and undulating land and scrub forests with forest blanks on the hills. Due to paucity of ground water for irrigation, the rain fed agriculture area lacks sufficient soil and moisture to support good agriculture.

Baruah, used GIS as tool in watershed hydrology and irrigation water management, this powerful tool holds a very large potential in the field of regional and micro-level spatial planning particularly in micro-watershed planning and management. A GIS can help pull together various types of disparate data such as remote sensing data, census data, records from different administrative bodies, topographical data and field observations to assist researchers, planners, project officers and decision-makers in resource management. Creation of a spatial database is the first step in micro-level planning. This is followed by spatial analysis to help identify problem areas and, finally, the steps towards planning to mitigate problems are taken by marking out action areas.

Taking a watershed as the spatial unit of study, appropriate physiographic and morphometric parameters can be taken into account to enable proper micro-watershed management.

Sarangi et.al (2004), used GIS tool in watershed hydrology and irrigation water management. Watershed hydrology plays a significant role in generation and quantification of runoff and sediment loss from watersheds. With an aim to asses runoff and soil loss GIS tool was used to assist in data base development which acted as input to a developed conceptual model (Small Watershed Runoff Generation Model, SWARGEM). The input to the model was in the form of data tables and digitised maps comprising of soil parameters, topological information and land use features of Banha watershed under Damodar Valley Corporation, Bihar, India. The topological information indicated the elevations of corners of square grid array. The model used 4-point pour-point technique to route surface flow from one grid to the other in an overlaid grid array of the Banha watershed. The digitised watershed topology and square grid array was created using ARC/INFO GIS tool (Version 3.5). Manning's formulae was used to route water over the entire watershed coupled with water budgeting technique corresponding to rainfall events. The out put of the model generated event based Direct Runoff Hydrographs(DRH) for the watershed. The non-parametric statistical analysis (Wilcoxon's matched pair signed rank test) performed on the predicted value and observed runoff rate at the oulet of the watershed revealed that there is no significant difference between the observed and predicted values at 0.05 probability level. The topological information extracted using GIS was also used to obtain the geomorphological parameters of the watershed. The hypsometric analysis which is under geologic geomorphological component was performed using GIS tool. The analysis showed the erosion status of watershed, which is moderately prone to erosion and is at equlibrium stage.

Sah et.al.(1997), worked for Subwatershed Prioritization for Watershed Management using Remote Sensing and GIS. Delineating the wathershed area into subwatershed for priority based conservation work is essential and appropriate for the developing countries like Nepal. Considering its drainage system can do such delineation. The delineated subwatersheds were used for prioritization. Prioritization can be done by considering their forest loss, soil loss and land sensitivity, which is defined as the locational relationship between forest loss and soil loss. These factors were used to extract the DSI, SI and PC, which were considered as the condition indicator of the subwatershed. Using these condition indicators, a new method of prioritization for conservation .work was proposed by the qualitative matrix analysis. Based on prioritization, subwatershed conservation management activities were proposed. Finally, it can be said that remote sensing and GIS in combination with USLE model can be used as appropriate tools for sub wathershed prioritization.

Greenfield et. al, developed Watershed Erosion and Sediment Load Estimation Tool, The Watershed Erosion and Sediment Load Estimation Tool is an ArcView-based system that can be used to estimate soil erosion and sediment loads from watersheds. The potential erosion from each source (grid) cell in the watershed is calculated using the Universal Soil Loss Equation (USLE), in which the USLE factors such as K, LS, C and P are automatically calculated based on spatial data layers such as soil, Digital Elevation Map (DEM), land use, road network, and management practices. The potential sediment load to user-specified assessment points in the watershed is estimated by using one of three alternative methods for computing sediment delivery ratio. The user is provided the capability to easily and quickly prepare alternative scenarios to determine the effects of land use changes, best management practices (BMPs), and road management practices on the erosion and sediment estimates. BMPs that affect the source of the erosion (e.g., tillage practices) and those that affect the sediment pathways (e.g., ponds, buffer strips) are considered separately. Other features such as grouping the estimates by source, automatic report generation, and scenario tracking are also provided.

Samad et.al (1997)applied GIS and RS for Soil Erosion and Hydrological Study of the Bakun Dam Catchment Area, Sarawak. The Universal Soil Loss equation (USLE) was applied to predict annual soil loss in the study area, using the integration of satellite remote sensing and Geographic Information System (GIS) technologies Parameters of the USLE used to generate the relevant raster layers for soil erosion spatial modeling in the GIS are - (i) rainfall erosivity, (ii) slope length/gradient, (iii) cover- conservation method and (iv) soil erodibility. The analysis was done in MICSIS (Micro-computer spatial Information system), an image processing and GIS software package developed specifically for erosion modeling under the Malaysian-China cooperation.

2.2. RUNOFF

Runoff is the drainage of precipitation from a catchments, which flows out through its natural drainage system, after the occurrence of infiltration and other losses from the precipitation (rainfall). The excess rainfall flow out through the small natural channel on the land surface to the main drainage channel (Ghansyam Das 2002)

The surface runoff process, when rain falls, the leaves and stems of the vegetation intercept the first drops of water. This is usually referred to as interception storage as the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage), after which runoff is generated.

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity (of a dry soil) is high but, as the storm continues, it decreases until it reaches a steady value termed as final infiltration rate (Fig. 3.1).

The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

2.2.1. Factors affecting runoff

Apart from watershed characteristics such as land use and vegetation cover, topography and terrain profile, soil type and soil depth, which have a direct bearing on the occurrence, and volume of runoff.

2.2.1.1. Land use or vegetation cover

Vegetation is another important parameter that affects the surface runoff. From the studies in West Africa (Tauer & Humborg 1992) and Syria (Prinz et. al. 1999) proved that an increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff. Vegetation density can be characterized by the size of the area covered under vegetation. There is a high degree of congruence between density of vegetation and suitability of the soil used for croping

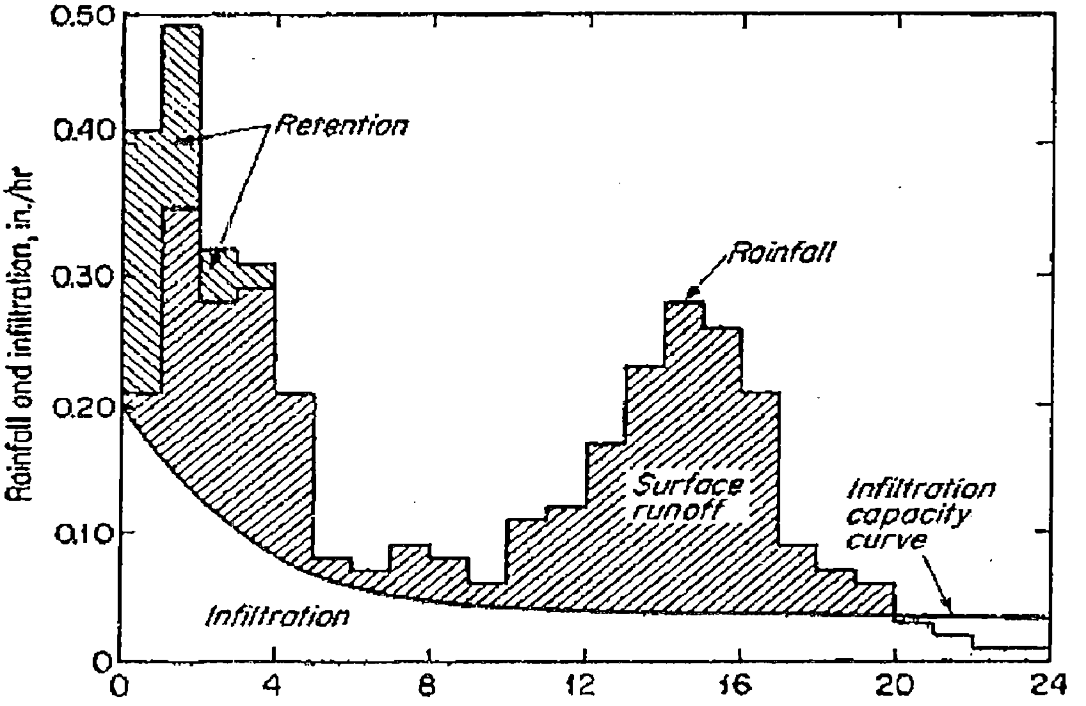


Figure 3.1. Rainfall – runoff – infiltration relationship

2.2.1.2. Topography and terrain profile

The land form along with slope gradient and relief intensity are other parameters, which are important in computing runoff. The terrain analysis can be used for determination of the length of slope, a parameter regarded of very high importance for the suitability of an area for macro-catchments water harvesting. With a given inclination, the runoff volume increases with the length of slope. The slope length can be used to determine the suitability for macro or micro- or mixed water harvesting systems decision making (Prinz et. al. 1998)

2.2.1.3. Soil type & soil depth

The suitability of a certain area either as catchments or as cropping area in water harvesting depend strongly on its soils characteristics viz.(1) surface structure; which influence the rainfall-runoff process, (2) the infiltration and percolation rate; which determine water movement into the soil and within the soil matrix, and (3) the soil depth including soil texture; which determines the quantity of water which can be stored in the soil.

2.2.2. Prediction of Design Peak Runoff Using Hydrologic Soil Cover Complex Number Method

There are a number of methods used for estimation of runoff. Methods suitable for small watershed are Rational Method, Cook's Method, Table Method and Hydrologic Soil Cover Complex Number Method

The Hydrologic soil Cover Complex Number Method which is commonly called the Cover Number Method was developed by The US Department of Agricultural and Natural Resources Conservation Service (NRSC), formerly known as the Soil Conservation Service (SCS). As compared to other methods, it is relatively simple both in term of the input and the conceptual framework.

The major factors that determine the Curve Number are the hydrologic Soil Group (HSG), Cover Type, treatment and hydrologic condition of watershed.

2.2.2.1. Hydrologic Soil Group

SCS developed soil classification system that consists of four groups, which are identified by the letters A, B, C and D. Soil characteristics that are associated with each groups are:

Group A. Under this category soils have a low runoff potential due to high infiltration rates even when saturated (7.6 mm/hr to 11.4 mm/hr). These soils primarily consist of deep sands, deep loess, and aggregated silts.

Group B. Such soils have a moderately low runoff potential due to moderate infiltration rates when saturated (3.8 mm/hr to 7.6 mm/hr). These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (shallow loess, sandy loam).

Group C. Soil of this category have a moderately high runoff potential due to slow infiltration rates (1.3 mm/hr to 3.8 mm/hr if saturated). These soils primarily consist of soils in which a layer near the surface impedes the downward movement of water or soils with moderately fine to fine texture such as clay loams, shallow sandy loams, soils low in organic content, and soils usually high in clay.

Group D. Such soils have a high runoff potential due to very slow infiltration rates (less than 1.3 mm/hr if saturated). These soils primarily consist of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface, shallow soils over nearly impervious parent material such as soils that swell significantly when wet or heavy plastic clays or certain saline soils.

2.2.2.2. Cover Type

The most cover types are vegetation, bare soil and impervious surface. There are a number of methods for determining cover type. The most common are field reconnaissance, aerial photograph and land use map.

2.2.2.3. Treatment

Treatment is a cover type modifier to describe the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced

2.2.2.4. Hydrologic Condition

Hydrologic cond*ition* indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residu e cover on sample areas. *Good hydrologic* condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) cover; (c) amount of grass or close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

2.2.2.5. Antecedent Moisture Condition

The amount of rainfall in a period of 5 to 30 days preceding a particular storm referred to as antecedent rainfall and the resulting condition of the condition in regard to potential runoff is referred to as an antecedent condition. This condition, which is most often, called antecedent moisture condition influences the direct runoff that occurs from a given storm, the effect of antecedent rainfall may also be influenced by infiltration and evapotranspiration during the antecedent period, which in turn affects direct runoff.

To determine the antecedent moisture storm conditions from data normally available, SCS developed three conditions, which were labeled II, III, and I. The soil condition for each is as follows:

AMC I: A condition of watershed soils where the soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes place.

AMC II: The average cases for annual floods, that is, an average of the conditions, which have preceded the occurrence of the maximum annual flood on numerous watersheds.

AMC III; when heavy rain fail or light rainfall and low temperatures have occurred during the 5 days previous to the given storm and the soil is nearly saturated.

2.2.2.6. Curve Number

A curve number is an index that represents the combination of hydrologic soil group and land use and land treatment classes. Empirical analysis suggests that the CN was a function of three factors: soil group, the cover complex, and antecedent moisture conditions. Appendix A shows the CN values for different land uses, treatment, and hydrologic conditions. Basic SCS Direct Runoff Equation

In developing the SCS rainfall - runoff relationship the total rainfall was separated into three components; direct runoff (Q), actual retention (F), and the initial abstraction (Ia). Conceptually, the following relationship between P, Q, Ia, and F are assumed:-

$F/S = Q/(P\text{-}Ia)$ 2.1

The actual retention is given by

$F = (P\text{-}Ia.) - Q$ 2.2

From Eq.2.1 and Eq. 2.2,the following equation was derived for runoff, Q; -

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad \text{.......... 2.3}$$

Where, S = potential maximum retention.

To simplify Eq. 2.3, empirical relation between the variables S and Ia. was developed from data collected from various watersheds in U.S.A. This empirical evidence resulted in the following equation:

$Ia. = 0.2\ S$ for AMC II 2.4

$Ia. = 0.3\ S$ for AMC I 2.5

$Ia. = 0.1\ S$ for AMC III 2.6

The final basic equation developed for computing the direct runoff depth is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{.......... 2.7}$$

Where, Q = direct runoff (mm)

P= rainfall (mm)

S = maximum potential retention (mm)

Runoff for other antecedent moisture conditions can similarly be obtained using the relations given in Eq. 2.5 and Eq.2.6 in Eq.2.3 The variable S in Eq.2.7 is the function of the curve number. The relation between S and CN which was developed from empirical analysis and is given by :

$$S = \frac{25400}{CN} - 254 \quad \text{......} \quad 2.8$$

Effect of Orientation of Spatially Distributed Curve Number

The averaging procedure used to determine runoff necessarily has an effect on the derived result. Traditionally, an average curve number is determined for I the watershed being analyzed and this 'value is then propagated through Eq. 2.4, 2.5, 2.6, 2.7 and 2.8. An alternative (weighted runoff) procedure is to postpone the averaging step until after the spatially varied curve numbers have been converted to spatially varied runoff. The consequences of the use of the weighted runoff procedure were recently examined by Grove et al. (1998) in Moglen (2000). These two procedures can be summarized as follows:

. Traditional Procedure: Determine a lumped (weighted average) curve number (representative of n sub-areas with different curve numbers). Perform one calculation each for Eq.2.4, 2.5, 2.6, 2.7 and 2.8. The result from Eq.2.7 is the lumped runoff, Q_L from the watershed

Weighted Runoff Procedure: Determine runoff values (representative of n sub-areas or pixels with different curve numbers) by performing n calculations each for Eq.2.4, 2.5, 2.6, 2.7 and 3.8. Determine a weighted average runoff from these n values. The result of this average is the distributed runoff, Q_D.

Because of the non-linearity's in Equations Eq.2.4, 2.5,2.6, 27 and 2.8, a bias is observed such that

Q_L . Q_D

where the equality only applies if there is no variation in curve number within the basin

New Procedure (allow for infiltration infinitely downstream) proposes to continue along the spirit of the analysis undertaken by Grove et al. (1998) to account not only for spatial variability, but also the spatial organization of the varied curve number values. The runoff produced from Eq. 2.7 for an arbitrarily chosen pixel will naturally proceed downhill, eventually finding its way to a location of concentrated flow (termed a swale or channel in NRCS methods). From the perspective of the downhill pixel, runoff and rainfall are the same: they are both sources of an input volume of water. Eq .2.7 can be modified to reflect this perspective,

$$Rd = \frac{[(\sum Ru + P) - Ia]^2}{(\sum Ru + P + Sd - Ia)} = \frac{[(\sum Ru + P) - 0.2Sd]^2}{(\sum Ru + P) + 0.8Sd} \quad \ldots 2.9$$

where

Rd : the runoff leaving the downstream pixel (in units of pixel-mm or pixel inches);

Ru : the summation of the runoff from all immediately upstream pixels (in pixel mm or pixel inches);

Sd : the storage of the downstream pixel (in pixel-mm or pixel inches).

This new unit of measure, the "pixel mm" or "pixel inch" is necessitated by the flow accumulation nature of Eq. 2.9. Pixel-inches are converted back to inches after the runoff of all pixels within the watershed has been determined. The runoff, Rd (in pixel mm or pixel inches), is divided by the number of pixels draining respectively to each pixel within the watershed

2.3. SOIL EROSION

Soil erosion is caused by detachment and removal of soil particles from land surface. It is natural physical phenomenon which helped in shaping the present form of earth's surface (G. Das 2002)

Soil erosion is a process of land denudation involving both detachment and transportation of the surface soil materials. It is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place, resulting in exposure of subsurface soil and siltation of reservoirs and natural streams elsewhere is leads to general reduction of raised land. The various important agents of soil erosion are running water, groundwater, wind, glacier, gravity etc. Excessive erosion from the area may be harmful in the following ways:

It may lead to severe loss of valuable fertile soil which affects the agricultural productivity .

The loss of the soil cover reduces the water retention capacity of the land and may result in increased runoff

The downstream surface water resources are polluted by both dissolved and undissolved substances captured by the eroding water.

Structure and agricultural field lying downstream are damaged or otherwise devalued by the sediments deposited in or on them.

2.3.1. Types of Erosion

Soil erosion has been classified according to the erosive agents (factors causing the occurrence and affecting the course of erosion processes): water, glacier, snow, wind, man, animals, etc.; by the forms which arise due to the effects of exogenous agents on the soil surface and by intensity the extent in which the soil particles are detached and transported. The form of soil erosion by water are sheet erosion and rill erosion, gully erosion, hillside erosion and stream bank erosion (Tideman 1996)

Sheet erosion: Soil erosion resulting from raindrop splash and surface runoff is often called as sheet erosion. This is the uniform removal of soil in thin layers from sloping surface of soil between rills. Although important, sheet erosion is often unnoticed because it occurs gradually. The rain drops cause the soil particles to be detached and the following sedimentation reduces infiltration rate by sealing the soil pores.

Rill Erosion: When water takes the path of least resistance to flow over the soil its forms minute channels. Rill erosion is the removal of soil by water from small well advanced channels in which the overland flow concentrates. Detachability transportability of soil particles are both greater during rill erosion than during erosion because of higher 'velocities. Rill erosion is most serious in regions where stone are of high intensity and the top soils are loose and shallow

Gully Erosion: If the channel formed in the land are so deepened and widened! erosion that their size is greater than those of common rills, then the land is no longer readily useable. The effect is then termed as gully erosion. These channels carry, during and immediately after rains. Gullies are usually formed by (i) water fall eroded the gully head, (ii) channel erosion caused by water flowing through the gully ~ alternate freezing and thawing of exposed soil banks and (iv) slides and mass moved of soil in the gully. Gullies are also referred to as ravines

Stream erosion: is the scouring of materials which form the water channel and the cutting of banks by running water.

Landslide Erosion: This form of erosion caused by landslide, is common on steep hill slopes, which are subject to heavy rainfall because the soil gets saturated with water and its weight increases. Also the water weakens the cohesion between the soil particles. Under this conditions the soil yields to gravity and slide down.

2.3.2. The Universal Soil Loss Equation USLE

Wischmeier and Smith (1960 and 1978) developed the Universal Soil Loss Equation (USLE) for prediction of gross soil erosion. The USLE is an empirical model most widely used for estimation of soil loss from sheet and rill erosion. The equation states that:

$$A = R\,K\,LS\,C\,P \quad \text{..........} \quad 2.10$$

Where: A = Average annual soil loss in tons per hectare year

R = Rainfall/runoff erosivity

K = Soil erodibility

LS = Hill slope length and steepness

C = Cover-management

P = Support practice

The R factor is an expression of the erosivity of rainfall and runoff at a particular location. The value of "R" increases as the amount and intensity of rainfall increases.

The K factor is an expression of the inherent erodibility of the soil or surface material at a particular site under standard experimental conditions. The value of "K" is a function of the particle-size distribution, organic-matter content, structure, and permeability of the soil or surface material

The LS factor is an expression of the effect of topography, specifically hill slope length and steepness, on rates of soil loss at a particular site. The value of "LS" increases as hill slope length and steepness increase, under the assumption that runoff accumulates and accelerates in the down slope direction. This assumption is usually valid for lands experiencing overland flow but may not be valid for forest and other densely-vegetated

The C factor is an expression of the effects of surface covers and roughness, soil biomass, and soil-disturbing activities on rates of soil loss at a particular site. The value of "C" decreases as surface cover and soil biomass increase, thus protecting the soil from rain splash and runoff

The P factor is an expression of the effects of supporting conservation practices, such as contouring, buffer strips of close-growing vegetation, and terracing, on soil loss at a particular site. The value of "P" decreases with the installation of these practices because they reduce runoff volume and velocity and encourage the deposition of sediment on the hill slope surface. The effectiveness of certain erosion-control practices varies substantially due to local conditions. For example, contouring is far more effective in low-rainfall areas than in high-rainfall areas.

2.3.2.1. Rainfall/runoff Erosivity Factor

The erosivity factor of rainfall (R) is a function of the falling raindrop and rainfall intensity (Wischmeier and Smith 1958) in G Das (2002) found that the product of the kinetic energy of the raindrop and the maximum intensity of rainfall over a duration of 30 minutes, in a storm as the EI value. It has been established that this value gives a very good correlation for estimation of soil loss, and is the most reliable single estimate of potential of rainfall erosivity.

The EI values are determined from the recording rain gauge data of each storm. The rainfall mass curve is devided into small increments, and for each increment the values for intensity of rainfall and their raindrop-kinetic energy (E) are calculated.

From these calculated values, the maximum intensity of rainfall during 30 minutes continuous duration (I_{30}), is then determined. The multiple of this value with E, gives the EI_{30} value. The erosivity of rain is calculated for each storm, and these value are summed up for the desired periods, namely weeks, months, years, etc. The kinetic energy is calculated by the following formula (Wischmeier and Smith, 1978) in G Das (2002)

Kinematic energy of Rainfall (E) = . E_i 2.11

Where:

$$E_i = \sum_{i=1}^{N} (210.3 + 89 \log_{10} I_i) \quad \ldots\ldots 2.12$$

Where :

E = total kinetic energy of rainfall

Ei = rainfall kinetic energy of the i th increment (per storm) m-t/ha-cm

Ii = average intensity of rainfall during the i th increment (each storm), cm/ha

N = total number of discrete increment

The kinetic energy of rainfall can also be calvulated as follows :

$$E_i = (200 + 87 \log_{10} I_i)\, P_i$$

Where :

Ei = kinetic energy of the i th rain increment, J/m^3

Ii = average intensity of rainfall intensity in the i th increment ,cm/hr

Pi = depth of rainfall in the i th increment, cm

E = $\sum$Ei = kinetic energy of rainfall, J/m^2

Rainfall Factor (R) = $\sum$Erosion Index 2.13

$= \sum EI_{30}$ J-cm/m^2-h or Mj-mm/ha-h

or

$$\text{Rainfall Factor (R)} = \sum_{i=1}^{N} \frac{EiI30}{100} \quad \ldots 2.14$$

Where

Ei = rainfall kinetic energy, kg-m/m^2-mm

I_{30}= maximum intensity of rainfall during a continuous periode of 30 minutes, mm/h

n = number of rainstorm per year

For meteorological stations that di\o not have automatic recording rain gauges, the following relation can be used to approximate EI_{30} values.

a. Feasibility Study Report, Identification Study and Detail design of Small Pond in East Java Province of Indonesia used approximate :

$EI_{30} = E \times I_{30} \times 10^{-2}$ 2.15

E = 14.374 R 2.16

I30 = R/(77.178+1.010xR) 2.17

Where

EI_{30} = rain erosivity index (ton cm/ha-hr)

E = rainfall kinetic energy (ton m/ha cm)

R = monthly rainfall (mm)

I_{30} = maximum rain intensity within 30 minutes

b. Bols, (1978) developed formula for Java, for estimation of rainfall factor :

$$EI_{30}\text{ monthly} = 8.119\ Rm^{1.21} \times N^{-0.44} \times R_{max}^{0.53} \quad \ldots\ldots\ldots\ldots 2.18$$

Where

Rm = average monthly rainfall in cm

R_{max} = average maximum daily rainfall in cm

N = average number of rainy days per month

2.3.2.2. Soil Erodibility Factor, K

The soil-erodibility factor K represents: (1) susceptibility of soil or surface material to erosion, (2) transportability of the sediment, and (3) the amount and rate of runoff given a particular rainfall input, as measured under a standard condition.

Fine-textured soils that are high in clay have low K values (about 0.05 to 0.15) because the particles are resistant to detachment. Coarse-textured soils, such as sandy soils, also have low K values (about 0.05 to 0.2) because of high infiltration resulting in low runoff even though these particles are easily detached. Medium-textured soils, such as a silt loam, have moderate K values (about 0.25 to 0.45) because they are moderately susceptible to particle detachment and they produce runoff at moderate rates. Soils having a high silt content are especially susceptible to erosion and have high K values, which can exceed 0.45 and can be as large as 0.65. Silt-size particles are easily detached and tend to crust, producing high rates and large volumes of runoff.

Organic matter in the soil reduces erodibility because it produces compounds that bind particles together, increasing aggregation and reducing the susceptibility of the particles to detachment by raindrop impact and surface runoff. Also, organic matter improves biological activity and increases infiltration rates, which reduces runoff and erosion.

Permeability of the soil profile affects K because it affects runoff rates. Soil structure affects K because it affects detachment and infiltration rates. Mineralogy has a significant effect on K for some soils, including subsoils.

Vladimir et al,(1981) give a table of magnitude of soil erodibility by knowing the organic matter content and textural class of the soil, the magnitude of soil erodibility can be found..

Table 2.1: Table 1: Magnitude of Soil Erodibility Factor (*K*). (after Novotny and Olem 1994)

Textural Class	K for Organic Matter Content (%)		
	< 0.5	2.0	4.0
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
loamy very find sand	0.44	0.38	0.30
sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.25
Silt loam	0.48	0.42	0.29
S i 1 t	0.60	0.52	0.42
Sandy Clay Loam	0.27	0.25	0.21
Clay Loam	0.28	0.25	0.21
Silty Clay loam	0.37	0.32	0.26
Sandy Clay	0.14	0.13	0.12
Silty Clay	0.25	0.23	0.19
Clay		0.13 - 0.20	

2.3.2.3. Hill slope Length and Gradient Factor (LS)

The effect of topography on erosion is accounted for by the LS factor in USLE, which combines the effects of a hill slope-length factor, L, and a hills lope-gradient factor, S. Generally speaking, as hill slope length and/or hill slope gradient increase, soil loss increases. As hills lope length increases, total soil loss and soil loss per unit area increase due to the progressive accumulation of runoff in the down slope direction . As the hill slope gradient increases, the velocity and erosivity of runoff increases. The following sections of this chapter describe the effects of L and S on soil-loss rates, the interactions between L and S, and their combined effects on soil loss, and the ability of USLE to estimate soil loss from non-uniform, complex, hill slopes.

Hill slope-Length Factor (L)

If soil loss is entirely generated by inter rill erosion, which is nearly always uniform along a hill slope, the L value will be 1 for all lengths. However, if the soil loss is generated entirely by rill erosion, the L value will increase linearly with length because rill erosion increases in the down slope direction as runoff accumulates. Soil loss is usually combination of both inter rill and rill erosion; L values remain nearly constant as hill slope lengths increase when inter rill erosion predominates along hill slopes, or increase when rill erosion predominates.

Wischmeier and Smith (1965), they derived the expression for the relation between soil loss and slope length after long term observation. The expression is

$$L = (\lambda / 22.13)^{m} \quad \text{.......... 2.19}$$

Where :

λ= slope length measured from the water divide of the slope (m)

m = exponent dependent upon slope gradient and may also be influenced by soil properties, type of vegetation etc

Recommended exponent values (Wischmeier and smith, 1978) are given in the following table below:

Table 2.2 Recommended Value of *m*

Slope gradient (%)	*m*
S < 1.0	0.2
1.0 . S < 3.5	0.3
3.5 . S < 4.5	0.4
4.5 . S < .	0.5

Hill slope-Gradient Factor (S)

The hill slope-gradient factor, S, reflects the effect of hill slope-profile gradient on soil loss. For a unit plot, with a 9 percent gradient as described earlier, the S value is equal to 1. The S values vary from above to below 1, depending on whether the gradient is greater than or less than that of the unit plot. Soil losses increase more rapidly as gradient increases than as length increases. Also, rill erosion is affected more by hill slope gradient than is inter rill erosion.

The gradient of a hill slope profile is defined as the change in elevation per change in horizontal distance, expressed in percent. The gradient of a particular hill slope can be measured in the field using a rod and Abney or hand level, electronic survey level, or a GPS unit, at the same time that length is measured. Hill slope gradients may also be estimated from digital aerial surveys or specific site maps but, again, accuracy decreases as the map scale decreases.

On the basis of field measurements and experiments on soil monoliths Masgrave, (1947), Zingg (1940), Neal (1938), and others derived and empirical relation between soil loss and slope gradient. Mathematically this relation is expressed as :-

$$S = f\left[(Sw)^n\right] \quad \ldots 2.20$$

Where :

S = Soil Loss

Sw= Slope gradient

n = power value whose value range from 0.8 to 1.5 (n in Masgrave expression = 1.35, Zingg = 1.4, and Neal = 0.8)

Wischmeier and Smith (1962) processed a large number of data on intensity of erosion process obtained from experimental stations. Taking in to account the relationships derived by the authors mentioned above (Eq. 2.10), they derived the following equation:-

$$S = f\left[\frac{0.43 + 0.30 * Sw + 0.043 * (Sw)^2}{6.613}\right] \quad \ldots 2.21$$

Where :

S = Slope gradient factor

Sw= Slope gradient (%)

The combination effect of the slope gradient and slope length can be calculated from the following equation :-

$$LS = (\lambda / 22.13)^m * \left[\frac{0.43 + 0.30 * Sw + 0.043 * (Sw)^2}{6.613}\right] \quad \ldots 2.22$$

2.3.2.4. Cover-Management Factor C

The cover-management factor (C) represents the effects of vegetation, management, and erosion-control practices on soil loss. As with other USLE factors, the C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot as defined in earlier chapters.

The C factor represents the effect of plants, soil covers, soil biomass (roots and incorporated residue), and soil-disturbing activities on soil loss. USLE uses a sub-factor method to compute soil-loss ratios (SLR), which are the ratios of soil loss at any given time in the cover-management sequence to soil loss from the standard condition. The sub factors used to compute a soil-loss ratio value are prior land use, canopy cover, surface cover, surface roughness, and soil moisture. The C value is the average soil-loss ratio weighted by the distribution of rainfall EI (energy x intensity) during the year.

Canopy Cover

Canopy cover is the vegetative cover above the soil surface that intercepts raindrops but does not contact the soil surface. Any portion of a plant touching the soil surface is considered surface cover as discussed below. The two characteristics of canopy are utilized in the USLE calculations: (1) the percent of surface covered by the canopy, and (2) the height within the canopy from which intercepted rain drops re-form into water droplets and fall to the ground; this fall distance is known as the "effective fall height." Open spaces in a canopy, whether within the perimeter of a plant canopy or between adjacent plants, are not considered as canopy. When measuring or estimating canopy cover, planners should try to get a birds-eye view of the area.

The effective fall height is measured from the ground up to the level within the canopy from which the majority of water droplets fall. The effective fall height of a canopy varies with the vegetation type, the density of the canopy, and the architecture of the plants.

Surface Cover

Surface cover is material in contact with the soil that both intercepts raindrops and slows surface runoff. It includes all types of cover, such as mulches and rock fragments, live vegetation in contact with the soil surface, cryptogamic crusts (which are formed by mosses or fungi in the soil), and plant litter. To be effective, surface cover must be anchored to the surface or of sufficient size so that it is not blown away by wind or washed away by runoff. USLE takes into account the overlap of surface covers and rock, if both are present. The percent rock cover is entered through the K-factor screen and transferred to the C-factor computations.

The effectiveness of surface cover, such as mulch, varies depending on several factors, including the dominant type of soil erosion occurring on the slope, the slope gradient, the extent of contact between the surface cover and the soil, and the type of surface-cover material itself. In general, surface cover does a better job of reducing rill erosion rates than it does in reducing inter rill erosion rates (Foster, 1982). Therefore, if erosion of a bare soil is primarily due to rilling, the addition of a given amount of cover material will reduce erosion more than if the same amount of cover material were placed on a soil that erodes primarily by inter rill erosion processes.

On steep hill slopes (greater than 10% gradient) more of the total erosion often results from rill rather than inter rill processes. Conversely, on flatter hillsslopes (less than 3% gradient), more of the total erosion often results from inter rill rather than rill processes. Again, because surface cover reduces the rill erosion rates more than the inter rill erosion rates, a given amount of cover material results in a greater reduction in soil loss on steep slopes than on flat hill slopes.

The effectiveness of the surface cover depends on good contact between the soil and the cover material, and on the cover remaining in place. If the cover, whether straw mulch or manufactured materials, does not make full contact with the soil, is erched above the soil by clods, or stays suspended above depressional areas, severe rill erosion can occur beneath it. Therefore, mulch must be placed to ensure maximum contact with the soil.

Based on research by Meyer et al., (1971, 1972) mulch on construction sites is less effective than on agricultural land. Therefore, a relatively low b value is used in the program when mulch is placed on subsoil, even when properly applied, because the contact and bonding between the mulch and subsoil is assumed to be less effective than the contact and bonding between the mulch and topsoil. The smallest b value is used when the contact is fair, but not good, between the mulch and the soil, because there remains vulnerable soil beneath the cover. Mulch should always be anchored to the soil to ensure that runoff or wind does not remove the material.

Surface Roughness

Soil-disturbing operations leave two types of surface roughness: oriented and random. Oriented roughness has a recognizable pattern. The ridges and furrows left by "cattracking" or a chisel plow used in the preparation of a seedbed are examples of oriented roughness. Oriented roughness redirects surface runoff, and may trap some sediment When the ridges and furrows are very nearly on the contour, runoff flows around the slope, rather than directly down slope, thus reducing the erosivity of the runoff. Oriented roughness is considered in the P factor. Random roughness is considered in the C factor.

Random roughness is defined as the standard deviation of the elevation from a plane across a tilled area after oriented roughness is taken into account. It has no recognizable pattern and is the result of clods and aggregates produced by various soil-disturbing activities. The depressions between the clods cause water to pond, slows runoff, increases infiltration, and stores sediment, all of which helps to reduce erosion rates. The amount of random roughness created by a particular operation varies with the initial condition of the site, the tillage implement and its use, soil texture, and soil moisture at the time of disturbance.

Cover-Management Systems

A set of plant types, surface covers, and operations constitutes a cover-management system. The complete list of plant types, surface covers, and operations, together with the dates of planting or implementation, must be assembled for the computation of C values.

Table 2.3. Cover and Management Factor (C) for Indonesia (Hamer 1980)

No.	Crop Management	C Value
1.	Bare Cultivable Soil	1.00
2.	Irrigated Sawah	0.01
3.	Rainfed Sawah	0.05
4.	Upland crop (tegalan), not-specified	0.70
5.	Cassava	0.80
6.	Interplanted cassava and soybean	0.20 *
7.	Maize	0.70
8.	Beans	0.60
9.	Potato	0.40
10.	Groundnut	0.20
11.	Rice	0.50
12.	Sugarcane	0.20
13.	Serai Wangi (Cymopophagon	0.40
14.	Tales (yam)	0.85
15.	Spices (chili, ginger)	0.90
16.	Brachiaria grass for stock feed	
	at establisment stage	0.30 *
	subsequent years	0.02 *
17.	Shrub/grassland	0.30
18.	Multistory mixed garden	
	high density ground cover	0.10
	medium-density ground cover	0.30
	low-density ground cover	0.50
19.	Estate crops (poor ground cover)	
	Rubber	0.80
	Tea	0.50
	Oil Palm	0.50
	Coconut	0.80
20.	Natural forest,primary,well-generated	
	high litter	0.001
	low litter	0.005
21.	Surface mullah	
	litter or straw, 6 MT/ha/yr	0.30 *
	litter or straw, 3 MT/ha/yr	0.50 *
	litter or straw, 1 MT/ha/yr	0.80 *

* Based on research data by the Soil Research Institute Bogor, Indonesia

2.3.2.5. Support-Practice Factor, P

The support-practice (P) and cover-management (C) factors are very important in USLE soil-loss estimates for mined land and construction-site reclamation planning because these factors represent practices designed to reduce erosion. The P value in USLE is the ratio of soil loss with a specific support practice to the corresponding soil loss with straight-row upslope and down slope tillage.

The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The supporting mechanical practices include tillage (furrowing, soil replacement, seeding, etc.), strips of close-growing vegetation, deep ripping, terraces, diversions, and other soil-management practices orientated on or near the contour that result in the collection and storage of moisture and reduction of runoff (AH- 703, Renard et al., 1997).

An overall P value is computed as a product of P sub-factors for individual support practices, which are typically used in combination. For example, contouring almost always accompanies terracing. On mined land or construction-site reclamation projects, a Towner disk or chisel plow is often used in combination with a rangeland drill. Additionally, many structures such as straw-bale barriers, gravel filters, silt fences, continuous berms, and bench terraces are used on mined land and construction sites to control or minimize sediment transport from reclamation areas.

Tillage and planting operations performed on the contour are very effective in reducing erosion from storms of low to moderate intensity that are common in many areasof the United States. However, contouring provides little protection against high-intensity, long- duration storms. Values for the contouring sub-factor in USLE should be near 1.0 (little effectiveness) when the 10-year frequency, single-storm index (10-yr EI) is high and infiltration into the soil is slow, and should be low (greater effectiveness) when 10-year EI is low and infiltration is high.

Table 2.4. Conservation Support Practice Factor (P) (Hamer 1980)

No.	Conservation Practice	P Value *
1.	Bench terraces **	
	high standard design/construction	0.04
	medium standard design/construction	0.15
	low standard design/construction	0.35
2.	Traditional terrace ***	0.40
3.	Hillside trenches (silt pit)	0.30
4.	Contour cropping	
	0 - 8% slope	0.50
	0 - 20% slope	0.75
	higher than 20% slope	0.90

* Because of the experimental procedure used to derive these data, and the values shown also incorporate the changes in slope steepness and length associated with terrace construction. When using these values no additional adjustments are needed in the L and S factors as a result of treatment: both should be set at 1.00

** Based on soil loss ratios obtained by the Soil Research Institute Bogor, Indonesia. All bench terraces were constructed so that the vertical interval from one terrace base to next = 0.6 m and the distance between terrace risers (out edges) along slope direction = 5.5 m

High standard bench terrace refers to rock or grass stabilized risers, with frontal bunds and designed water disposal system

Medium-standard terraces refers to an ideal or well established terrace but with out frontal bund or water disposal

Low-standard terrace refers to a non stabilized well-constructed and maintained terrace

*** Traditional terrace refers to the shallow cut run across slopes (ridges) without stabilizer

2.4. ENGINEERING MEASURE FOR CATCHMENT PROTECTION

Engineering measures aim to reduce or prevent sheet erosion and gully erosion and restore degraded agricultural and non agricultural land. They provide necessary gestation period and help in building up desired moisture regims to carry out other measures of land stabilization such as afforestation. Important principles to be kept in view while planning engineering control measures are :

1. Increase the time of concentration for allowing more runoff water to be absorbed and held by the soil
2. Break a long slope into several short one for reducing the flow velocity below critical limits
3. Prevent excessive soil and water loss

A large variety of engineering measures are available for serving the above mention purpose as indicated in Table 2.5

2.4.1. Measures on Agricultural Land

2.4.1.1. Contour Bunding

Contour bunding is also called narrow base terracing. Contour bund are low height earthen embankment a long contour or with permissible deviation from contour. These are recommended for rolling (slope less than about 6%) and flatter lands with scanty or erratic rainfall (annual rainfall less than 100cm). It can be adopted on all type of relatively permeable soil except the clayey or deep black cotton soils. Purpose is to intercept the runoff flowing down the slope as well as to control soil erosion. Surplussing arrangements may be required to remove excessive runoff resulting from high intensity of rains.

2.4.1.2. Terraces

A terrace is an earth embankment, constructed across the slope, to control run off and minimize soil erosion. A terrace act as an intercept to land slope, and divides the sloping land surface into strips. In limited widths of strips, the length of runoff is reduced. It has been found that soil loss is proportional to the square root of the length of slope, i.e by shortening the length of run soil erosion is reduced. The soil eroded by the runoff, scour and the raindrop splash flows down the slope, and gets blocked up by terraces. The scour of soil surface because of soil runoff water is initiated by the runoff at a velocity above the critical value, attained during a flow on a long length of the sloping run. By shortening the length of run, the runoff velocity remains less than the critical value and thus soil erosion owing to scour is prevented. Terraces are classified into two major type: broad base terraces and bench terraces.

Table 2.5. Engineering Measures for catchment protection

CLOSURE	AGRICULTURAL LAND	NON AGRICULTURAL LAND		WATER HARVESTING & WATER STORAGE
Contour, staggered Graded trenches	- Contour cultivation	-Ravine	- Torrent	- Silt trap
- Stone wall	- Contour bunding			
- Barbed wire	- Grade bunding	-Peripheral bund	- Check dams	-Sediment detention dam
- Live hedges	- Broad based terrace			-Catcment treatment
	- Bench terracing	- Drops		-Dugout pond
	- Surplusing arragement	- Retaining Walls	- Revetment/ training walls	-Impounding type
	- Diversion drains	- Plugs		-Storage
				-Bundhies
	- Land leveling and grading	- Check dams with surplussing arragement	- Training of Nala	-Diverson
			- Nala Plugs	-Percolation Pond
	- Grassed waterways	- Grassed waterways	- Nala bundjies	

Broad-base terraces

These types of terraces consist of a ridge which has a fairly broad base and a flatter slope, so that farm machinery can easily pass over the ridge. On these types of terraces, even the ridge area is cultivated and no land is lost to agricultural operation because of terracing. Broad-base terraces are of two types:

1. Graded terraces
2. Level terraces

Graded terraces. Graded or drainage terraces are constructed in high rainfall areas (> 600 mm), where the excess runoff needs to be removed quickly and safely to protect the crops from water logging. These terraces are provided with either a constant or a variable grade along the terrace length to convey the excess runoff safely into a vegetated outlet channel. In drainage type terraces, a channel is normally provided, along with the ridge on the upstream side, to convey the excess runoff to the outlet. In some cases, the whole strip of the terrace system is used as a channel for conveyance of the runoff to the outlet. This system is practiced where the excess runoff generated is less, and water can be allowed more time to get absorbed in the soil and thus increase its soil moisture. Thus, graded terraces can be of two types: (a) terraces with a proper channel, (b) terraces without a proper channel

Level terraces. Level or ridge types of terraces are also of two types-wide-based and narrow based-depending on the width of the ridge and the channel. Narrow-based terraces have widths in the range of 1.2 to 2.5 m, and are not suitable for operation of farm machinery.

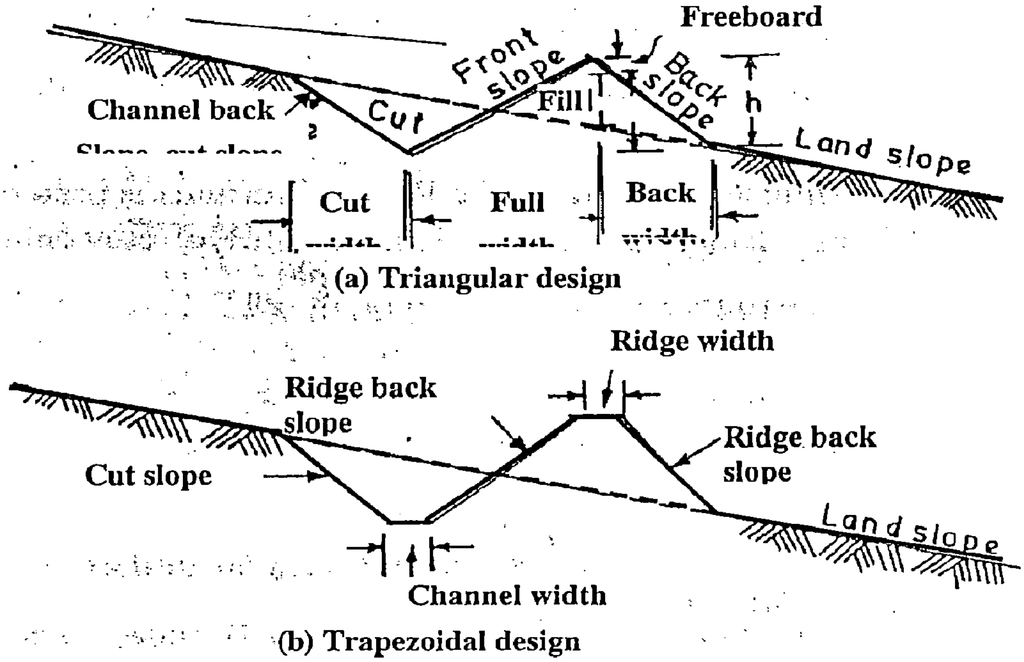


Figure.2.2. Cross-sectional view of a broad-base terrace. (G. Das 2002)

Through graded terraces, the excess runoff is removed at a velocity which does not cause erosion of soil. It is called the non-erosive velocity. The design of graded terraces basically involves the design of three parameters, namely the spacing, the capacity, and the cross-section

Bench terraces

Bench terraces are constructed to reduce the gradient of slopes of hill sides to help impede runoff paths, and thus prevent soil erosion. In hilly areas, bench terraces are extensively used as agricultural field plots, but their construction is costly. Bench terraces cause extensive interventions in the landscape and are objected to by environmentalists, in the present day context of environment consciousness.

Bench terraces are constructed on hill sides which have slope gradients in the range of 15-30% or more and the land surface has a medium to high degree of hazard of soil erosion. The dimensions of these terraces depend on the gradient of the slope, depth profile of the soil, volume of the earthwork involved, and the crops to be grown, etc. The different components of a bench terrace are described in Figure. 2.2

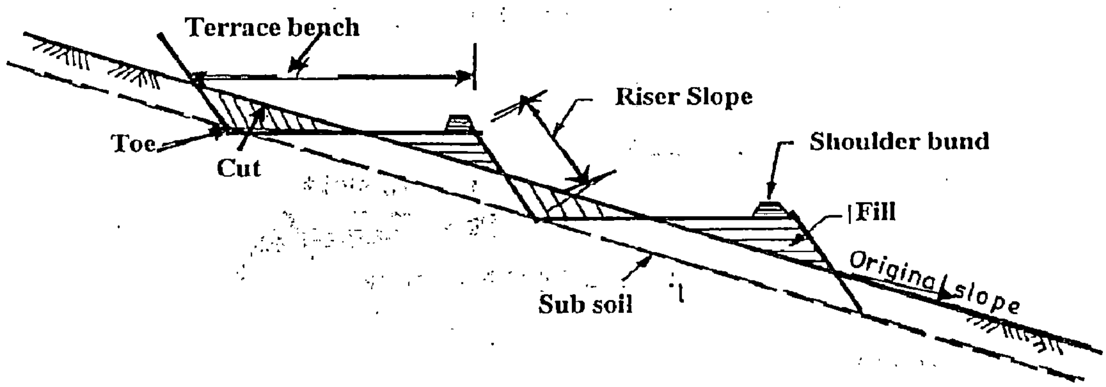


Figure 2.3 Component of a bench Terraces (G. Das 2002)

Bench terracing transforms a steep land surface into a series of nearly levelled steps across the slope of the land. These terraces convert the erodable sloping lands into farm lands that are safe for cultivation. Though these terraces are costly to construct, they are being used as no other better land is available for cultivation in such areas. During construction of such types of terraces, it is assumed that the excavated earth from the upper-half of the terrace is deposited on the lower-half of the terrace. That is, the *cut* is equal to the *fill.* Care needs to be exercised during construction on steep land slopes, because the fill material may become unstable on high slopes. Filling a ploughed land gives better stability to the fill material.

Depending on the soil, climate and crop, bench terraces are classified into the following categories:

1. Levelled and table top
2. Outward sloping
3. Inward sloping
4. Peutorican

Figure 2.4 shows the schematic views of various categories of bench terraces

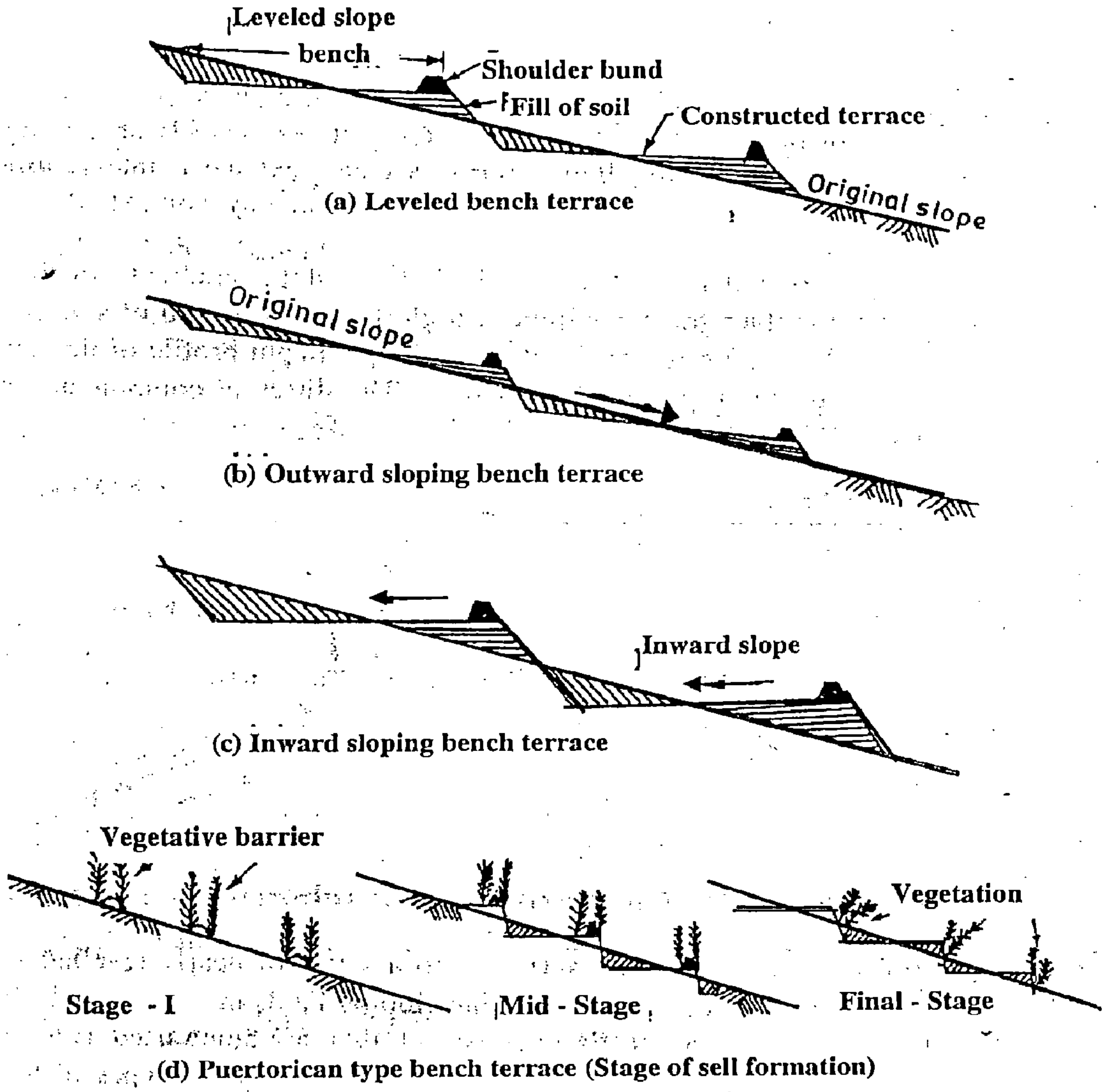


Figure 2.4. Different categories of bench terraces. (G. Das 2002)

2.5. CONCLUDING REMARKS

In the present chapter few related papers are presented. In addition to that the basic theory of runoff computations, erosion and engineering measures, which are used in the present study are discussed. The GIS is one of the main tool for the present study, therefore basic component of GIS are described separately in chapter 3

CHAPTER III
BASIC GEOGRAPHICAL INFORMATION SYSTEM (GIS) CONCEPT

3.1. GIS AND DECISION MAKING

Geographic Information Systems (GIS) can be defined as a computerized system that deals with spatial data in terms of their collection, storage, management, retrieval, conversion, analysis, modeling, and display/output. It evolved as means of assembling and analyzing diverse spatial data. The development of GIS is the result linking parallel developments of several other spatial data processing disciplines, such as cartography, computer aided design, remote sensing technology, surveying and photogrammetry. Due to increasing complexity of the real world situations, more challenges emerge in knowing about the precious earth, and also in planning and decision making processes. Today, GIS is considered as an important tool in planning and decision-making. It has been found applied in many fields, such as cadastral mapping, land use planning, forestry, wildlife management, infrastructure planning, zoning, military, environmental monitoring, network planning, facility selecting, including socio-economic applications (taxation, census, marketing, health planning).

The success with which a GIS can be used is determined by several factors that can be grouped as follows:

The Dataset – We cannot use the data if we do not have. Getting the relevant data is important for an efficient GIS and the most cost effective data collection would be to collect only the data we need. The optimum data quality is the minimum level of quality that can be satisfactorily used for intended purpose.

Data Organization – Data is of no value unless the right data can be in the right place at the right time.

The Model – A good model is the simplest model that correctly and consistently predicts the behavior of the real world for the phenomena of interest.

The Criteria – the criteria used should be such that is understandable to a same level by all involved, such as analyst, decision-makers, other stakeholders, etc.

3.2. GIS COMPONENTS

A GIS is comprised of hardware, software, data, humans, and a set of organizational protocols. These components must be well integrated for effective use of GIS, and the development and integration of these components is an iterative, ongoing process. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development, and the establishment of protocols for GIS use are often more difficult and time-consuming endeavors.

3.3.1. Hardware for GIS

A fast computer, large data storage capacities, and a high-quality, large display form the hardware foundation of most GIS (Fig. 3.1). A fast computer is required because spatial analyses are often applied over large areas and/or at high spatial resolutions. Calculations often have to be repeated over tens of millions of times, corresponding to each space we are analyzing in our geographical analysis. Even simple operations may take substantial time if sufficient computing capabilities are not present, and complex operations can be unbearably long-running. While advances in computing technology during the 1990s have substantially reduced the time required for most spatial analyses, computation times are still unacceptably long for a few applications.

While most computers and other hardware used in GIS are general purpose and adaptable for a wide range of tasks, there are also specialized hardware components that are specifically designed for use with spatial data. Many non-GIS endeavors require the entry of large data volumes, including inventory control in large markets, parcel delivery, and bank transactions. However, GIS is unique in the volume of coordinate data that must be entered.

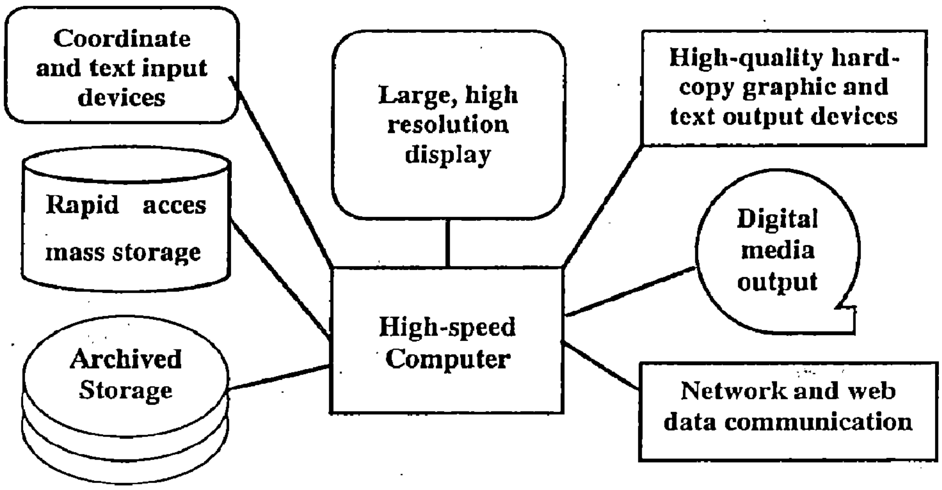


Figure 3.1 GIS are typically used with a number of general purpose and specialized hardware component.

3.3.2. GIS Software

GIS software provides the tools to manage, analyze, and effectively display and disseminate spatial data and spatial information. GIS by necessity involves the collection and manipulation of the coordinates we use to specify location. We also must collect qualitative or quantitative information on the non-spatial attributes of our geographic features of interest. We need tools to view and edit these data, manipulate them to generate and extract the information we require, and produce the materials to communicate the information we have developed. GIS software provides the specific tools for some or all of these tasks.

There are many public domain and commercially available GIS software packages, and many of the commercial packages originated at academic or government-funded research laboratories. The Environmental Systems Research Institute (ESRI) line of products, including Arc/Info, is a good example. Much of the foundation for Arc/Info was developed during the 1960s and 1970s at Harvard University in the Laboratory of Computer Graphics and Spatial Analysis. Alumni from Harvard carried these concepts with them to Redlands, California when forming ESRI, and included them in their commercial products.

The function commonly provided by GIS software are :

Data entry - manual coordinate capture - attribute capture - digital coordinate capture - data import Editing - manual point, line and area feature editing - manual attribute editing - automated error detection and editing Data management - copy subset, merge data - versioning - data registration and projection - summarization, data reduction - documentation	Analysis - spatial query - attribute query - interpolation - connectivity - proximity - proximity and adjacency - buffering - terrain analysis - boundary dissolve - spatial data overlay - moving window analysis - map algebra Out put - map design and layout - hardcopy map printing - digital graphic production - export format generation - metadata output - digital map serving

3.3. DATA, DATASET AND DATABASE

Data is information represented in the format of digit, letter and symbol used to describe status, behavior and their consequence of geographical object. There are some inner relations and different between data and information, as defined above, data indicates those value recorded and stored in computer, the meaning of the value represented is information.

Dataset is the minimum body of data used for data transform, storage, manipulation, copying, and other activities. Usually, there is one type of spatial data feature as point, line or polygon employed to represent one kind of geographical object such as river or topography or building. In most cases, data layer have the same meaning with dataset, but a few data layer can be organized into one dataset in some special occasions.

Database, as the word per se means data and base, is the combination of dataset according to the defined logical principles. Usually, the dataset in one database share the same data structure, data storage method, data format and similar data management interface. Except the dataset contained, database itself has some functions as data updating, data manipulation (extracting, clipping, overlaying, statistics), and user propriety definition.

3.3.1. Primary data and secondary data

Data and information representing the real world can be stored in simplified forms and processed to facilitate decision-making (Fig. 3.2) or it can also be presented later in simplified forms to suit specific needs. Geographical data come in many different forms. A basic distinction can be made between primary and secondary data.

Primary data refers to the sorts of information that can be collected first hand by fieldwork and questionnaire survey. The primary geo-spatial data can be collected from the sources, such as Geodetic Surveying and Geodetic Control Networks; Surveying; Photogrammetry; and Remote Sensing.

Secondary data are those found in published sources, such as official statistics, maps and aerial photographs, or are gathered by some agency other than you. Secondary data acquisition refers to the process of converting existing maps or other documents into a suitable digital form. There exists lot of secondary data but sometimes not all of them are available for use. Sometimes no convenient secondary data source exists and one has collect the necessary data conducting field survey which can be time consuming and expensive.

There are number of important points relating to why we collect data in the first instance and this should be considered on the ground of sound scientific approach of the problem before the real data collection process start. Depending upon the objectives, there may be two approaches. The *Inductive* approach, also called as classical method, involves observation and collection of data in the first stage followed by statement of

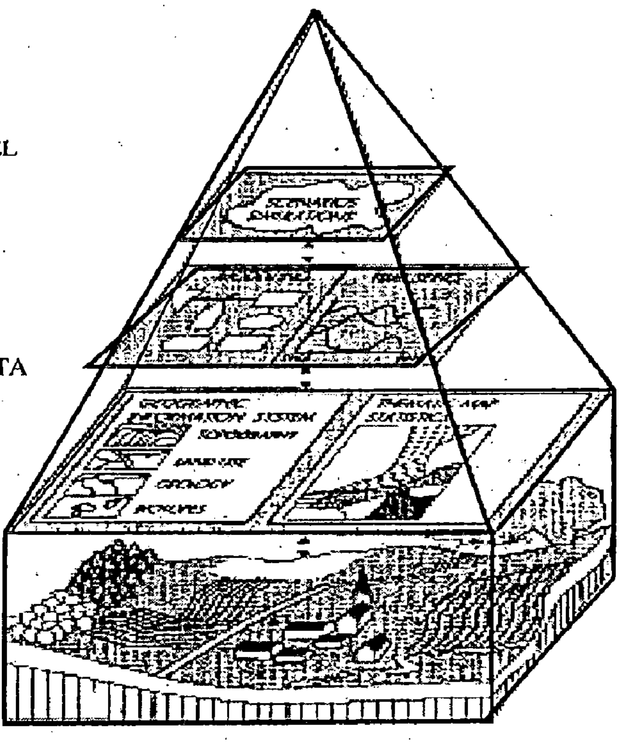


Figure 3.2. A decision making Pyramid. (Bernhardsen,1992 after Grossman, 1983)

theory and verification, where as the *Deductive* approach, also called as critical rational method, involves setting up the problem at the first stage followed by collection of necessary data and statement or theory at later stages.

3.3.2. Geospatially Data

Geo-spatial data are also called as Geographical data, Geographic data, Geographic *Information, GIS data, Earth-sciences data or Geo-scientific data,* and *spatial data.* Geographical data are information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth. The main difference between geographical data and other data is that the later helps answer question like, what? or where? as the former answers both what? and where? It is because that it contains *Geometric* or *Spatial* data for spatial elements and *Attribute* data (Figure 3.3). *Spatial data* is used to describe the location of geographical object, and attribute data describe the fundamental characteristics of the phenomena involved. For instance, the objects classified as buildings may have a number stores attributes with legitimate values of 1 to 10, etc. *Attribute data* can in turn be sub-divided into *Qualitative* and *Quantitative* data.

Historically several terms have been used to describe the data in a GIS database, among them *features, objects, or entities*. The term *feature* derives from cartography and is commonly used to identify *"features shown on a map,"* while *entity* and *object* are terms from computer science used to identify the elements in a database. The normal dictionary definitions of these terms are:

Object: a thing that can be seen or touched; material thing that occupies space characterized by type, attribute, geometry, relation and quality.

Entity: a thing that has definite, individual existence in reality (e.g. house number)

Feature: the make, shape, form or appearance of a person or thing (e.g. circle, linear)

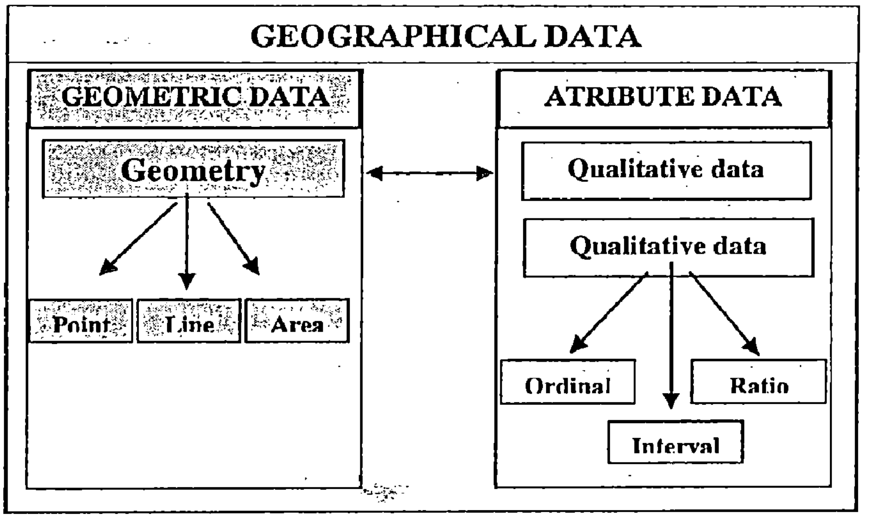


Figure 3.3. Geographical data can be divided into geometric and attribute data (Bernhardsen, 1992)

3.3.3. Spatial Elements

Spatial objects in the real world can be thought of as occurring as four easily identifiable types: *Points, Lines, Areas,* and *Surfaces* (Figure 3.4). Collectively, they can represent most of the tangible natural and human phenomena that we encounter on an everyday basis. In general, points, lines, and areas are used to explicitly represent real- world objects, where as surfaces are mostly used for volumetric representation, such as to represent hills, valleys. Thus, all data can be considered to be explicitly spatial.

Point features are spatial phenomena each of which occurs at one location in space. Each feature is said to be discrete in that it can occupy only a given point in space at any time and considered to have *no spatial dimension* – no width or length. Example of such feature would be a house or a village. But a village can be represented by point feature or area feature as well depending upon the resolution of data.

Line features are conceptualized as occupying only a *single dimension* in coordinate space. They are represented as the series of single coordinates connected to each other. Roads, rivers, are the examples of linear features. The resolution or scale of given dataset once again places a fundamental limitation to conceive them as having any width. Linear features, unlike point features, allow us to measure their spatial extent/length.

Area features have *two dimensions* both length and width dimensions. Area is composed of series of lines that begin and end at the same location. We can describe their shapes and orientations, and the amount of territory occupied as well. In database, the term polygon is often used instead of area. Again, physical size in relation to the scale determines whether an object is represented by an area or by a point.

It is often that area is divided into regular squares or rectangles so that all objects are described in terms of areas. This entire data structure is called a *grid*. Each square or rectangular is known as a cell and represents a uniform value. Adding the dimension of height to area features allows us to observe and record the existence of *Surfaces*. Surfaces have *three dimensions* – length, width, and height. For instance, hills, valleys, and ridges can be described by citing their locations, amount of area they occupy, how they are oriented, and by noting their heights.

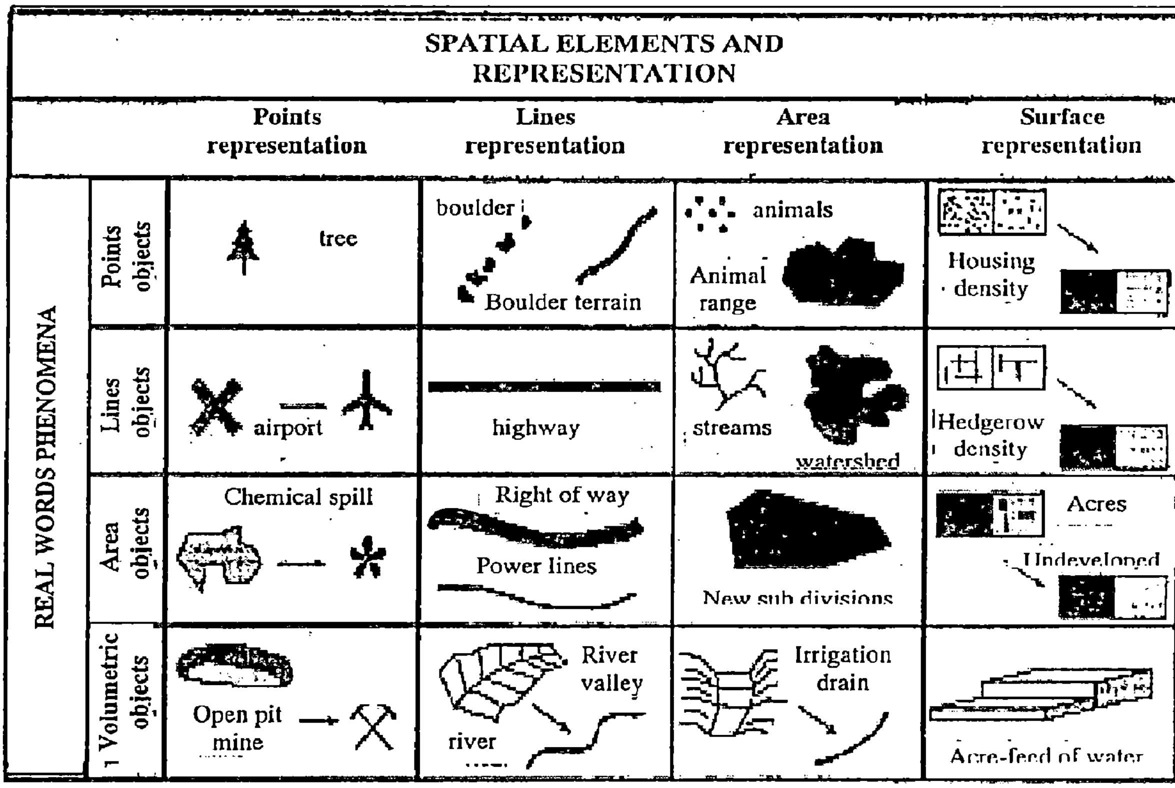


Figure 3.4. Spatial Elements and Representation (DeMers, 2000)

3.3.4. Basic data Models

Spatial elements can be represented in two models: *Vector* and *Raster/Grid* (Figure 3.5). In the vector model, the spatial locations of features are defined on the basis of coordinate pairs. These can be discrete, taking the form of points (POINT or NODE data); linked together to form discrete sections of line (ARC or LINE data); linked together to form closed boundaries encompassing an area (AREA or POLYGON data). Attribute data pertaining to the individual spatial features is maintained in an external database. The data model used by the software, like Arc/Info, ArcView is Vector model.

In raster model, one or group of cell/grid/pixel depending upon the grid resolution represents spatial elements. Most of raster models adhere strictly to a single attribute per cell structure although some raster models support the assignment of values to multiple attributes per discrete cell.

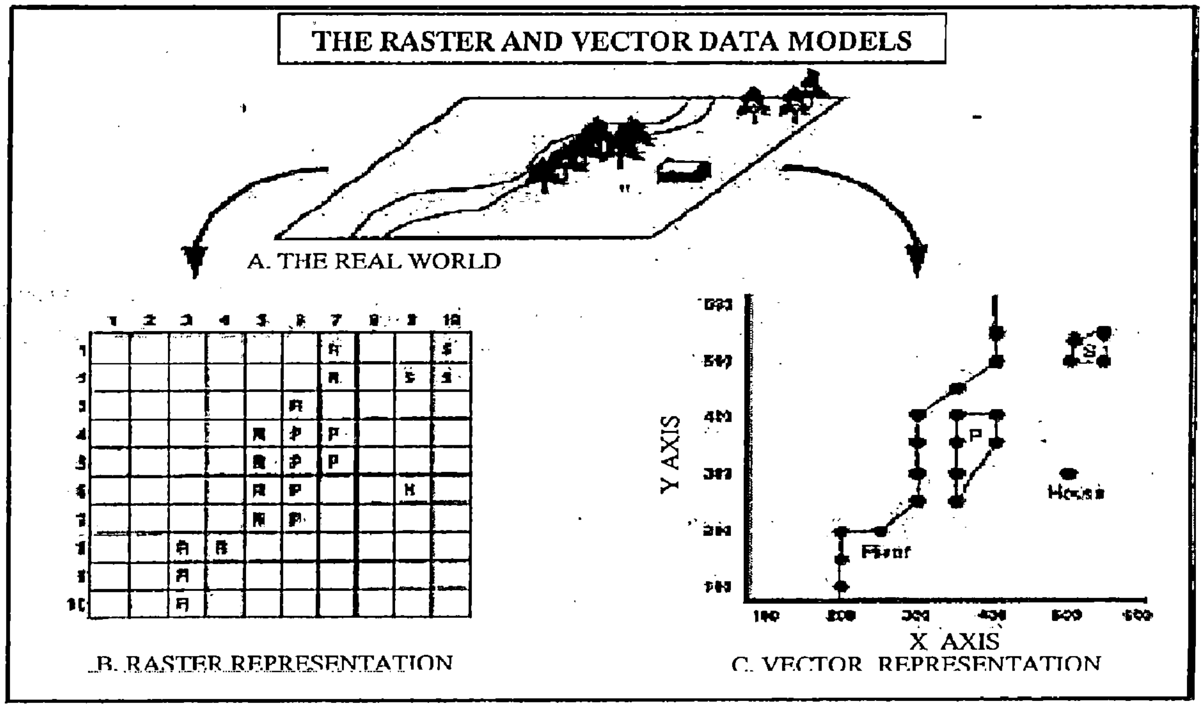


Figure 3.5. Comparison of raster and vector models (Aronoff, 1991)

Table 3.1 presents the advantages and disadvantages of Vector and Raster model. Vector data sets can have topology, i.e. in addition to the position of every feature; the spatial relationships of adjacency and connectivity between features are also maintained. Topological relationships are stored in a series of relational databases. Each database stores information about a feature. For example, a database would store the information about each individual arc, such as Number of the arc, Beginning node number, Ending node number, Polygon to its left, and Polygon to its right.

Within this model spatial data is not continuous but is divided into discrete units. In terms of recording where individual cells are located in space, each is referenced according to its row and column position within the overall grid. To fix the relative spatial position of the overall grid, i.e. to *geo-reference* it, the four corners are assigned planar co-ordinates. An important concept concerns the size of the component grid cells and is referred to as grid resolution. The finer the resolution the more detailed and potentially closer to ground truth a raster representation becomes. Unlike the vector model there are no implicit topological relationships in the data. The following information should always be recorded when assembling, compiling and utilizing raster data:

. Grid size (number of rows and columns)

. Grid resolution

. Geo-referencing information, e.g. corner co-ordinate, source projection

Table 3.1. Vector vs Raster Data Model

Vector	Raster
Advantages	
Compact data structure (less data volume)	Simple data structure
Efficient topology encoding, good for operations, such as network analysis	Easier and efficient overlay operation
Better graphics for precise expression	High spatial variability is efficiently represented
	Efficient in manipulation and enhancement of digital images
Disadvantages	
Complex data structure	Large data volume (data compression technique can overcome this problem)
Implementation of overlay operations is difficult	Difficult to represent topological relationships
Inefficient representation of high spatial variability	Less aesthetic graphic output
Not effective for manipulation and enhancement of digital images	Not good for some operations, such as network analysis

3.3.5. Data Analysis and Modelling

The most significant characteristics of GIS are the provision of the capabilities for data analysis and spatial modeling. These functions use the spatial and non-spatial attribute data of the

GIS database to answer questions about the real world. The database in 6IS is the model of the real world that can be used to simulate certain aspects of reality.

A model may be represented in words, m mathematical equations or as a set of spatial relationships displayed on a map. The general problem in data analysis is: users query -* database link -*• output.

The user has particular specification, constraints or query. The database contains information in the form of maps that can be used to answer the users query. All that is necessary is to establish a link between database and output that will provide the answer the form of a map, table, or figure. The link is any function that can be used to convert data from one or more input maps, into an output.

2.3.5.1. Analysis; Functions

The power of GIS lies in its ability to analyze spatial and attribute data together. A large range of analysis procedure/ functions have been divided in to four categories: retrieval, red classification and measurement overlay; Distance and connectivity; and neighborhood.

2.3.5.2. Retrieval, Reclassification and Measurement Operations

In these functions retrieval of both spatial and attribute data are made and only attribute data are modified. Creation of new spatial elements is not made.

Retrieval operations: This involves the selective search and manipulation and output of data. Retrieval operation includes the retrieval of data using:

- geometric classification,
- symbolic specifications,
- a name of code of an attribute,
- conditional and logical statement.

Reclassification procedures: This procedure involves the operation that reassign thematic values to the categories of a existing map as a function of the initial value, the position size or shape of the spatial configuration associated with each category (for instance a soil map reclassified into erodibility map). In raster based GIS, numerical values are often used for indicate classes. A cell might be assigned the value to indicate classes. Classification is done using simple data layers as well as with multiple data layers as part of an overlay operation.

Measurement operations: Spatial data measurement includes: calculation of distance,length of lines, areas and perimeter of polygons, and volumes. Measurements involving points are: distance from a point to a point, a line, a polygon, enumeration of the total number as well as the enumeration of points falling within the polygon.

2.3.5.3. Overlay Operation

Overlay operation creates a new data set containing new polygons formed from intersection of the boundaries of the two or more sets of separate polygonal layers. There are two common overlay operations: arithmetic and logical. Arithmetic overlay includes operation such as addition, subtraction, division and multiplication of each value in a data layer by the value in the corresponding location in the second data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied. The logical overlay operation is done using the rules of Boolean logic. Boolean algebra uses the operations of AND, OR, XOR, NOT to see whether a particular condition is true or false .

2.3.5.4. Neighborhood Operation

This involves the creation of new data based on the consideration of roving window of neighboring points about selected target locations. They evaluate characteristics of an area surrounding spatial location. In all neighborhood operations, it is necessary to indicate one or more target locations, the neighborhood considering each target and the type of function to be executed The typical neighborhood operation in most GISs are; search topographic functions and interpolation.

Search functions: This constitutes one of the most commonly use neighborhood function. Value assignment to each target feature is made on the basis of some characteristics of its neighborhood. The basic parameters required to be defined in a neighbor search are targets, the neighborhood, and the functions to be applied to the neighborhood to generate neighborhood value. The search area is usually square, rectangular or circular whose size is determine by the analyst.

Topographic functions: Topography refers to surface characteristics such as the slope, relief and form of the area The topography of a surface can be presented in a digital elevation model (DEM). DEM represents a topographic surface terms of a set of elevation values measured at a finite number, o points, and contains terrain features of geo morphological importance such as valleys and ridges, peaks and pits (Valenzuela 1990). Topographic functions are used to calculate values that describe the topography of an area. The most common transformations working with elevation data are the slope and aspect - slope face direction.

Interpolation: This procedure predicts unknown values at any sampled sites using the known values of existing observations neighboring locations. Point and aerial interpolation involve variety of methods such as polynomial regression, kriging , splines , trend surface analysis, Fourier- series and moving averages (Burrough, 1986; Valenzuela, 1990). The quality of interpolation results is a function of the precision, accuracy, number and distribution of the known points used in the. calculation and the manner in which the mathematical function models reality. The un known values are the n calculated according to this function.

2.3.5.5. Connectivity Functions

Connectivity operation is those that estimate values (quantitative or qualitative) by accumulating them over the area that is being traversed. These operations require the specification of the manner in which the spatial elements arc interconnected, specification of the rules that control the movements allowed along the spatial elements and the unit of measurements. Connectivity functions are grouped in to contiguity, proximity, and network and spread operation.

Contiguity: contiguity measures characterized spatial units that are connected. A contiguous area is formed by a group of spatial units that have one or more common characteristics and constitute a unit. Common measures of contiguity are the size of the contiguous area and the shortest and the longest straight line distance across the area.

Proximity: This involves the measurement of the distance between features, the measurement unit can be distance in length, travel distance in time or other units. The necessary parameters, which must be specified to measure proximity, are the features or objects (roads, houses, etc.), the units of measure (meter, length, etc.), a function to calculate proximity (Euclidean distance), and area to be analyzed. A buffer zone may be the result of a proximity analysis.

Network: network functions are commonly used in analysis that require moving resources from one location to another. G I S is used to perform network analysis such as prediction of network loading, |or instance, transport of water and sediment in fluvial system, route optimization such as air line scheduling, urban transportation, services or municipal garbage collection, and resources allocation, eg. subdivision of municipal districts into zones that can be efficiently serviced by hospitals and schools. In network analysis four components are usually considered: a set of resources (eg. sediment transport by water), one or more locations where the resources are located (eg. a fluvial system), d destination (eg. outlet of the watershed), and a set of constraints (eg. only permanent streams of higher order).

2.3.5.6. Modeling

A model is the simplest representation of reality in which it presents significant features or relationships in a generalized form, i.e, it is the selective approximation of reality (Valenzuela, 1990). A model can be descriptive (describes the real world, eg. map), predictive (predicts what might occur under certain conditions, eg. USLE, soil erosion model) or decisive model. A characteristic of modeling is the use of the attribute data, i.e, each map has one or several tables that include a specific single datum (attribute) of the pertinent map.

3.3.6. Data output

Data output is the operation of presenting the results of data manipulation in a form that is understandable to a user or in a form that allows data transfer to another computer system. The basic output formats from a GIS are hard copy, soft copy, am) electronic outputs (Fig. 3.6) . Maps and historical tabulations are output in the hard copy format by the help of hard copy output devices such as dot matrix pi-inters, ink jet plotters, pen plotters, matrix camera, color laser printer, etc.

Soft copy output is the format as viewed on a computer monitor. It may be text or graphics in monochrome or color. Soft copy display are used only for temporary display. The soft copy device most often used in GIS is computer monitor", cathode ray tube.

Output In electronic format consist of computer compatible files. They are used to transfer data to another computer system either for additional analysis or to produce a hard copy output at a remote location.

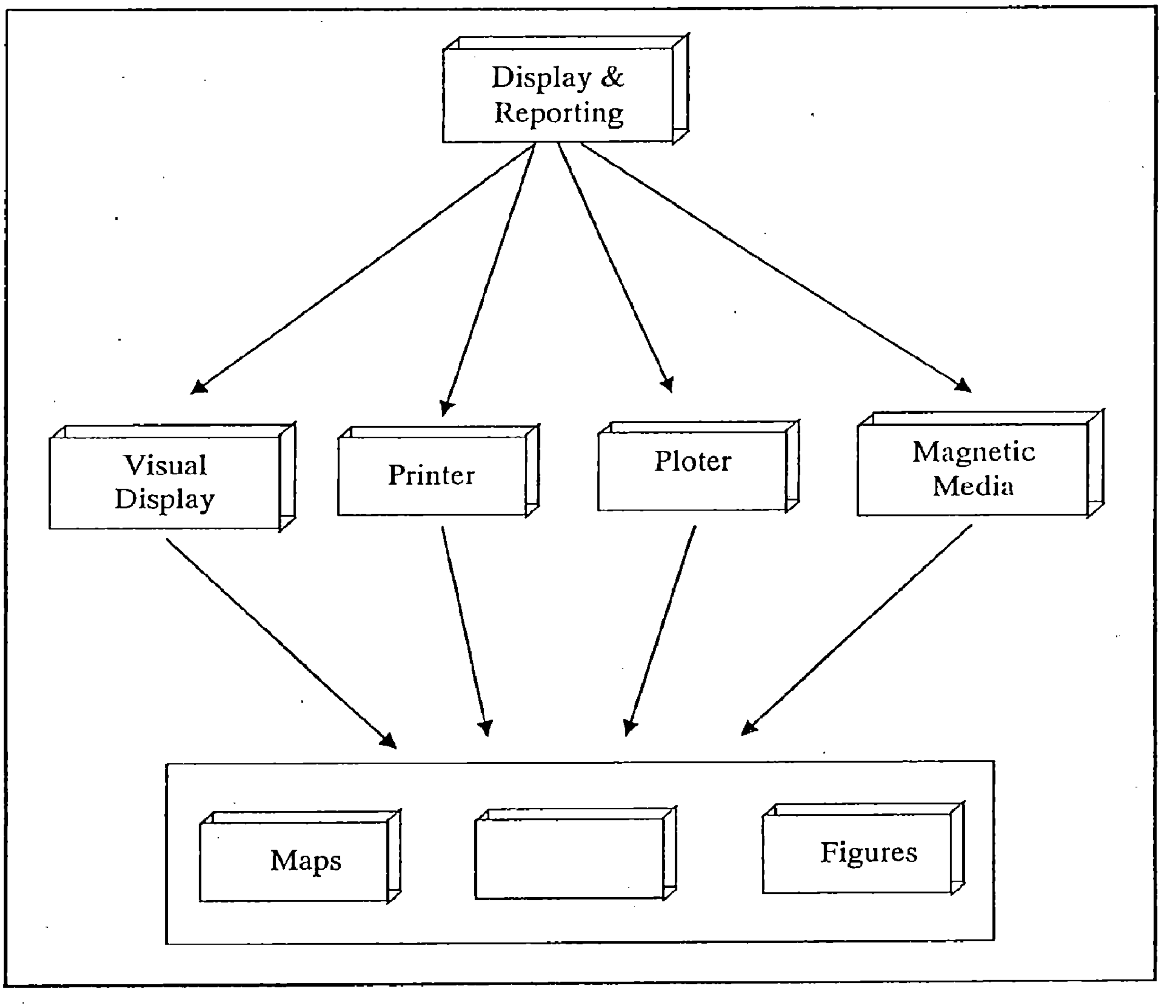


Figure 3.6. GIS Data output (Burrough, 1986)

3.4. COORDINATE SYSTEM AND MAP PROJECTION

To analyze, manipulate, measure and store reasonably, geospatial data must be put into one certain spatial coordinate system. There are two kinds of coordinate system for geo-spatial data, *Spherical* and *Cartesian* coordinate system (Fig.3.7). In *spherical coordinate* system, each point feature can be described uniquely with a pair of latitude and longitude value although latitude and longitude are not uniform across the Earth's surface.

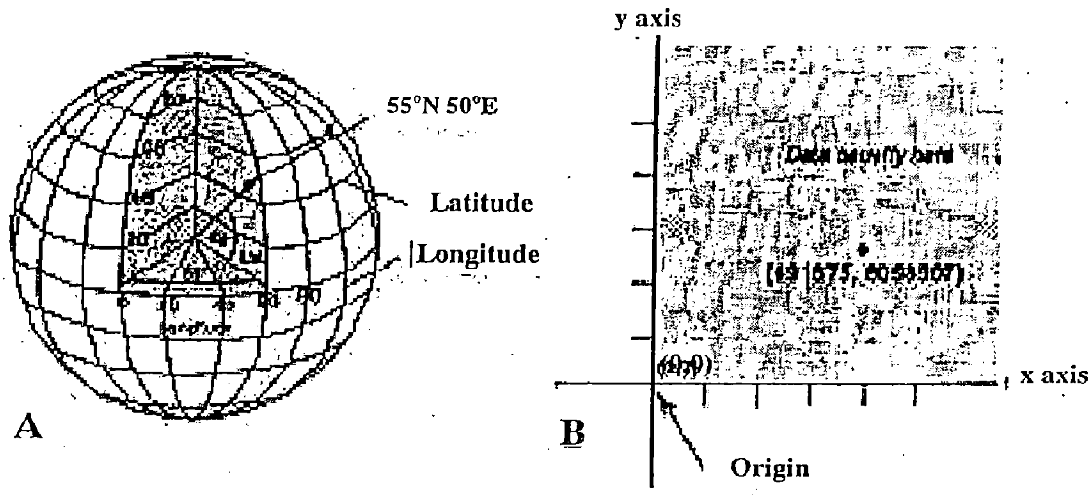


Figure 3.7. Spherical and Cartesian Coordinate System

In *Cartesian* or *Planar* coordinate system, each point feature on the Earth will be projected onto a flat surface by a pair of x and y coordinates on a grid. Using this system, the coordinates at the origin are x = 0 and y = 0. On a girded network and equal spacing, the horizontal line in the center of the grid is call the x-axis, and the central vertical is call y-axis. Therefore, coordinate value; measures of length, angle and area are uniform in this coordinate system

The main co-ordinate reference systems for describing a geographic position mathematically are geodetic reference systems and map projections. *Geodetic reference systems* are used for describing the figure of the Earth and positions on it: *ellipsoids* (and the *sphere*) are used for describing the horizontal position. The shape of an ellipsoid is defined by a Semi-major and Semi-minor axis, and there are several spheroids available for use in different parts of the world. Each of them assume different semi-major and semi-minor axis. *Geoids* are the gravity related model for referencing the elevation. Geodetic reference systems have a *datum*, which defines the position of the spheroid relative to center of the earth. It defines the origin and orientation of latitude and longitude lines. There are two types of datum. *The latitude and longitude of a point, the azimuth of a line from that point, and the two radii needed to define the geometric reference surface that best approximates the surface of the earth* *in the region of the survey define horizontal datum. Vertical datum* ensures that elevation and depth measurements are held to a common vertical standard.

When we try to transform the location information on three-dimensional earth surface onto a two-dimensional map, *projection* is needed. In other words, *Map projections* are used to map the curved surface of an ellipsoid to a plane. This achieved by transforming the values with mathematical expressions. There are three major projection types, namely Planar (also know as Azimuthal), Conic, and Cylindrical projections depending on the shape of the developable surface (Fig. 3.8).

Azimuthal projections, points are projected from the surface of the Earth to the plane. A commonly used projection of this type is the stereographic conformal projection. This type of projection includes Gnomonic, Stereographic, Orthographic, Azimuthal Equal Area, Azimuthal Equidistant, and Globular projection. Planar or Azimuthal Projections are used most often to map Polar Regions.

Conic projections result from conceptually transferring the earth's coordinates onto a cone. This family of projection includes Simple Conic, Two-Standard Parallel Conic, Lambert's Conformal, Albert's Equal Area, Conic Equidistant, Polyconic, and Bonne Projection.

Cylindrical projections are a family of projections resulting from conceptually transferring the earth's coordinates onto a cylinder. Cassini or Cassini-Soldner, Gall's Cylindrical, Mercator, Lambert's Cylindrical Equal-Area, and Transverse Mercator projection. *Universal Transverse Mercator (UTM)* projection system is one of the commonly used projection systems.

The two most commonly used projection system are Geographic and Universal Transverse Mercator (UTM). These coordinate systems can successfully be used in the context of GMS countries.

Geographic Coordinate System – In this system, all horizontal lines are called *latitude or parallels* and the vertical lines are called longitude or *meridians*. As the meridians line toward the poles, the distance represented by one degree of longitude decreases unit it equals zero at the North Pole and the South Pole. The origin of the Spherical coordinate is defined by the intersection of 0^o latitude or the equator and 0^o longitude or the Prime Meridian passing through the Greenwich in U.K.

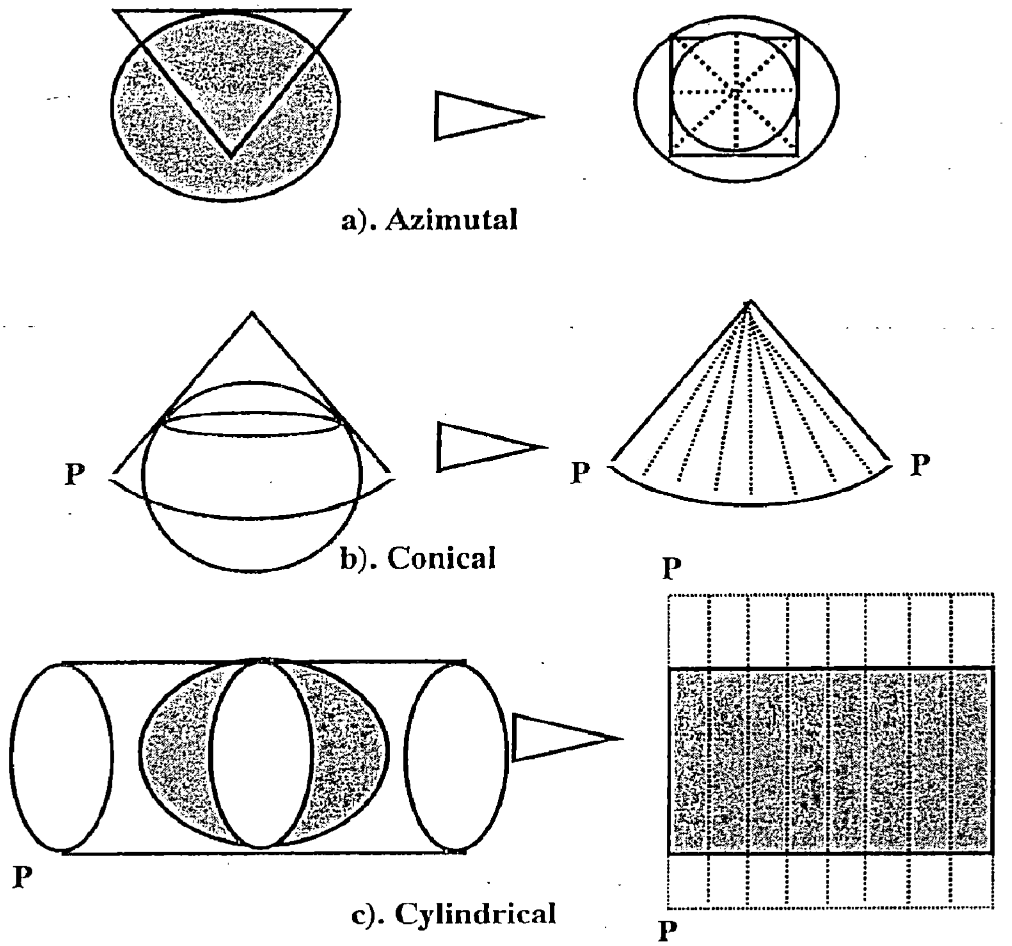


Figure 3.8. Map projections (Redraw from Berharnsen, 1992)

Latitude and longitude are angled measured from the Earth's center (not perpendicular) to a point on the Earth's surface. And they are measured in degrees, minutes and second (DMS) or decimal degree (DD). For example latitude 0° is located at the Equator, 90° is at the North Pole, and -90° is at the South Pole. The position of a point is uniquely defined by two angles: Latitudes 0° is the Prime Meridian, and longitude moving east from the Prime Meridian is measured positive up to 180°. On the other hand, longitude moving west from the Greenwich is measured negatively to – 180° (Fig.2.8). It is note that the Spherical or Geographic Coordinate System is a projection less that may be used for the input, storage, and exchange of digital map data.

Although it may also be used for the output of hardcopy maps, it is not, however, structurally suited for that purpose for smaller areas.

Universal Transverse Mercator (UTM) - is an international plane (rectangular) coordinate system developed by the U.S. Army. In this system, the world is divided into 60 zones, each covering 6 degrees of longitude. In latitude, extends from 84o N to 80o S (Fig.3.9). The origin of each zone is the intersection of the central meridian at the equator. High degree of accuracy is possible due to separate projection for each UTM zone. UTM values are calculated in meters. To eliminate negative coordinates, the projection alters the coordinate values at the origin. The value given to the central meridian is the *false easting*, and the value assigned to the Equator is the *false northing*. For locations in the Northern Hemisphere, the origin is assigned a false easting of 500,000 meters, and a false northing of 0. For locations in the Southern Hemisphere, the origin is assigned a false easting of 500,000 meters and a false northing of 10,000,000 meters (10,000 km). In addition to minimize geometric distortion across each zone, the scale at the central meridian is reduced by a *scale factor* equal to 0.9996. This produces two parallel lines of zero distortion approximately 180 km either side of the central meridian.

The UTM system is consistent for the globe and is universal approach to accurate geo-referencing by preserving the local shape of the area (conformal type), thus frequently used. Of the disadvantages, the problems arise in working across zone boundaries and also there does not exist simple mathematical relationship between coordinates of one zone and an adjacent zone. UTM projection should preferably be used within the limits of any given zone. For example, the Kingdom of Thailand has been divided into two vertical zones (zone 47 and 48). Thus, projecting whole country in either zone is not desirable. This system may be used for the input, storage, and exchange of digital map data, as well as for the output of hardcopy maps.

Selecting a map projection depends on the location of area to be mapped. Virtually any map projection is acceptable while mapping a relatively small area. The

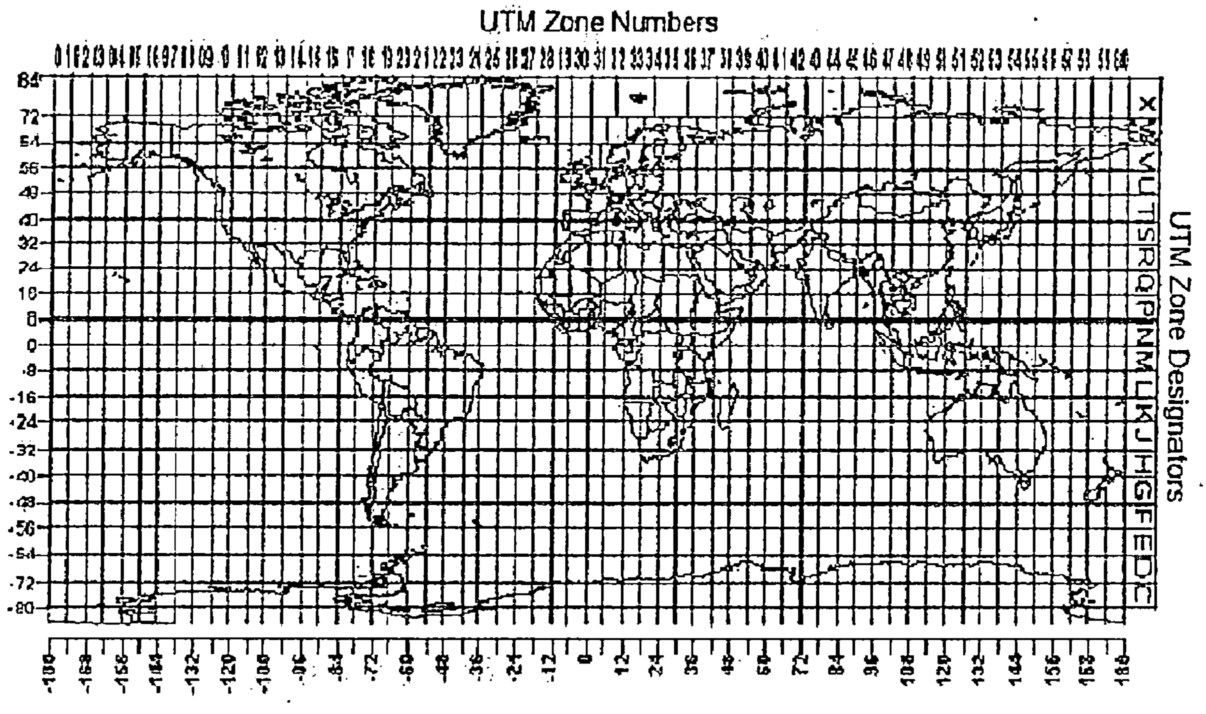


Figure 3.9. UTM System

Source :http://everest.hunter.cuny.edu/mp/cylind.html

choice of map projection becomes more critical while mapping larger areas. Building or storing of data in the context of GMS can be done using Geographic Coordinate System. Data can also be projected to (tropical region); the cylindrical map projection (e.g. UTM) gives the best result with minimum distortion. For transforming Geographical coordinates to other projection system, cylindrical map projections (e.g. UTM) are the appropriate systems as the GMS lies in the tropical region. For the purpose of transforming, we need to use spheroid and datum. In case of GMS countries, the spheroid called 'Southeast Asia' (semi-major axis 6378155 km., semi-minor axis 6356773.3205) is suitable one. The other global use spheroid called 'Modified Everest' (semi-major axis 63777304.063, semi-minor axis 6356103.039) can also be used. It is suggested to use the local datums for each countries whenever available.

3.5. GIS AND DECISION SUPPORT SYSTEM

The successful operational applications of GIS require -.. institutional setting and must support the management of resources or some problem solving processes. Furthermore, it must exist within an organizational setting that is capable of providing it with proper support.

The recent development of decision support system (DSS) brought a new concept of integrating GIS and resource models into a tightly-coupled system in that the systems more likely to be used to aid decision making. Out of the combination of DSS and GIS emerges an entirely new system called spatial decision support system (SDSS). SDSSs are new classes of computer systems that combine the technologies of GISs and DSSs to aid decision makers with problems that have spatial dimension. Figure. 3.10 presents the melding of GIS and DSS into SDSS.

SDSSs are oriented towards the decision makers and offers one unifying framework for integrating GIS and DSS including the models within the DSS, i.e, the SDSS framework offers a means to increase the utility of both GISs and DSSs to assist decision makers.

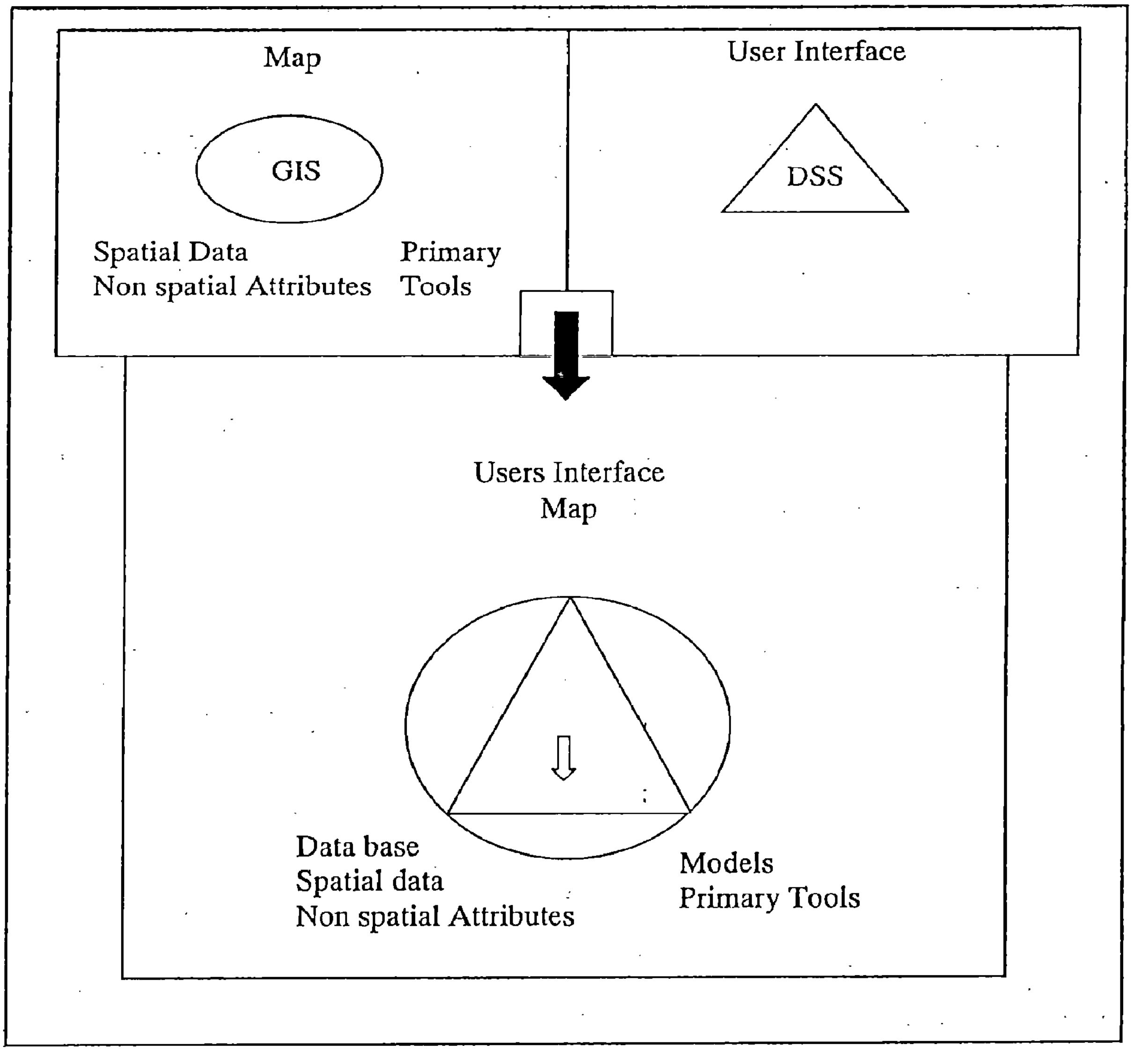


Figure 3.10. Presentation of SDSS as combination of GIS & DSS (Michael et al,1993)

CHAPTER IV
DESCRIPTION OF STUDY AREA

4.1. GENERAL

For the present study two watersheds namely Jati and Singgahan of East Java Province of Indonesia are considered. These watersheds locate in Trenggalek District, East Java Province Indonesia,. Trenggalek is located in the South coast area of East Java, between 111 24' and 112 11' east longitude and between 7 53' and 8 34' South latitude. In the north it is bordered on the district of Tulungagung, the West on the district of Ponorogo, the South on Indonesian Ocean. Two the third of its area consist of mountainous land area and the rest is the basin area. The total area of this region is 126.140 Ha out of 48 % is the forest area and the rest consists of farm land, dry land, housing area etc. There are 4 assistants to regent/ district, 13 sub districts, 157 villages, 509 small villages and 4,107 small district society. In 1993 the number of the population was 639,000, by the population density of 506/km2 and its growth of population is 0.53 %. Figure 4.1 represent The Study Area.

Those watersheds are under development of Brantas River Basin.. The Brantas River plays an important role in the economic development not only in East Java Province but also for nation wide. The more holistic approach to the water resources development and management has been successfully developed in Brantas River Basin. The Brantas River Basin Development Executing Office has constructed more than 20 major structures in the basin since the last 30 years.

The Brantas river is the second largest river in Java Island, Indonesia.The length of the river is about 320 km and catchment area of about 12,000 sq km. Average annual rainfall is about 2,000 mm and annual surface run off is about 12 billion m3 Population in the basin is around 14 million people (1998) In the past, the problems in the basin were annual floods that suffered the people living in the flood plain and villages, shortage of water availability during dry season caused reduction of food production, in balance of water allocation among consumers, low water quality and shortage of electricity (hydropower).

Development of the Brantas river basin was started in 1961 . A series of Master Plan had been formulated to overcome the problems in the basin. Basic concept of the development was comprehensive and integrated development, that was " **one river, one plan, one coordinated management"** , because of water is a dynamic resources, that flowing from upstream down to the estuary as an unity. Even though the river was flowing across the boundary of districs, prefectures or countries, it has to be managed as an unity to avoid conflict of interest Up to year 2000, benefits of the Brantas river basin development were : **Flood control** (protected of about 56,000 ha of land), **Irrigation** (supply water for about 345,000 ha pady field), **Electricity** (producing electricity of about 900 million kWh / year), **Drinking water** (supply raw water of about 200 million m^3/year), **Industrial water** (supply raw water of about 120 million m^3 / year), **Fishery, Recreation,** etc The Brantas river basin has supported around 25 % of national stock of rice. Development of the Brantas river basin has raised up social life prosperity in economy, social and culture within the river basin.

Soil and land use data of the proposed small ponds consists of soil type and present land uses along the catchment area, dam site, and impounding area as well as beneficiary area. All the above data are skimmed from the soil maps and several books of agro-ecological features of each Sub-districts of East Java Province (Ministry of Agriculture, 1996).

The agro-ecological zones of the project area, which are at most spreading within the Brantas River Basin, are classified in accordance with the following components:

a. Soil order
b. Wet regime
c. Temperature regime
d. Physiography

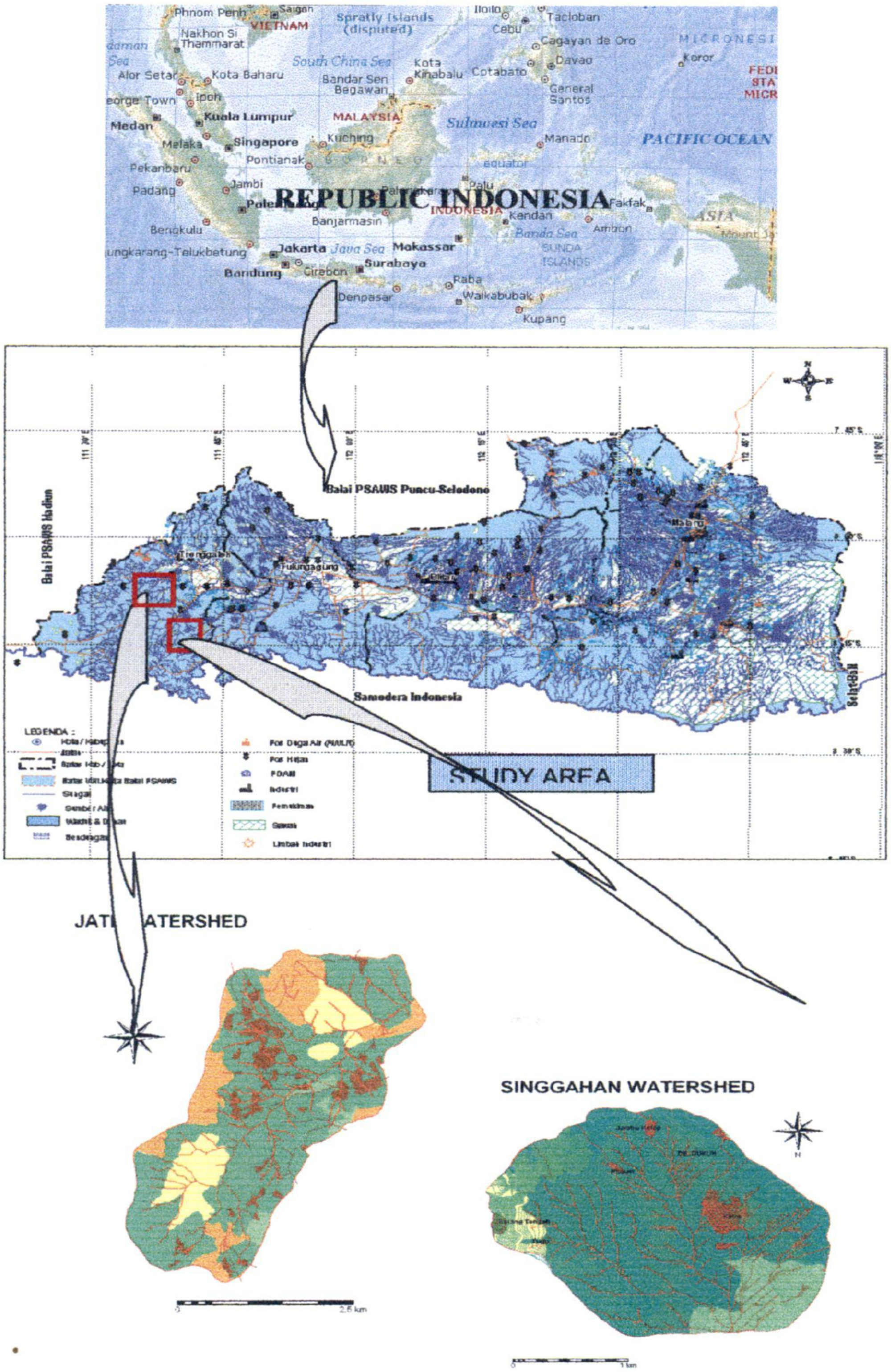


Figure 4.1 The Study Area

4.1.1. Soil Order

Soil order spreading over the East Java region is classified into seven (7) order of 11 order as classified in "soil taxonomy". The seven orders are:

a) Andisol : This soil was resulted from the volcanic ash weathering, which is dominated by a non-crystal amorph mineral.

b) Vertisol : Heavy black clay, which is cracked in the dry season and muddy in the wet season.

c) Oxisol : Aging weathering soil that is merely dominated by unwashed minerals like caolinite and oxide

d) Mollisol :Organic layered soil characterized by its good physical feature and high saturated alkaline content.

e) Alfisol :Fairly weathered soil, containing accumulated clay with high saturated alkaline content.

f) Inceptisol :Low developed horizon soil.

g) Entisol :Very new formed soil without horizon, except on its top.

4.1.2. Alkali Regime

Alkali regime is learnt from the "Agroclimatic Map of Java and Madura (Oldeman, 1975), covers:

a) Perudic : short dry period regime, is that a regime of less than 2 months dry in a consecutive ways per year (Type A and B1)

b) Udic : Fairly dry period regime, is that a regime of 2 to 4 months dry in a consecutive ways per year (Type B2, C2, and D2)

c) Ustic : Long dry period regime, is that a regime of more than 4 months dry in a consecutive ways per year (Type C3, D3, and E)

4.1.3. Temperature Regime

The temperature regime, which is very attributable to the agricultural commodity development, is a soil temperature of 50 cm in depth. Soil temperature regime of East Java region can be described as follows:

a) Isohyperthermic : its mean annual temperature is more than 22° C, spreading on a 0 – 700 m high above sea level.

b) Isothermic :Its mean annual temperature is 15°C - 22°C, spreading on a 700 – 1500 m high above sea level.

c) Isomesic : Its mean annual temperature is 8°C - 15°C, spreading on a 1500 – 2500 m high above sea level.

4.1.4. Physiography

Physiographically, the region is classified in accordance to its slope conditions. Its direct effect to the agricultural potential depends on its erosion sensitivity. Based on the topographic map, the regional physiographical condition is classified into three groups, as follows:

a) Flat to gently sloping :The area with less than 3% slope degree and different height of less than 5m.

b) Undulating to rolling :The area with less than 3% - 15% slope degree and different height of 5 – 50 m.

c) Hilly to mountainously :The area with more than 15% slope degree and different height of 50 m.

Population and community in the study area site is analyzed based on the statistic data of 2001. The information of population and community consists of number of population, population density, population growth, number of household, number of farm households and average annual income/household.

Source of daily domestic water requirement consists of dug well, hand pump well, spring, untreated river water, PDAM and purchasing raw water from out side by mobile water tank. Based on the field survey results, most of the people take water from both dug-well and hand pump and the rest from river and spring.

Agricultural sector is of the main livelihood of the people of the study areas. Average percentage of farming households is 73.87 %. Types of crops that are common in the project area consist of paddy, Maize, Soybean, Mungbean, Groundnut, Tobacco and Sugarcane. Average paddy production is respectively 2.7 ton/ha in rain-fed and 4.1 ton/ha in irrigated paddy fields. Maize production is of 0.8 ton/ha to 3.2 ton/ha. Soybean production is ranges between 0.8 – 1.2 ton/ha, groundnut production is ranges between 0.6 – 1 ton/ha. Existing irrigation system consists of technical, semi-technical, and traditional irrigation systems facilitated by such works as weir, free intake, intake structure from pond and pump, with water sources supplied from river, spring, and groundwater.

Climate data record for all three watersheds collected from nearest climatologic station at Wlingi Dam in period 1997 to 2001 recorded data. Rainfall data collected from Station Pule (Station. No. 51) and Station Watulimo (Station No.49) for Jati and Singgahan watersheds respectively. The period's data collected is from 1987 to 2000. The climatological data for the study area is given in Appendix B

Based on Review of Water Resources Development Study for Water Supply in Brantas River Basin under Wonorejo Multipurpose Dam Construction project, those watersheds have identified for construction of water harvesting structure small pond type.

4.2. JATI WATERSHED

4.2.1. General Information

(i). Name of Watershed : Jati

(ii). Name of River/River Basin : Jati

(iii) Land use

- Settlement/residential : 88 ha
- Paddy field : 32 ha
- Rain fed and secondary cropp : 181 ha
- Bush/ pasture lands : 143 ha
- Forest/plantation tress : 703 ha

(iv) Geography

- Coordinate : 8^0 16' 59.59" S - 111^0 54' 28.74" E
  Bakosurtanal Landuuse Map 1:25,000
  Sheet: Pule/Dongko
  No. of Map : 1507-533/1507-331
- Elevation : 255.47 from m.a.s.l.
- Land form : Steeply Undulation Ridge
- Average Slope : 8.60 %
- Geological Formation : Alluvial, Colluvial, Sandstone
- Soil type : Oxisol/Inceptisol
- Soil Texture : Moderate
- Average slope : 8.60 %

(v) Hydrology and Climatology

Description	Rainfall (mm)	Climate			
		Temperature (° C)	Humidity (%)	Sunshine (%)	Wind Vel. (km/hour)
Yearly average	2,071	25.73	78.10	62.27	1.48
Name of Station	Pule, Station No..51	Wlingi Dam			
Observation period	1987 – 2000	1997 – 2001			

4.2.2. Benefited Village Profile

(i). Population and Main Occupation

No.	Description	Village
1.	Nos. of population (year :2001)	4,311
2.	Population density (person/km)	517
3.	Average of growth population (%)	0.56

4.	Nos. of Household	1,446
5.	Main Occupation : a. Farming (Household No's.) b. Other Main Occupation - Animal husbandry - Gardener - Construction Laborer - Trader/Industry - Government official/Soldier	 911 148 63 37 235 52
6.	Average Income/year (rupiah)*	541,475

* District Data

(ii). Land & Farm Land Ratio

No.	Description	Area (Ha)
1.	Settlement	51
2.	Paddy field - Technical irrigation - Semi technical irrigation - Simple irrigation	 - 36 46
3.	Rain fed	-
4.	Up land	320
5.	Bush	-
6.	Estate	-
7.	Forest	281
8.	Others	-
Farm Land per household (ha/house)		0.44
Irrigated farm land per household (ha/house)		0.09

(iii). Agriculture Food Crop Production (ton/ha)

Crop	Paddy field			Rainfed	Upland
	Technical	Semi technical	Simple Irrigation		
WS Paddy	-	4	3.5	-	-
DS I Paddy	-	3	-	-	-
DS II Paddy	-	-	-	-	-
Maize	-	-	-	-	0.8
Soybean	-	1	1	-	-

(iv). Water Resources and Allocation

a) Irrigation

Resources	Water tapping	Area Served		Availability/ year (month)	Name of scheme
		(Ha)	(%)		
Spring/River	Free intake Weir	82 -	20.40 -	8 -	- -
Rain		320	79.60	5	-

b) Water Supply

Resources	Water Tapping	Water Supply	(Q) Lt/sc	HH (No's)	Water Price (Rp/month.)
River	Bucket	By foot	-	506	-
Groundwater					
- Deep well	-	-	-	-	-
- Shallow well	Bucket	By foot	-	940	-

4.2.3. Present Condition of Beneficiary Area

(i) Irrigation

Description	Irrigated Paddy field			Rainfed			Upland		
	Crop area (ha)	Intensity (%)	Product. (t/ha)	Crop area (ha)	Intensity (%)	Product. (t/ha)	Crop area (ha)	Intensity (%)	Product. (t/ha)
Paddy WS	51	100	4	-	-	-	-	-	-
Paddy DS-I	25.5	50	3	-	-	-	-	-	-
Paddy DS-II	-	-	-	-	-	-	-	-	-
Maize	-	-	-	-	-		-	-	-
Soybean	25.5	50	1	-	-	-	-	-	-
Total Crop Intensity	200			-			-		

(ii). Water Supply

Resources	Water Tapping	Water Supply	Distance of take (km)	Served	
				House hold	Persons
Spring	-	-	-	-	-
River	Bucket	By foot	0.5	260	1,040

4.2.4. Proposed Development Plan

i) Small Pond

- Name of Pond : Ngompak Pond
- Location : District : Trenggalek
  - Sub district : Suruh
  - Village : Suruh
  - Sub Village : Ngompak
- Distance From : Sub district : 3 km

District	: 16 km
- Type	: Homogeneous fill
- Dam body, Height/Length	: 10.5 m / 43.5 m
- Spillway type, Height/Wide	: Side Spillway, 2.25 m / 30 m
- Cacthment area	: 1,135 ha
- Impounding area	: 0.21 ha
- Storage Volume	: 6,430 m^3

ii) Irrigation Development Plan

- Area	: 51 ha
- Purposed Cropping Pattern	: Paddy - Paddy - Soybean
- Crop Intensity	: 300 %
- Unit Diversion Requirement	: 1.55 l/sec
- Discharge Diversion Requirement	: 0.079 m^3/sec
- Intake	: Right
- Method of Irrigation	: Gravity

iii) Water Supply Development Plan

- Nos. of Beneficiary	: 277 Household (1106 Persons)
- Supply Design	: 60 l/day/capita
- Requirement	: 66.36 m^3/day
- Intake	: Right
- Method of Water Supply	: Gravity
- Pipe Line Requirement	: 1,500 m

iv) Access Road Development Plan

- Existing	: Footpath (Up land)
- Length	: 200 m
- Wide	: 5 m

4.3. SINGGAHAN WATERSHED

4.3.1. General Information

(i). Name of Watershed : Singgahan

(ii). Name of River/River Basin : Singgahan

(iii).Land Use (%)

- Settlement/Residential : 18.7 ha
- Paddy field : 24 ha
- Tree plantation : 57.8 ha
- Forest : 420 ha

(iv). Average slope : 12.10 %

(v). Geography

- Coordinate : 8^0 15' 27.37" S - 111^0 41' 24.71" E
  Bakosurtanal Landuse Map 1:25,000
  Sheet: Prigi/Kampak
  No. of Map : 1507-514/1507-532
- Elevation : 67.18 from m.a.s.l.
- Land form : Moderately Undulation Ridge
- Average Slope : 12.10%
- Geological Formation : Alluvial, Colluvial, Andesite

6. Hydrology and Climatology

Description	Rainfall (mm)	Climate			
		Temperature (° C)	Humidity (%)	Sunshine (%)	Wind Velocity (km/hour)
Yearly average	2,331	25.73	78.10	62.27	1.48
Name of Station	Watulimo, Station No..49	Wlingi Dam			
Observation period	1987 – 2000	1997 – 2001			

4.3.2. Benefited Village Profile

(i). Population and Main Occupation

No.	Description	Village
1.	Nos. of population (year :2001)	4,802
2.	Population density (person/km)	672
3.	Average of growth population (%)	0.67
4.	Nos. of Household	1,095
5.	Main Occupation :	
	a. Farming (Household No's.)	788
	b. Other Main Occupation	
	- Animal husbandry	35
	- Gardener	21
	- Construction Laborer	27
	- Trader/Industry	190
	- Government official/Soldier	34
6.	Average Income/year (rupiah)*	541,475

* District Data

(ii). Land & Farm Land Ratio

No.	Description	Area (Ha)
1.	Settlement	53
2.	Paddy field - Technical irrigation - Semi technical irrigation - Simple irrigation	 - - 61
3.	Rain fed	88
4.	Up land	218
Farm Land per household (ha/house)		0.46
Irrigated farm land per household (ha/house)		0.08

(iii). Agriculture Food Crop Production (ton/ha)

Crop	Paddy field			Rainfed	Upland
	Technical	Semi technical	Simple Irrigation		
WS Paddy	-	-	4	3	-
DS I Paddy	-	-	-	-	-
DS II Paddy	-	-	-	-	-
Maize	-	-	-	-	0.8
Soybean	-	-	1	1	-

(iv)..Water Resources and Allocation

a) Irrigation

Resources	Water tapping	Area Served (Ha)	Area Served (%)	Availability/ year (month)	Name of scheme
Spring/River	Free intake	61	16.62	8	-
	Weir	-	-	-	-
Rain		306	83.38	5	-

b) Water Supply

Resources	Water Tapping	Water Supply	(Q) Lt/sc.	HH (No's)	Water Price (Rp/month.)
River	-	-	-	-	-
Spring	Free intake	Pipe connecting	1.5	415	1,000
Groundwater					
- Deep well	-	-	-	-	-
- Shallow well	Bucket	By foot	-	680	-

4.3.3. Present Condition of Beneficiary Area

(i). Irrigation

Description	Irrigated Paddy field			Rainfed			Upland		
	Crop area (ha)	Intensity (%)	Product. (t/ha)	Crop area (ha)	Intensity (%)	Product. (t/ha)	Crop area (ha)	Intensity (%)	Product. (t/ha)
Paddy WS	10	100	4	-	-	-	-	-	-
Paddy DS-I	5	50	3	-	-	-	-	-	-
Paddy DS-II	-	-	-	-	-	-	-	-	-
Maize	-	-	-	-	-		-	-	-

Soybean	3	30	1	-	-	-	-	-	-
Total Crop Intensity	180			-			-		

(ii). Water Supply

Resources	Water Tapping	Water Supply	Distance of take (km)	Served	
				House hold	Persons
Spring	Free intake	Pipe connecting	0.5-3.5	325	1,300

4.3.4. Proposed Development Plan

(i). Small Pond

- Name of Pond (Ref.) :Winong Sawahan Pond (TR-2)
- Location :District : Trenggalek
  - Sub district : Watulimo
  - Village : Sawahan
  - Sub Village : Winog Sawahan
- Distance From Sub district : 3 km
  - District : 22 km
- Type : Gravity stone masonry
- Dam body, Height/Length : 9 m / 72.5 m
- Spillway type, Height/Wide : Crest Over Flow, 1.6 m / 25 m
- Cacthment area : 507 ha
- Impounding area : 0.62 ha
- Storage Volume : 21,778 m^3

(ii). Irrigation Development Plan

- Area : 10 ha
- Purposed Cropping Pattern : Paddy - Paddy - Soybean
- Crop Intensity : 300 %
- Unit Diversion Requirement : 1.55 l/sec

- Discharge Diversion Requirement : 0.015 m^3/sec
- Intake : Left
- Method of Irrigation : Gravity
- Conveyance Channel Length : 600 m

(iii). Water Supply Development Plan

- Nos. of Beneficiary : 350 Household (1399 Persons)
- Supply Design : 60 l/day/capita
- Requirement : 83.94 m^3/day
- Intake : Left
- Method of Water Supply : Gravity
- Pipe Line Requirement : 2,000 m

CHAPTER V

APPLICATION OF GIS IN WATERSHED MANAGEMENT

5.1. INTRODUCTION

To assess the soil loss and rainfall-runoff from watershed under consideration the Universal Soil Loss Equation (USLE) and SCS rainfall-runoff, empirical equation model are used.

All the parameter of the USLE and SCS runoff empirical methods are geographic in character, so that they can be referenced to a particular location. Rainfall distribution, land use and land cover, soil type and information on conservation practices are often available in the form of maps or can be mapped through collection of data from possible sources or field investigation or/and remote sensing studies. Due to the geographic nature of these parameters, USLE and SCS run-off models can be easily be modeled into GIS. Assessment and prediction of soil loss and runoff potential from any watershed is desired using GIS. Thus decision making also can be done based on simple representation from GIS based study.

5.2. SOFTWARE USE

The GIS software used in this study is ILWIS (Integrated Land and Water Information System). It was developed at the Computer Center Of International Institute of Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands. ILWIS provides users with state of art of data gathering, data input, data storage, data manipulation and analysis and data output capabilities, merging and integrating conventional GIS procedures with image processing capability and a relational database. The system is tailored for use with microcomputers and uses both vector and raster graphics data (Valenzuela, 1988).

As a GIS and remote Sensing software package, ILWIS allows to input, manage, analysis and present geographical data. Information on the spatial and temporal pattern and processes on earth surface can be generated from this data.

5.3. RAINFALL EROSIVITY INDEX

This Study uses both spatial and geographical data set from different sources. Spatial data includes rainfall data, and geographical data includes land use map, drainage map, soil map and contour map. Rainfall erosivity index determination requires ranfall and geographical data which are discussed in subsequent paragraphs.

Rainfall data is the backbone of any hydraulic study and act as input for SCS runoff model and also Soil Loss model using USLE. Average monthly rainfall for twelve years available data is given in Table 5.1.

Land use map and topographical maps are obtained from Various Earth Surface Map published by National Survey and Mapping Coordination Board ***(Bakosurtanal)*** Indonesia, sheet number 1507-533 , Pule First Edition 2001

As mention in chapter four, the rainfall data used in this study are obtain from Pule Rainfall Station (STA. 51) for Jati Watershed and Watulimo Rainfall Station (STA. 49) for Singgahan Watershed, in District Trenggalek East Java. The USLE method require rainfall erosivity index data. Due to unavailability of data on 30 -minutes storm events during the preparation of this paper, average monthly erosivity index values were generated from monthly rainfall through Eq.2.15 to obtain yearly erosivity index values. The values corresponding to each month in a year of rainfall Erosivity Index are given in Table 5.1 for Jati Watershed and Table 5.2 for Singgahan Watershed, for SCS runoff model, the rainfall data used are average monthly rainfall data, that have been generated from twelve years data collection from respective station. Rainfall data is given in appendix-B-2

Table 5.1. Average Rainfall

MONTH	Sta Pule	Sta Watulimo
JAN	310.79	264.79
FEB	310.37	264.64
MAR	272.49	218.86
APR	197.16	203.43
MAY	100.29	155.86
JUN	114.27	166.86
JUL	66.98	116.86
AUG	35.52	125.64
SEP	53.64	99.50
OCT	142.45	229.07
NOV	206.93	280.36
DEC	257.87	220.86

Source : Feasibility Study Report Small Pond East Java

Example Calculation of Rainfall Erosivity Index

Jati Watershed

Month : January

Average monthly rainfall = 310.79 mm

Rainfall kinetic energy (E) = 14.374 x 310.79

= 6,870.46 (ton m/ha cm)

Maximum rain intensity I_{30} = 310.79/(77.178+1.010 x 310.79)

= 0.79 mm/hr

Rain erosivity index EI_{30} = $6{,}870.46 \times 0.79 \times 10^{-2}$

= 54.60 (ton cm/ha-hr)

Singgahan Watershed

Month : July

Average monthly rainfall = 116.86 mm

Rainfall kinetic energy (E) = 14.374 x 116.86

= 2,400.53 (ton m/ha cm)

Maximum rain intensity I_{30} = 116.86/(77.178+1.010 x 116.86)

= 0.60mm/hr

Rain erosivity index EI_{30} = 2,400.53 x 0.60 x 10^{-2}

= 14.37 (ton cm/ha-hr)

Table 5.2 Rainfall Erosivity Index (ton/ ha. Yr) for Jati Watershed

MONTH	R	E	I_{30}	EI_{30}
JANUARI	310.79	6,870.46	0.79	54.60
FEBRUARY	310.37	6,860.29	0.79	54.50
MARCH	272.49	5,964.55	0.77	46.12
APRIL	197.16	4,212.24	0.71	30.06
MAY	100.29	2,036.78	0.56	11.45
JUNE	114.27	2,343.54	0.59	13.91
JULY	66.98	1,319.70	0.46	6.10
AUGUST	35.52	667.39	0.31	2.10
SEPTEMBER	53.64	134.20	0.09	0.13
OCTOBER	142.45	2,970.06	0.64	19.14
NOVEMBER	206.93	3,337.71	0.67	22.31
DECEMBER	257.87	5,621.16	0.76	42.93
Total EI_{30}				303.34

Source : Feasibility Study Report Small Pond East Java

Table 5.3 Rainfall Erosivity Index (ton/ ha. Yr) for Singgahan Watershed

MONTH	R	E	I_{30}	EI_{30}
JANUARI	264.79	5,783.48	0.77	44.44
FEBRUARY	264.64	5,780.13	0.77	44.41
MARCH	218.86	4,712.49	0.73	34.58
APRIL	203.43	4,356.33	0.72	31.35
MAY	155.86	3,271.59	0.66	21.74
JUNE	166.86	3,520.45	0.68	23.91
JULY	116.86	2,400.53	0.60	14.37
AUGUST	125.64	2,595.08	0.62	15.98
SEPTEMBER	99.50	2,019.47	0.56	11.31
OCTOBER	229.07	4,949.33	0.74	36.75
NOVEMBER	280.36	6,149.89	0.78	47.85
DECEMBER	220.86	4,758.80	0.74	35.01
Total EI_{30}				297.73

Source : Feasibility Study Report Small Pond East Java

5.4. METHODOLOGY

The methodology followed in this study is preparation of base map involving map acquisition, conversion into digital form, creating Digital Elevation Model (DEM) from contour map source, polygonizing polygon map, and overlay operation. From the map prepared, modeling of rainfall runoff and soil loss in watershed is done. The following flow chart in Figure 5.1 illustrates the complete methodology used to modeling rainfall-runoff and soil loss models.

5.4.1. Scanning and digitizing

In developing both USLE and SCS runoff model database, original source maps have been scanned and digitized by onscreen method, through a Raster to Vector Software package (R2V). First scanning of source map is done in Tag Image File (TIF) format, and then digitized and saved as project file in 'Shp' format.

Layer generation from this scanning procedure are boundary, land use, drainage and contour maps. At this stage, map referencing should be done by putting control points. A digitizer records the location of spatial features by means of digitizer oordinates. To correctly register features in a map, the relationship between map and digitizer coordinates needs to be established. A minimum of three control points and the

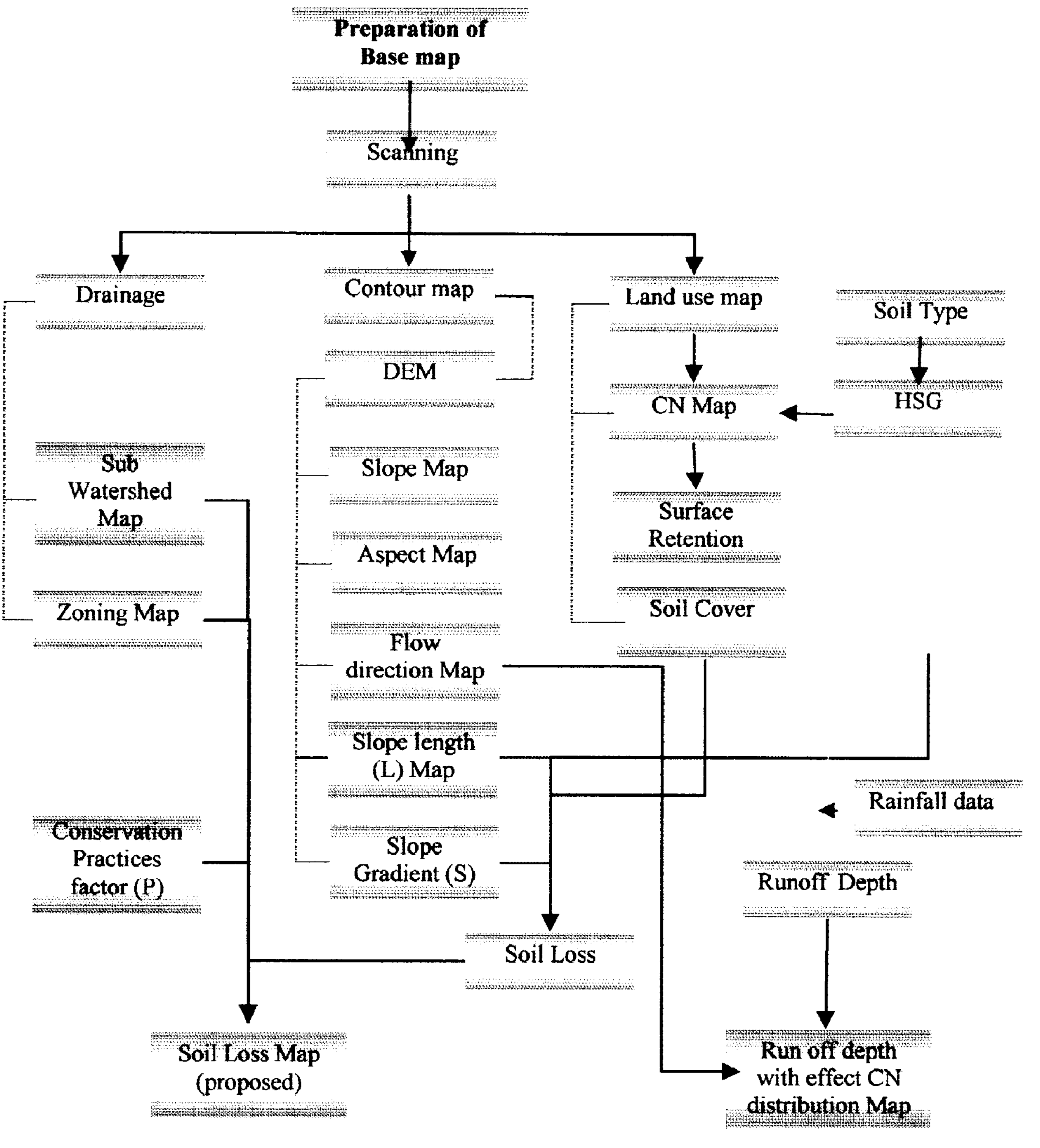


Figure 5.1 Flow chart of The Methodology of This Study

corresponding map coordinates should be specified by user in order to complete the transformation between digitizer and map coordinates.

5.4.2. Error Involved in Digitization and Editing The errors

The most important errors that may occur during digitization are dead end segment, the segment being not connected to another segment, intersection without node, segment overlays another segment with out node, same segment is digitized twice, self overlap etc.After the digitization of the segments, care should be taken that they are error-free. The error were checked and corrected by the facilities available in ILWIS under check segment vector-digitize module

5.4.3. Polygonization

The next is a polygonization process. The specific polygons for any given polygon file were assigned, the identification name and color values. It is worth to note that polygon feature attribute labels are normally entered only after the topology of the digitized data has been checked and corrected if necessary. In GIS package used program facilities are also available for calculation of perimeter and area of each polygon through statistical standard ILWIS.

5.4.4. Coordinate System and Georeferences

A coordinate system define the possible XY – coordinate or LatLon-coordinates that be used in maps and thus stores information on the kind of coordinates which are used in maps. A coordinate system may have information on the map's projection, ellipsoid and datum.

A georeference is needed for raster maps and uses a coordinate system. A georeference is a service object, which store the relation between the rows and columns in raster maps and ground coordinates. Description Coordinate System and Georeferences of study are are :

Coordinate System Projection "Cat"

Projection : Polygonic

Datum : Indonesian 1974

Ellipsoid : Indonesian 1974

Ellipsoid Parameter :

a = 6378160.000

1/f = 298.247.000.000

False Easting = 5 0000.000000

False Northing = 0.000000

Central Meridian : 111° 40' 000" E

Central Parallel : 0° 0' 000" N

5.4.5. Vector to Raster Conversion (Rasterization)

Because most of the analysis and overlay operation are easily and efficiently implemented in the raster model, all maps encoded in vector structure(both in polygon and segment) are converted into raster structure (Rasterization). Before starting rasterization, a georeference should be created. Boundary and land use maps which are already in polygon form are rasterized through polygon to raster mode.

5.4.6. Creating a DEM :Contour Interpolation

The creation of Digital Elevation Model (DEM) from a segment map (contour map) is done with the contour interpolation operation in ILWIS. Before interpolation, the same procedure correction of segment map should be done and input contour value (elevation) for each contour line segment map. The Digital Elevation Model (DEM) of Jati Watershede is shown in Figure 5.2 and for Singgahan Watershed is shown in Figure 5.3

For créating a slop map and slope direction (aspec) from DEM, the slope angle or slope presentage can be calculate in X and Y direction using DEM.

Slope_percentage = ((HYP (Dx,Dy)/pixsize (DEM)) * 100

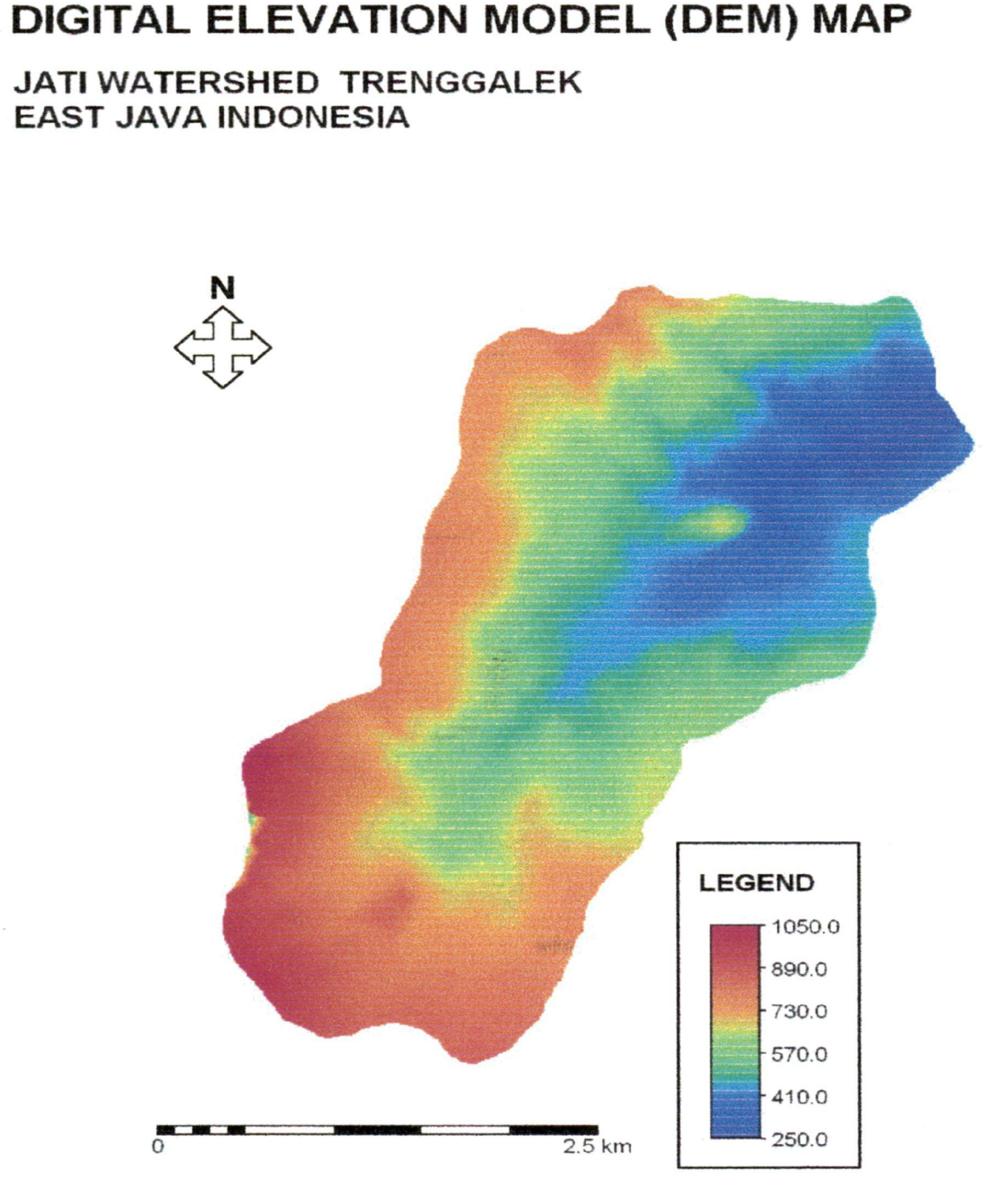


Figure 5.2 Digital Elevation Model (DEM) Jati Watershed

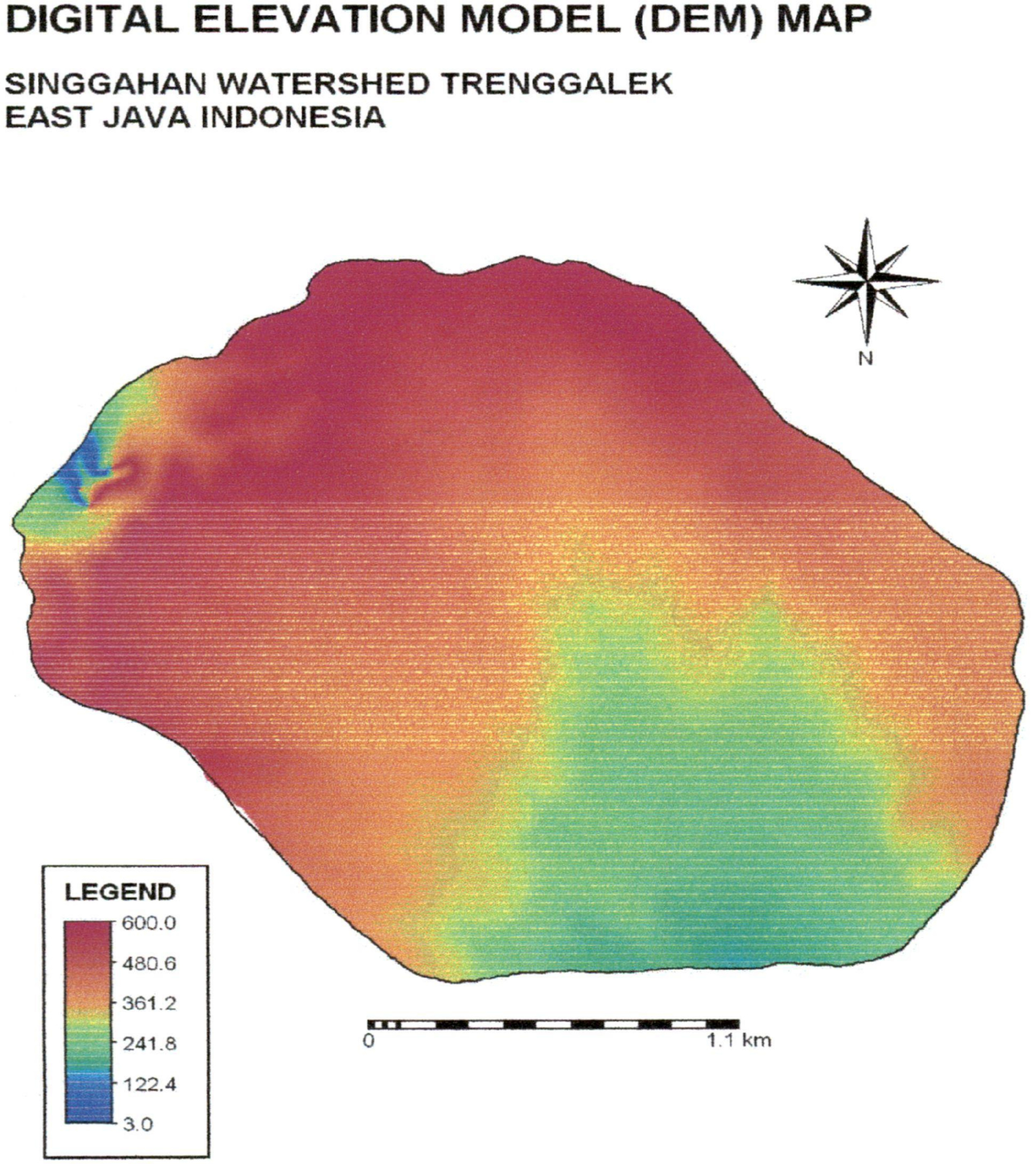


Figure 5.3 Digital Elevation Model (DEM) Singgahan Watershed

In this formula, HYP (hypotenuse) is an interval mapCalc/TableCalc function to calculate the position root of the sum of square Dx plus square Dy (Pythagoras rule), Dx is the horizontal gradient map, and Dy the vertical gradient map. In this formula, the numerator is divided by pixel size, using the internal function pixsize (map). Since the gradient is expressed in meters difference per pixel, the result should be in meters difference per meter. The value 100 in the formula gives the slope in percentages.

The slope direction (or slope aspect) can also calculated by combining gradient map, wihch result from applying horizontal and vertical filter on DEM

Aspect =RADDEG (ATAN2 (Dx,Dy) + pi)

RADDEG and ATAN2 are internal MapClc/TabCalc fuctions, ATAN2 (x,y), return the angle in radian of two input values, x is horizontal, y is vertical. The function RADDEG, is used to convert from radians to degrees. The value for pi ( ) is 3.1415926535 69... ..... The map Dx is the horizontal gradient map, and Dy the vertical gradient map. The formula results in values between 0° and 360°, according to the degress of the geological compass.

The slope percentage and slope slope aspect of Jati Watershed is shown in Figure 5.4 and Figure 5.5 and slope percentage and slope aspect of Singgahan Watershed is shown in Figure 5.6 and Figure 5.7

5.4.7. Overlay Operation

Overlay operation are part of most spatial process and generally form the core of GIS projects. These operations combine several maps and thus give new information that was not present in the individual maps. In overlay operations new spatial elements are created on the basis of multiple input maps.

In ILWIS overlay operation are only performed on raster maps. The raster maps used in the analysis have the same georeference. They have the same number of pixel, ordered in line and columns, the same pixel size and the same coordinate. There are two tools in ILWIS for combining maps, one is Map Calculation and the other is Cross Table operation. In the present study. Analytical procedures involved in these operations are briefly described under the subsequent headings.

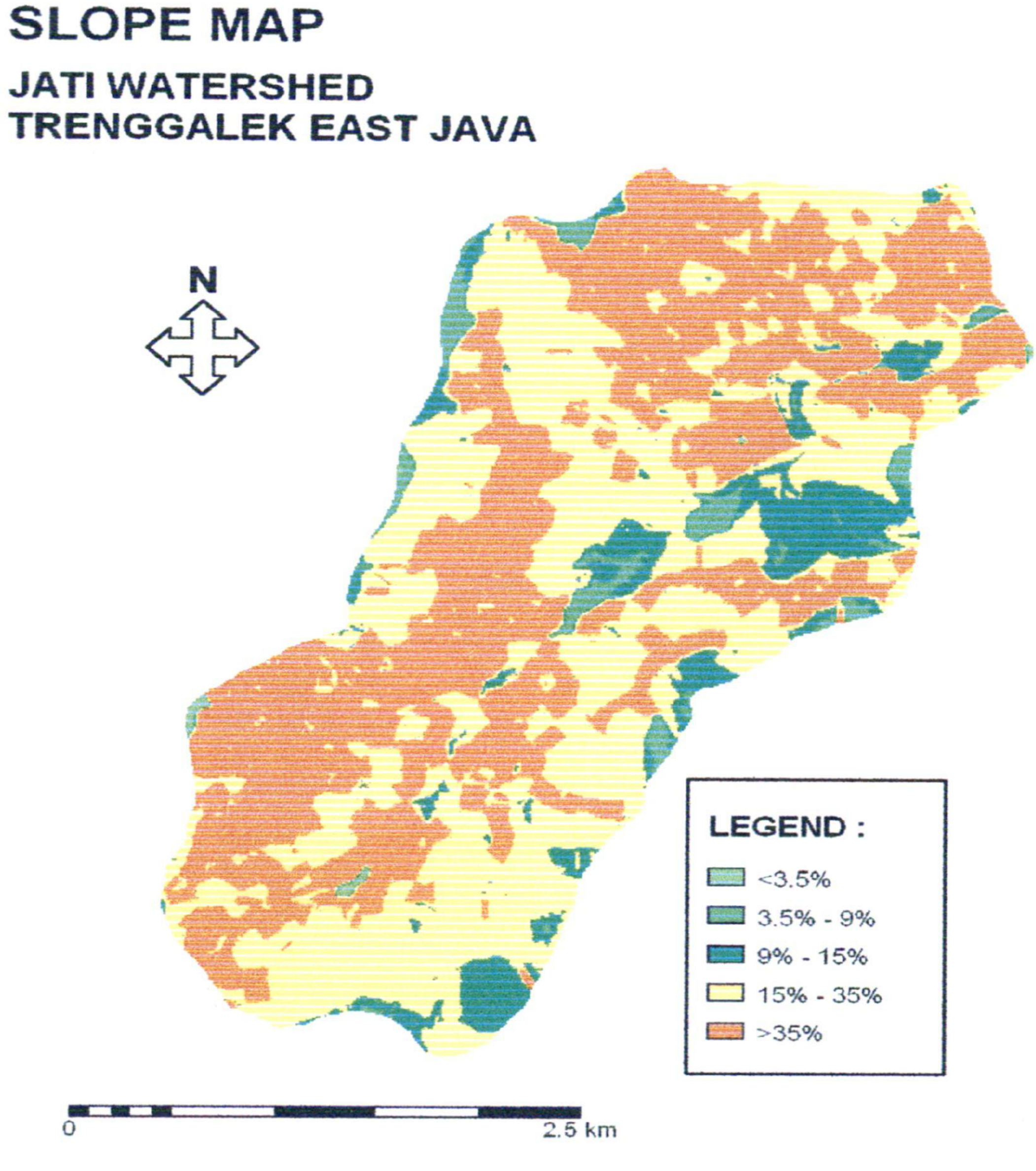


Figure 5.4. Slope in percent Map Jati Watershed

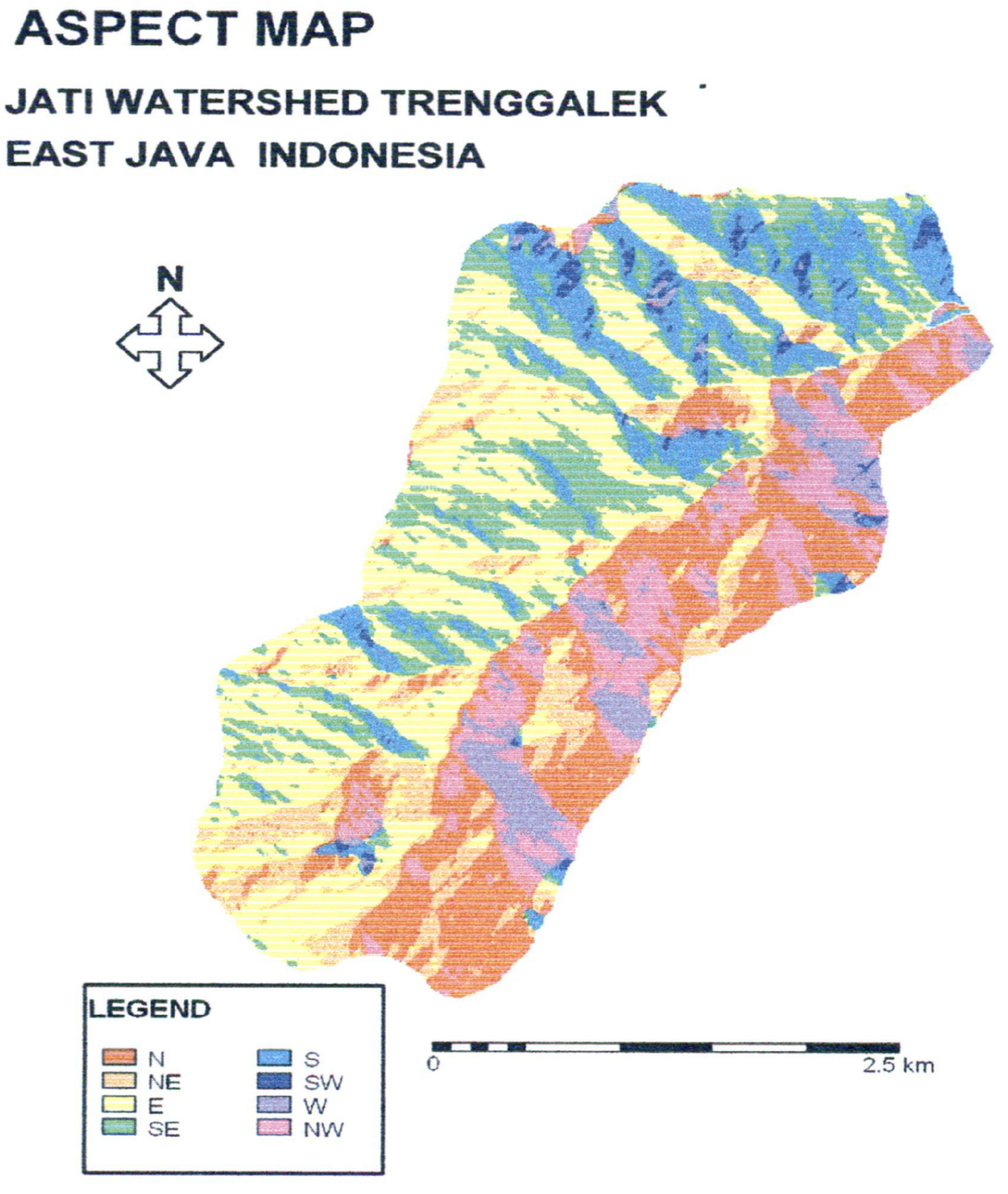


Figure 5.5. Aspect Map Jati Watershed

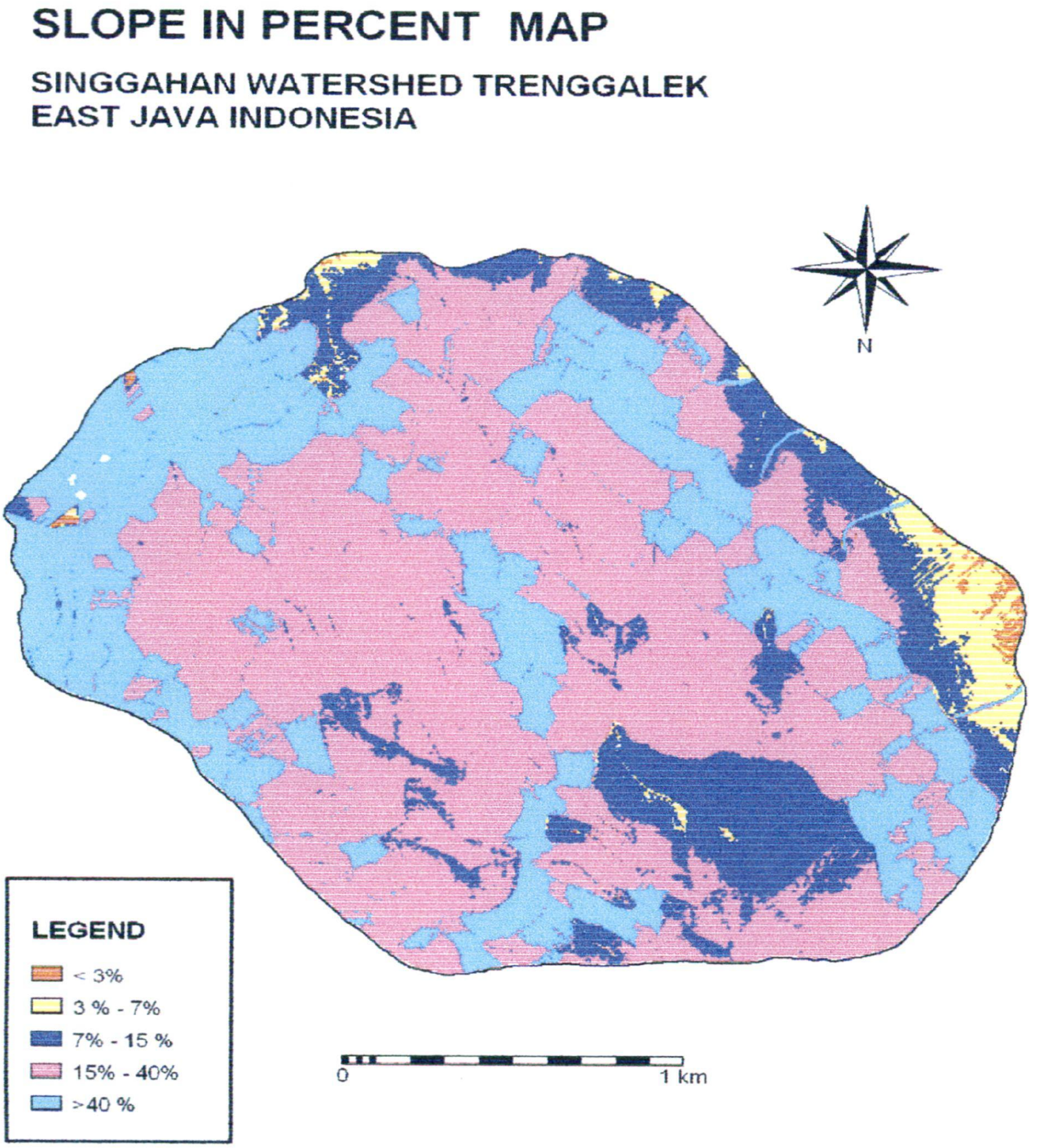


Figure 5.6 Slope in percent Map Singgahan Watershed

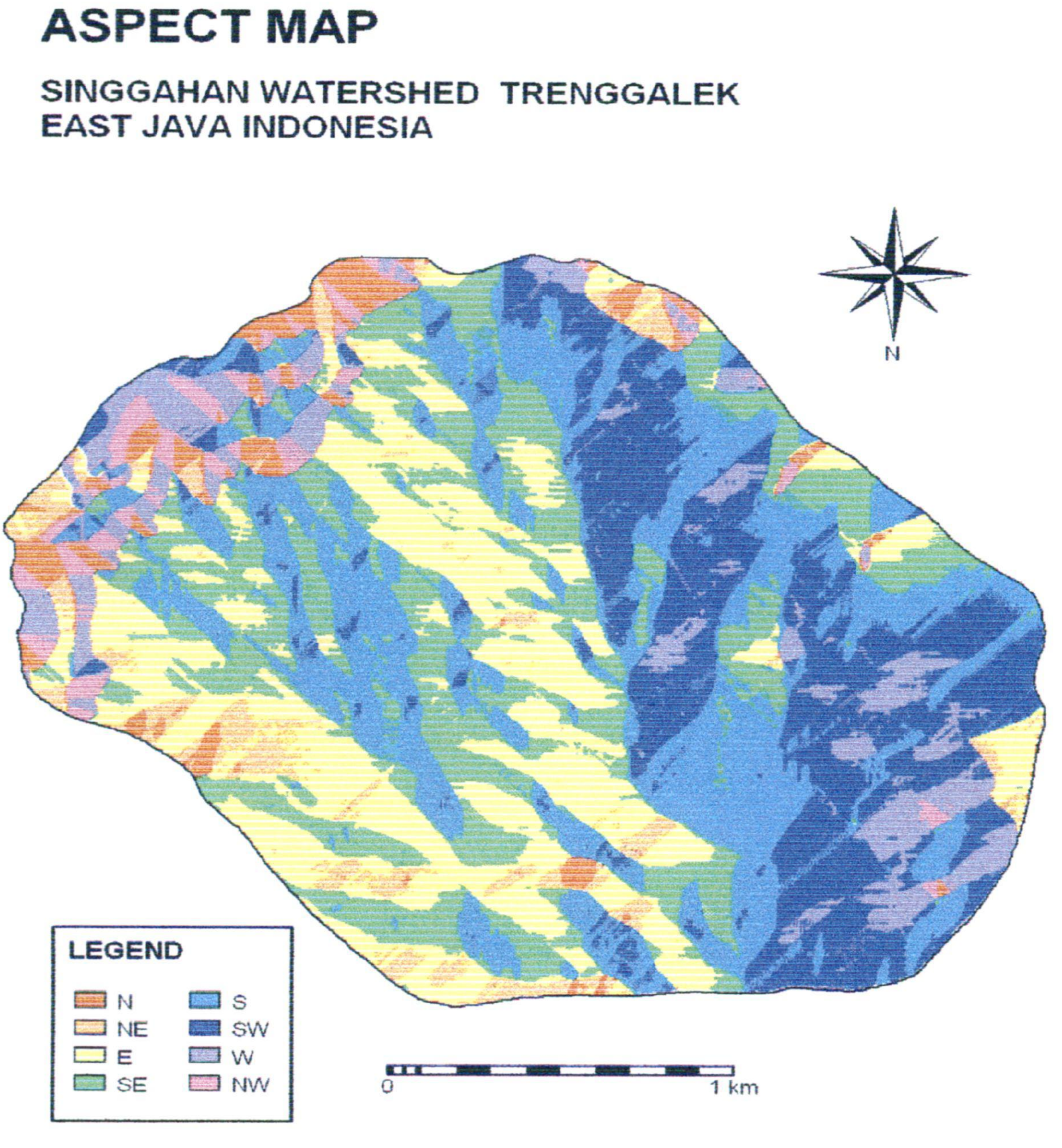


Figure 5.7 Aspect Map Singgahan Watershed

5.5. SCS RUNOFF MODEL PARAMETER

As mention in previous chapter, the evaluation of SCS runoff model for any given basin integrates two parameters, Hydrologic Soil Cover Complex and antecendent moisture condition of the soil.

The soil of watershed was classified into hydrologic soil group depending on the permeability and the physical characteristic of the soil. The two watersheds has sandy loam type of soil.

The land use/land cover image was used as input information image for hydrologic soil cover complex. Residential districts by average lot size of 0.8093713 hectare (2 acres) are used for assuming the residential characteristic. Agricultural land is categoriesed into two cover types and treatment i.e, rainfed "paddy" field with Straight Row (SR) treatment, and dry field with secondary cropping under contoured and terraced treatment (C & T). Both of them are under poor hydrologic condition which are have less infiltration and tend to increase runoff. The remaining landuse of watershed are pasture, grassland or range continuous forage for grazing with fair hydrologic condition, and forest with wood-grass combination (orchard or tree plantation/farm) under poor hydrologic condition. The Hydrologic Soil Group for each land use are given in Table 5.4. After the condition of the land use was evaluated, each polygon map of land use map are encoded through polygon map editor.

The Curve Number Map was generated by editing the value of polygon land use map with appropriate Curve Number from the Table 5.4 or through map calculation of raster land se map with logical function :

CN map = (iff landuse=1,landuse*65, ?) .... for residential, and so on

For further analysis the Curver Number (CN) andd Landuse Maps in form of polygon maps are converted to raster maps form. Fig. 5.8 and Fig. 5.9 represent landuse map and CN map of Jati Watershed,. Fig.5.10. and fig 5.11 represent landuse map and CN map of Singgahan Watershed

Table 5.4 Hydrologic Soil Group in the Study area

No.	Landuse	Condition	Curve Number (CN)	Code
1.	Reidential	-	65	1
2.	Rainfed "padi" filed	Poor	72	2
3.	Dry Field with secondary cropping	Poor	76	3
4.	Wood farm (plantation)	Poor	73	4
5.	Pasture land	Fair	69	5
6.	Forest	Fair	73	6

For creating maximum potential soil moisture retention (S), the maximum potential soil moisture retention was evaluated making use of Curver Number Map. The S image map was created by overlaying with arithmetic map calculation from CN map

Smap = (25400/CN map) - 254.

Figure 5.12 represents Surface retention map of Jati Watershed and Figure 5.13 represents surface Retention of Singgahan Watershed

Runoff Depth map was created using S map and with the input value of average monthly rainfall.

$$Rmap = (P-0.2*Smap)^2/(P + 0.8 * Smap)$$

for January :

$$Rmap = (241.87 - Smap)^2/(241.87 + 0.8 * Smap)$$

Effect of orientation of spatially distribution Curve Number (Moglen Method), can be generated by application of Eq. 3.9. In this model Runoff from upper cell (Ru)is needed. The runoff from upper pixel (Ru) is flow accumulation in pixel from upper pixel corresponding to DEM. So for generating flow accumulation ILWIS standard modul was used.

f dir = (Map Flow Direction mpr, DEM)

Flow accumulation = Map Flow Accumulation (fdir)

MOGLEN MODEL

Moglen = ((flow accumulation + P) - 0.2 * Smap)^2/ (Flow accumulation +P + 0.8*S)

EXAMPLE FOR JANUARY

Moglen = ((Flow acc mpr + 241.87)-0.2*S)^2/(Flow acc mpr +241.87 +0.8*S))

Figure 5.14, and 5.15, represent runoff depth map and runoff accumulation map of Jati Watershed, for average rainfall of January. Figure 5.16 and 5.17 represent runoff depth map and runoff accumulation map of Singgahan Watershed for the average rainfall of month of January.

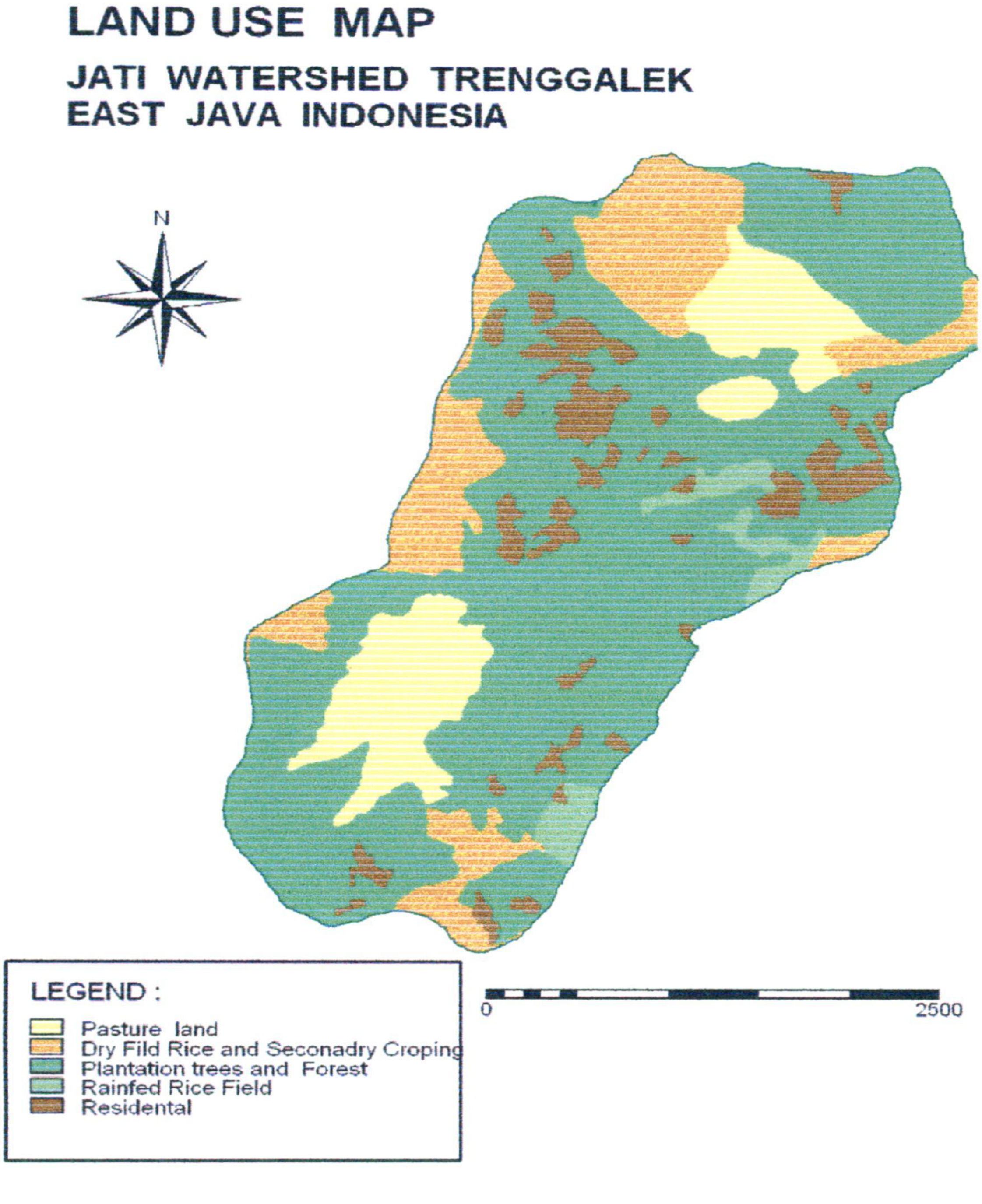


Figure 5.8 Land use Map of Jati Watershed

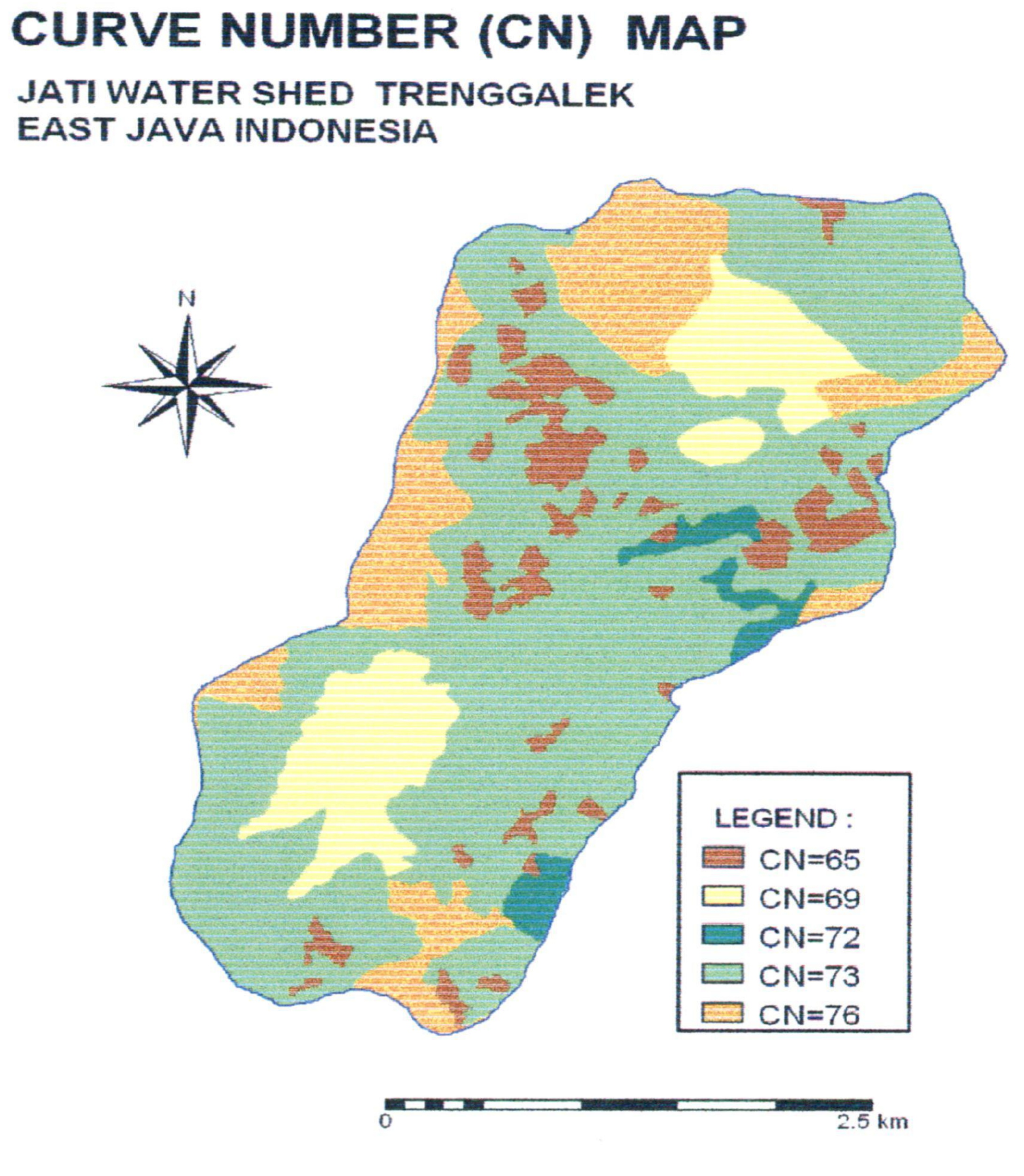


Figure 5.9 Curve Number (CN) Map of Jati Watershed

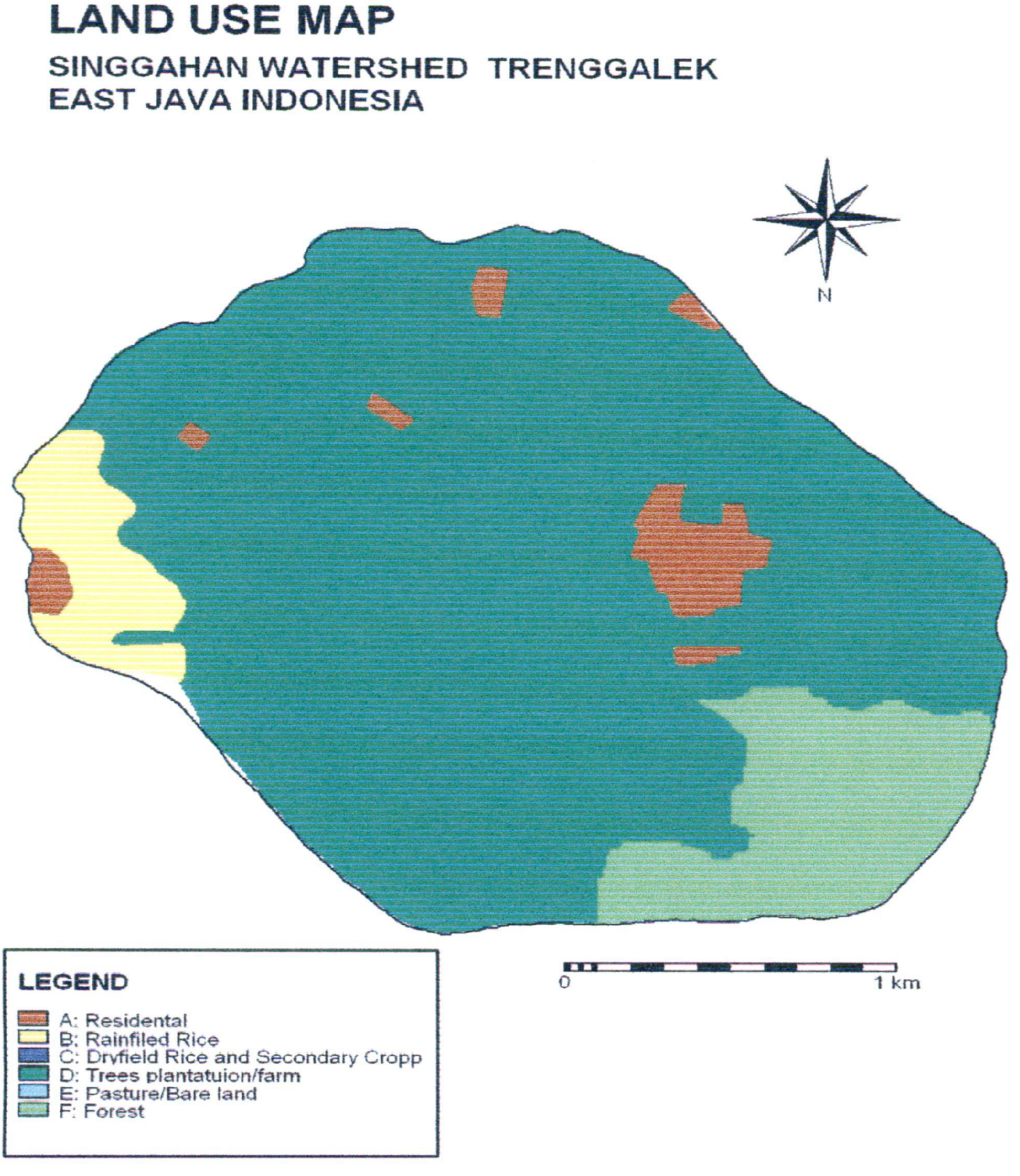


Figure 5.10 Landuse Map of Singgahan Watershed

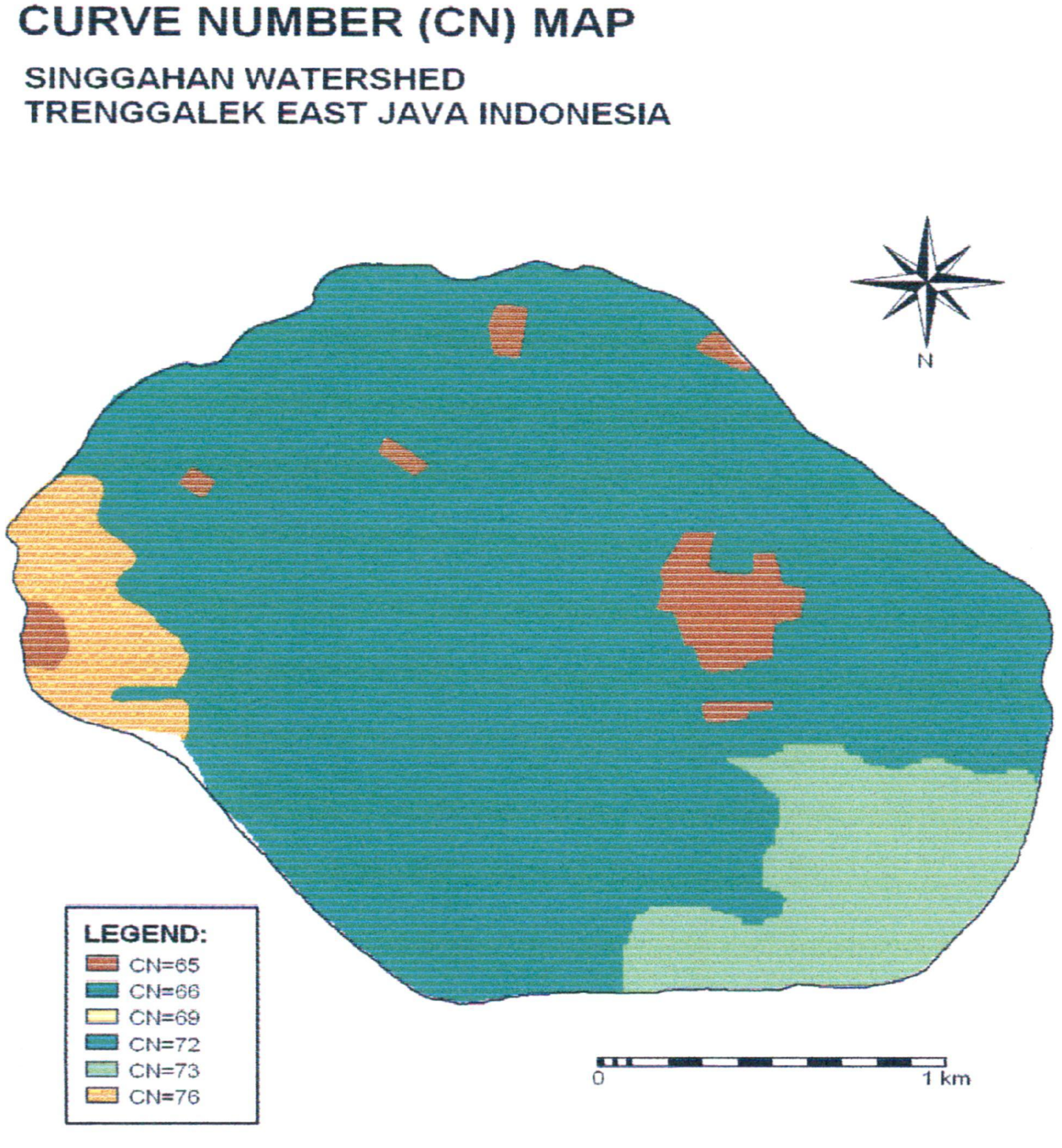


Figure 5.11 Curve Number Map of Singgahan Watershed

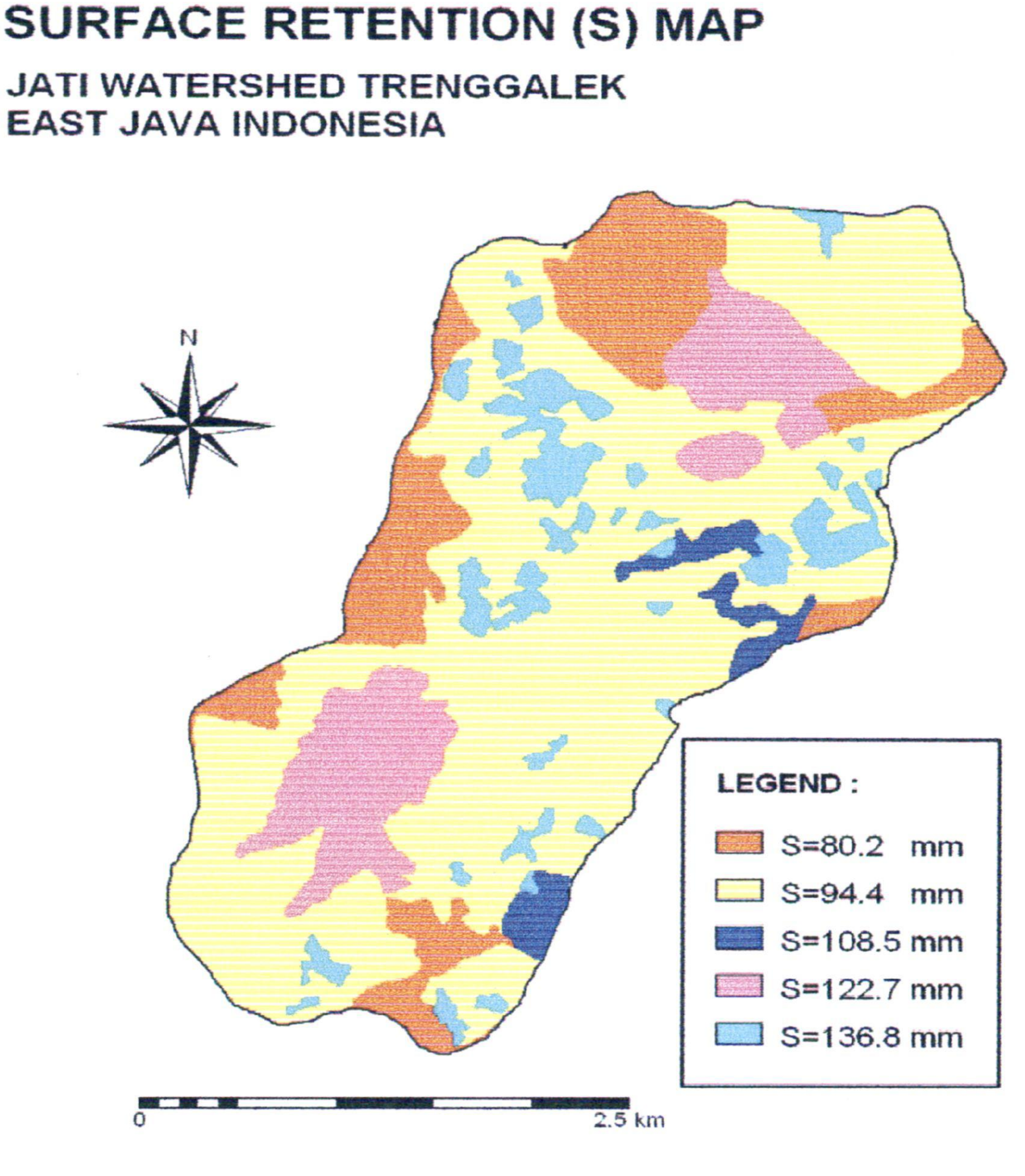


Figure 5.12 Surface Retention (S) Map of Jati Watershed

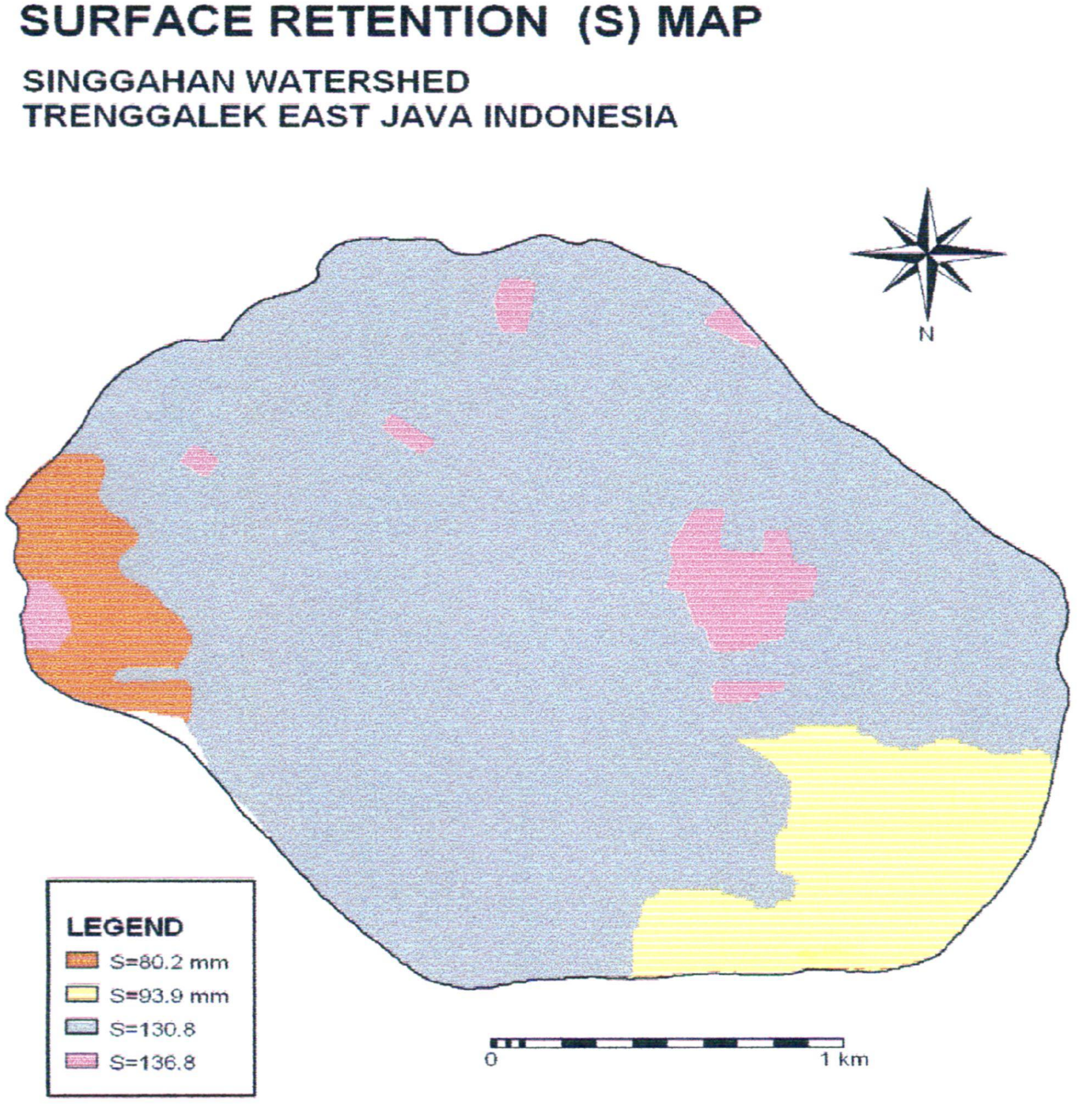


Figure 5.13 Surface Retention (S) Map of Singgahan Watershed

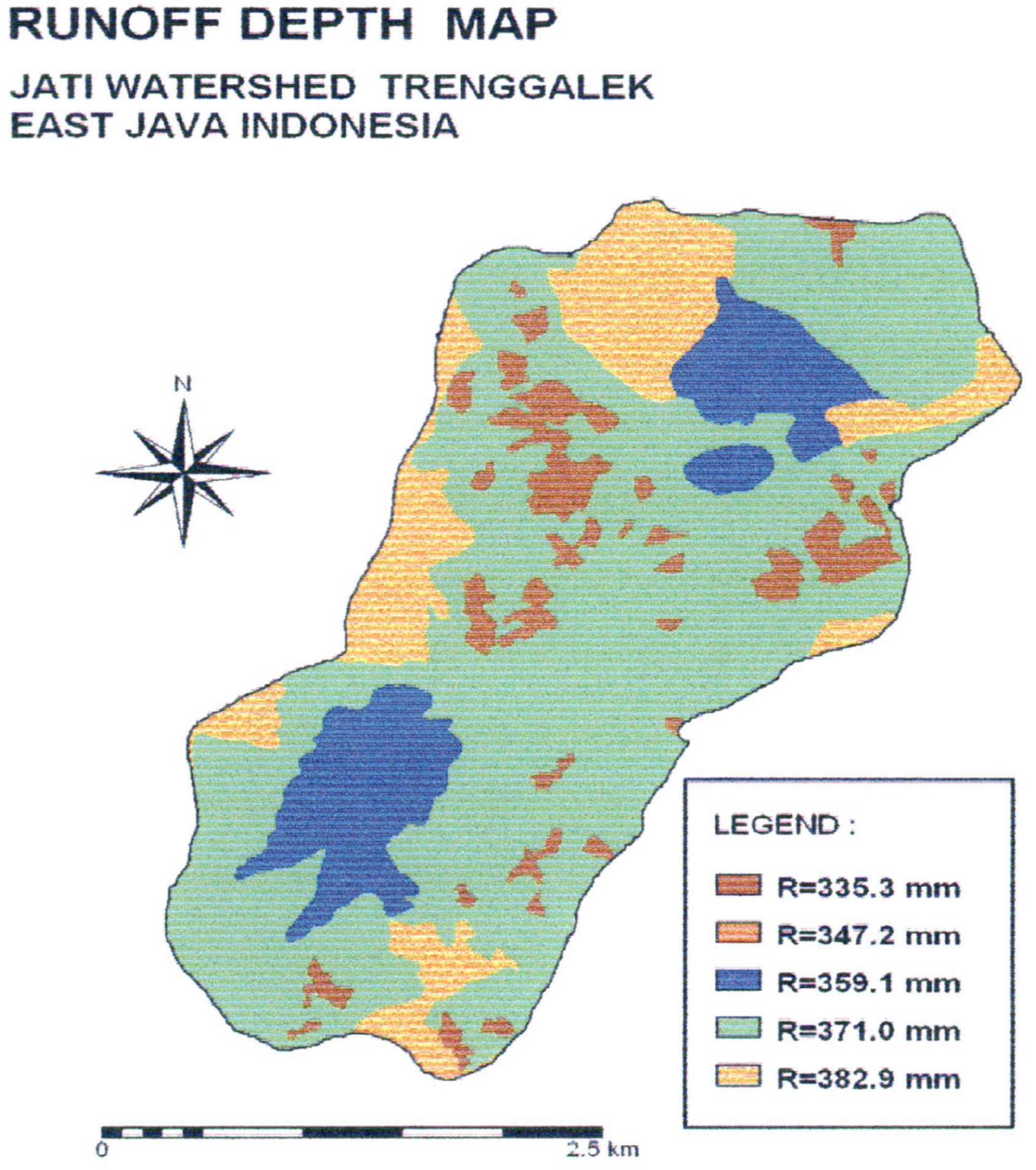


Figure 5.14 Run off Depth Map of Jati Watershed

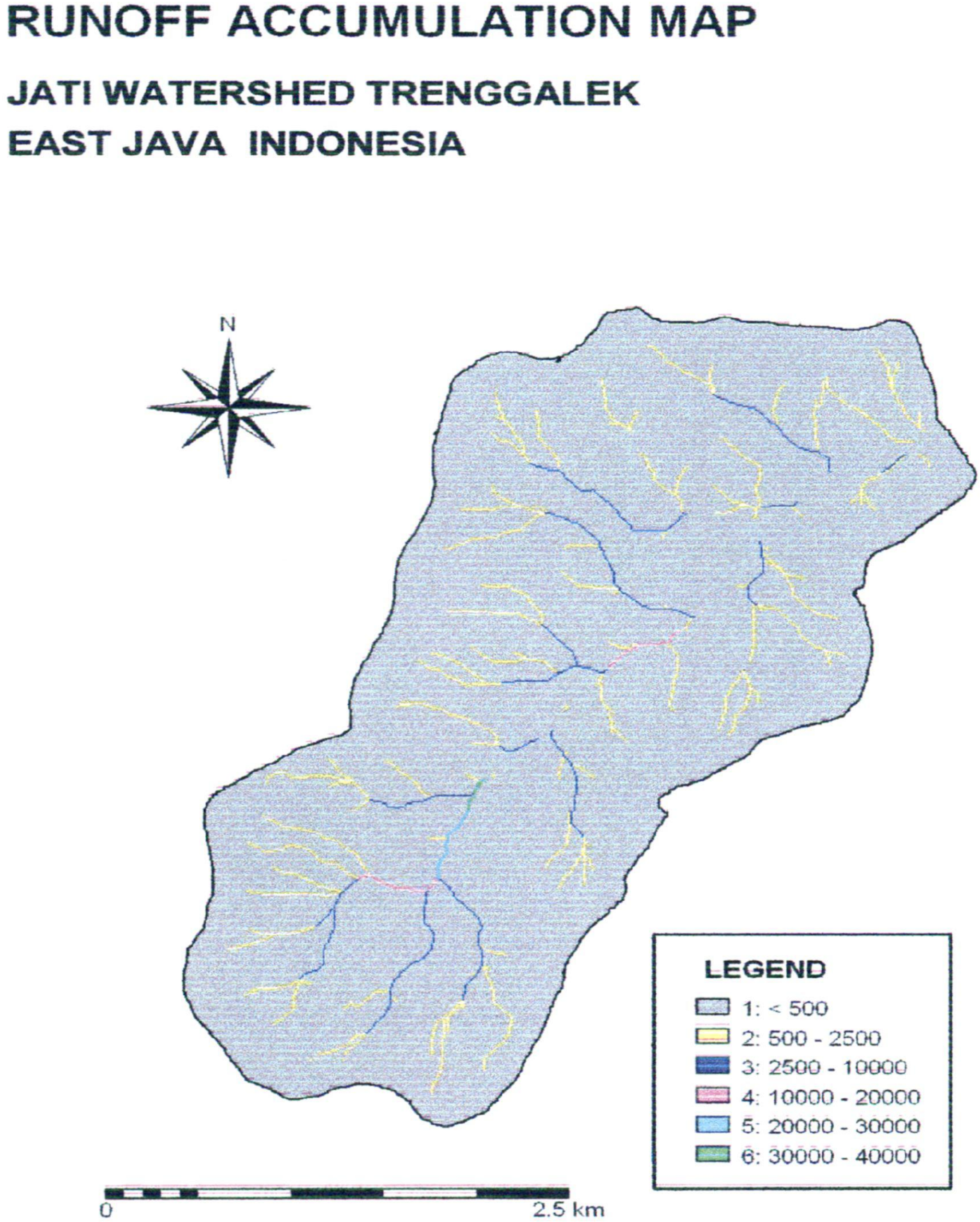


Figure 5.15 Flow Accumulation Depth Map of Jati Watershed

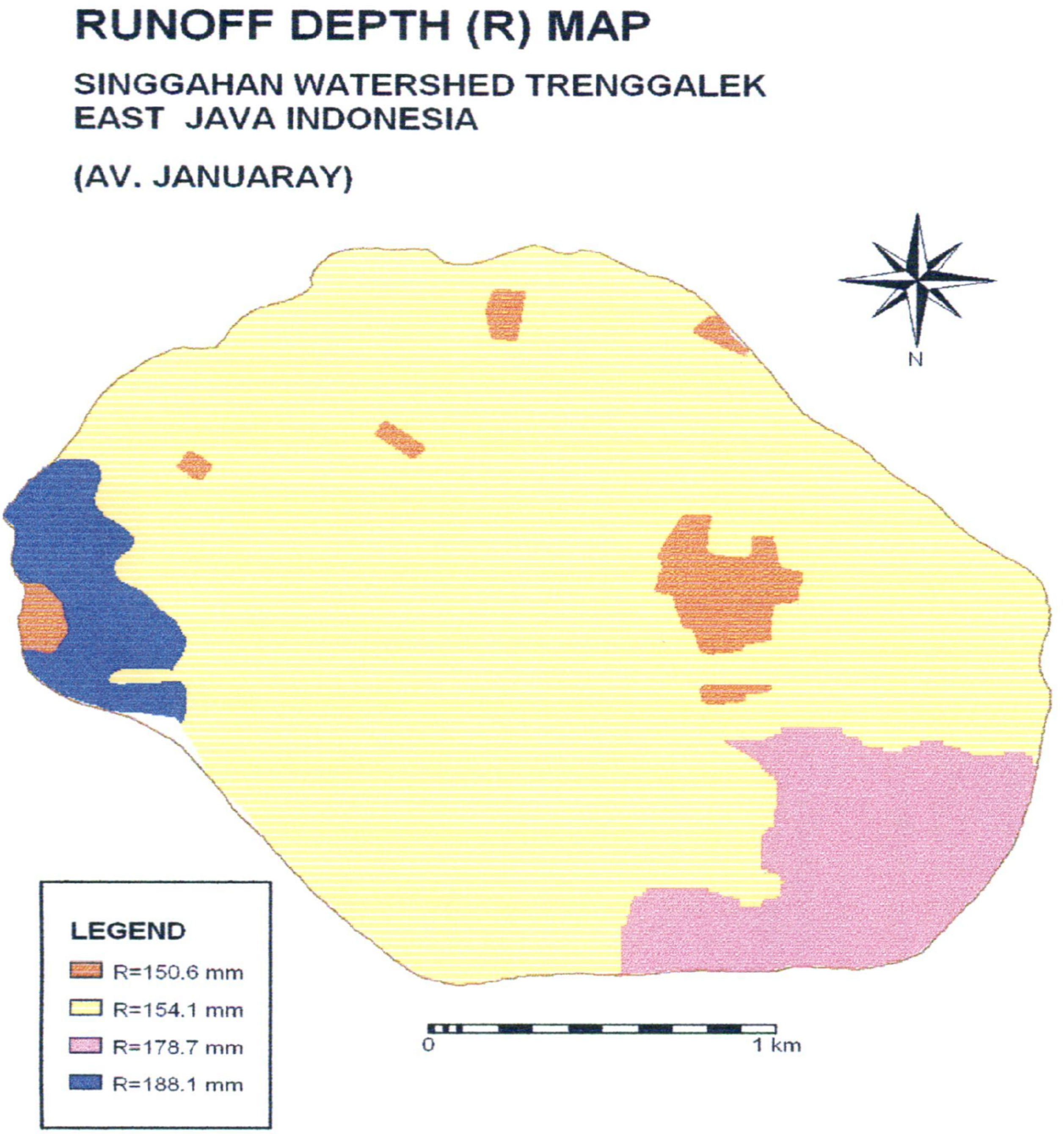


Figure 5.16 Runoff Depth Map of Singgahan Watershed

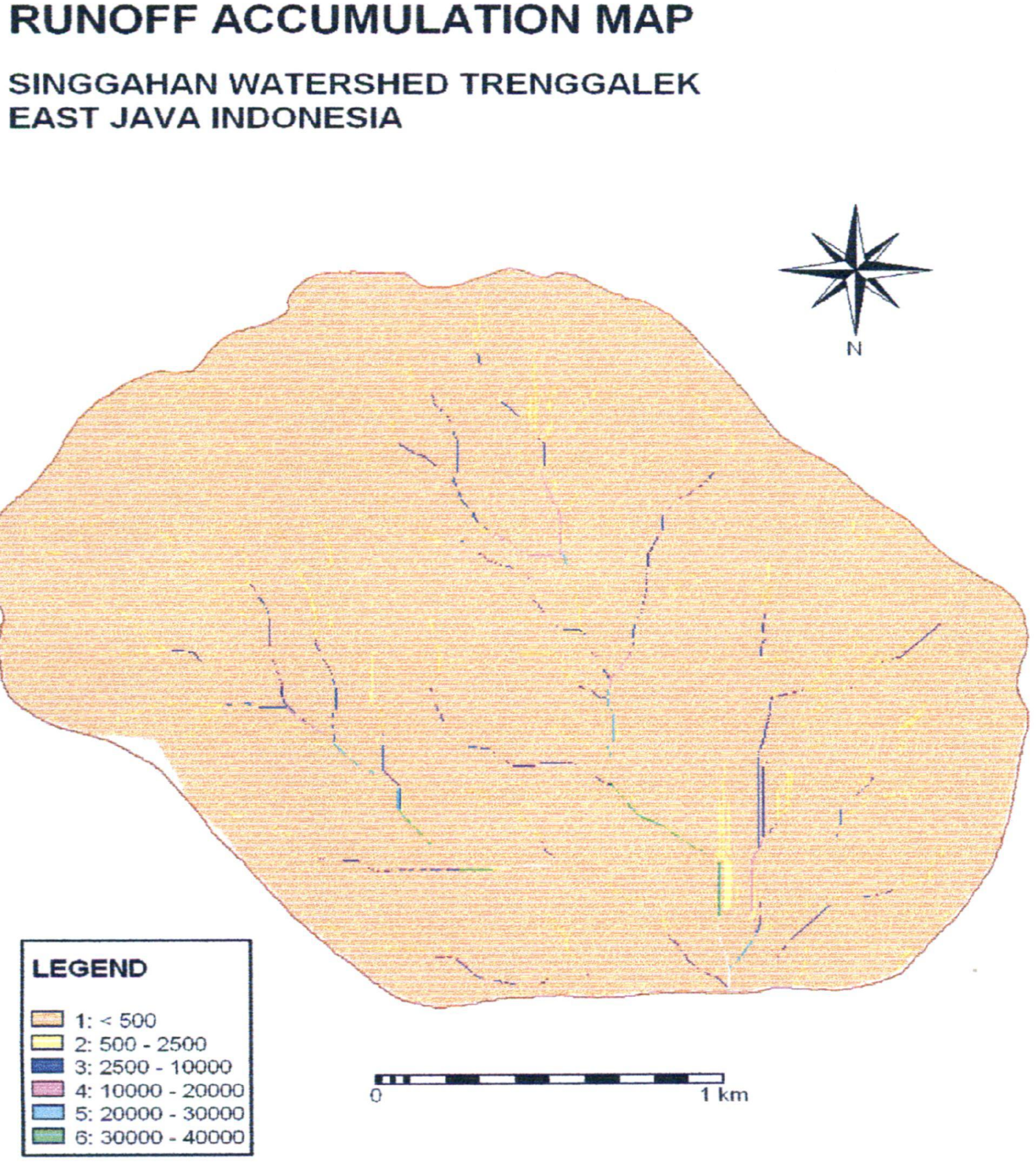


Figure 5.17 Flow Accumulation Depth Map of Singgahan Watershed

5.6. SOIL LOSS FACTOR MODEL

Rainfall Erosivity Index Factors as obtained in Tables 5.2 and 5.3 are used as input in USLE for calculation soil loss those catchments, on annual basis.

Soil Erodibility Factor.

Sandy laom whit type organic matter content about 2% has been considered as 0.24 (Table 3.1), which acts as data in USLE for both watersheds. Figure 5.18 represents soil erodibility factor map of Jati Watershed and Figure 5.19 represents soil erodibility factor Singgahan Watershed

Topographic factor.

To generate the topographic factor, L and S factors are calculated initially. Employing the slope map and taking the pixel size as slope length, L factor value are obtained. In this analysis, the slope map was classified according to the recommended *m* (Table 3.2), for different slope classes and the *m* value and . = pixel size are used in Eq.3.16.. S factor was directly calculated using average slope image. Finally by arithmetic overlay operations

Slope Length (L)= $(\lambda/ 22.13)^m$

```
Length1map; iff(Slope>=4.5,POW((PIXSIZE(DEMff)/22.13),0.5),?)
Length2 map; iff(3.5<=Slope and
                 4.5>Slope,POW((PIXSIZE(DEMff)/22.13),0.4),?)
Length3 map; iff(1<=Slope and
                 3.5>Slope,POW((PIXSIZE(DEMff)/22.13),0.3),?)
Length4 map;iff(Slopefin<1,POW((PIXSIZE(DEMff)/22.13),0.2),?)
L map =MapGlue(Length1,Length2,Length3,Length4,replace)

S map =(0.43+0.3*slope/100+0.043*SQ(slopen))/6.613
LSmap = L map * S map
```

LS factor map was generated. Figure 5.20 represents LS map of Jati Watershed and figure 5.21 represents LS map of Singgahan Watershed

For determination Crop Management Factor (C), various land mapping were considered. Land use/land cover input data was used to assign the C value to each cover type or groups cover. The evaluation and calculation of C value for each cover unit was made on basis of information available on characteristic of the cover units (as given in chapter three). Desired values for condition in Indonesia were taken from Table 3.3 and C was calculated .Figure 5.22 represent Crop Management Factor Map of Jati Watershed and Figure 5.23 represent Crop management factor of Singgahan Watershed.

For estimation Soil Conservation Practice Factor (P), slope image was classified and used to select a region with appropriate soil loss hazard and soil conservation practices. To create P factor map, slope image zoning map and sub watershed were cross overlayed. The output image from this overlay will represent sub watershed and zoning with special hazard of soil loss and special characteristic of slope and land use. Based on this information the appropriate soil conservation practices will be applied.

Figure 5.18 Soil Erodibility Factor (K) Map of Jati Watershed

Figure 5.19 Soil Erodibility Facctor (K) Map of Singgahan Watershed

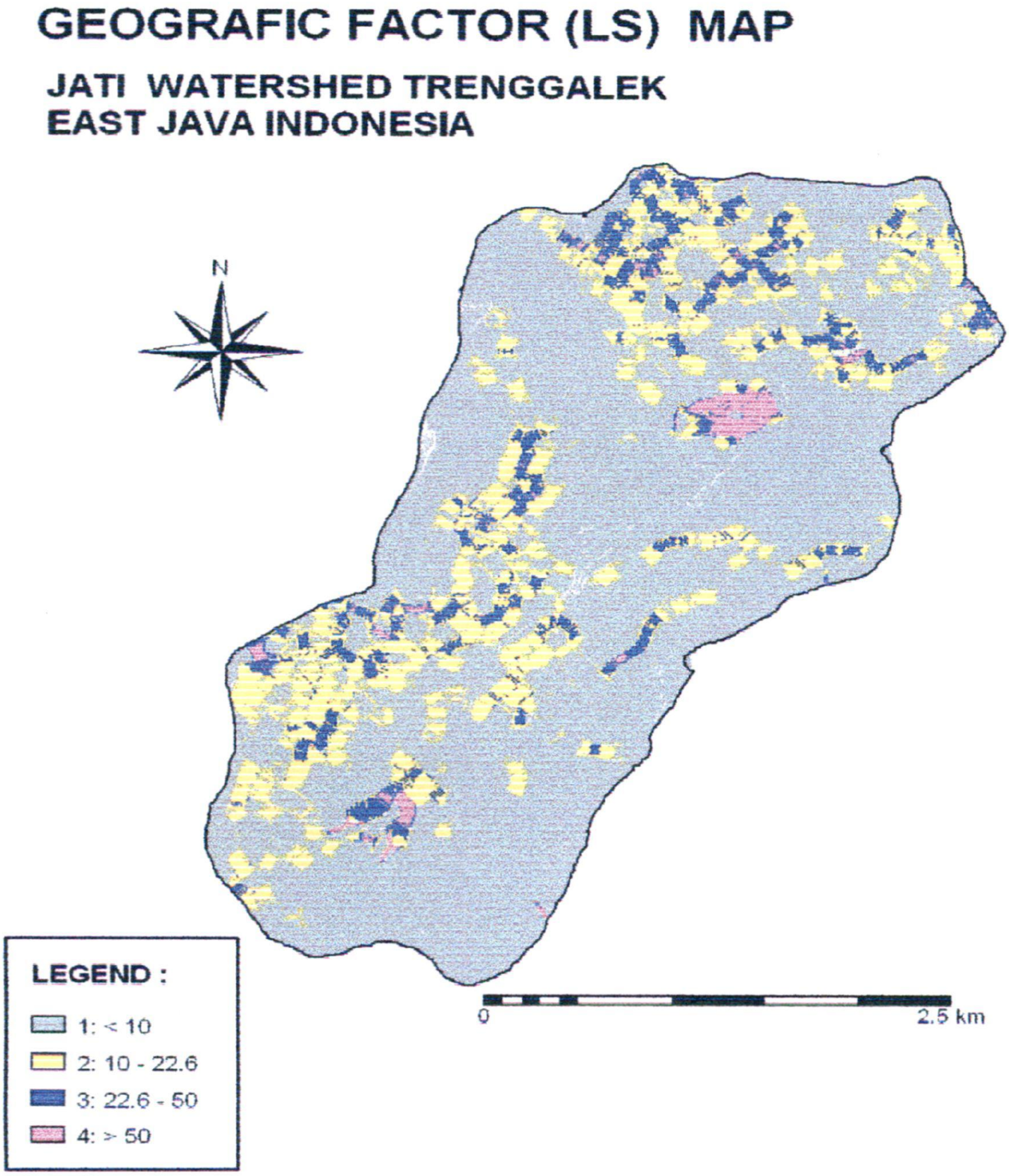


Figure 5.20 Length Slope Factor (LS) Map of Jati Watershed

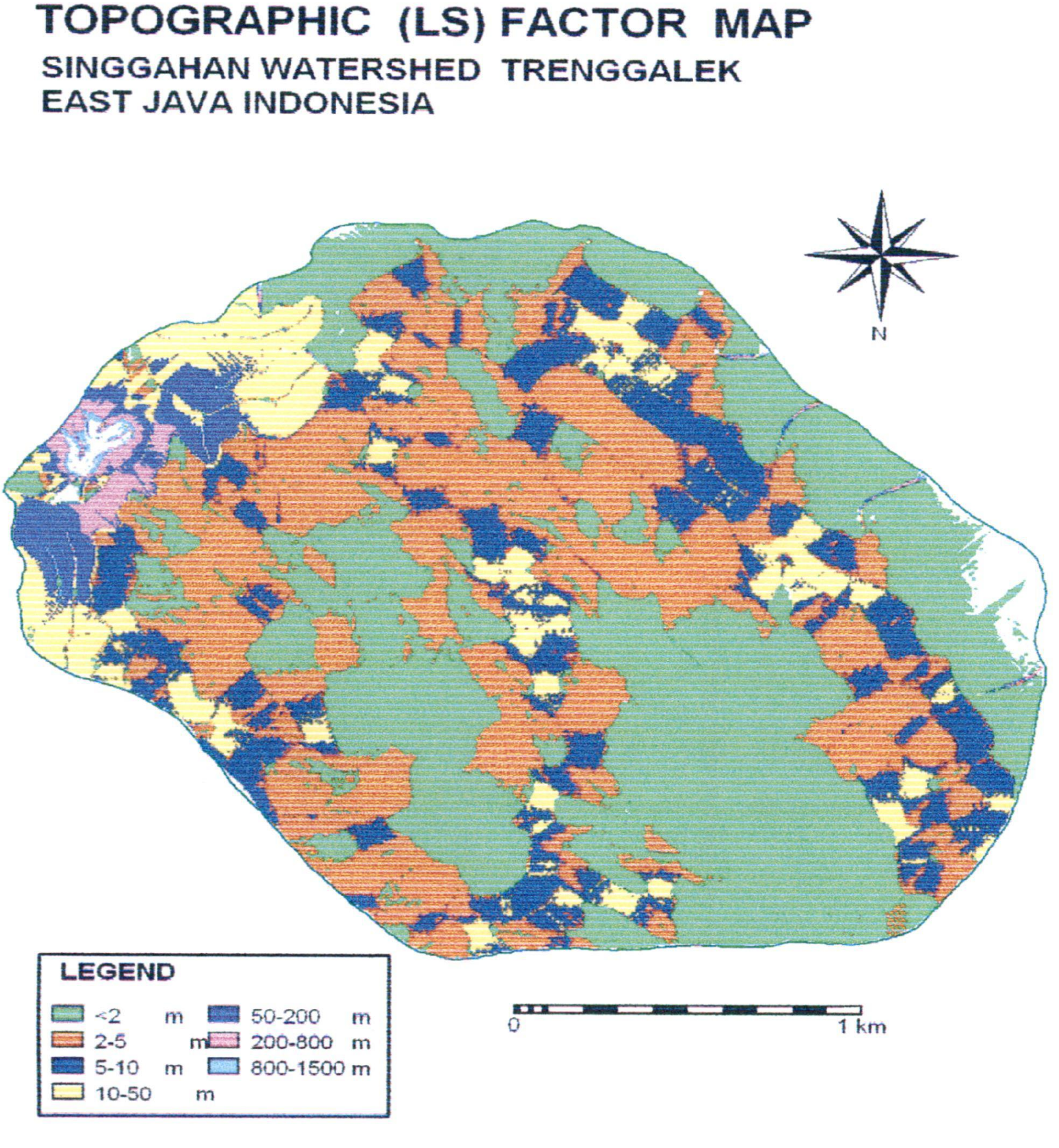


Figure 5.21 Length Slope Factor (LS) Map of Singgahan Watershed

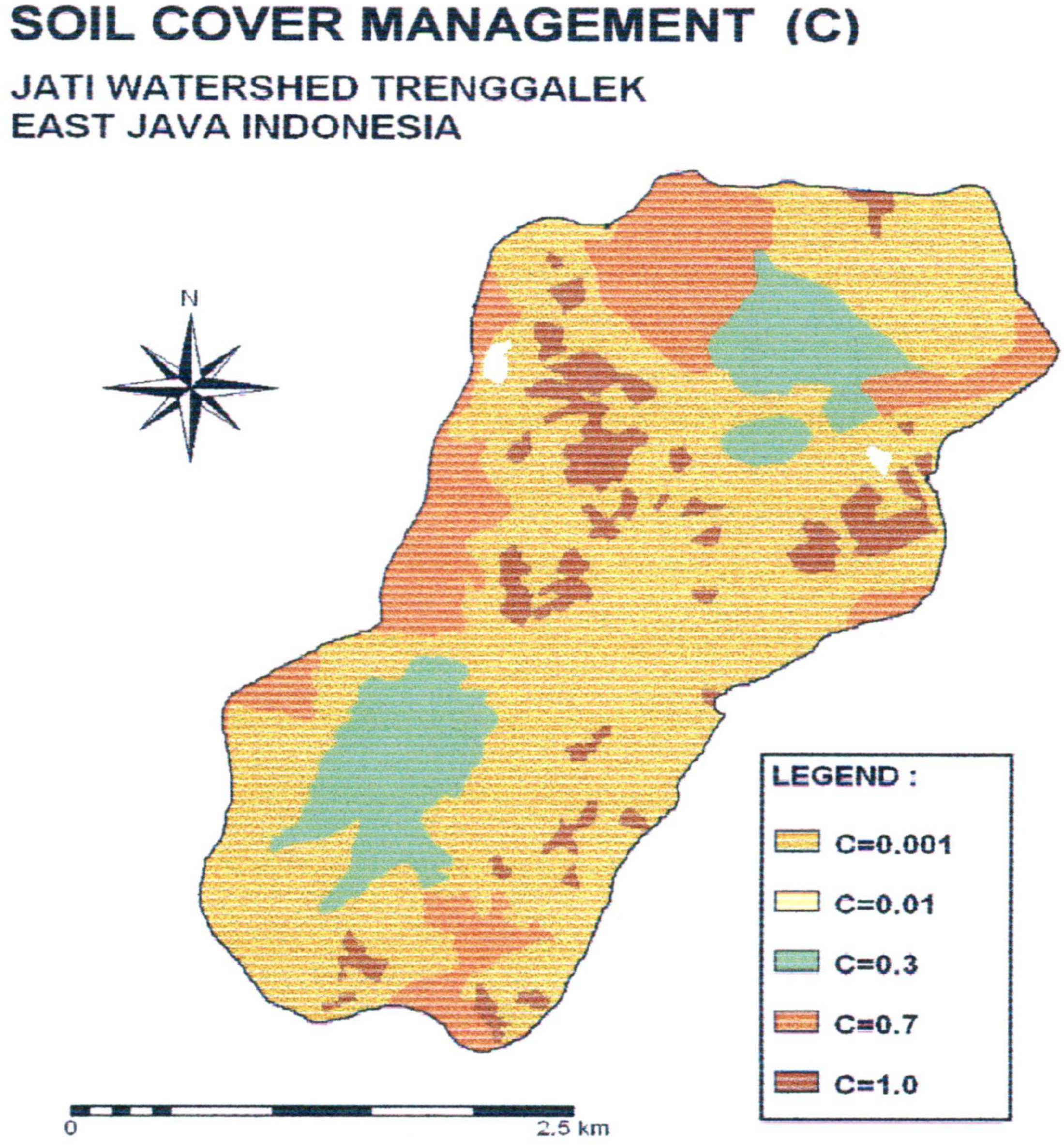


Figure 5.22 Crop management Factor (C) Map of Jati Watershed

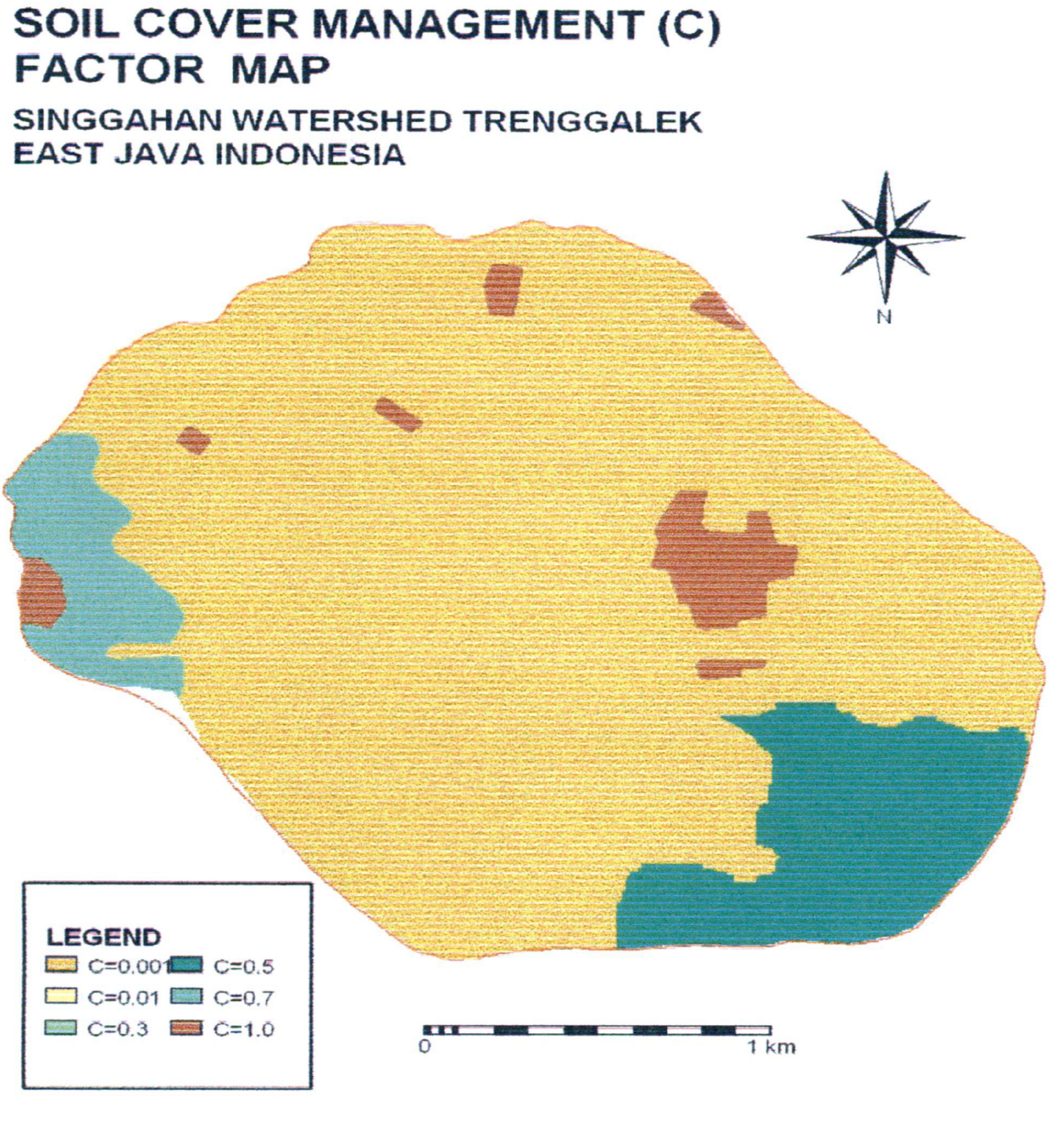


Figure 5.23 Crop management Factor (C) Map of Singgahan Watershed

CHAPTER VI
RESULT AND DISCUSSION

6.1. GENERAL

In the previous chapter, the Universal Soil Loss Equation (USLE) and SCS rainfall-runoff empirical equation were used to assess the soil loss and rainfall-runoff from Jati and Singgahan Watershed.

The maps were digitized through R2V software package. After the removal of errors, polygonization was done to obtain various required maps e.q. Boundary maps, landuse maps, etc. Overlaying was done to obtain a combined map.

The assessment of runoff using SCS, both conventional and modified (Moglen) models, were made based on the average monthly rainfall from twelve years rainfall data record. The result of the assessment was compared with the low flow analysis given by the Feasibility Report of Identification Study and Detail Design Small Pond East Java Indonesia. The comparison was done to check whether the above models are applicable for present watersheds.

The original intent of this study was to calculate water balance and amount of water that in expected to be store in small pond, along with rate of soil loss under existing soil cover management and soil conservation practices such under proposed soil conservation practices.

Figure 6.1 and 6.2 represent that the runoff volume (month by month) given by the two models (SCS Conventional and Modified), when the both SCS methods, were compared, it was observed that, the SCS conventional followed the rainfall pattern in a more idealistic manner, i.e, yielding more runoff with more rainfall. In case of the modified SCS, the runoff was more or less constant, showing little

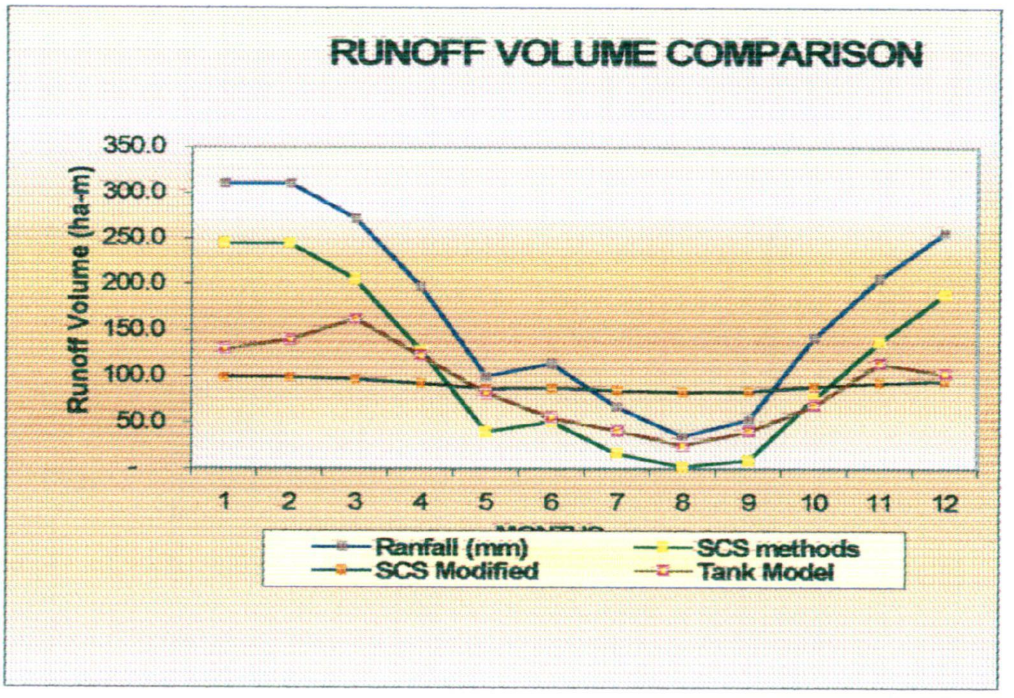


Figure 6.2. Runoff Volume of Jati Watershed

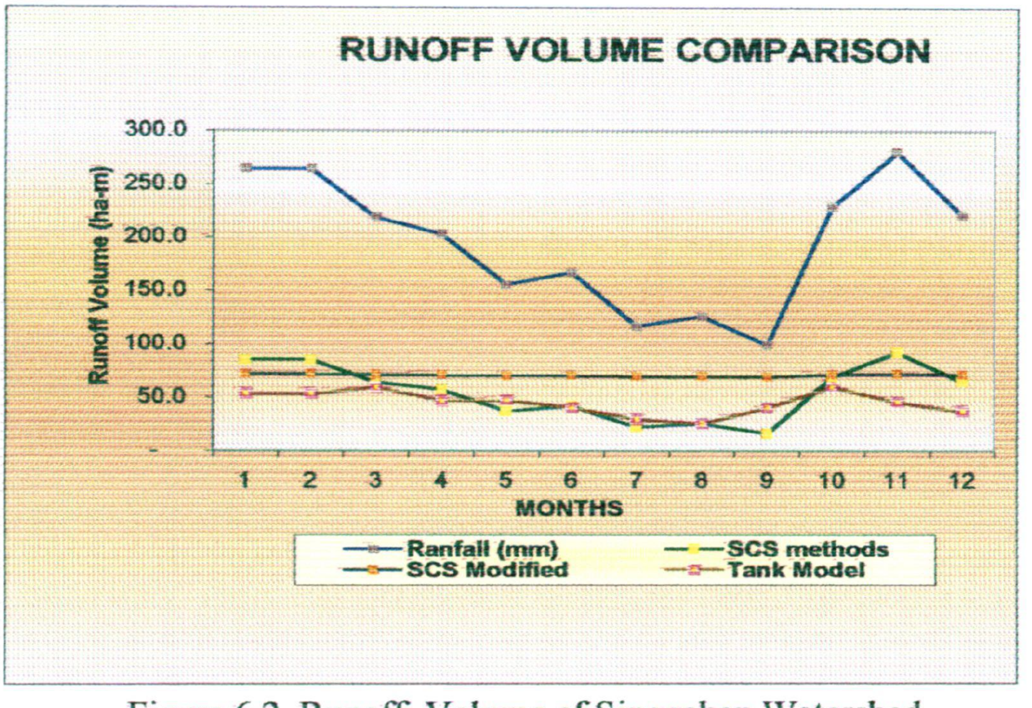


Figure 6.2. Runoff Volume of Singgahan Watershed

variation with respect to the rainfall. In case of tank model,except for the months of January, February ad March, the trend matches with that of the actual rainfall.

For Assessments of water balance, the components required are runoff volume itself and water losses. Water losses assessment in a watershed includes water requirement (both irrigation water requirement and domestic water requirement), and evaporation losses. The assessment of runoff volume for water balance calculation in this study is developed using modified SCS . The result of the water balance in the outlet of watershed is a surplus/deficit condition of runoff volume viability on the moth wise basis. The surplus/deficit of runoff volume is nothing but amount of runoff which be expected can to be used to fulfill water requirement in the beneficiary area. The final water balance (given in term of surplus/deficit) is the difference between the water balance (surplus/deficit) at the outlet of watershed and total water requirement of the beneficiary area. Surplus/deficit condition are used to calculate the requirement of storage capacity of small pond.

For Assessment of soil loss, it is known that the amount of eroded soils don't get transported completely in streams due to the natural process of deposition along the course of flow, during transportation. Therefore the process of modeling soil loss-gain is very important to estimate the actual amounts that contribute to the process of sedimentation. The basic concept in this study for modeling the soil loss process relates the weighted-soil loss due to water erosion and the corresponding volumes of sediments that are expected to be trapped in the small pond.

6.2. JATI WATERSHED

The result of rainfall-runoff model of Jati watershed is summarized in the Table 6.1 and Figure 6.1. From the table and figure it can be seen that by SCS conventional method, the maximum runoff volume is 245.65 ha-m and by SCS modified, it is 99.1 ha-m produced by 310 mm rainfall occur in the month of January. While the minimum runoff volume is 2.46 ha-m and 83.1 ha-m for both methods respectively produced by 35.5 mm rainfall occur in the month of August. On the other hand, from same input of rainfall value, the tank model method predicted 129.37 ha-m and 25.71 ha-m runoff volume. respectivelly

Table 6.1. Runoff Volume Jati Watershed

MONTH	Rainfall (mm)	Runoff (Ha-m)		
		SCS	Moglen	Tank Model
JAN	310.8	245.65	99.1	129.37
FEB	310.4	245.22	99.1	139.81
MAR	272.5	205.09	96.8	162.85
APR	197.2	128.01	92.4	122.08
MAY	100.3	40.23	86.7	81.69
JUN	114.3	51.46	87.4	54.95
JUL	67.0	16.82	84.9	41.52
AUG	35.5	2.46	83.1	25.71
SEP	53.6	9.41	84.1	40.95
OCT	142.5	75.97	89.2	68.83
NOV	206.9	137.75	93.0	114.57
DEC	257.9	189.84	95.8	102.85

For assessment of water balance of Jati Watershed, the watershed is divided into six sub-watershed ie; sub-watersheds i.e, A,B,C,D,E and F. In the entire watershed as such, thre is deficit of runoff volume in the months of April, May, June, august , September and December, whereas the remaining months, there is surplus. It can be observed from the Table 6.2 and Figure 6.3. The details of water balance for sub-watersheds are given in Table 6.2a, 6.2b and 6.2c

For assessment of soil loss, a model for soil erosion as resulted from USLE as developed in this study which is shown in Figures 6.4 and 6.5, for existing condition proposed condition respectively. Figure 6.4 gives estimation of soil loss due to water erosion, which is very much dependent on topographic factor and soil conservation practices. USLE model gives estimate of soil mass loss due to water erosion without providing any estimate of soil gain during the course of transport as sediment. Figure

6.5 gives the actual soil loss as resulted from our model. In this study, Jati Watershed was divided into six sub-watershed and for assessment soil loss purpose this watershed was further categorized into five zones. Zone I is the upper portion of watershed, zone II in the middle upper, zone III in the middle lower, zone IV in the lower and zone V is a special zone which actually lies in zone IV. As shown in Figure 6.3, zone V is the most critical zone where the rate of soil loss is more than 400 ton/ha yr. The second zone has a rate of soil loss more than 400 ton/ha yr is lower portion of zone III. As seen from figure 5.2 and figure 5.4, both zones III and V have slopes more than 30%. In this rate of soil erosion may be due to the steep slope and due to absence of any appropriate soil conservation practices, in these two zone. The amount of soil loss shown in Figure 6.4 seems acceptable considering the topography, soil type, agricultural practices, and surface runoff.

On the basis of this study, it is proposed that in a particular location if the soil loss is more than 400 ton/ha-yr, conservation practices in form of bench terraces with high standard construction should be adopted. If location experiences soil loss of 50 – 400 ton/ha-yr, then bench terraces with minimum medium standard construction. Figure 6.4 shows the rate of soil loss after application of soil conservation practices. Table 6.3 shown result of calculation soil loss foe each sub-watershed and each zone existing condition, therefore table 6.4 shown result of calculation soil loss foe each sub-watershed and each zone proposed condition.

Table 6.2a Water balance Jati Watershed Sub Watershed A and B (ha-m)

MONTH	Sub Watershed									
	A			382.28	ha	B			209.93	ha
	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit
JAN	47.67	25.43	2.131	0.013	20.09	13.27	13.97	1.852	0.020	-2.57
FEB	47.64	21.12	1.907	0.012	24.61	13.28	11.60	1.657	0.018	0.01
MAR	46.96	24.66	1.711	0.013	20.58	12.82	13.54	1.487	0.020	-2.23
APR	45.76	21.76	4.079	0.013	19.91	12.06	11.95	3.545	0.019	-3.45
MAY	44.08	22.71	3.666	0.013	17.69	11.01	12.47	3.187	0.020	-4.67
JUN	44.29	20.60	3.410	0.013	20.27	11.15	11.31	2.964	0.019	-3.14
JUL	43.54	22.05	2.301	0.013	19.17	10.72	12.11	2.000	0.020	-3.41
AUG	43.04	25.78	1.140	0.013	16.11	10.40	14.16	0.991	0.020	-4.77
SEP	43.32	26.13	1.882	0.013	15.30	10.53	14.35	1.636	0.019	-5.48
OCT	44.80	26.67	0.683	0.013	17.43	11.46	14.64	0.593	0.020	-3.79
NOV	45.90	24.19	0.687	0.013	21.01	12.15	13.29	0.598	0.019	-1.75
DEC	46.65	25.72	4.262	0.013	16.65	12.72	14.12	3.705	0.020	-5.13
TOTAL										

Table 6.2b Water balance Jati Watershed Sub Watershed C and D (ha-m)

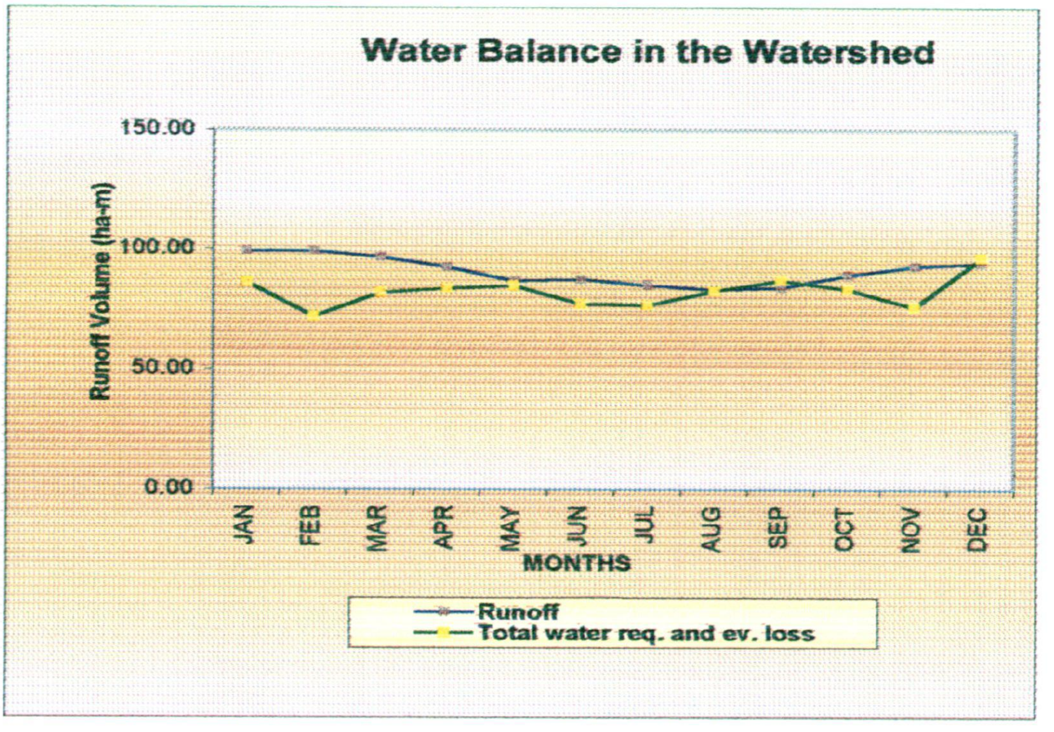
MONTH	Sub Watershed									
	C			127.68	ha	D			105.48	ha
	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit
JAN	14.08	8.49	0.624	0.028	4.93	5.64	7.02	0.804	0.020	-2.20
FEB	14.08	7.05	0.558	0.026	6.44	5.63	5.83	0.719	0.018	-0.93
MAR	13.75	8.24	0.501	0.028	4.99	5.37	6.80	0.645	0.020	-2.10
APR	13.13	7.27	1.194	0.027	4.64	4.83	6.00	1.538	0.019	-2.73
MAY	12.34	7.59	1.073	0.028	3.65	4.16	6.27	1.383	0.020	-3.51
JUN	12.45	6.88	0.998	0.027	4.54	4.23	5.68	1.286	0.019	-2.76
JUL	12.07	7.37	0.674	0.028	4.01	3.95	6.09	0.868	0.020	-3.02
AUG	11.84	8.61	0.334	0.028	2.87	3.74	7.11	0.430	0.020	-3.82
SEP	11.97	8.73	0.551	0.027	2.67	3.87	7.21	0.710	0.019	-4.07
OCT	12.66	8.91	0.200	0.028	3.52	4.45	7.36	0.257	0.020	-3.18
NOV	13.22	8.08	0.201	0.027	4.91	4.89	6.68	0.259	0.019	-2.06
DEC	12.09	8.59	1.248	0.028	2.22	5.24	7.10	1.608	0.020	-3.48
TOTAL										

Table 6.2c Water balance Jati Watershed Sub Watershed E and F (ha-m)

MONTH	Sub Watershed									
	E			264.06	ha	F			59.42	ha
	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit	runoff	EPVT loss	irr water requirement	water suply	Surplus/ defisit
JAN	15.98	17.57	3.682	0.011	-5.28	2.50	3.95	0.433	0.001	-1.89
FEB	15.98	14.59	3.294	0.010	-1.91	2.49	3.28	0.387	0.001	-1.18
MAR	15.53	17.03	2.956	0.011	-4.47	2.34	3.83	0.347	0.001	-1.84
APR	14.59	15.03	7.047	0.011	-7.49	2.05	3.38	0.829	0.001	-2.16
MAY	13.41	15.69	6.334	0.011	-8.63	1.68	3.53	0.745	0.001	-2.60
JUN	13.58	14.23	5.892	0.011	-6.55	1.73	3.20	0.693	0.001	-2.17
JUL	13.05	15.23	3.975	0.011	-6.17	1.56	3.43	0.467	0.001	-2.34
AUG	12.65	17.81	1.970	0.011	-7.14	1.45	4.01	0.232	0.001	-2.79
SEP	12.87	18.05	3.252	0.011	-8.44	1.51	4.06	0.382	0.001	-2.93
OCT	13.95	18.42	1.180	0.011	-5.66	1.83	4.15	0.139	0.001	-2.45
NOV	14.70	16.71	1.188	0.011	-3.20	2.09	3.76	0.140	0.001	-1.81
DEC	15.31	17.76	7.364	0.011	-9.83	2.28	4.00	0.866	0.001	-2.58
TOTAL										

Table 6.2 Water balance Jati Watershed (ha-m)

MONTH	Total					BENEFICIARY AREA			Surplus/defisit
	runoff	EPVT loss	irr. water requirement	water suply	Surplus/ defisit	irr. water requirement	water suply	Total water requirement	
JAN	99.13	76.43	9.53	0.09	13.09	7.42	0.21	7.62	5.47
FEB	99.10	63.46	8.52	0.08	27.04	6.64	0.19	6.82	20.22
MAR	96.78	74.10	7.65	0.09	14.94	5.95	0.21	6.16	8.78
APR	92.42	65.38	18.23	0.09	8.72	14.20	0.20	14.39	-5.68
MAY	86.68	68.26	16.39	0.09	1.94	12.76	0.21	12.96	-11.02
JUN	87.42	61.90	15.24	0.09	10.19	11.87	0.20	12.07	-1.87
JUL	84.89	66.28	10.28	0.09	8.23	8.01	0.21	8.21	0.02
AUG	83.12	77.47	5.10	0.09	0.46	3.97	0.21	4.17	-3.71
SEP	84.07	78.52	8.41	0.09	-2.95	6.55	0.20	6.75	-9.70
OCT	89.15	80.14	3.05	0.09	5.86	2.38	0.21	2.58	3.28
NOV	92.96	72.70	3.07	0.09	17.09	2.39	0.20	2.59	14.50
DEC	94.29	77.29	19.05	0.09	-2.14	14.83	0.21	15.04	-17.18
TOTAL					102.47				3.09



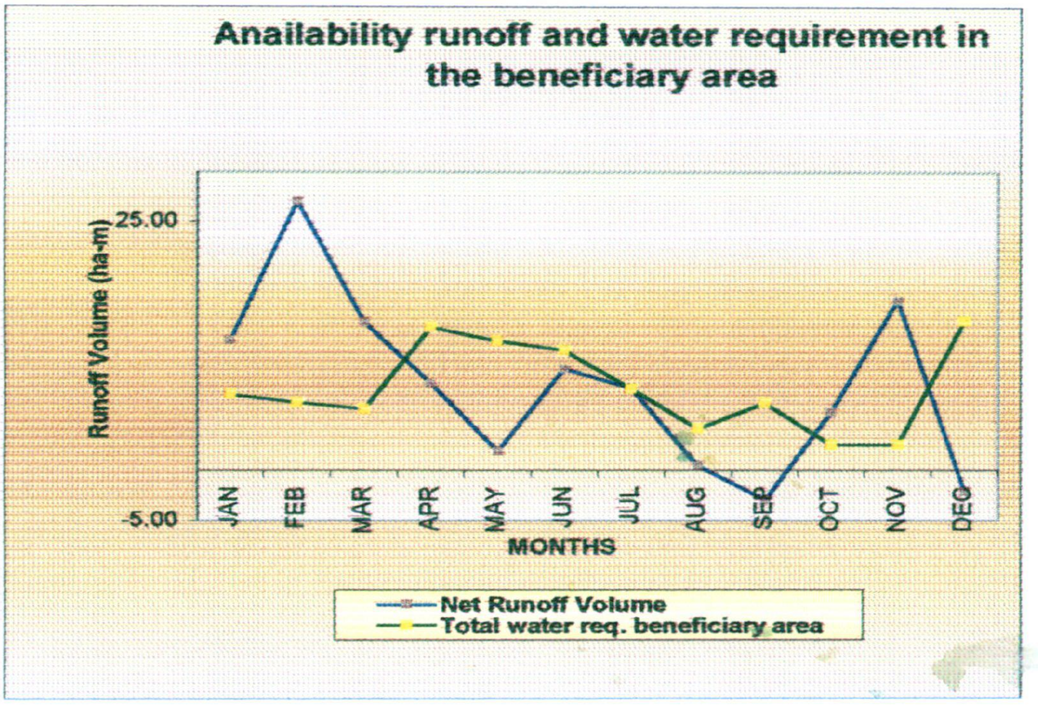


Figure 6.3. Water balance Condition Jati Watershed

Table 6.3. Soil loss, existing condition (with out Conservation Practices) ton/ha/yr

Sub Catchment		ZONE					
		I	II	III	IV	V	Total
A	Area	107.59	172.88	99.31	0.11		379.89
	Soil Loss	624,328.00	656,058.50	116,388.00	-		1,396,774.50
	Rate of Soil Loss	5,802.84	3,794.88	1,171.97	-		10,769.69
B	Area		62.70	114.39	29.67		206.76
	Soil Loss		176,735.20	287,115.90	14,416.70		478,267.80
	Rate of Soil Loss		2,818.74	2,509.97	485.90		5,814.62
C	Area		24.80	53.47	44.74	0.88	123.89
	Soil Loss		24,476.00	67,161.60	8,662.40	-	100,300.00
	Rate of Soil Loss		986.94	1,256.06	193.62	-	2,436.61
D	Area			28.31	67.46	8.09	103.86
	Soil Loss			53,658.90	564,893.30	2,471,887.30	3,090,439.50
	Rate of Soil Loss			1,895.40	8,373.75	305,548.49	315,817.65
E	Area		95.09	95.09	108.09		298.27
	Soil Loss		743081.8	876,054.90	735,760.30		2,354,897.00
	Rate of Soil Loss		7,814.51	9,212.90	6,806.92		23,834.34
F	Area			11.47	46.98		58.45
	Soil Loss			12,264.50	367,087.00		379,351.50
	Rate of Soil Loss			1,069.27	7,813.69		8,882.95
Total	Area	107.59	355.47	402.04	296.94	8.97	1,171.01
	Soil Loss	624,328.00	1,600,351.50	1,412,643.80	1,690,819.70	2,471,887.30	7,800,030.30
	Rate of Soil Loss	5,802.84	4,502.07	3,513.69	5,694.15	275,572.72	6,660.94

Table 6.4. Soil loss, proposed condition (with Conservation Practices) ton/ha/yr

Sub Catchment		ZONE					
		I	II	III	IV	V	Total
A	Area	107.59	172.88	99.31	0.11		379.89
	Soil Loss	93756.5	98424	17469.8	-		209,650.30
	Rate of Soil Loss	871.42	569.32	175.91	-		1,616.66
B	Area		62.70	114.39	29.67		206.76
	Soil Loss		26617.9	11478.6	14,416.70		52,513.20
	Rate of Soil Loss		424.53	100.35	485.90		1,010.78
C	Area		24.80	53.47	44.74	0.88	123.89
	Soil Loss		1145.5	2684.7	8,662.40	-	12,492.60
	Rate of Soil Loss		46.19	50.21	193.62	-	290.02
D	Area			28.31	67.46	8.09	103.86
	Soil Loss			8156.9	84805.9	98614.9	191,577.70
	Rate of Soil Loss			288.13	1,257.13	305,548.49	307,093.75
E	Area		95.09	95.09	108.09		298.27
	Soil Loss		29620	31121.6	26667.4		87,409.00
	Rate of Soil Loss		311.49	327.29	246.71		885.49
F	Area			11.47	46.98		58.45
	Soil Loss			490.7	14718.6		15,209.30
	Rate of Soil Loss			42.78	313.30		356.08
Total	Area	107.59	355.47	402.04	296.94	8.97	1,171.01
	Soil Loss	93,756.50	155,807.40	71,402.30	149,271.00	98,614.90	568,852.10
	Rate of Soil Loss	871.42	438.31	177.60	502.70	10,993.86	485.78

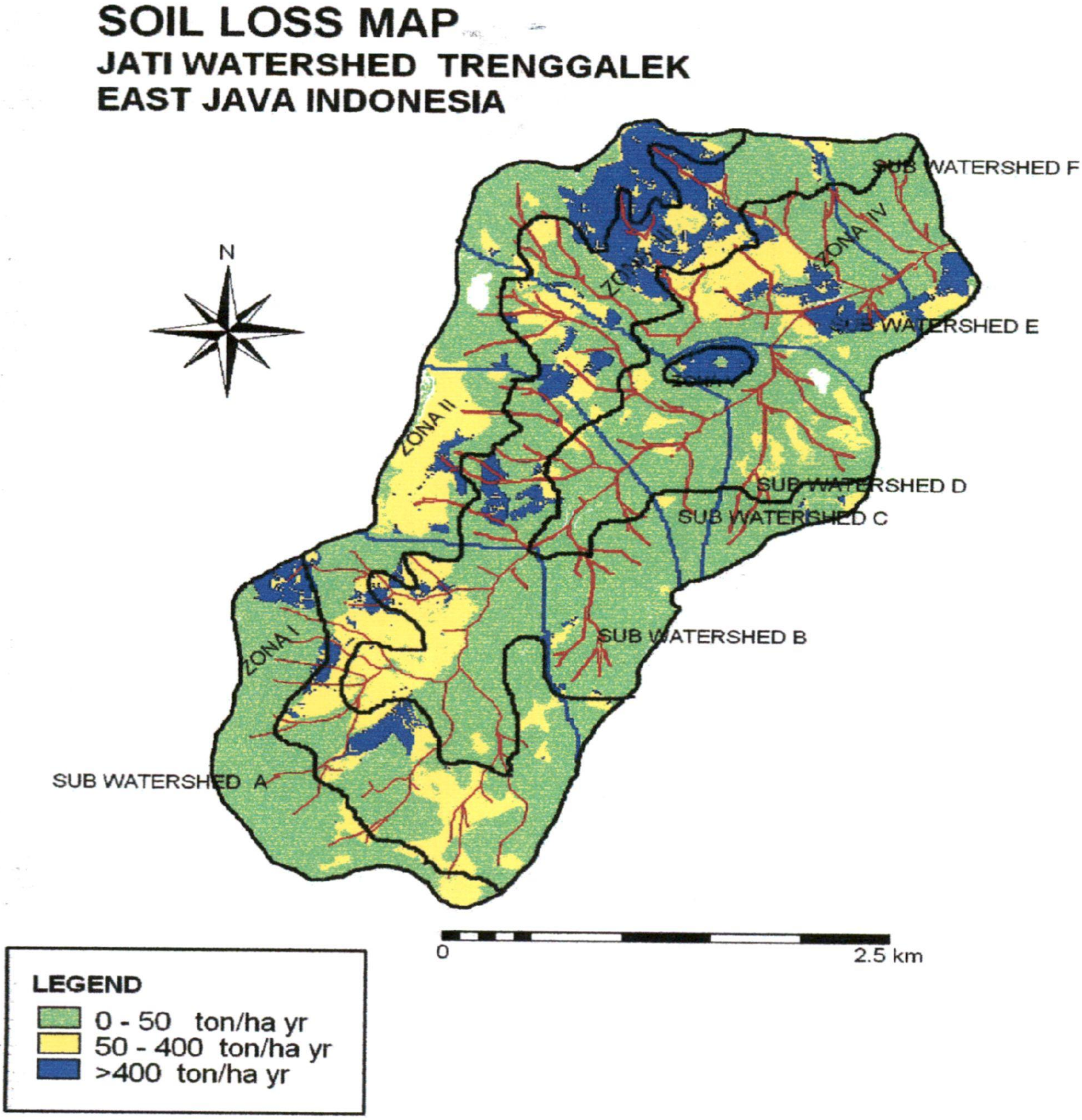


Figure 6.4. Soil Loss Map Existing Condition

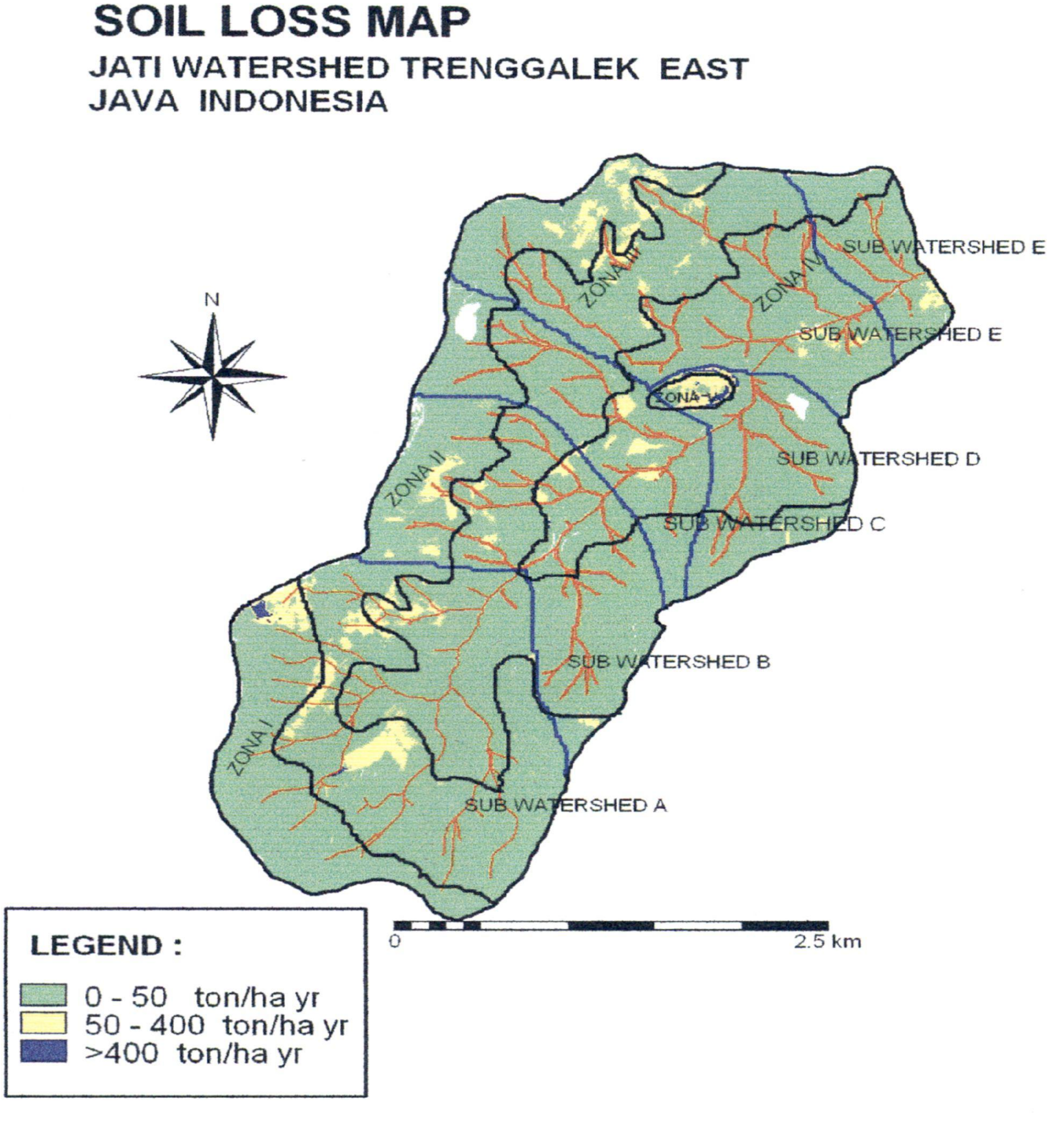


Figure 6.5. Soil loss Map Proposed Condition

6.3. SINGGAHAN WATERSHED

The result of rainfall-runoff model of Singgahan watershed is summarized in the Table 6.5 and Figure 6.2. From the table and figure it is observed that by SCS conventional method, maximum runoff volume is 92.51 ha-m and by SCS modified is 72.3 ha-m produced by 280.4 mm rainfall occur in the month of November, while the minimum runoff volume is 22.8 ha-m and 69.5 ha-m for both methods respectively produced by 116.9 mm rainfall occur in July. On the other hand from tank model method, the maximum and minimum runoff volume are 59.65 ha-m and 25.39 ha-m respectively in the month October and August

For assessment of water balance of Singgahan Watershed, the Singgahan watershed is divided into three sub-watershed ie; sub-watershed A,B, and C. All the sub watersheds get surplus of runoff. The surplus runoff maybe due to the fact that almost the entire watershed is under dense forest which mean less human consumption and evaporation. The complete condition of water balance of Singgahan Watershed shown in Table 6.6 and Figure 6.6. The water balance for each sub-watershed is given in Table 6.6a.

For assessment of soil loss, a model for soil erosion as resulted from USLE as developed in this study is shown in Figures 6.7 and 6.8 for existing condition proposed condition respectively. Figure 6.7 gives predicted soil loss as resulted from our model. In this study, Singgahan Watershed was divided into three sub-watersheds, further categorized into two zones. Zone I is the upper portion of watershed where the land use is dominated by residential and rain fed fields, and zone II in lower location of watershed which is dominated by dense forest and tree. As seen from Figure 6.7, soil loss in zone I is more than 400 ton/ha-yr.

The proposed soil erosion control measures are the same as given for Jati watershed, i.e, bench terraces which high standard construction for places with soil loss of more than 400 ton/ha-yr and bench terraces with minimum medium standard construction for place with soil loss 50 – 400 ton/ha-yr. Table 6.7 shown result of calculation soil loss foe each sub-watershed and each zone existing condition, therefore table 6.8 shown result of calculation soil loss foe each sub-watershed and each zone proposed condition.

Out of the two watershed, good water balance and lesser soil losss wsa observed in Singgahan watershed, which is characteristic by thick forest and less human inhabitation.

Table 6.5. Runoff Volume Singgahan Watershed

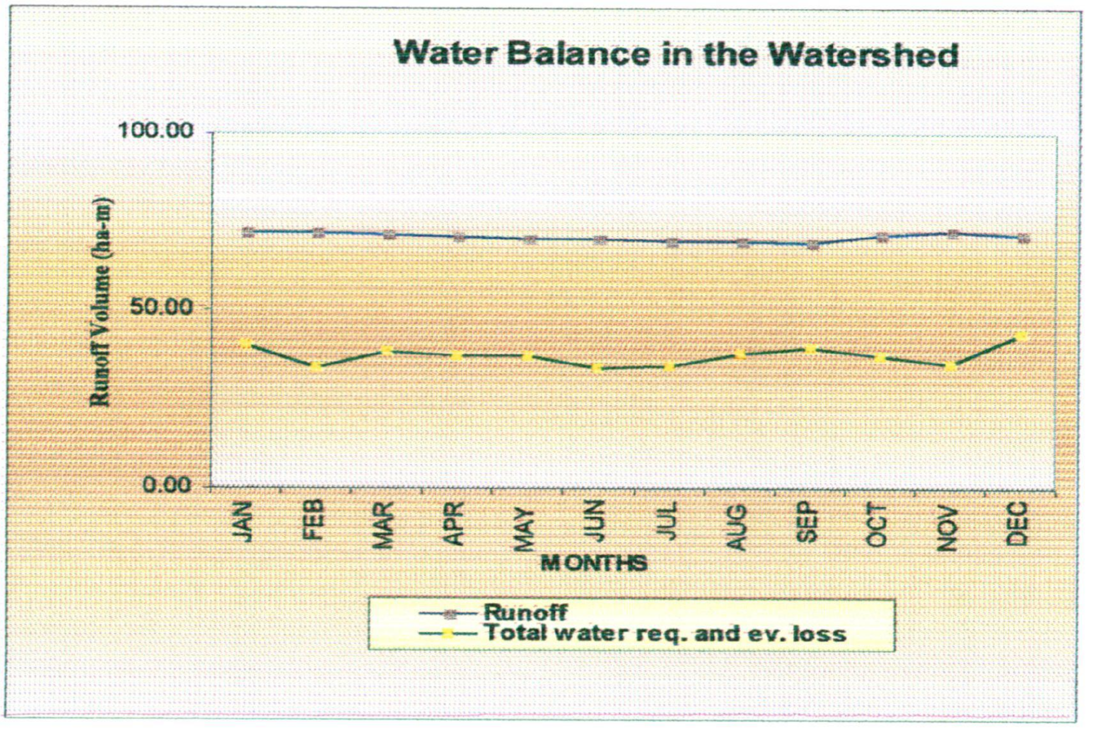
MONTH	Rainfall (mm)	Runoff (Ha-m)		
		SCS	Moglen	Tank Model
JAN	264.8	85.22	72.0	53.36
FEB	264.6	85.17	72.1	52.89
MAR	218.9	64.24	71.2	59.29
APR	203.4	57.37	71.0	46.71
MAY	155.9	37.16	70.2	46.96
JUN	166.9	41.68	70.3	39.97
JUL	116.9	22.08	69.5	29.12
AUG	125.6	25.32	69.7	25.39
SEP	99.5	16.04	69.2	40.28
OCT	229.1	68.84	71.4	59.65
NOV	280.4	92.51	72.3	45.39
DEC	220.9	65.14	71.3	36.72

Table 6.6a. Water balance Singgahan Watershed in ha-m

MONTH	Sub Watershed														
	A			203.5	ha	B			200.4	ha	C			117.2	ha
	runoff	EPVT loss	irr. water require-ment	water suply	Surplus /defisit	runoff	EPVT loss	irr. water require-ment	water suply	Surplus/ defisit	runoff	EPVT loss	irr water require-ment	water suply	Surplus /defisit
JAN	25.31	13.83	4.364	0.038	7.08	29.80	13.63	0.000	0.141	16.03	16.93	7.97	0.00	0.055	8.91
FEB	25.31	11.51	3.792	0.035	9.97	29.82	11.34	0.000	0.132	18.35	16.93	6.63	0.000	0.051	10.25
MAR	25.04	13.46	3.542	0.038	8.00	29.52	13.26	0.000	0.141	16.12	16.67	7.75	0.000	0.055	8.86
APR	24.94	11.89	6.690	0.037	6.33	29.44	11.71	0.000	0.137	17.59	16.61	6.85	0.000	0.053	9.71
MAY	24.67	12.36	5.228	0.038	7.05	29.16	12.17	0.000	0.141	16.84	16.33	7.12	0.000	0.055	9.16
JUN	24.73	11.18	5.078	0.038	8.43	29.22	11.01	0.000	0.141	18.07	16.38	6.44	0.000	0.055	9.89
JUL	24.45	11.92	3.530	0.038	8.96	28.92	11.74	0.000	0.141	17.04	16.13	6.86	0.000	0.055	9.21
AUG	24.51	13.91	1.755	0.038	8.80	28.97	13.71	0.000	0.141	15.13	16.18	8.01	0.000	0.055	8.11
SEP	24.36	14.12	2.912	0.038	7.29	28.83	13.90	0.000	0.141	14.79	16.03	8.13	0.000	0.055	7.84
OCT	25.11	14.45	0.000	0.038	10.62	29.58	14.23	0.000	0.141	15.21	16.73	8.32	0.000	0.055	8.36
NOV	25.39	13.16	1.128	0.038	11.07	29.89	12.96	0.000	0.141	16.78	17.01	7.58	0.000	0.055	9.37
DEC	25.05	14.01	7.033	0.038	3.97	29.53	13.80	0.000	0.141	15.59	16.68	8.07	0.000	0.055	8.56
TOTAL															

Table 6.6. Water balance Singgahan Watershed in ha-m

MONTH	Total					BENEFICIARY AREA			Surplus/defisit
	runoff	EPVT loss	irr. water	water suply	Surplus/ defisit	irr. water requirement	water suply	Total water requirement	
JAN	72.05	35.43	4.36	0.23	32.02	1.811	0.260	2.07	29.95
FEB	72.06	29.48	3.79	0.22	38.57	1.57	0.24	1.82	36.75
MAR	71.23	34.47	3.54	0.23	32.98	1.47	0.26	1.73	31.25
APR	70.98	30.44	6.69	0.23	33.63	2.78	0.25	3.03	30.60
MAY	70.16	31.65	5.23	0.23	33.05	2.17	0.26	2.43	30.62
JUN	70.34	28.63	5.08	0.23	36.39	2.11	0.26	2.37	34.02
JUL	69.49	30.52	3.53	0.23	35.21	1.47	0.26	1.73	33.48
AUG	69.66	35.63	1.76	0.23	32.04	0.73	0.26	0.99	31.05
SEP	69.22	36.15	2.91	0.23	29.92	1.21	0.26	1.47	28.46
OCT	71.42	37.00	0.00	0.23	34.18	0.00	0.26	0.26	33.92
NOV	72.28	33.70	1.13	0.23	37.22	0.47	0.26	0.73	36.49
DEC	71.26	35.88	7.03	0.23	28.12	2.92	0.26	3.18	24.94
TOTAL					403.33				381.54



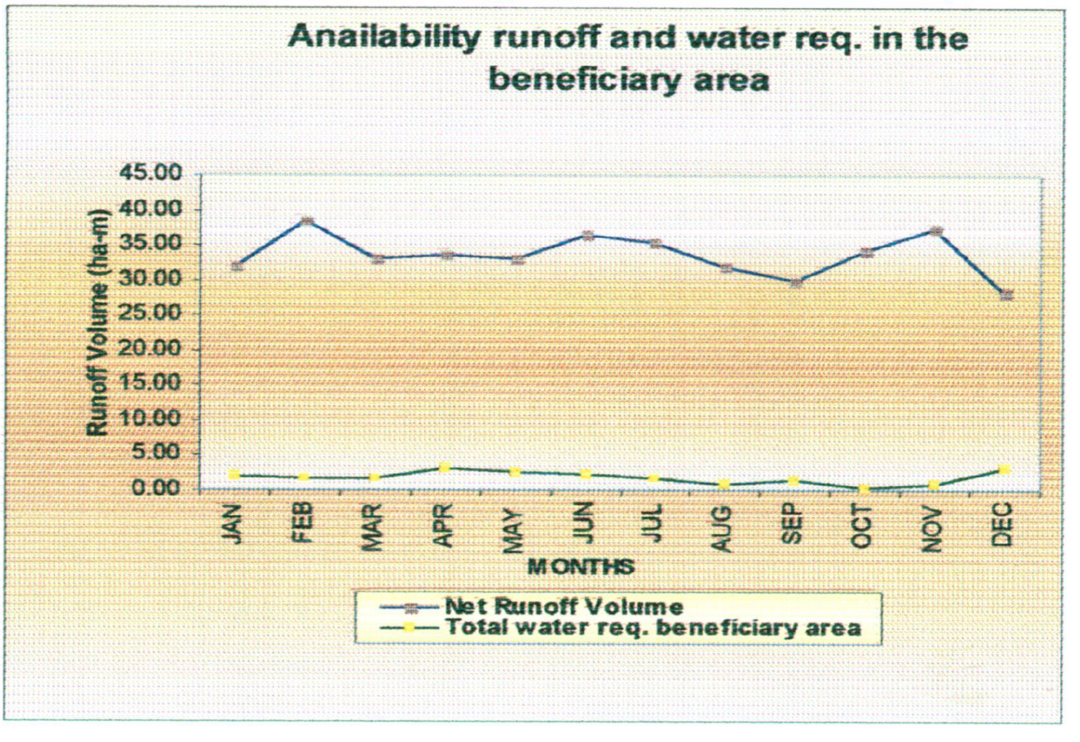


Figure 6.6 Water Balance Condition Singgahan Watershed

Table 6.7. Soil loss, existing condition (with out Conservation Practices) ton/ha/yr

Sub Watershed		ZONE I	ZONE II	ZONE Total
A	Area	27.60	175.25	202.85
	Soil Loss	79,250,328.00	1,042,109.80	80,292,437.80
	Rate of Soil Loss	2,871,648.81	5,946.50	395,831.49
B	Area		200.45	200.45
	Soil Loss		47,049.60	47,049.60
	Rate of Soil Loss		234.72	234.72
C	Area		117.04	117.04
	Soil Loss		460,342.40	460,342.40
	Rate of Soil Loss		3,933.21	3,933.21
Total	Area	27.60	492.74	520.33
	Soil Loss	79,250,328.00	1,549,501.80	80,799,829.80
	Rate of Soil Loss	2,871,648.81	3,144.70	155,285.00

Table 6.8. Soil loss, proposed condition (with Conservation Practices) ton/ha/yr

Sub Watershed		ZONE I	ZONE II	ZONE Total
A	Area	27.60	175.25	202.85
	Soil Loss	2,811,031.80	1,276,761.30	4,087,793.10
	Rate of Soil Loss	101,858.20	7,285.48	20,152.30
B	Area		200.45	200.45
	Soil Loss		47,049.60	47,049.60
	Rate of Soil Loss		234.72	234.72
C	Area		117.04	117.04
	Soil Loss		460,342.40	460,342.40
	Rate of Soil Loss		3,933.21	3,933.21
Total	Area	27.60	492.74	520.33
	Soil Loss	2,811,031.80	1,784,153.30	4,595,185.10
	Rate of Soil Loss	101,858.20	3,620.92	8,831.25

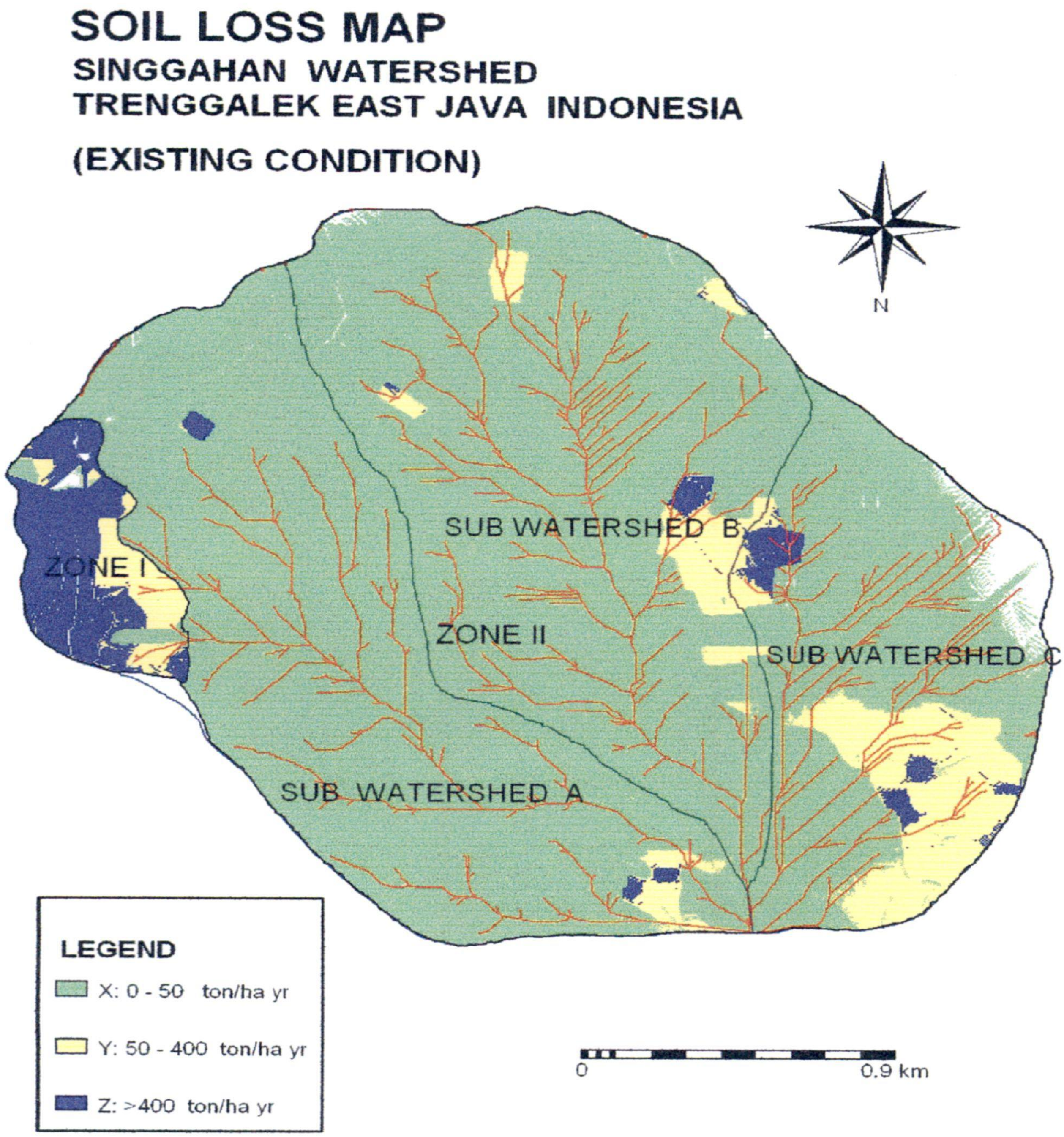


Figure 6.7. Soil loss Map Existing Condition

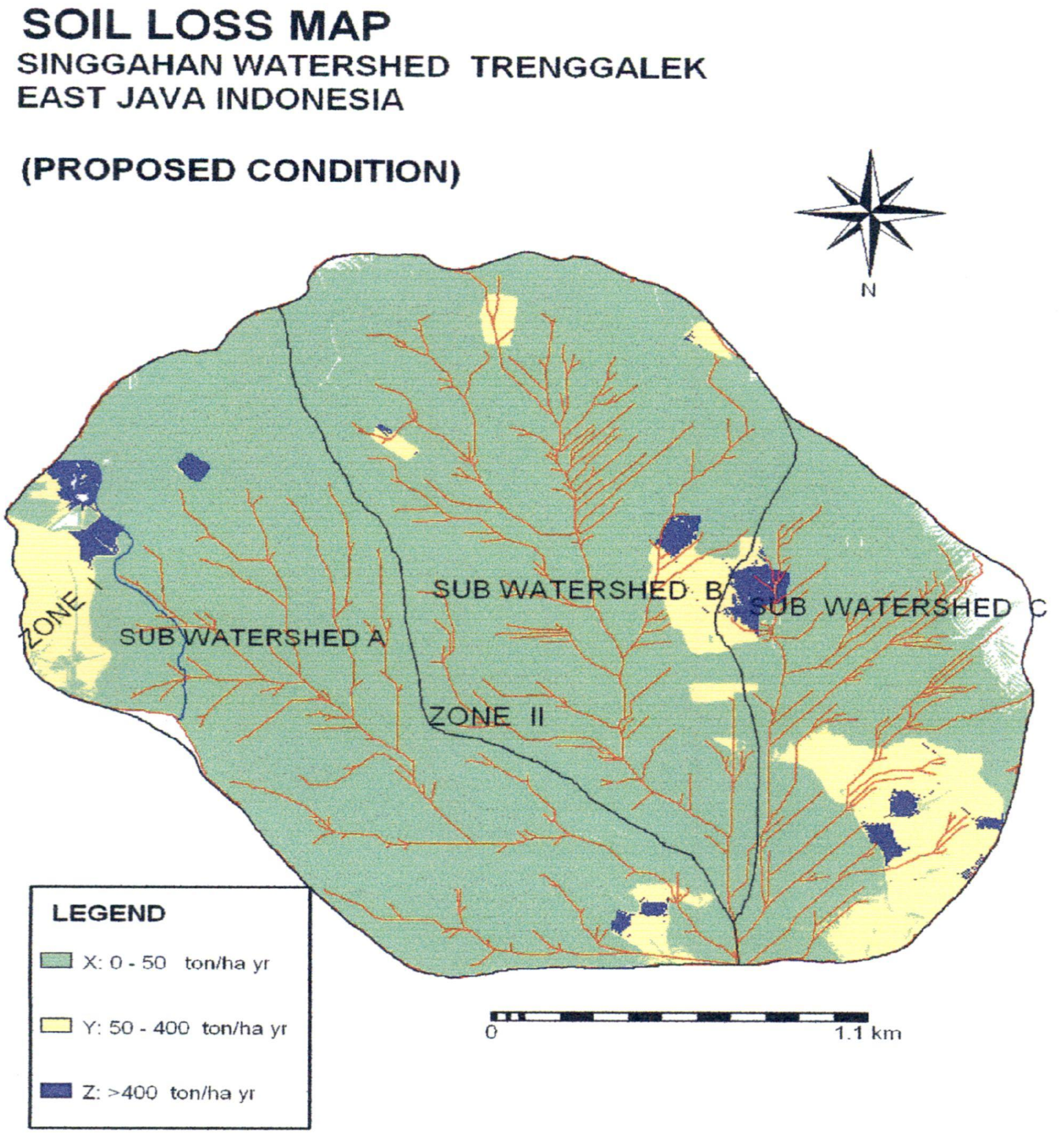


Figure 6.8. Soil loss Map Proposed Condition

CHAPTER VII
CONCLUSION

The Strongest attributes of computer based Geographic Information System (GIS's) approach as compared to manual procedure are usefullness based on easy of updating, flexibility for use and cost effectiveness. The possibility of integrating resource models with GIS holds great promises in resources management and decision making. This study demonstrated the succesfull integration of SCS rainfall-runoff and USLE models with GIS.

In the process of evaluating various parameters of SCS rainfall-runoff and USLE empirical models, data in analog form were converted into digital format through digitization program in vector structure. Then, these data which were acquired in vector format were rasterized into common transformation scale and common digital database was created.

Using this spatial database, the SCS rainfall-runoff and USLE models parameters were evaluated and then runoff estimation and soil loss model were created. The aim of creation of those models are to evaluated water balance and soil loss hazard of Jati and Singgahan Watersheds in East Java Province of Indonesia.

Based on the study for both the watersheds silent fatures of the study are : ..

i) Calculation of runoff is done by SCS modified model
ii) Calculation of soil loss using USLE model with some assumption :
   a) Type of soil is same entire watershed.
   b) Rainfall erosivity index generated from average monthly rainfall correlation as per used in calculation of soil loss in report of Report Identification Study and Detailed Design of Small Ponds, Review of Water Resources Development Study for Water Supply in Brantas River Basin under Wonorejo Multipurpose Dam Construction Project.
   c) Soil cover adopted is commonly used for Indonesia Condition
   d) Management Soil Practices factor adopted also commonly used in Indonesia condition i.e, bench terraces, with some categories applicability.

On the basis of the study following conclusion can be drawn :

i) For Jati Watershed, the analysis is made by considering six sub-watershed. The division of the sub-watershed was made in light of drainage map. In addition to that five zones were considered based on the slope, so that appropriate treatment could be suggested. The main features of the output for Jati Watershed are :

a) The slope range of watershed varies from 3.5 % to 35 % from DEM

b) Land Use Map generated, shows the watershed has area under plantation trees

c) Runoff depth under existing condition does not vary much within the watershed. For example it varies from 335.3 mm to 382.9 for month of January.

d) Surplus runoff volume generated from the watershed is 102.47 ha-m.

e) After the use of this surplus runoff for the beneficiary area, 3.09 ha-m annually will remaining as surplus.

f) Rate of soil loss with existing condition is 6,660.94 ton/ha-yr and after applied soil conservation practices is 485.78 ton/ha-yr

ii) For Singgahan Watershed the analysis is made by considering three watershed. The division of the sub-watershed was made in light of drainage map. In addition to that two zones were considered based on the slope, so that appropriate treatment could be suggested. The main features of the output for Singgahan Watershed are :

a) The slope range of watershed varies from 3.5 % to 35 % from DEM

b) Land Use Map generated, shows the watershed has area under plantation trees

c) Runoff depth under existing condition does not vary much within the watershed. For example it varies from 150.6 mm to 188.1 for month of January.

d) Surplus runoff volume generated from the watershed is 403.33 ha-m.

e) After the use of this surplus runoff for the beneficiary area, 485.78 ha-m annually will remaining as surplus.

f) Rate of soil loss with existing condition is 155,285.0 ton/ha-yr and after applied soil conservation practices is 8,831.25 ton/ha-yr

Evaluation of water balance of two watersheds shows that in Singgahan watershed more surplus runoff surplus is available as compared to Jati Watershed. On the other hand evaluation of soil loss reveals that both the watersheds in existing condition have very high soil loss. Through this study in order to reduce the soil loss in the two watersheds, it is suggested to apply high standard bench terraces in locations which have soil loss is more than 400 ton/ha yr as shown in the image of model (Fig. 6.4 and 6.7)

The other suggestion is given to Government of East Java Province of Indonesia to take care in two watershed especially management of hazard of soil loss, otherwise a small pond as planned by the government will will be useless. It is also recommended for Singgahan pond, that the pond can be constructed as a percolation pond because of availability of huge surplus volume.

REFERENCES

Anonymous, Texas Department of Transportation, Hydraulic design Manual, Revised march 2004

Anonymous, The Study on Comprehensive Management Plan for The Water Resources of Brantas River Basin, in The Republic of Indonesia (1998). Nippon Koei Co, Ltd and Nikken Consultant INC

Anonymous, Final Report Identification Study and Detailed Design of Small Ponds, Review of Water Resources Development Study for Water Supply in Brantas River Basin under Wonorejo Multipurpose Dam Construction Project

A. K. Sharma and R. R. Navalgund, A. K. Pandey and K. K. Rao, Micro-watershed development plans using Remote Sensing and GIS for a part of Shetrunji river basin, Bhavnagar district, Gujarat, Map India 1999

Aronoff (1991), Geographic information System, WDLP Publication P.O bax 585, Station B Ottawa, Ontario KIP SP 7 Canada

A. Sarangi, P. Enright, C.A. Madramootoo, Development of User Interface in ArcGIS for Watershed Management, Map India 2004

A.Sarangi, N.H. Rao, Sheena M. Brownee, A.K. Singh, Use of Geographic Information System (GIS) tool in watershed hydrology and irrigation water management, Map India 2004

Ashish Pandey and A. K. Sahu, Generation of curve number using Remote Sensing and Geographic Information System, Map Asia 2002

Bhuwneshwar Prasad. Sah Kiyoshi Honda & Shunji Murai, Subwatershed Prioritizationfor Watershed Management using Remote Sensing and GIS, ACRS 1997

Burrough (1986), Principles of Geographic Information System for Land Resources in Water Resources, Journal of Water Resources Planning & Management Vol. 119 (2)

Chiradeep Adhikari, A GIS - Remote Sensing compatible rainfall-surface runoff model for regional level planning, Map India 2003

DeMers. 2000. Fundamentals of Geographic Information, Systems. Ch. 11.

Ghamsyam Das (2002) , Hydrology and Soil Conservation Engineering Practice. Hall India

Glenn E Moglen,2000, Effect of Orientation of Spatially distributed Curve Numbers in runoff Calculations, Journal of The American Water Resources Association 36 (6) : 1391-1400

Grove, M J Harbor and B Engel, 1998, Composite vs Distributed Curve Numbers : Effect on Estimates of Storm Runoff depth, Journal American Water Resources Association 34 (5) : 1015-1039

Hadi Meamarian, Hamid Esmaeilzadeh, Seid Mohmmad Tajbakhsh, The Sediment yield potential estimation of Kashmar urban watershed using MPSIAC model in the GIS framework, Map India 2003

Hatibu.N, O.B. Mziarai and Rockstrom (1976), The Information technology for planning RWH: Exploit the power of knowledge. Sida's Regional Land Management Unit, 2000

J. G. Krishnayya.Angira Baruah, Use of Geographic Information System (GIS) tool in watershed hydrology and irrigation water management, GIS Development 2003

J. Greenfield, M. Lahlou, L. Swift, Jr., and H.B. Manguerral, Watershed Erosion and Sediment Load Estimation Tool

Musgrave, G W (1947). The Quantitative evaluation of Factor's in Water Erosion; a First approximation. J soil & Water Conservation, 2 : 133-8Terrence J Toy and George R Foster, Guidelines for Use of Revised Universal Soil Loss Equation (RUSLE) version 1.06

Meyer, L.D., W.H. Wischmeier, and W.H. Daniel. 1971. Erosion, runoff, and revegetation of denuded construction sites. Am. Soc. Agr. Eng., Trans. 14:138- 141.

Meyer, L.D., C.B. Johnson, and G.R. Foster. 1972. Stone and woodchip mulches for erosion control on construction sites. J. Soil and Water Cons. 27:264-269.

Michael DeMers (2000). *Fundamentals of Geographic Information Systems*, (Second Edition), New-York: John Wiley & Sons, Inc

M K Jain (1999), Remote sensing and GIS Application in Rainfall-Runoff Modeling, National Institute of Hydrology Roorkee.

Mulugeta Tades Geleta, Application of Geographic Information System in Watershed Management, Dissertation, WRDTC, University of Roorkee, 1992

Novotny, V. and Olem, H. (1994) Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.

Paritosh Gupta and Rajendra M Tamhane, Damanjit S Minhas and A K Mookerjee, Application of Geographical Information System (GIS) tools in watershed analysis, Map India 2004

Prinz, D., Oweis, T. & Oberle, A., 1998. Rainwater Harvesting for Dry Land Agriculture - Developing a Methodology Based on Remote Sensing and GIS. Proceedings, IXIII CIGR Congress, Rabat, 2-6.2.1998 . ANAFID, Rabat, Morocco

PRINZ, D., (1999). Traditional Irrigation Techniques To Ease Future Water Scarcity. Proceedings, 17th International Congress on Irrigation and Drainage. Water and Agriculture in the Next Millenium, Granada 11-19.09.1999. ICID, New Delhi (in print)

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agricultural Handbook 703, 404 pp.

Roslinah Samad, Norizan Abdul Patah, Soil Erosion and Hydrological Study of the Bakun Dam Catchment Area, Sarawak Using Remote Sensing and Geographic Information System (GIS), ACRS 1997

S.K. Jain, N Kumar, T Ahmad, SLRUP model and GIS for estimation of runoff in part of Sudluj Catchment, India, Hydrological Science Jurnal, 43 dec. 1998.

Tauer, W. and G. Humborg (1992). *Runoff irrigation in the Sahel zone: Remote sensing and geographical information system for determining potential sites.* CTA, Wageningen. 192 pp

Tideman (1996) watershed Management, Guidelines for Indian Condition, omega. Scientific Publishers New Delhi

Tomlison, RF, Calkins, HW & Marble, D.F, Computer Handling of Geographical Data, The UESCO Press

Valenzuela, CR (1980), Introduction to Geographic Information System, ITC Publication No.22, ITC Enschede

Vladimir and Novotny& Gordon Cherters (1991), Handbook of Non-Point Polution Potential Hydrology Application of Space technology (Proceeding of the Cocoa Beach workshop, Florida, august 1985) IAAS Publ. No.160

Wischmeier W.H. and Smith D.D. 1958. Rainfall energy and its relationship to soil loss. *Trans. Amer. Geophys. Union* 39: 285-291.

Wischmeier W.H. and Smith D.D. 1960. A universal soil loss estimating equation to guide conservation farm planning. *Proc. 7th Inter. Congress Soil Science Soc.* Vol. 1: 418-425.

Weismeier and Smith (1965), predicting rainfall Erosion losses from Crop Land East of Rocky Mountain, Agri Handbook, No.282 R.S. USDA

Wischmeier W.H. and Smith D 1978. Predicting rainfall erosion losses: a guide to conservation planning. *USDA-ARS Agriculture Handbook* N° 537, Washington DC.58 p.

ZINCK, J. A., & VALENZUELA, C. R. 1990. Soil geographic database: structure and appication examples. ITC Journal 1990-3, 270-293.

Zingg, A.W. 1940. Degree and length of land slope as it affects soil losses in runoff. Am. Soc. Agr. Eng., Trans. 21:59-64.

S.K. Jain, N Kumar, T Ahmad, SLRUP model and GIS for estimation of runoff in part of Sudluj Catchment, India, Hydrological Science Jurnal, 43 dec. 1998.

APPENDIX A-1

Runoff Curve Numbers for Urban Area

Cover Type and Hydrologic Condition	Average Percent Impervious Area	A	B	C	D
Open space (lawns, park, golf courses, cemeteries, etc)					
• Poor condition (grass cover <50%)		68	79	86	89
• Fair condition (grass cover 50% to 75%)		49	69	79	84
• Good condition (grass cover>75%)		39	61	74	80
Paved parking lots, roofs, driveways, etc (excluding right-of-way)		98	98	98	98
Streets and roads:					
• Paved: curbs and storm drains (excluding right-of-way)		98	98	98	98
• Paved: open ditches (including right-of-way)		83	89	92	93
• Gravel(including right-of-way)		76	85	89	91
• Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
• Natural desert landscaping (pervious areas only)		63	77	85	88
• Artificial desert landscaping (impervious weed barrier, desert shrub with 1-to2 inch sand or gravel mulch and basin border		96	96	96	96
Urban districts:					
• Commercial and business	85	89	92	94	95
• Industrial	72	81	88	91	93
Residential districts by average lot size:					
• 1/8 acre or less (town houses)	65	77	85	90	92
• ¼ acre	38	61	75	83	87
• 1/3 acre	30	57	72	81	86
• ½ acre	25	54	70	80	85
• 1 acre	20	51	68	79	84
• 2 acre	12	46	65	77	82
Developing urban areas :					
Newly graded areas (pervious area only, no vegetation)		77	86	91	94

Notes: Values are for average runoff condition, and $I_a = 0.2S$.
The average percent impervious area shown was used to develop the composite RCNs Other assumptions are: impervious area are directly connected to the drainage system, impervious areas have a RCN of 98, and pervious area considered equivalent to open space in good hydrologic condition

APPENDIX A-2

Runoff Curve Numbers Cultivated Agricultural Land[1]

Cover Type	Treatment[2]	Hydrologic Condition[3]	A	B	C	D
Fallow	Bare soil		77	86	91	94
	Crop residue	Poor	76	85	90	93
	cover (CR)	Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR+CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured ©	Poor	70	79	84	88
		Good	65	75	82	86
	C+CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T +CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR+CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C+CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or	SR	Poor	66	77	85	89
broadcast		Good	58	72	81	85
Legumes or C		Poor	64	75	83	85
Rotation		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Notes: [1] Values are average runoff condition, and $I_a = 0.2S$

[2] Crop residue cover applies only if residue is on at least 5 percenr of the surface throughout the year

[3]Hydrologic condition is based on a combination of factors affecting infiltration and runoff: density and canopy of vegetative areas, amount of year-round cover, amount of grass or closes-seeded legumes in rotations, percent of residue cover on land surface (good>20percent), and degree of roughness.

Poor : factor impair infiltration and tend to increase runoff

Good: Factor encourage average and better infiltration and tend to decrease runoff

APPENDIX A-3

Runoff Curve Numbers for Other Agricultural Lands

Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush-brush-weed-grass mixture, with brush the major element	Poor	78	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods-grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads-building, lane, driveways, and surrounding lots		59	74	82	86

Notes: Values are average runoff condition, and $I_a = 0.2S$

Pasture : Poor is <50% ground cover or heavily grazed with no mulch, Fair is 50% to 75% ground cover and not heavily grazed, and Good is>75% ground cover and lightly or only occasionally grazed

Meadow: poor is 50% ground cover, Fair is 50% to 75% ground cover, Good is>75% ground cover.

Woods/grass: RCNs shown were computed for areas with 50 percent grass (pasture) cover. Other combination of conditions may be computed from RCNs for woods and pasture.

Woods: poor is forest litter, small trees, and brush destroyed by heavy grazing or regular burning. Fair is woods grazed but not burned and with some forest litter covering the soil. Good is woods protected from grazing and with litter and brush adequately covering soil.

APPENDIX A-4

Runoff Curve Numbers for Arid and Semi Arid Rangelands

Cover Type	Hydrologic Condition	A	B	C	D
Herbaceous-mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen-mountain brush Mixture of oak brush, aspen, Mountain mahogany, bitter brush, Maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper- pinyon, juniper, Or both; grass undersory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Saltbush, greasewood, creosote Bush, blackbrush, bursage, palo Verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Notes: Values are average runoff condition, and $I_a = 0.2S$

Hydrologic Condition : Poor is <30% ground cover (litter, grass, and brush overstory), fair is 30% to 70% ground cover, Good is >70% ground cover.

Curve Number for Group A have been developed only for desert shrub.

CLIMATIC DATA of JATI WATERSHED

CLIMATIC DATA : SUNSHINE DURATION (n in hour)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Month											
1	1997	3.04	2.32	6.32	5.20	6.48	6.88	6.72	7.28	6.72	6.32	5.20	4.24
2	1998	5.36	4.80	4.24	4.64	5.28	4.64	5.12	6.24	4.48	3.92	4.00	4.16
3	1999	3.52	3.60	3.52	4.32	6.00	6.40	6.24	6.48	6.32	4.88	4.08	3.76
4	2000	4.16	2.72	3.76	3.92	5.60	6.08	5.92	6.32	5.92	3.92	2.64	5.44
5													
6													
	Average	4.02	3.36	4.46	4.52	5.84	6.00	6.00	6.58	5.86	4.76	3.98	4.40

CLIMATIC DATA : TEMPERATURE (T in $^{\circ}$c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Month											
1	1997	25.90	26.10	26.80	26.50	26.00	24.90	23.20	23.50	24.20	25.70	26.90	26.90
2	1998	27.50	25.50	25.30	25.50	25.80	25.40	25.40	25.50	24.20	25.90	26.20	26.20
3	1999	25.70	25.10	25.60	25.40	25.40	25.90	24.60	25.70	25.00	25.50	25.60	26.30
4	2000	26.60	26.60	26.80	26.80	26.90	25.20	25.00	25.30	27.10	25.60	25.90	26.30
5													
6													
	Average	26.43	25.83	26.13	26.05	26.03	25.35	24.55	25.00	25.13	25.68	26.15	26.43

CLIMATIC DATA : AVERAGE HUMIDITY (Rh in %c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Month											
1	1997	80.00	83.00	79.00	81.00	79.00	77.00	76.00	76.00	74.00	72.00	75.00	77.00
2	1998	77.00	82.00	83.00	83.00	81.00	81.00	81.00	72.00	80.00	80.00	80.00	80.00
3	1999	82.00	81.00	81.00	83.00	74.00	77.00	71.00	69.00	67.00	74.00	78.00	80.00
4	2000	78.00	79.00	80.00	82.00	81.00	79.00	78.00	75.00	76.00	78.00	79.00	78.00
5													
6													
	Average	79.25	81.25	80.75	82.25	78.75	78.50	76.50	73.00	74.25	76.00	78.00	78.75

CLIMATIC DATA : MAXIMUM HUMIDITY (Rhmax in %c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Month											
1	1997	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	1998	94.00	98.00	98.00	96.00	92.00	100.00	100.00	100.00	96.00	100.00	96.00	96.00
3	1999	98.00	98.00	96.00	96.00	99.00	96.00	99.00	99.00	100.00	99.00	100.00	96.00
4	2000	100.00	100.00	100.00	100.00	98.00	98.00	100.00	100.00	100.00	100.00	98.00	98.00
5													
6													
	Average	98.00	99.00	98.50	98.00	97.25	98.50	99.75	99.75	99.00	99.75	98.50	97.50

CLIMATIC DATA : WIND (U = Km/hour)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Month											
1	1997	2.90	1.70	1.50	1.00	1.30	1.20	1.40	1.40	1.50	1.80	2.30	1.30
2	1998	1.40	1.00	0.80	0.70	0.50	0.80	0.60	1.50	1.20	1.40	1.00	0.80
3	1999	0.70	1.40	1.20	0.90	0.80	1.50	1.60	2.20	2.90	2.20	1.30	1.30
4	2000	2.20	2.40	1.20	0.90	1.30	0.90	3.00	1.90	2.40	2.40	1.40	2.20
5													
6													
	Average	1.80	1.63	1.18	0.88	0.98	1.10	1.65	1.75	2.00	1.95	1.50	1.40

MEAN DAILY DURATION OF MAXIMUM POSSIBLE SUNSHINE HOURS (N) FOR DIFFERENT MONTH AND LATITUDES

No	LS	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	30	13.90	13.20	12.40	11.50	10.60	10.20	10.40	11.10	12.00	12.90	13.60	14.00
2	25	13.50	12.00	12.30	11.60	10.90	10.60	11.00	11.50	12.00	12.70	13.30	13.70
3	20	13.20	12.80	12.30	11.70	11.30	10.90	11.30	11.60	12.00	12.60	13.10	13.30
4	15	12.90	12.60	12.20	11.80	11.40	11.20	11.30	11.60	12.00	12.50	12.80	13.00
5	10	12.60	12.40	12.10	11.80	11.60	11.50	11.60	11.80	12.00	12.30	12.60	12.70
6	5	12.30	12.30	12.10	12.00	11.90	11.80	11.80	11.90	12.00	12.20	12.30	12.40
7	0	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EXTRA TERRESTRIAL RADIATION (Ra) EXPRESSED IN EQUIVALENT EVAPORATION IN MM/DAY

No	LS	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	20	17.30	16.50	15.00	13.00	11.00	10.00	10.40	12.00	13.90	15.80	17.00	17.40
2	18	17.10	16.50	15.10	13.20	11.40	10.40	10.80	12.30	14.10	15.80	16.80	17.10
3	16	16.90	16.40	15.20	13.50	11.70	10.80	11.20	12.60	14.30	15.80	16.70	16.80
4	14	16.70	16.40	15.30	13.70	12.10	11.20	11.60	12.90	14.50	15.80	16.50	16.60
5	12	16.60	16.30	15.40	14.00	12.50	11.60	12.00	13.20	14.70	15.80	16.40	16.50
6	10	16.40	16.30	15.50	14.20	12.80	12.00	12.40	13.50	14.80	15.90	16.20	16.20
7	8	16.10	16.10	15.50	14.40	13.10	12.40	12.70	13.70	14.90	15.80	16.00	16.00
8	6	15.80	16.00	15.60	14.70	13.40	12.80	13.10	14.00	15.00	15.70	15.80	15.70
9	4	15.50	15.60	15.60	14.90	13.80	13.10	13.40	14.30	15.10	15.60	15.50	15.40
10	2	15.30	15.70	15.70	15.10	14.10	13.50	13.70	14.50	15.20	15.50	15.30	15.10
11	0	15.00	15.50	15.70	15.30	14.40	13.90	14.10	14.80	15.30	15.40	15.10	14.80

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EFFECT OF TEMPERATURE F(T) ON LONGWAVE RADIATION (Rn1)

T	0	2	4	6	8	10	12	14	16	18	20	22
f(T)	11.00	11.40	11.70	12.00	12.40	12.70	13.10	13.50	13.80	14.20	14.60	15.00

T	24	26	28	30
f(T)	15.40	15.90	16.30	16.70

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EFFECT OF VAPOUR PRESSURE F(ed) ON LONGWAVE RADIATION (Rn1)

n/N	-	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55
f(n/N)	0.01	0.15	0.19	0.24	0.28	0.33	0.37	0.42	0.46	0.51	0.55	0.60

n/N	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
f(n/N)	0.64	0.69	0.73	0.78	0.82	0.86	0.91	0.95	1.00

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

CLIMATIC DATA of SINGGAHAN WATERSHED

CLIMATIC DATA : SUNSHINE DURATION (n in hour)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1997	3.04	2.32	6.32	5.20	6.48	6.88	6.72	7.28	6.72	6.32	5.20	4.24
2	1998	5.36	4.80	4.24	4.64	5.28	4.64	5.12	6.24	4.48	3.92	4.00	4.16
3	1999	3.52	3.60	3.52	4.32	6.00	6.40	6.24	6.48	6.32	4.88	4.08	3.76
4	2000	4.16	2.72	3.76	3.92	5.60	6.08	5.92	6.32	5.92	3.92	2.64	5.44
5													
6													
	Average	4.02	3.36	4.46	4.52	5.84	6.00	6.00	6.58	5.86	4.76	3.98	4.40

CLIMATIC DATA : TEMPERATURE (T in ^{0}c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1997	25.90	26.10	26.80	26.50	26.00	24.90	23.20	23.50	24.20	25.70	26.90	26.90
2	1998	27.50	25.50	25.30	25.50	25.80	25.40	25.40	25.50	24.20	25.90	26.20	26.20
3	1999	25.70	25.10	25.60	25.40	25.40	25.90	24.60	25.70	25.00	25.50	25.60	26.30
4	2000	26.60	26.60	26.80	26.80	26.90	25.20	25.00	25.30	27.10	25.60	25.90	26.30
5													
6													
	Average	26.43	25.83	26.13	26.05	26.03	25.35	24.55	25.00	25.13	25.68	26.15	26.43

CLIMATIC DATA : AVERAGE HUMIDITY (Rh in %c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1997	80.00	83.00	79.00	81.00	79.00	77.00	76.00	76.00	74.00	72.00	75.00	77.00
2	1998	77.00	82.00	83.00	83.00	81.00	81.00	81.00	72.00	80.00	80.00	80.00	80.00
3	1999	82.00	81.00	81.00	83.00	74.00	77.00	71.00	69.00	67.00	74.00	78.00	80.00
4	2000	78.00	79.00	80.00	82.00	81.00	79.00	78.00	75.00	76.00	78.00	79.00	78.00
5													
6													
	Average	79.25	81.25	80.75	82.25	78.75	78.50	76.50	73.00	74.25	76.00	78.00	78.75

CLIMATIC DATA : MAXIMUM HUMIDITY (Rhmax in %c)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1997	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	1998	94.00	98.00	98.00	96.00	92.00	100.00	100.00	100.00	96.00	100.00	96.00	96.00
3	1999	98.00	98.00	96.00	96.00	99.00	96.00	99.00	99.00	100.00	99.00	100.00	96.00
4	2000	100.00	100.00	100.00	100.00	98.00	98.00	100.00	100.00	100.00	100.00	98.00	98.00
5													
6													
	Average	98.00	99.00	98.50	98.00	97.25	98.50	99.75	99.75	99.00	99.75	98.50	97.50

CLIMATIC DATA : WIND (U = Km/hour)
STATION = WLINGI DAM
ELEVATION = 174 m

No	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1997	2.90	1.70	1.50	1.00	1.30	1.20	1.40	1.40	1.50	1.80	2.30	1.30
2	1998	1.40	1.00	0.80	0.70	0.50	0.80	0.60	1.50	1.20	1.40	1.00	0.80
3	1999	0.70	1.40	1.20	0.90	0.80	1.50	1.60	2.20	2.90	2.20	1.30	1.30
4	2000	2.20	2.40	1.20	0.90	1.30	0.90	3.00	1.90	2.40	2.40	1.40	2.20
5													
6													
	Average	1.80	1.63	1.18	0.88	0.98	1.10	1.65	1.75	2.00	1.95	1.50	1.40

MEAN DAILY DURATION OF MAXIMUM POSSIBLE SUNSHINE HOURS (N) FOR DIFFERENT MONTH AND LATITUDES

No	LS	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	30	13.90	13.20	12.40	11.50	10.60	10.20	10.40	11.10	12.00	12.90	13.60	14.00
2	25	13.50	12.00	12.30	11.60	10.90	10.60	11.00	11.50	12.00	12.70	13.30	13.70
3	20	13.20	12.80	12.30	11.70	11.30	10.90	11.30	11.60	12.00	12.60	13.10	13.30
4	15	12.90	12.60	12.20	11.80	11.40	11.20	11.30	11.60	12.00	12.50	12.80	13.00
5	10	12.60	12.40	12.10	11.80	11.60	11.50	11.60	11.80	12.00	12.30	12.60	12.70
6	5	12.30	12.30	12.10	12.00	11.90	11.80	11.80	11.90	12.00	12.20	12.30	12.40
7	0	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EXTRA TERRESTRIAL RADIATION (Ra) EXPRESSED IN EQUIVALENT EVAPORATION IN MM/DAY

No	LS	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	20	17.30	16.50	15.00	13.00	11.00	10.00	10.40	12.00	13.90	15.80	17.00	17.40
2	18	17.10	16.50	15.10	13.20	11.40	10.40	10.80	12.30	14.10	15.80	16.80	17.10
3	16	16.90	16.40	15.20	13.50	11.70	10.80	11.20	12.60	14.30	15.80	16.70	16.80
4	14	16.70	16.40	15.30	13.70	12.10	11.20	11.60	12.90	14.50	15.80	16.50	16.60
5	12	16.60	16.30	15.40	14.00	12.50	11.60	12.00	13.20	14.70	15.80	16.40	16.50
6	10	16.40	16.30	15.50	14.20	12.80	12.00	12.40	13.50	14.80	15.90	16.20	16.20
7	8	16.10	16.10	15.50	14.40	13.10	12.40	12.70	13.70	14.90	15.80	16.00	16.00
8	6	15.80	16.00	15.60	14.70	13.40	12.80	13.10	14.00	15.00	15.70	15.80	15.70
9	4	15.50	15.80	15.60	14.90	13.80	13.10	13.40	14.30	15.10	15.60	15.50	15.40
10	2	15.30	15.70	15.70	15.10	14.10	13.50	13.70	14.50	15.20	15.50	15.30	15.10
11	0	15.00	15.50	15.70	15.30	14.40	13.90	14.10	14.80	15.30	15.40	15.10	14.80

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EFFECT OF TEMPERATURE F(T) ON LONGWAVE RADIATION (Rn1)

T	0	2	4	6	8	10	12	14	16	18	20	22
f(T)	11.00	11.40	11.70	12.00	12.40	12.70	13.10	13.50	13.80	14.20	14.60	15.00

T	24	26	28	30
f(T)	15.40	15.90	16.30	16.70

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

EFFECT OF VAPOUR PRESSURE F(ed) ON LONGWAVE RADIATION (Rn1)

n/N	-	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55
f(n/N)	0.01	0.15	0.19	0.24	0.28	0.33	0.37	0.42	0.46	0.51	0.55	0.60

n/N	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
f(n/N)	0.64	0.69	0.73	0.78	0.82	0.86	0.91	0.95	1.00

Source : Crop Water Requirement, Food and Agriculture Organitation Revised 1977

ESTIMATE EVAPOTRANSPIRATION in JATI WATERSHED

EL. CLIMATIC STATION = 174 m
EL. MEAN CATHMENT AREA = 500 m

Albedo : 25.00 %
LS : 8.10
Coefficient, a : 0.25
Coefficient, b : 0.46

MONTH	TOTAL DAY	DATA						DATA CORRECTION						ANALYSIS									RESULT	
		T	Rh	Rhmax	n/N	U2	Ra	Tc	n/Nc	U2c		ea	ed	D	W	f(T)	f(u)	f(ed)	f(n/N)	Rs	Rn	c	ETo	ETo
		c	%	%	%	km/hour	mm/day	c	%	m/sec	km/day	mbar	mbar	-	-	-	-	m	-	mm/day	mm/day	-	mm/day	mm/month
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	m	(18)	(19)	(20)	(21)	(22)	(23)
JAN	31	26.4	79.25	98.00	32.20	1.80	16.12	24.47	28.94	0.58	50.23	30.68	24.31	1.48	0.70	15.54	0.41	0.12	0.36	6.27	4.01	1.10	3.936	61.000
FEB	28	25.8	81.26	99.00	27.18	1.63	16.11	23.87	23.92	0.52	45.35	29.59	24.05	1.34	0.68	15.42	0.39	0.12	0.32	5.88	3.80	1.09	3.591	50.270
MAR	31	26.1	80.75	98.50	36.86	1.18	15.50	24.17	33.60	0.38	32.79	30.13	24.33	1.41	0.69	15.48	0.36	0.12	0.40	6.37	4.02	1.11	3.771	58.445
APR	30	26.1	82.25	98.00	38.06	0.88	14.39	24.09	34.80	0.28	24.42	30.00	24.67	1.39	0.69	15.47	0.34	0.12	0.41	6.00	3.72	1.10	3.421	51.309
MAY	31	26.0	78.75	97.25	49.86	0.98	13.08	24.07	46.60	0.31	27.21	29.95	23.59	1.38	0.68	15.46	0.34	0.13	0.52	6.20	3.63	1.10	3.492	54.122
JUN	30	25.4	78.50	98.50	51.66	1.10	12.38	23.39	48.40	0.36	30.70	28.76	22.58	1.24	0.66	15.32	0.35	0.13	0.54	5.97	3.40	1.10	3.281	49.218
JUL	31	24.6	76.50	99.75	51.39	1.65	12.68	22.59	48.13	0.53	46.05	27.40	20.96	1.10	0.63	15.16	0.39	0.14	0.53	6.10	3.46	1.10	3.437	53.271
AUG	31	25.0	73.00	99.75	55.58	1.75	13.69	23.04	52.32	0.57	48.84	28.16	20.56	1.18	0.65	15.25	0.40	0.14	0.57	6.86	3.92	1.12	4.039	62.608
SEP	30	25.1	74.25	99.00	48.83	2.00	14.89	23.17	45.57	0.65	55.81	28.37	21.07	1.20	0.65	15.28	0.42	0.14	0.51	6.98	4.16	1.12	4.223	63.339
OCT	31	25.7	76.00	99.75	38.82	1.95	15.81	23.72	35.56	0.63	54.42	29.33	22.29	1.31	0.67	15.39	0.42	0.13	0.42	6.65	4.13	1.11	4.157	64.427
NOV	30	26.2	78.00	98.50	31.88	1.50	16.01	24.19	28.62	0.48	41.86	30.18	23.54	1.41	0.69	15.49	0.38	0.13	0.36	6.20	3.95	1.10	3.866	57.987
DEC	31	26.4	78.75	97.50	34.96	1.40	16.01	24.47	31.70	0.45	39.07	30.68	24.16	1.48	0.70	15.54	0.38	0.12	0.39	6.44	4.09	1.10	3.963	61.428
AVERAGE		25.73	78.10	98.63	41.44	1.48	14.72	23.77	38.18	0.48	41.39	29.44	23.01	1.33	0.67	15.40	0.38	0.13	0.44	6.33	3.86	1.10	3.76	57.29

Irrigation Water Requirement for Jati Watershed

Station Climatology : Wingi Dam
Rainfall : Putg

Description	Unit	Jan.1	Jan.2	Jan.3	Feb.1	Feb.2	Feb.3	Mar.1	Mar.2	Mar.3	Apr.1	Apr.2	Apr.3	May.1	May.2	May.3	Jun.1	Jun.2	Jun.3	Jul.1	Jul.2	Jul.3	Aug.1	Aug.2	Aug.3	Sep.1	Sep.2	Sep.3	Oct.1	Oct.2	Oct.3	Nov.1	Nov.2	Nov.3	Dec.1	Dec.2	Dec.3
Basic Data :																																					
Eto	(mm/day)	4.29	4.29	4.29	3.95	3.95	3.95	4.16	4.16	4.16	3.79	3.79	3.79	3.83	3.83	3.83	3.59	3.59	3.59	3.72	3.72	3.72	4.35	4.35	4.35	4.56	4.56	4.56	4.50	4.50	4.50	4.22	4.22	4.22	4.34	4.34	4.34
P	(mm/day)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
R80	(mm)	40.08	60.57	63.37	54.02	47.22	50.46	45.07	41.77	31.90	20.11	44.84	12.78	5.10	-	-	7.92	10.07	-	-	-	-	-	-	-	-	-	-	-	5.95	5.77	-	12.18	16.58	27.71	44.94	22.72
Days	(day)	10.00	10.00	11.00	10.00	10.00	8.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00
Re=R80*0.7/day	(mm/day)	2.81	4.24	4.03	3.78	3.31	4.41	3.16	2.92	2.02	1.41	3.14	0.89	0.36	-	-	0.55	0.71	-	-	-	-	-	-	-	-	-	-	-	0.42	0.37	-	0.85	1.16	1.94	3.15	1.45
R50	(mm)	76.00	110.50	142.00	105.00	74.00	98.00	112.00	84.50	72.50	53.50	74.50	43.00	31.50	20.50	5.00	28.00	35.00	2.00	5.50	14.00	-	-	-	-	-	-	-	-	12.00	24.50	19.50	59.00	41.00	81.50	88.50	61.00
Re=R50/day	(mm/day)	7.60	11.05	12.91	10.50	7.40	12.25	11.20	8.45	6.59	5.35	7.45	4.30	3.15	2.05	0.45	2.80	3.50	0.20	0.55	1.40	-	-	-	-	-	-	-	-	1.20	2.23	1.95	5.90	4.10	8.15	8.85	5.55
Eo=Eto*1.1	(mm/day)	4.72	4.72	4.72	4.34	4.34	4.34	4.58	4.58	4.58	4.17	4.17	4.17	4.22	4.22	4.22	3.95	3.95	3.95	4.09	4.09	4.09	4.79	4.79	4.79	5.01	5.01	5.01	4.95	4.95	4.95	4.64	4.64	4.64	4.77	4.77	4.77
M=Eo+P	(mm/day)	6.72	6.72	6.72	6.34	6.34	6.34	6.58	6.58	6.58	6.17	6.17	6.17	6.22	6.22	6.22	5.95	5.95	5.95	6.09	6.09	6.09	6.79	6.79	6.79	7.01	7.01	7.01	6.95	6.95	6.95	6.64	6.64	6.64	6.77	6.77	6.77
T	(day)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
S	(mm)	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
K=M*T/S		1.01	1.01	1.01	0.95	0.95	0.95	0.99	0.99	0.99	0.93	0.93	0.93	0.93	0.93	0.93	0.89	0.89	0.89	0.91	0.91	0.91	1.02	1.02	1.02	1.05	1.05	1.05	1.04	1.04	1.04	1.00	1.00	1.00	1.02	1.02	1.02
LP=M*e^k/(e^k-1)	(mm/day)	10.58	10.58	10.58	10.33	10.33	10.33	10.49	10.49	10.49	10.22	10.22	10.22	10.25	10.25	10.25	10.08	10.08	10.08	10.17	10.17	10.17	10.63	10.63	10.63	10.78	10.78	10.78	10.74	10.74	10.74	10.53	10.53	10.53	10.62	10.62	10.62
	CROPPING PATTERN : PADDY - PADDY - SOYBEAN																																				
Area (ha) WS / DS.I / DS.II																																					
Paddy Kc1		1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00													LP	LP	LP	1.10
Kc2		1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00													LP	LP	LP
Kc3		LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.63	0.00													LP	LP
Total paddy 0																																					
Maize																																					
Soybean																						0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45							
																							0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45						
																								0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45					
Groundnut																																					
Total Palawija 0 0																																					
Cropped area 0 0																																					
Land Preparation (LP)	(mm/day)	-	-	-	-	-	-	-	-	10.49	10.22	10.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.53	10.62	10.62	-
	(mm/day)	-	-	-	-	-	-	-	-	-	10.22	10.22	10.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.62	10.62	10.62
	(mm/day)	10.58	-	-	-	-	-	-	-	-	-	10.22	10.22	10.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.62	10.62
	(mm/day)	3.53	-	-	-	-	-	-	-	3.50	8.83	10.22	6.82	3.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.51	7.08	10.62	7.03
Etc (Paddy)	(mm/day)	4.72	4.72	4.59	4.14	4.14	3.87	2.62	-	-	-	-	4.17	4.22	4.22	4.10	3.77	3.77	3.52	2.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.77
	(mm/day)	4.72	4.72	4.72	4.22	4.14	4.14	4.08	2.62	-	-	-	-	4.22	4.22	4.22	3.84	3.77	3.77	3.65	2.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	(mm/day)	-	4.72	4.72	4.34	4.22	4.14	4.37	4.08	2.62	-	-	-	-	4.22	4.22	3.85	3.84	3.77	3.91	3.65	2.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	(mm/day)	3.15	4.72	4.88	4.23	4.17	4.05	3.69	2.23	0.87	-	-	1.39	2.81	4.22	4.18	3.86	3.80	3.69	3.30	2.00	0.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.59
Etc (Palawija)	(mm/day)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.73	1.57	2.65	3.42	4.08	4.43	4.32	3.87	3.05	1.62	0.83	-	-	-	-
Total Etc	(mm/day)	3.15	4.72	4.88	4.23	4.17	4.05	3.69	2.23	0.87	-	-	1.39	2.81	4.22	4.18	3.86	3.80	3.69	3.30	2.00	0.78	0.73	1.57	2.65	3.42	4.08	4.43	4.32	3.87	3.05	1.62	0.83	-	-	-	1.59
Replacement of Impounding Area WLR	(mm/day)		3.30		3.30		3.30								3.30		3.30		3.30																		
	(mm/day)			3.30		3.30		3.30								3.30		3.30		3.30																	
	(mm/day)				3.30		3.30		3.30								3.30		3.30		3.30																
	(mm/day)	-	1.10	1.10	2.20	1.10	2.20	1.10	1.10	-	-	-	-	-	1.10	1.10	2.20	1.10	2.20	1.10	1.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Field Requirement NFR for Paddy	(mm/day)	5.87	3.58	3.75	4.65	3.95	3.84	3.63	2.41	4.35	7.41	9.09	9.31	7.87	7.32	7.28	7.50	6.19	7.89	6.40	5.10	2.78	2.00											4.35	7.14	9.47	9.22
Net Field Requirement NFR for Palawija	(mm/day)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.73	1.57	2.65	3.42	4.08	4.43	4.32	-	-	-	-	-	-	-	-
Diversion requirement DR for Paddy	(l/s/ha)	0.84	0.58	0.60	0.75	0.64	0.62	0.58	0.39	0.70	1.19	1.48	1.50	1.27	1.18	1.17	1.21	1.00	1.27	1.03	0.82	1.45	0.32	-	-	-	-	-	-	-	-	-	-	0.70	1.15	1.52	1.48
Diversion requirement DR for Palawija	(l/s/ha)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.12	0.25	0.43	0.55	0.65	0.71	0.69	-	-	-	-	-	-	-	-
Diversion requirement DR	(l/s/ha)	0.84	0.58	0.60	0.75	0.64	0.62	0.58	0.39	0.70	1.19	1.48	1.50	1.27	1.18	1.17	1.21	1.00	1.27	1.03	0.82	1.45	0.44	0.25	0.43	0.55	0.65	0.71	0.69	-	-	-	-	0.70	1.15	1.52	1.48
Diversion requirement	(10^4m3/ha)	815	487	572	646	551	428	505	335	864	1.072	1.282	1.293	1.083	1.018	1.112	1.042	880	1.095	889	708	425	378	218	405	475	563	616	600	-	-	-	-	604	982	1.318	1.409

Cropping Pattern Planning	Paddy I	LP	Paddy II	Soybean	LP

APPENDIX B-2

ESTIMATE EVAPOTRANSPIRATION In CATHMENT AREA of SINGGAHAN WATERSHED

EL. CLIMATIC STATION = 174 m
EL. MEAN CATHMENT AREA = 350 m

Albedo : 25.00 %
LS : 8.25
Coefficient, a : 0.25
Coefficient, b : 0.48

MONTH	TOTAL DAY	DATA						DATA CORRECTION					
		T	Rh	Rhmax	n/N	U2	Ra	Tc	n/Nc	U2c		ea	ed
		c (1)	% (2)	% (3)	% (4)	km/hour (5)	mm/day (6)	c (7)	% (8)	m/sec (9)	km/day (10)	mbar (11)	mbar (12)
JAN	31	26.4	79.25	98.00	32.17	1.80	16.14	25.37	30.41	0.55	47.74	32.37	25.65
FEB	28	25.8	81.25	99.00	27.17	1.63	16.13	24.77	25.41	0.50	43.09	31.23	25.38
MAR	31	26.1	80.75	98.50	36.86	1.18	15.50	25.07	35.10	0.36	31.16	31.79	25.67
APR	30	26.1	82.25	98.00	38.08	0.88	14.37	24.99	36.32	0.27	23.20	31.65	26.03
MAY	31	26.0	78.75	97.25	49.89	0.98	13.06	24.97	48.13	0.30	25.86	31.61	24.89
JUN	30	25.4	78.50	98.50	51.70	1.10	12.35	24.29	49.94	0.34	29.17	30.36	23.83
JUL	31	24.6	76.50	99.75	51.41	1.65	12.66	23.49	49.65	0.51	43.76	28.93	22.14
AUG	31	25.0	73.00	99.75	55.60	1.75	13.67	23.94	53.84	0.54	46.41	29.73	21.70
SEP	30	25.1	74.25	99.00	48.83	2.00	14.89	24.07	47.07	0.61	53.04	29.95	22.24
OCT	31	25.7	76.00	99.75	38.81	1.95	15.81	24.62	37.05	0.60	51.71	30.95	23.52
NOV	30	26.2	78.00	98.50	31.85	1.50	16.03	25.09	30.09	0.46	39.78	31.84	24.84
DEC	31	26.4	78.75	97.50	34.93	1.40	16.03	25.37	33.17	0.43	37.13	32.37	25.49
AVERAGE		25.73	78.10	98.63	41.44	1.48	14.72	24.67	39.68	0.46	39.34	31.07	24.28

MONTH	ANALYSIS									RESULT	
	D	W	f(T)	f(u)	f(ed)	f(n/N)	Rs	Rn	c	ETo	ETo
	- (13)	- (14)	- (15)	- (16)	m m	- (18)	mm/day (19)	mm/day (20)	- (21)	mm/day (22)	mm/month (23)
JAN	1.73	0.73	15.73	0.40	0.12	0.37	6.39	4.10	1.10	4.095	63.475
FEB	1.56	0.71	15.61	0.39	0.12	0.33	6.00	3.89	1.10	3.746	52.451
MAR	1.64	0.72	15.67	0.35	0.12	0.42	6.49	4.10	1.11	3.937	61.028
APR	1.62	0.71	15.65	0.33	0.12	0.43	6.10	3.80	1.10	3.575	53.628
MAY	1.61	0.71	15.65	0.34	0.12	0.53	6.28	3.71	1.10	3.631	56.287
JUN	1.44	0.69	15.51	0.35	0.13	0.55	6.05	3.47	1.10	3.406	51.088
JUL	1.26	0.66	15.34	0.39	0.13	0.55	6.18	3.52	1.10	3.555	55.109
AUG	1.36	0.68	15.44	0.40	0.14	0.58	6.95	4.00	1.12	4.172	64.672
SEP	1.38	0.68	15.46	0.41	0.13	0.52	7.09	4.24	1.12	4.368	65.517
OCT	1.52	0.70	15.57	0.41	0.13	0.43	6.77	4.22	1.11	4.309	66.796
NOV	1.65	0.72	15.67	0.38	0.12	0.37	6.32	4.04	1.10	4.022	60.325
DEC	1.73	0.73	15.73	0.37	0.12	0.40	6.56	4.18	1.11	4.129	63.994
AVERAGE	1.54	0.70	15.59	0.38	0.12	0.46	6.43	3.94	1.11	3.91	59.53
										Total	714.37

Irrigation Water Requirement for Singgahan Irrigation Area

Station Climatology : Wingi Dam
Rainfall Watulimo

Description	WS	DS I	DS II		Unit	Jan 1	Jan 2	Jan 3	Feb 1	Feb 2	Feb 3	Mar 1	Mar 2	Mar 3	Apr 1	Apr 2	Apr 3	May 1	May 2	May 3	Jun 1	Jun 2	Jun 3	Jul 1	Jul 2	Jul 3	Aug 1	Aug 2	Aug 3	Sep 1	Sep 2	Sep 3	Oct 1	Oct 2	Oct 3	Nov 1	Nov 2	Nov 3	Dec 1	Dec 2	Dec 3
Basic Data :																																									
Eto					(mm/day)	4.39	4.39	4.39	4.04	4.04	4.04	4.27	4.27	4.27	3.89	3.89	3.89	3.92	3.92	3.92	3.66	3.66	3.66	3.78	3.78	3.78	4.41	4.41	4.41	4.63	4.63	4.63	4.58	4.58	4.58	4.31	4.31	4.31	4.44	4.44	4.44
P					(mm/day)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	[illegible]	2.00
R80					(mm)	28.88	31.42	43.32	30.58	30.61	43.19	15.29	25.10	25.80	19.01	18.24	15.44	4.87	15.78	11.79	6.37	15.17	6.91	-	-	-	-	-	-	-	-	-	-	18.33	13.77	19.11	23.38	17.14	17.57	[illegible]	29.30
Days					(day)	10.00	10.00	11.00	10.00	10.00	8.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	10.00	11.00	10.00	10.00	10.00	10.00	[illegible]	11.00
Re=R80*0.7/day					(mm/day)	2.02	2.20	2.76	2.14	2.14	3.78	1.07	1.76	1.64	1.33	1.28	1.08	0.34	0.96	0.75	0.45	1.06	0.48	-	-	-	-	-	-	-	-	-	-	1.28	0.84	1.34	1.64	0.85	1.23	[illegible]	1.86
R50					(mm)	68.00	74.00	75.00	87.50	73.00	82.00	64.00	48.50	78.00	55.50	48.00	47.00	21.00	39.50	40.00	24.50	64.00	31.00	5.50	25.00	12.00	-	-	-	-	-	-	11.00	50.50	82.50	53.50	82.00	73.50	80.00	[illegible]	99.50
Re=R50/day					(mm/day)	6.80	7.40	6.82	8.75	7.30	10.25	6.40	4.85	7.09	5.55	4.80	4.70	2.10	3.95	3.64	2.45	6.40	3.10	0.55	2.50	1.09	-	-	-	-	-	-	1.10	5.05	5.89	5.35	8.20	7.35	8.00	[illegible]	8.05
Eo=Eto*1.1					(mm/day)	4.83	4.83	4.83	4.45	4.45	4.45	4.69	4.69	4.69	4.28	4.28	4.28	4.31	4.31	4.31	4.03	4.03	4.03	4.16	4.16	4.16	4.85	4.85	4.85	5.09	5.09	5.09	5.04	5.04	5.04	4.74	4.74	4.74	4.89	4.89	4.89
M=Eo+P					(mm/day)	6.83	6.83	6.83	6.45	6.45	6.45	6.69	6.69	6.69	6.28	6.28	6.28	6.31	6.31	6.31	6.03	6.03	6.03	6.16	6.16	6.16	6.85	6.85	6.85	7.09	7.09	7.09	7.04	7.04	7.04	6.74	6.74	6.74	6.89	[illegible]	6.89
T					(day)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	[illegible]	30.00
S					(mm)	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	[illegible]	200.00
K=M*T/S						1.02	1.02	1.02	0.97	0.97	0.97	1.00	1.00	1.00	0.94	0.94	0.94	0.95	0.95	0.95	0.90	0.90	0.90	0.92	0.92	0.92	1.03	1.03	1.03	1.06	1.06	1.06	1.06	1.06	1.06	1.01	1.01	1.01	1.03	[illegible]	1.03
LP=M*e^k/(e^k-1)					(mm/day)	10.65	10.65	10.65	10.40	10.40	10.40	10.57	10.57	10.57	10.30	10.30	10.30	10.31	10.31	10.31	10.13	10.13	10.13	10.21	10.21	10.21	10.57	10.87	10.87	10.83	10.83	10.83	10.80	10.80	10.80	10.60	10.60	10.60	10.69	[illegible]	10.69
					CROPPING PATTERN : PADDY - PADDY - SOYBEAN																																				
Area (ha)	WS	DS I	DS II																																						
Paddy	0	0		Kc1		1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00													LP	LP	LP	1.10
	0	0		Kc2		1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00													LP	LP	LP
	0	0		Kc3		LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00	LP	LP	LP	LP	1.10	1.10	1.10	1.07	1.05	1.05	0.98	0.83	0.00												LP	LP
Total paddy	0	0	0																																						
Maize																																									
Soybean			0																								0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45						
			0																									0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45					
			0																										0.50	0.58	0.75	0.92	1.00	1.00	0.88	0.70	0.45				
Groundnut																																									
Total Palawija	0	0	0																																						
Cropped area	0	0	0																																						
Land Preparation (LP)					(mm/day)	-	-	-	-	-	-	-	-	10.57	10.30	10.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.60	10.69	[illegible]	-
					(mm/day)	-	-	-	-	-	-	-	-	-	10.30	10.30	10.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.69	[illegible]	10.69
					(mm/day)	10.65	-	-	-	-	-	-	-	-	-	10.30	10.30	10.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]	10.69
					(mm/day)	3.55	-	-	-	-	-	-	-	3.52	6.86	10.30	6.86	3.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.53	7.13	[illegible]	7.13
Etc (Paddy)					(mm/day)	4.83	4.83	4.69	4.24	4.24	3.95	2.69	-	-	-	-	4.28	4.31	4.31	4.19	3.85	3.85	3.59	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.89
					(mm/day)	4.83	4.83	4.83	4.32	4.24	4.24	4.18	2.69	-	-	-	-	4.31	4.31	4.31	3.92	3.85	3.85	3.70	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					(mm/day)	-	4.83	4.83	4.45	4.32	4.24	4.48	4.18	2.69	-	-	-	-	4.31	4.31	4.03	3.92	3.85	3.97	3.70	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
					(mm/day)	3.22	4.83	4.78	4.34	4.27	4.15	3.78	2.29	0.90	-	-	1.43	2.87	4.31	4.27	3.93	3.87	3.76	3.35	2.03	0.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.63
Etc (Palawija)					(mm/day)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.74	1.59	2.69	3.47	4.12	4.50	4.40	3.94	3.10	1.85	0.85	-	-	-	-
Total Etc					(mm/day)	3.22	4.83	4.78	4.34	4.77	4.15	3.78	2.29	0.90	-	-	1.43	2.87	4.31	4.27	3.93	3.87	3.76	3.35	2.03	0.79	0.74	1.59	2.69	3.47	4.12	4.50	4.40	3.94	3.10	1.85	0.85	-	-	-	1.53
Replacement of Impounding Area WLR					(mm/day)		3.30		3.30		3.30								3.30		3.30		3.30																		
					(mm/day)			3.30		3.30		3.30								3.30		3.30		3.30																	
					(mm/day)				3.30		3.30		3.30								3.30		3.30		3.30																
					(mm/day)	-	1.10	1.10	2.20	1.10	2.20	1.10	1.10	-	-	-	-	-	1.10	1.10	2.20	1.10	2.20	1.10	1.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Field Requirement NFR for Paddy					(mm/day)	6.75	5.73	5.17	6.40	5.73	4.57	5.81	3.83	4.78	7.53	11.02	9.21	7.97	6.45	6.62	7.69	5.91	7.48	6.45	5.13	2.79	2.00											4.68	7.90	[illegible]	8.89
Net Field Requirement NFR for Palawija					(mm/day)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.74	1.59	2.69	3.47	4.12	4.50	-	-	-	-	-	-	-	-	-
Diversion requirement DR for Paddy					(l/s/ha)	1.08	0.92	0.82	1.03	0.84	0.73	0.93	0.58	0.77	1.21	1.77	1.48	1.28	1.04	1.06	1.24	0.95	1.20	1.04	0.82	0.45	0.32	-	-	-	-	-	-	-	-	-	-	0.75	1.27	[illegible]	1.43
Diversion requirement DR for Palawija					(l/s/ha)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	0.28	0.43	0.56	0.66	0.72	-	-	-	-	-	-	-	-	-
Diversion requirement DR					(l/s/ha)	1.08	0.92	0.82	1.03	0.84	0.73	0.93	0.58	0.77	1.21	1.77	1.48	1.28	1.04	1.06	1.24	0.95	1.20	1.04	0.82	0.45	0.44	0.28	0.43	0.56	0.66	0.72	-	-	-	-	-	0.75	1.27	[illegible]	1.43
Diversion requirement					($10^3 m^3/ha$)	937	795	783	888	776	506	807	505	730	1,046	1,530	1,279	1,107	895	1,012	1,068	821	1,039	896	712	427	380	221	411	482	572	625	-	-	-	-	-	850	1,097	[illegible]	1,359

Resume Irrigation Water Requirement JATI Watershed

		Paddy (mm/day)	Palawija (mm/day)	Total (mm/day)	Total (mm/month)
January	I	5.78		5.78	134.85
	II	3.58		3.58	
	III	3.75		3.75	
February	I	4.65		4.65	120.66
	II	3.96		3.96	
	III	3.84		3.84	
March	I	3.63		3.63	108.25
	II	2.41		2.41	
	III	4.35		4.35	
April	I	7.41		7.41	258.10
	II	9.09		9.09	
	III	9.31		9.31	
May	I	7.87		7.87	231.98
	II	7.32		7.32	
	III	7.28		7.28	
June	I	7.50		7.50	215.80
	II	6.19		6.19	
	III	7.89		7.89	
July	I	6.40		6.40	145.58
	II	5.10		5.10	
	III	2.78		2.78	
August	I	2.00	0.73	2.73	72.15
	II		1.57	1.57	
	III		2.65	2.65	
September	I		3.42	3.42	119.10
	II		4.06	4.06	
	III		4.43	4.43	
October	I		4.32	4.32	43.20
	II			0.00	
	III			0.00	
November	I			0.00	43.50
	II			0.00	
	III	4.35		4.35	
December	I	7.14		7.14	269.72
	II	9.47		9.47	
	III	9.42		9.42	
				Average	146.91
				Tola (mm/yr)	1,762.89

Resume Irrigation Water Requirement SINGGAHAN Watershed

		Paddy (mm/day)	Palawija (mm/day)	Total (mm/day)	Total (mm/month)
January	I	6.75	-	6.75	181.11
	II	5.73	-	5.73	
	III	5.12	-	5.12	
February	I	6.40	-	6.40	157.37
	II	5.23	-	5.23	
	III	4.57	-	4.57	
March	I	5.81	-	5.81	147.01
	II	3.63	-	3.63	
	III	4.78	-	4.78	
April	I	7.53	-	7.53	277.64
	II	11.02	-	11.02	
	III	9.21	-	9.21	
May	I	7.97	-	7.97	216.99
	II	6.45	-	6.45	
	III	6.62	-	6.62	
June	I	7.69	-	7.69	210.74
	II	5.91	-	5.91	
	III	7.48	-	7.48	
July	I	6.45	-	6.45	146.52
	II	5.13	-	5.13	
	III	2.79	-	2.79	
August	I	2.00	0.74	2.74	72.84
	II		1.59	1.59	
	III		2.69	2.69	
Septembe r	I		3.47	3.47	120.87
	II		4.12	4.12	
	III		4.50	4.50	
October	I		-	0.00	0.00
	II		-	0.00	
	III		-	0.00	
November	I		-	0.00	46.83
	II		-	0.00	
	III	4.68	-	4.68	
December	I	7.90	-	7.90	291.87
	II	11.51	-	11.51	
	III	8.89	-	8.89	
				Average	155.81
				Tola (mm/yr)	1,869.78

APPENDIX B-4

WATER REQUIREMENT

1. Water Demand for Domestic Uses

Domestic water demand for population in and around pond beneficiary area assumed as 60 lt/person/day. Domestic demand will supply by pond with growth population as long 10 to 20 years.

Formula of growth population as follow as:

$$Pn = Po\ (1 + r)^n$$

which:

Pn = total population in last plan year (head)

Po = total population in beginning plan year (head)

r = population growth ratio (%)

n = total year

Total domestic water demand calculated by formula given below:

$$Q = n \times q$$

which:

Q = total water demand (m^3/day)

n = total population (head)

q = total water demand per people (60 l/day/head)

2. Irrigation Water Demand

The water requirement for irrigation per hectare was value of effective factors crop requirement and influent factors of irrigation water demand, which were:

2.1 Land Preparation

Water required during land preparation phase in order to easier plougher and preparing of soil moisture regarding growth of plant.

Van de Goor/Zylstra method (1968) was adopted to calculate water demand, base on the change of water loss due evaporation and percolation to the field already saturated during land preparation period, approximate in 30 days by depth of water about 250 mm or 8.33 mm/day (according to the planning without Bero-KP 01). Mean value for Indonesia resulted by this following equation:

$$IR = M e^k / (e^k - 1)$$

which :

IR = Water requirement (mm/day).

M = $E_0 + P = (1,1\ ET_0 + P)$ (mm/day), this was peak of water requirement (evaporation + percolation).

K = MT/S

T = Time of land preparation (day)

S = Saturation requirement

2. 2 Consumptive Use

The consumptive use was water requirement to replace losses water due evaporation. Water evaporated by water surface or even through plant's leaves. When those process occur in the same time, namely evapotranspiration, mixed between evaporation and transpiration. Thus amount of water requirement as much as losses water due evapotranspiration. Consumptive use calculated by following formula:

$$ET_C = k_C \times ET_O$$

which :

ET_C = Consumptive use (mm/day)

ET_O = potential Evapotranspiration (mm/day), calculated by Penmman Metode.

K_C = Crop coeffisient, depend on kind, sort and crop age.

Table 5.1 Crop Coefficient Table

Period (15-days)	Paddy	Maize	Soybean
1	1.10	0.50	0.50
2	1.10	0.59	0.75
3	1.05	0.96	1.00
4	1.05	1.05	1.00
5	0.95	1.02	0.82
6	0.00	0.95	0.45

Source : Kriteria Perencanaan 01 (KP-01)

2.3 Percolation

Infiltration as process water filtrate from surface on to the ground (un-saturated zone). Percolation was water filtrate from un-saturated zone to the saturated zone, this process useless for crop. For planning, standard percolation 2,0 mm/day used for estimate water requirement in paddy field.

2.4Change of Water Layer

Decreasing of water surface at paddy field need to be done for fertilization and weeding. Base on this treatment, water layer must be change. For calculating, replacing amount 50 mm (3,33 mm/day) made each half of second month and fourth month, after transplanting. This subject not require for palawija cause different culture practical.

2.5 Irrigation Efficiency

Bassically, water loss that affects irrigation efficiency occurs during the conveyance of water from diversion to the field area and water for the land. Total irrigation efficiency cover conveyance efficiency and farm efficiency for paddy, s assumed to be 65% (KP-01 and FENCO). The efficiency is decided into primary and secondary efficiency 90%, tertiary channel efficiency 80%. For design purposes, standard efficiency take 72% (primary and secondary channel).

3. Effective Rainfall

Data in order to calculate effective rainfall collected from nearest station. Monthly rainfall by unit from five recent years and calculation method used Gumbel distribution statistic method (80 percent probability of return period, R80). Effective rainfall was 70% of 80% probability for paddy :

Paddy effective rainfall = 0.7 x R80/15

Method used for palawija effective rainfall was table of FAO KP-01(Indonesian Irrigation Standard Design), relation between mean monthly rainfall and mean evapotranspiration.

RAINFALL DATA FOR SINGGAHAN WATERSHED

Station : Watulimo
No. STA : 49
Elevation : 299

MONTH		YEAR													
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
JAN	I	167.00	43.00	114.00	176.00	157.00	226.00	291.00	68.00	226.00	60.00	67.00	104.00	102.00	83.00
	II	165.00	178.00	81.00	122.00	171.00	123.00	83.00	288.00	220.00	100.00	50.00	50.00	60.00	132.00
FEB	I	89.00	149.00	96.00	44.00	-	204.00	60.00	138.00	259.00	70.00	87.00	182.00	140.00	282.00
	II	132.00	54.00	137.00	196.00	166.00	59.00	105.00	318.00	131.00	16.00	222.00	221.00	66.00	82.00
MAR	I	69.00	20.00	158.00	130.00	16.00	29.00	49.00	159.00	111.00	10.00	36.00	227.00	196.00	344.00
	II	49.00	129.00	89.00	127.00	56.00	79.00	34.00	345.00	117.00	128.00	28.00	179.00	43.00	107.00
APR	I	-	98.00	134.00	-	102.00	85.00	133.00	182.00	126.00	38.00	-	200.00	59.00	81.00
	II	38.00	228.00	61.00	77.00	139.00	55.00	64.00	361.00	166.00	124.00	13.00	121.00	93.00	70.00
MAY	I	18.00	102.00	222.00	84.00	-	37.00	-	98.00	86.00	33.00	15.00	117.00	61.00	198.00
	II	82.00	108.00	102.00	147.00	-	61.00	99.00	-	136.00	54.00	50.00	41.00	-	231.00
JUN	I	23.00	199.00	96.00	115.00	-	-	97.00	-	378.00	51.00	140.00	73.00	30.00	29.00
	II	58.00	124.00	161.00	211.00	13.00	40.00	116.00	-	145.00	-	46.00	132.00	13.00	46.00
JUL	I	59.00	30.00	152.00	43.00	12.00	137.00	-	-	17.00	51.00	17.00	131.00	5.00	6.00
	II	110.00	8.00	58.00	235.00	-	10.00	84.00	12.00	53.00	58.00	15.00	306.00	-	27.00
AUG	I	1.00	-	157.00	65.00	-	10.00	22.00	-	-	221.00	-	119.00	19.00	10.00
	II	45.00	-	253.00	360.00	-	292.00	104.00	-	10.00	43.00	-	21.00	7.00	-
SEP	I	-	41.00	15.00	22.00	-	351.00	16.00	-	-	30.00	-	16.00	-	3.00
	II	-	70.00	8.00	4.00	-	449.00	20.00	-	-	-	-	340.00	2.00	6.00
OCT	I	-	35.00	57.00	5.00	-	599.00	83.00	-	114.00	83.00	31.00	158.00	22.00	44.00
	II	28.00	120.00	360.00	235.00	27.00	194.00	28.00	54.00	250.00	236.00	22.00	156.00	36.00	230.00
NOV	I	4.00	367.00	180.00	35.00	343.00	50.00	49.00	5.00	139.00	133.00	13.00	151.00	95.00	207.00
	II	528.00	226.00	108.00	82.00	145.00	189.00	184.00	72.00	181.00	157.00	23.00	22.00	101.00	136.00
DEC	I	360.00	16.00	202.00	98.00	69.00	96.00	370.00	100.00	46.00	123.00	25.00	41.00	130.00	31.00
	II	202.00	178.00	131.00	208.00	119.00	27.00	70.00	17.00	145.00	36.00	88.00	60.00	68.00	36.00
TOTAL		2,227.00	2,523.00	3,132.00	2,821.00	1,535.00	3,402.00	2,161.00	2,217.00	3,056.00	1,855.00	988.00	3,168.00	1,348.00	2,421.00

RAINFALL DATA FOR JATI WATERSHED

Station : PULE
No. STA : 51
Elevation : 625

MONTH		YEAR													
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
JAN	I	166.77	79.89	154.79	140.81	234.68	184.75	205.72	139.81	215.71	83.89	141.81	43.94	244.67	93.87
	II	164.78	118.84	173.77	256.65	127.83	207.72	178.76	276.63	197.73	29.96	135.82	45.94	146.80	158.79
FEB	I	88.88	200.73	187.75	118.84	142.81	366.50	63.91	178.76	311.58	27.96	208.72	26.96	109.85	308.58
	II	131.82	57.92	240.67	177.76	154.79	81.89	128.83	203.72	254.66	45.94	93.87	143.81	98.87	188.74
MAR	I	68.91	170.77	96.87	233.68	126.83	156.79	89.88	235.68	168.77	39.95	42.94	130.82	220.70	236.68
	II	48.93	124.83	158.79	133.82	93.87	96.87	55.92	208.72	282.62	131.82	37.95	142.81	99.87	178.76
APR	I	-	55.92	51.93	16.98	187.75	142.81	216.71	93.87	202.73	75.90	118.84	87.88	63.91	72.90
	II	37.95	82.89	186.75	52.93	167.77	193.74	114.84	129.82	84.89	58.92	104.86	91.88	9.99	54.93
MAY	I	6.99	52.93	100.86	26.96	80.89	28.96	36.95	48.93	-	-	72.90	76.90	69.91	293.60
	II	-	83.89	110.85	95.87	3.00	52.93	16.98	-	52.93	9.99	-	-	-	80.89
JUN	I	121.84	134.82	134.82	62.91	39.95	104.86	81.89	-	134.82	-	31.96	18.97	31.96	4.99
	II	36.95	59.92	152.79	98.87	9.99	19.97	85.88	-	39.95	-	17.98	143.81	-	29.96
JUL	I	30.96	17.98	88.88	27.96	6.99	73.90	24.97	-	29.96	2.00	-	154.79	11.98	-
	II	30.96	15.98	39.95	38.95	4.99	2.00	6.99	-	49.93	38.95	-	218.70	-	19.97
AUG	I	-	61.92	60.92	3.99	3.00	7.99	41.94	1.00	4.99	17.98	-	19.97	-	-
	II	6.99	-	16.98	24.97	2.00	149.80	19.97	-	-	7.99	-	44.94	-	-
SEP	I	-	24.97	-	53.93	4.99	116.84	13.98	-	3.00	2.00	2.00	34.95	-	-
	II	32.96	37.95	-	-	-	228.69	19.97	-	4.99	-	-	169.77	-	-
OCT	I	-	15.98	-	-	-	281.62	9.99	-	94.87	46.94	11.98	36.95	-	34.95
	II	4.99	126.83	59.92	52.93	2.00	281.62	25.96	14.98	79.89	311.58	11.98	357.52	15.98	114.84
NOV	I	4.99	138.81	99.87	-	112.85	21.97	63.91	16.98	67.91	21.97	-	321.57	170.77	98.87
	II	115.84	188.74	11.98	11.98	45.94	244.67	134.82	59.92	261.65	8.99	37.95	67.91	549.26	16.98
DEC	I	357.52	22.97	156.79	77.89	131.82	227.69	126.83	169.77	51.93	284.62	192.74	-	126.83	62.91
	II	156.79	111.85	60.92	243.67	220.70	179.76	155.79	22.97	59.92	34.95	72.90	185.75	65.91	47.94
TOTAL		1,615.82	1,987.31	2,346.83	1,952.36	1,905.42	3,454.33	1,921.40	1,801.56	2,655.41	1,282.27	1,337.19	2,566.53	2,037.25	2,099.16