HYDROLOGICAL MODELING OF WONOGIRI CATCHMENT USING REMOTE SENSING AND GIS

A DISSERTATION
Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT (CIVIL)

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JUNE, 2011

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the dissertation entitled **"HYDROLOGICAL MODELING OF WONOGIRI CATCHMENT USING REMOTE SENSING AND GIS"** in partial fulfillment of the requirement for the award of degree of **Master of Technology in Water Resources Development** in the Department of Water Resources Development and Management of Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during a period from July 2010 to June 2011 under the guidance of **Dr. Ashish Pandey,** Assistant Professor of Water Resources Development and Management, Indian Institute of Technology Roorkee, India and **Dr. Sharad Kumar Jain**, NEEPCO Chair Professor of Water Resources Development and Management, Indian Institute of Technology Roorkee, India.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

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This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

I wish to express my heartiest thanks to my respected guide **Dr. Ashish Pandey**, Assistant Professor, WRD&M, IIT-Roorkee and **Dr. Sharad Kumar Jain**, NEEPCO Chair Professor, WRD&M, IIT-Roorkee for pointed me to the topic Hydrological Modeling of Wonogiri Catchment Using Remote Sensing and GIS, as well as providing me valuable guidance, supervision and the inspirational support throughout the Dissertation.

I express my heartfelt thanks to **Prof. Nayan Sharma**, Head of WRD&M and to all other Faculty members of WRD&M for their suggestions and constant encouragements.

My heartful gratitude and indebtness goes to friends of **54th WRD Batch** and also to all my **Indonesian** and **Indian friends**, for their suggestions and help during the dissertation. I would also like to thank my **Indonesian 53th WRD Batch,** especially **Mr. Wisnu Pramudio**, for provided the data. Special thank to **Mr. Shakti Suryavanshi**, your expert contributions and confidence in me have supported me through this endeavour.

I am extremely grateful to **Mr. Bekak Kolimon**, ST., MT, Director of State Polytechnic, Kupang, Indonesia for Providing me an opportunity to do Masters degree in the department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, India. Also special thanks to **Mr. Yosefus Conterius**, **Mr. John Lada** and to **all faculty members** of State Polytechnic, Kupang,

Finally, A special and sincerest thanks to **my parents (late), Bu Zackheos, Usy Rince, Opy, Aris, Putri, Bu William, Usy Yuli, Via, Dian, Bu Malik, Usy Tory, Aman, Nona Lilo, Ashish, Bapak & mama Lusy sek, Mahanaim, Libanon, Filadelfia, Halleluyah, Pemuda R3JKK & Pemuda Fatufeto** for the warm love, persistent support, encouragement and prayers troughout of my study in India.

Above all, my deepest gratitude to the Almighty and thank Him from the bottom of my heart for His blessings, mercy and strength that made it possible for me to complete my dissertation.

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ABSTRACT

In this study, Geographical Information System (GIS), Remote Sensing (RS) and the SWAT (Soil and Water Assessment Tool) model are used for hydrological modeling of the Wonogiri catchment for simulation of runoff and evaluation of impact of land cover change on the surface runoff. The SWAT model was calibrated with the observed daily discharge measured at the watershed outlet for the year 1992-1999. After calibration the coefficient of determination (R^2), Relative Error (RE %) and Nash-Sutcliffe coefficient (E) were obtained as 0.913, 17.971 and 0.868 respectively. After calibration, the model was used for prediction of runoff.

The SWAT model was validated with the observed daily discharge measured at the watershed outlet for the year 1997-1999. For the model validation, the coefficient of determination (R^2), Relative Error (RE %) in and Nash-Sutcliffe coefficient (E) was obtained 0.908, 17.707 and 0.861 respectively. The SWAT model simulation results showed that the amount of runoff was increased when land use/Land cover was changed to Urban, Forest, Orchard and Paddy field. Change to urban area has resulted in increasing the amount of the runoff by 1.95%. For forest, orchard and paddy fields, impact on increasing the amount of the runoff by 1.13%, 0.64% and 1.12% respectively.

***Key Words**: Hydrological modeling, SWAT, Geographic Information Systems, Remote sensing, runoff*

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CHAPTER I

INTRODUCTION

1.1. Background

Water is a valuable natural resource and a universal asset. Sustainable management of natural resources on watershed basis is essential for maintaining the fragile balance between the productivity and different needs. Major problem in hydrology is the lack of adequate data to quantitatively describe a hydrologic process accurately. Remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. Satellite based remote sensing inputs over the past two decades have been playing a key role in the management of its natural resources. The GIS technology allows the modeler to acquire, organize, analyze and display model input and output data (Burrough, 1986). GIS has become an effective tool in watershed modeling as remote sensing derived information can be well integrated with the conventional database.

Water resource models provide insight into water resource problems by representing physical, environmental, economic, and/or social processes. For about last four decades, researchers have developed hydrological models of empirical or conceptual nature worldwide for prediction of hydrological variables. The applicability of these models is limited as they are mainly parameterized models and location specific. Use of physically based or conceptual, distributed parameter models have become increasingly popular to address catchment and higher level water resource management problems (Kannan 2007). Therefore, there is a need to simulate the hydrological processes by using physical process based models. Specifically, when fund and time are the constraints, it is not possible to treat the entire watershed area at a time. Physically based models include simulation models where the processes are simulated to test alternative scenarios and optimization models where objectives are specified and parameters are adjusted to meet the objectives. Many water resource models work around the spatial aspects of a problem by simplifying assumptions and parameterization (Walsh, 1993). One such model is the Soil and Water Assessment Tools (SWAT) model, which is a continuous time model that can, operates on a daily time step. The basic objective in model development was to predict the impact of management on runoff, sediment and agricultural chemical yields in large un-gauged basins.

Various researchers have tested the SWAT model on daily, monthly or annual basis for both runoff and sediment yield (Srinivasan et al. 1993; Srinivasan and Arnold, 1994;

Rosenthal et al., 1995; Cho et al., 1995; Tripathi et al., 2003). Little work has been done to know the impact of land use/ land cover change on runoff of the Wonogiri catchment, Indonesia. However, through the use of GIS and the associated software such data can be compiled and processed with relative ease. This study gives an approach to use physically based model (SWAT), GIS (ARC-GIS) and image processing software (ERDAS Imagine) to estimate the surface runoff of the Wonogiri catchment in Indonesia. The worldwide application of the SWAT reveals that it is a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decisions. (i) SWAT model is capable of simulating number of different physical processes occurred in a watershed, (ii) for the model purpose, a watershed may be partitioned into a number of sub-watershed, (iii) the use of sub-watershed in a simulated is particularly beneficial when different areas of the watershed are dominated by land use or soil dissimilar enough in properties to impact hydrology.

1.2. Objective of study

The objectives of this study are:

1. Calibration and validation of the SWAT model for runoff modeling in the Wonogiri catchment, Indonesia.
2. Effect of land use/ covers changes on the surface runoff of the Wonogiri catchment, Indonesia.

1.3. Organization of dissertation

The following aforesaid objectives are addressed through the following sections:

CHAPTER I	:	It provides the background of the study and objectives which are proposed to be achieved in this study.
CHAPTER II	:	This chapter covers review of literature relevant to this study
CHAPTER III	:	Presents details of the study area, data availability and methodology followed in this study
CHAPTER IV	:	Present the analysis and discussion of the results obtained in this study.
CHAPTER V	:	Conclusions of the study and suggestions for future works

CHAPTER II
REVIEW LITERATURE

This chapter presents a brief review of the available literature on calibration, validation and sensitivity analysis for hydrological model (SWAT) and evaluation of best management practices using Remote Sensing (RS) and Geographical Information System (GIS).

2.1. Catchment modeling using SWAT

Pisinaras et al. (2010) applied SWAT to Kosynthos River watershed located in Northeastern Greece. The 440 km^2 drainage basin was discretized into 32 sub-basins using an automated delineation routine. The multiple hydrologic response unit (HRU) approach was used and the basin was discretized into 135 HRUs. The model was calibrated and verified using continuous meteorological data from three stations, and runoff and nutrient concentrations measured at four monitoring sites located within the main tributaries of the watershed, for the time period from November 2003 to November 2006. Calibration and verification results showed good agreement between simulated and measured data. Model performance was evaluated using several statistical parameters, such as the Nash–Sutcliffe coefficient and the normalized objective function. The study showed that SWAT model, if properly validated, can be used effectively in testing management scenarios in Mediterranean watersheds. The SWAT model application, supported by GIS technology, proved to be a very flexible and reliable tool for water decision making.

Jie et al. (2010) applied the SWAT model in the Fenhe irrigation district. The information on hydrology, weather and water use from 1996 to 2001 in the Fenhe irrigation district was used to simulate and analyze the water balance. The sensitive parameters were estimated by Nash-Sutcliffe efficiency (NSE), relative error (RE) and coefficient of correlation (R^2). The model was further validated with the monthly flow data from 2002 to 2006. The results showed that the simulated results of two monitoring points meet the estimated requirements. The RE value of the average annual runoff at the Erba Station varied from-7.34% to 19.13% except a low RE value (-30.70%) in 2006. The RE of the average annual runoff at the Yitang station was from-17.21% to 9.86% with an exceptional RE value (-21.13%) in 2003. From the monthly simulated results, the R^2 of the monthly runoff at the Erba and Yitang stations was 0.81 and 0.77, respectively. The NSE of the monthly runoff was 0.72 and 0.65, respectively.

A modified SWAT model was applicable for water balance simulation at the Fenhe irrigation district.

Cho & Olivera (2009) used the Soil and Water Assessment Tool (SWAT) model to estimate runoff and hydrographs. They investigated the effect of the spatial distribution of land use, soil type, and precipitation on the simulated flows at the outlet of "small watersheds" (i.e., watersheds with times of concentration shorter than the model computational time step). The results obtained from that study provide insights on the relevance of taking into account the spatial distribution of land use, soil type, and precipitation when modeling small watersheds.

Manguerra & Engel (2007) described the important parameterization issues involved when modeling watershed hydrology for runoff prediction using the SWAT model with emphasis on how to improve model performance without resorting to tedious and arbitrary parameter by parameter calibration. The results of this study provide useful information for improving SWAT performance in terms of stream runoff prediction in a manner that is particularly useful for modeling ungaged watersheds wherein observed data for calibration is not available.

Bitew & Gebremichael (2011) assessed the suitability of commonly used high-resolution satellite rainfall products (CMORPH, TMPA 3B42RT, TMPA 3B42 and PERSIANN) as input to the semi-distributed hydrological model SWAT for daily streamflow simulation in Koga and Gilgel Abay watershed of the Ethiopian highlands. Results revealed that the utility of satellite rainfall products as input to SWAT for daily streamflow simulation strongly depends on the product type and the effect of watershed area on the suitability of satellite rainfall products for streamflow simulation also depends on the rainfall product.

Jain et al (2010) used the Soil and Water Assessment Tool (SWAT) for estimation runoff and sediment yield from an area of Suni to Kasol, an intermediate watershed of Satluj river which is located in Western Himalayas. The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the run-off and sediment yield from the study area.

Easton et al (2010) applied the SWAT model to predict runoff and sediment losses from the Ethiopian Blue Nile Basin. The model simulated saturation excess runoff from the landscape using a simple daily water balance coupled to a topographic wetness index in ways that are consistent with observed runoff processes in the basin. Analysis of model results indicate that upland landscape erosion dominated sediment delivery to the main stem of the Blue Nile in the early part of the growing season when tillage occurs and before the soil became wet and plant cover was established.

Kim et al (2011) used the SWAT model to evaluate the effects of flow regulation of the upstream Soyanggang and Chungju multi-purpose dams on the downstream flow regimes at the inlet of the Paldang Dam, a major water supply source of the Seoul metropolitan area, in the Han River basin, Korea. To evaluate the effects of regulation by the two dams on the downstream flow regimes, regulated and unregulated flow duration curves were constructed and analyzed. This method was revealed to be able to accurately reconstruct the flow duration curves, and then successfully evaluate the effects of regulation by the dams on the downstream flow regimes. The method proposed in this study is the first to accurately reconstruct the natural flow regime, and it is anticipated that the results of this study will be useful in the evaluation of the effects of flow regulation, as well as water resources planning and management.

Chen et al (2011) examined the potential for improving SWAT hydrologic predictions of root-zone soil moisture, evapotranspiration, and stream flow within the 341 km^2 Cobb Creek Watershed in southwestern Oklahoma through the assimilation of surface soil moisture observations using an Ensemble Kalman filter (EnKF). Comparisons against ground-based observations suggest that SWAT significantly under-predicts the magnitude of vertical soil water coupling at the site, and this lack of coupling impedes the ability of the EnKF to effectively update deep soil moisture, groundwater flow and surface runoff. The failed attempt to improve stream flow prediction is also attributed to the inability of the EnKF to correct for existing biases in SWAT-predicted stream flow components.

Graiprab et al (2010) applied the SWAT hydrological model for evaluating the sustainability of water resources management in Samat watershed, located in the Mae Nam Chi basin in Northeast Thailand. This was performed by assessing the impacts of future climate projections generated with the Providing Regional Climates for Impacts Studies (PRECIS) Regional Climate Model (RCM) on the hydrology of the watershed. The watershed was divided into three main subregions with a total of eleven subwatersheds using a Digital Elevation Model (DEM; scaled map 1:10,000). Land use, soil type, and watershed meteorological-hydrological data were used. The SWAT model was found applicable to the Samat watershed, and was further found to be able to analyze runoff characteristics in subwatersheds. This research found that during the years 2010 to 2050, once the region temperature has risen to the average of 0.8°C and rainfall has increased for another 4%, average runoff yield will be increased by 3%-5% when compared with the overall runoff yield in the watershed area. However, the rising trend of the runoff yield is considered minimal when compared with the expected double demand of water supply in the Samat watershed at that time.

Kim et al (2010) presented a method for estimating runoff CNs using the soil and water assessment tool (SWAT) model which can take into account watershed heterogeneities such as climate conditions, land use and soil types, using the study area in Chungju dam watershed in South Korea. The proposed CN estimation method uses the simulated flow data by SWAT instead of using measured flow data. This method, the SWAT-based CN estimation method, combined with the asymptotic CN method has advantages in estimating CN values spatially for each subbasin division considering watershed characteristics. A regression equation was then developed from this approach, which was used to estimate CN values that decrease exponentially as rainfall amounts increase without and with considering subsurface lateral flow. Runoff estimations based on the standard USDA–NRCS curve number (CN) table without calibration have a tendency to give inaccurate results when the CN values are applied in South Korea which has many high slope watersheds and that has a continental monsoon climate. Particularly for the design flood estimation, accurately calibrated CN values are required because the estimated peak flow is very sensitive to the selection of CN.

Wang & Xia (2010) used the improved SWAT2000 modeling system in the Huai River basin of China that incorporated the Shuffled complex evolution (SCE-UA) optimization algorithm and the multi-site and multi-objective calibration strategy. The implication of multi-objective is different for different types of outlets, i.e. streamflow for an ordinary outlet, inflow for a sluice, and water storage for a reservoir. Model parameters were redefined to improve model simulations. The surface runoff lag time (SURLAG) was extended as a spatially distributed parameter, and a correction coefficient was introduced to modify the saturated hydraulic conductivity. The results indicated that the released water from large reservoirs was blocked in the river channels by sluices located downstream. In the very dry year, the dam-sluice operations could result in an increase of the runoff volume during the non-flood season and a decrease in runoff during the flood season, but the changing magnitude during the non-flood season was much greater. An important conclusion of this case study is that the sluices in the Sha-Yin branch located in the north region and the dams in the southern mountainous region above the Wangjiaba Hydrological Station have played the most significant role in regulating the streamflow of the entire river basin. The methods addressed in this article can simulate hydrological regime in the river basins regulated by dams and sluices under different climatic conditions at the whole-watershed scale.

Tuppad et al (2010) used the SWAT model (2000 version) to evaluate the influence of rainfall input type and spatial scale on streamflow. Also this study was to evaluate the effects of spatial rainfall aggregation on predicted streamflow at five streamgage sites in the 6,316 km^2 Smoky Hill River/Kanopolis Lake watershed in central Kansas. NEXRAD Stage III hourly rainfall estimates were accumulated for 24 h periods for 1995 through 2002. The original NEXRAD grid cells, approximately 4 × 4 km, were aggregated with incrementally coarser spatial scale resolutions of 8, 16, 32, 64, 128, and 256 km. Interpolated ground-based rainfall data improved daily streamflow simulation compared to the SWAT default method of assigning subwatershed rainfall from the nearest raingage. Streamflow simulation improved further when NEXRAD-derived rainfall data were input for most of the aggregated grid-cell resolutions, However, the best model performance was not for the finest (4 km) grid resolution, but rather at resolutions ranging from 32 km to 128 km, depending on the location of streamflow measurement within the watershed. Greater variability in model performance was observed among the five streamgage sites within the watershed than among model runs using a range of aggregated grid-cell resolutions. The results indicated that greater rainfall spatial resolution for interpolated raingage data or, to a greater extent, aggregated NEXRAD precipitation data has the potential to improve SWAT simulation results compared to the typical use of nearest gage data.

Mukundan et al (2010) tested the effect of spatial resolution of soil data on the SWAT model predictions of flow and sediment and to calibrate the SWAT model for a watershed dominated by channel erosion. The state soil geographic (STATSGO) database mapped at 1:250,000 scale was compared with the soil survey geographic (SSURGO) database mapped at 1:12,000 scale in an ArcSWAT model of the North Fork Broad River in Georgia. Model outputs were compared for the effect of soil data before calibration using default model parameters as calibration can mask the effect of soil data. The model predictions of flow and sediment by the two models were similar, and the differences were statistically insignificant ($\alpha = 0.05$). These results were attributed to the similarity in key soil property values in the two databases that govern stream flow and sediment transport. The calibrated models indicated that channel erosion contributed most of the suspended sediment in this watershed.

These findings indicate that less detailed soil data can be used because more time, effort, and computational resources are required to set up and calibrate a model with more detailed soil data, especially in a larger watershed.

Moriasi & Starks (2010) investigated the effect of soils dataset resolution (State Soil Geographic Database and Soil Survey Geographic Database) on SWAT2005 streamflow simulation. Also determine the best combination of soil and precipitation datasets for the Cobb Creek, Lake Creek, and Willow Creek subwatersheds within the Fort Cobb Reservoir Experimental watershed, Oklahoma.

Easton et al (2011) used the SWAT model that simulates variable source area (VSA) runoff and is applied to two watersheds, New York State (NYS) watershed, and the head waters of the Blue Nile Basin (BNB) in Ethiopia. Most semi-distributed watershed water quality models divide the watershed into hydrologic response units (HRU) with no flow among them, so this is problematic when watersheds are delineated to include variable source areas (VSAs) because it is the lateral flows from upslope areas to downslope areas that generate VSAs. Although hydrologic modellers have often successfully calibrated these types of models, there can still be considerable uncertainty in model results. In this study, a topographic-index-based method is described and tested to distribute effective soil water holding capacity among HRUs, which can be subsequently adjusted using the watershed baseflow coefficient.

Mekonnen et al (2009) adapted the hydrological component of the SWAT model for two Ethiopian catchments based on primary knowledge of the coherence spectrum between rainfall and stream flow data. Spectrum analysis using the available nearby climatic data is made to limit the temporal and spatial scales (inverse rate coefficients) subject to the calibration of compartmentalized runoff models. The model structure of SWAT for the surface runoff and groundwater flow response is modified to make the time scales consistent with the results of the spectrum analysis. An optimization algorithm is developed to constrain and combine the model parameters with the spectrum analysis results.

Rouhani et al (2009) used the SWAT model to evaluate the effect of the division in number of subcatchments and the spatial distribution of areal rainfall on the prediction of streamflow in Nete River catchment (Flanders, Belgium). A multi-automatic calibration scheme (MACS), using the Shuffled Complex Evolution (SCE) optimization algorithm, was applied with a total of 6 delineations were examined. The performance of each model set-up was assessed with respect to the outlet measured daily total, quick and slow flow component. The analysis revealed that: (i) the NSEref decreases with the number of subcatchments in which the basin is divided, and (ii) simulations using a uniform rainfall distribution equal to the rainfall recorded in a rainfall station situated centrally in the catchment underperform as input.

Kim & Lee (2009) demonstrated the channel flow routing techniques used in the SWAT model and found that it can be appropriate for runoff simulation in Mihocheon Basin in South Korea (small basins). Simulated hydrographs have a tendency to underestimate peak flows or may send a false signal during the recession periods. This was particularly evident for sub-basins that had a short travel time of much less than a day. In order to enhance the channel routing module in SWAT, an alternative routing technique in which Manning relationship is combined with a simple channel reach continuity equation is proposed in the present study. The advantage of the proposed routing technique is that parameters are readily available from channel morphological data and that it is applicable to small basins.

Xu et al (2009) used the SWAT model to simulate the transport of runoff and sediment into the Miyun Reservoir, Beijing. They validated the performance of SWAT and the feasibility of using this model as a simulator of runoff and sediment transport processes at a catchment scale in arid and semi-arid area in North China, and related processes affecting water quantity and soil erosion in the catchment were simulated. The SWAT generally performs well and could accurately simulate both daily and monthly runoff and sediment yield. The simulated daily and monthly runoff matched the observed values satisfactorily. For sediment simulation, the efficiency is lower than that for runoff. Sensitivity analysis shows that sensitive parameters for the simulation of discharge and sediment yield include curve number, base flow alpha factor, soil evaporation compensation factor, soil available water capacity, soil profile depth, surface flow lag time and channel re-entrained linear parameter.

Jia et al (2009) used AVSWAT model to delineate subwatersheds. They developed a WebGIS-based system designed to predict rainfall-runoff and assess real-time water resources for Beijing to provide support for scientific decision making regarding solving water shortages while effectively reducing urban flood threats in the city. The system adopts a Browse Server (B/S) structure and combines the distributed hydrologic modeling and WebGIS techniques. For this system, a distributed hydrologic model of Beijing that adopts a grid cell-size of 1 km by 1 km and covers the city's entire area of 16,400 km^2 was developed and validated. This model employs a simple, yet practical rainfall-runoff correlation curve method to predict runoff, as well as prediction approaches for rainfall, evaporation, subsurface runoff and recharge to groundwater. In addition, a framework for the assessment of real-time water resources assessment based on hydrologic monitoring stations and the distributed model was established. Finally, a WebGIS-based system for rainfall-runoff prediction and real-time water resources assessment for Beijing was developed by integrating a data platform, the professional models and the WebGIS techniques. This system was successfully integrated into the hydrologic prediction practices of the General Station of Hydrology, Bureau of Beijing Water Affairs in 2005.

Zhang et al (2008) used optimization method (GA) and a multi-objective optimization algorithm (SPEA2) to optimize the parameters of the SWAT model to observed streamflow data at three monitoring sites within the Reynolds Creek Experimental Watershed, Idaho. Results indicated that different optimization schemes can lead to substantially different objective function values, parameter solutions, and corresponding simulated hydrographs. Thus, the selection of an optimization scheme can potentially impact modeled streamflow. Parameters estimated by optimizing the objective function at three monitoring sites consistently produced better goodness-of-fit than those obtained by optimization at a single monitoring site. This stresses the importance of collecting detailed, spatially distributed data to conduct simultaneous multi-site calibrations. When applied with multi-site data, the single-objective (GA) method better identified parameter solutions in the calibration period, but the multi-objective (SPEA2) method performed better in the validation period. Overall, the application of different optimization schemes in the Reynolds Creek Experimental Watershed demonstrated that the single-objective (GA) and the multi-objective (SPEA2) optimization methods can provide promising results for multi-site calibration and validation of the SWAT model.

2.2 Effect of Landuse/landcover using SWAT model

Setegn et al (2009) applied the SWAT2005 model to test the performance and feasibility of the SWAT model for prediction of streamflow in the Lake Tana Basin (Ethiopia). The model was calibrated and validated on four tributaries of Lake Tana; Gumera, GilgelAbay, Megech and Ribb rivers using SUFI-2, GLUE and ParaSol algorithms. The sensitivity analysis of the model to subbasin delineation and HRU definition thresholds showed that the flow is more sensitive to the HRU definition thresholds than subbasin discretization effect. SUFI-2 and GLUE gave good result. The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on streamflow and soil erosion.

Tibebe & Bewket (2010) used SWAT model to evaluate surface runoff generation and soil erosion rates for Keleta Watershed (a small watershed) in the Awash River basin of Ethiopia. Calibration and validation of the model was performed on monthly basis, and it could simulate surface runoff and soil erosion to a good level of accuracy. The simulated surface runoff closely matched with observed data (derived by hydrograph separation). The estimated soil loss rates were also realistic compared to what can be observed in the field and results from previous studies. The study demonstrates that the SWAT model provides a useful tool for soil erosion assessment from watersheds and facilitates planning for a sustainable land management in Ethiopia.

Abbaspour et al. (2007) applied SWAT model to the Thur catchment in Switzerland. In a national effort, since 1972, the Swiss Government started the ‘‘National Long-term Monitoring of Swiss Rivers’’ (NADUF) program aimed at evaluating the chemical and physical states of major rivers leaving Swiss political boundaries. The established monitoring network of 19 sampling stations included locations on all major rivers of Switzerland. This study complements the monitoring program and aims to model one of the program's catchments – Thur River basin (area 1700 km^2), which is located in the north-east of Switzerland and is a direct tributary to the Rhine. The program SWAT was used to simulate all related processes affecting water quantity, sediment, and nutrient loads in the catchment. The main objectives were to test the performance of SWAT and the feasibility of using this model as a simulator of flow and transport processes at a watershed scale. They concluded that simulation of hydrology, sediment and nutrient loads were of reasonable accuracy and such integrated models can be used for scenario analysis.

Ullrich et al. (2009) ran the sensitivity analysis for conservation management parameters (specifically tillage depth, mechanical soil mixing efficiency, biological soil mixing efficiency, curve number, Manning's roughness coefficient for overland flow, USLE support practice factor, and filter strip width) in SWAT. This analysis was aimed to improve model parameterization and calibration efficiency. In contrast to less sensitive parameters such as tillage depth and mixing efficiency, they parameterized sensitive parameters such as curve number values in detail. In the second step the analysis consisted of varying management practices (conventional tillage, conservation tillage, and no-tillage) for different crops (spring barley, winter barley, and sugar beet) and varying operation dates. Results showed that the model is very sensitive to applied crop rotations and in some cases even to small variations of management practices. But the different settings do not have the same sensitivity. Duration of vegetation period and soil cover over time was most sensitive followed by soil cover characteristics of applied crops.

Pandey et al (2005) used hydrologic balance of the watershed by physically based continuous time SWAT-2000 model which it is linked with raster-based geographical information system (GIS) to facilitate the input of the spatial data such as land use, soil maps and digital elevation models (DEM) for the development of management scenarios for the prioritised sub-watersheds. The attributes of sub-watersheds, tributary channels and main channel in each sub-watershed were considered. The study located in Banikdih watershed, Bokaro district of Jharkhand State and Purulia district of West Bengal State in Eastern India. Calibration and validation results revealed that the model was predicting the daily, monthly and seasonal surface runoff and sediment yield satisfactorily.

Tripathi et al (2006) used the SWAT model to study the effect of watershed subdivision on simulated water balance components (i.e. total runoff, percolation, ET and change in soil water content). Results of the study showed a perfect water balance for the Nagwan watershed under all of the decomposition schemes and also revealed that the number and size of sub-watersheds do not appreciably affect surface runoff. Except for runoff, there was a marked variation in the individual components of the water balance under the three decomposition schemes. Conclusion of this study that watershed subdivision has a significant effect on the water balance components.

Ghaffari et al (2010) used SWAT (AVSWAT2000) model to investigate the hydrological effects of land-use change in Zanjanrood basin, Iran. The model was used to simulate the main components of the hydrological cycle, in order to study the effects of land-use changes in 1967, 1994 and 2007. The results indicate that the hydrological response to overgrazing and the replacing of rangelands (grassland and shrubland) with rain-fed agriculture and bare ground (badlands) is nonlinear and exhibits a threshold effect. The runoff rises dramatically when more than 60% of the rangeland is removed. For groundwater this threshold lies at an 80% decrease in rangeland.

Alibuyong et al (2009) used SWAT model to simulate the effect of land use change on runoff volumes, sediment yield and streamflows. Model simulation results demonstrated that SWAT can predict runoff volumes and sediment yield in two Manupali River subwatersheds. Simulation of land use change scenarios using the SWAT model indicated that runoff volume and sediment yield increased by 3% to 14% and 200% to 273%, respectively, when 50% of the pasture area and grasslands is converted to cultivated agricultural lands. Consequently, this results in a decrease of baseflow of 2.8% to 3.3%, with the higher value indicating a condition of the watershed without soil conservation intervention. Moreover, an increase of 15% to 32% in runoff volume occurs when the whole subwatershed is converted to agricultural land. This accounts for 39% to 45% of the annual rainfall to be lost as surface runoff. While simulation results are subject to further validation, this study has demonstrated that the Soil and Water Assessment Tool (SWAT) model can be a useful tool for modeling the impact of land use changes in Philippine watersheds.

Hernandez et al (2000) described a procedure for evaluating the effects of land cover change and rainfall spatial variability on watershed response. Two hydrologic models were applied on a small semi-arid watershed; one model is event-based with a one-minute time step (KINEROS), and the second is a continuous model with a daily time step (SWAT model). This study demonstrates the feasibility of using widely available data sets for parameterizing hydrologic simulation models. The simulation results show that both models were able to characterize the runoff response of the watershed due to changes of land cover.

Githui et al (2009) used the SWAT model to investigate the impact of land-cover changes on the runoff of the River Nzoia catchment, Kenya. Land-cover changes were examined through classification of satellite images. Land-cover change scenarios were generated, namely the worst- and best-case scenarios. Historical land-cover change results showed that agricultural area increased from 39.6 to 64.3% between 1973 and 2001, while forest cover decreased from 12.3 to 7.0%. A comparison between 1970–1975 and 1980–1985 showed that land-cover changes accounted for a difference in surface runoff ranging from 55 to 68% between the two time periods. The land-cover scenarios used showed the magnitude of changes in runoff due to changes in the land covers considered. Compared to the 1980–1985 runoff, the land-cover scenarios generated changes in runoff of about −16% and 30% for the best and worst case scenarios respectively.

Githui et al (2010) investigated the hydrological effects of land-use change in Zanjanrood basin, Iran. The water balance was simulated using the AVSWAT-2000 model. The model was used to simulate the main components of the hydrological cycle, in order to study the effects of land-use changes in 1967, 1994 and 2007. The results indicate that the hydrological response to overgrazing and the replacing of rangelands (grassland and shrubland) with rain-fed agriculture and bare ground (badlands) is nonlinear and exhibits a threshold effect. The runoff rises dramatically when more than 60% of the rangeland is removed. For groundwater this threshold lies at an 80% decrease in rangeland.

Ma et al (2009) assessed & investigated the response of hydrological processes to land-cover/climate changes using SWAT and impacts of single factor, land-use/climate change on hydrological processes were differentiated. Land-cover maps revealed extensive reforestation at the expense of grassland, cropland, and barren land. A significant monotonic trend and noticeable changes had occurred in annual temperature over the long term. Long-term changes in annual rainfall and streamflow were weak; and changes in monthly rainfall (May, June, July, and September) were apparent. Hydrological simulations showed that the impact of climate change on surface water, baseflow, and streamflow was offset by the impact of land-cover change. Seasonal variation in streamflow was influenced by seasonal variation in rainfall. Land-cover change played a dominant role in mean annual values; seasonal variation in surface water and streamflow was influenced mainly by seasonal variation in rainfall; and land-cover change played a regulating role in this. Surface water is more sensitive to land-cover change and climate change: an increase in surface water due to increased rainfall was offset by a decrease in surface water due to land-cover change. A decrease in baseflow caused by changes in rainfall and temperature was offset by an increase in baseflow due to land-cover change.

Cao et al (2009) used the SWAT model to evaluate the impacts of land cover change on total water yields, groundwater flow, and quick flow in the Motueka River catchment, New Zealand. After the SWAT (Soil and Water Assessment Tool) model was calibrated and validated to historic flow records for the current land use conditions, two additional land cover scenarios (a prehistoric land cover and a potential maximum plantation pine cover). They focused on Low-flow characteristics and their potential impacts on availability for water abstraction and for support of in-stream habitat values. The results showed that the annual total water yields, quick flow and baseflow decreased moderately in the two scenarios when compared with the current actual land use. The annual water balance for the pine potential land cover scenario did not differ substantially from the prehistoric scenario for the catchment as whole. Simulated low flows for the prehistoric and potential pine land cover scenarios were both significantly lower than the low flows for the current land use. In summary, under the current land use conditions, both annual water yield and low flow are higher than was the case before human intervention in the area or in a maximum commercial reforestation scenario.

Fohrer et al (2002) applied of SWAT-G in terms of the effects of land use change on hydrologic processes. A set of three GIS-based models from the field of agricultural economy (ProLand), ecology (YELL) and hydrology (SWAT-G) was applied in the mountainous mesoscale watershed of the Aar, Germany. In a joint modeling exercise, a sequence of land use change scenarios was analyzed. It was assumed that the average field size for land use systems increases due to changes in the economic and administrative framework. The resulting land use maps were analyzed with YELL with regard to the habitat suitability for Emberiza citrinella and with the model SWAT-G in terms of the effects of land use change on hydrologic processes. Multi-functional trade-off relations between economic, ecological and hydrological landscape functions were compiled.

It can be concluded from the above that the physically-based SWAT model is a suitable tool to study the impact of lanuse-landcover changes.

CHAPTER III

METHODOLOGY

This chapter deals with the description of the study area, data acquisition and methods used for data processing. Delineation of watershed and generation of various maps including land use, soil texture and DEM are discussed in this chapter. Furthermore, methodologies for extracting some of the watershed parameters for model input are described in detail. Detailed procedure for preparation of land use/cover map using satellite imagery is also provided in this chapter. Overview and description of the model operation and its limitations along with the description of input files used for evaluating the SWAT model are also included. Procedures used for calibration and validation of the model and various criteria used for evaluating the model performances are also given in this chapter.

3.1. Study Area

The study area is located in Wonogiri, Central of Java Province, Indonesia, which covers catchment area of 1,350 km^2 and the Wonogiri dam with reservoir area of 90 km^2 (Figure 3.1). The Wonogiri dam was built in 1976 and completed in 1982, with funding from JICA (*Japan Interntional Cooperation Agency*). Wonogiri Dam is a multi function dam with the primary function as flood control. Besides, as a provider of water for irrigation, power generation, fisheries and tourism purpose. The Wonogiri reservoir watershed has 5 (five) major rivers namely Keduang River, Temon River, Tirtomoyo River, Alang River and Upper Solo River (Figure 3.2).

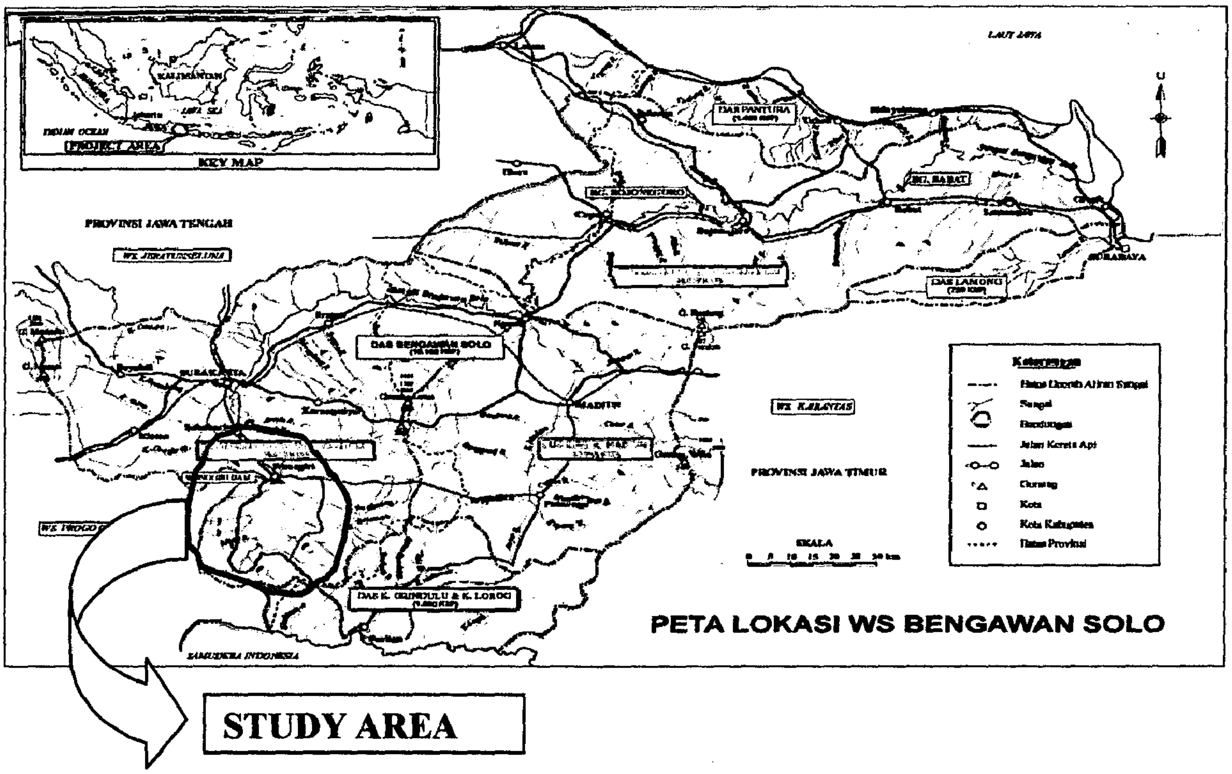

Fig. 3.1: Location map of the Study area

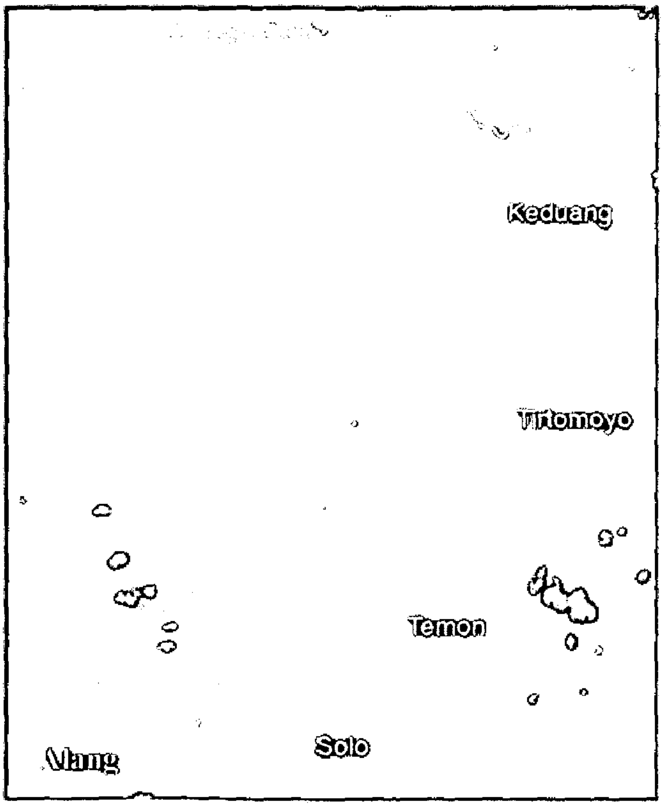

Figure 3.2 Main River at Wonogiri reservoir watershed

(Source: ETM Satellite image)

3.2. Data Acquisition

As a part of this project, various data including topographic and soil data, hydrologic data, satellite data and other necessary data were acquired from various sources.

3.2.1. Topography

The catchment area of Wonogiri Dam is topographically divided into the following three mountain regions extending east and west, and one plain area surrounding the Wonogiri reservoir. Southern area forms karst tableland with many small mountains of about 400 m elevation. Almost entire rainfall on the tableland infiltrates into underground, and there is no obvious runoff. There are some springs along the foot of the tableland. Middle area is characterized by EL.500 m-EL.1200 m ranging mountains and steep valleys extending east-west with dendritic drainage feature (Figure 3.3).

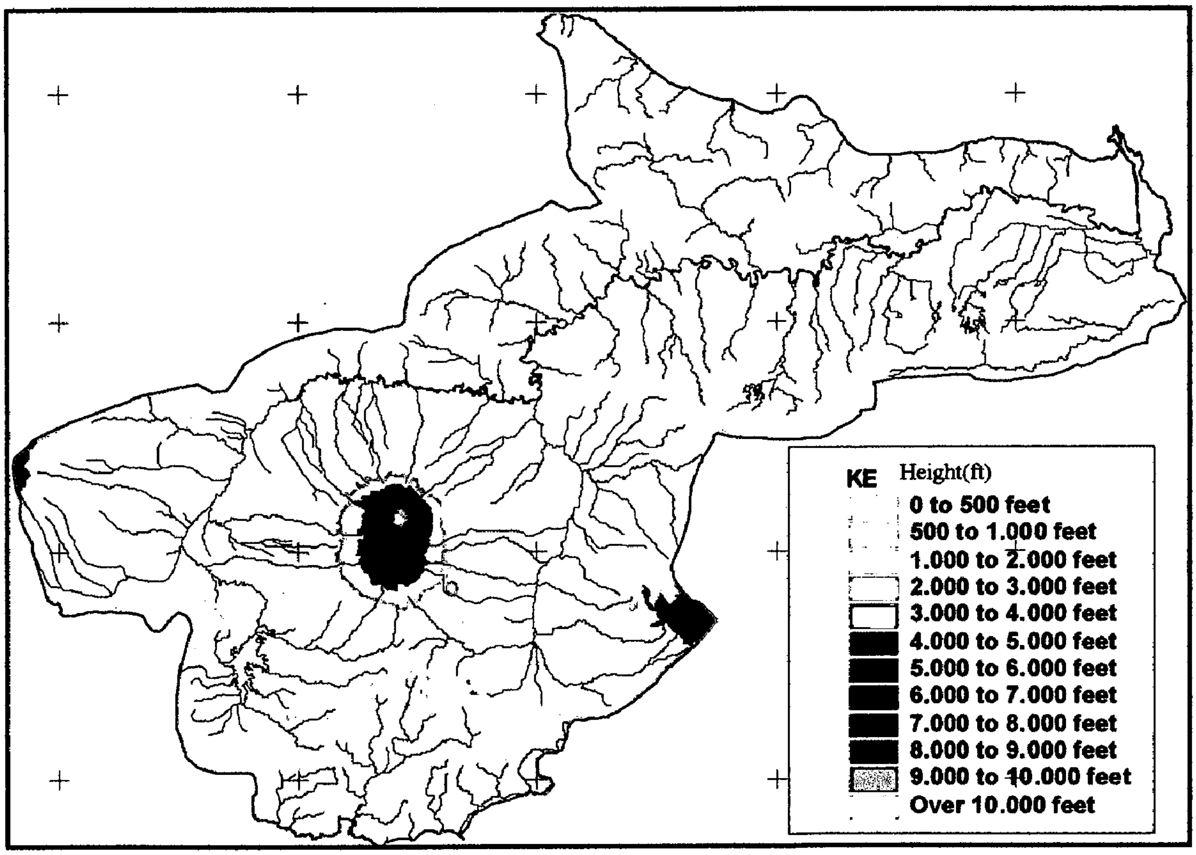

Figure 3.3 Topographic map of Wonogiri reservoir watershed

(Source: Solo BBWS, 2009)

3.2.2. Soil

The soil distributed in the Wonogiri watershed are classified into Mediteran, litosol, Latosol and Alluvial soil types (Figure 3.4). All of those soils are fine textured (clay to silt clay) and their soil fertility is generally poor, being susceptible to soil erosion. Among them, mediteran and latasol are categorized as highly fragile to surface soil erosion.

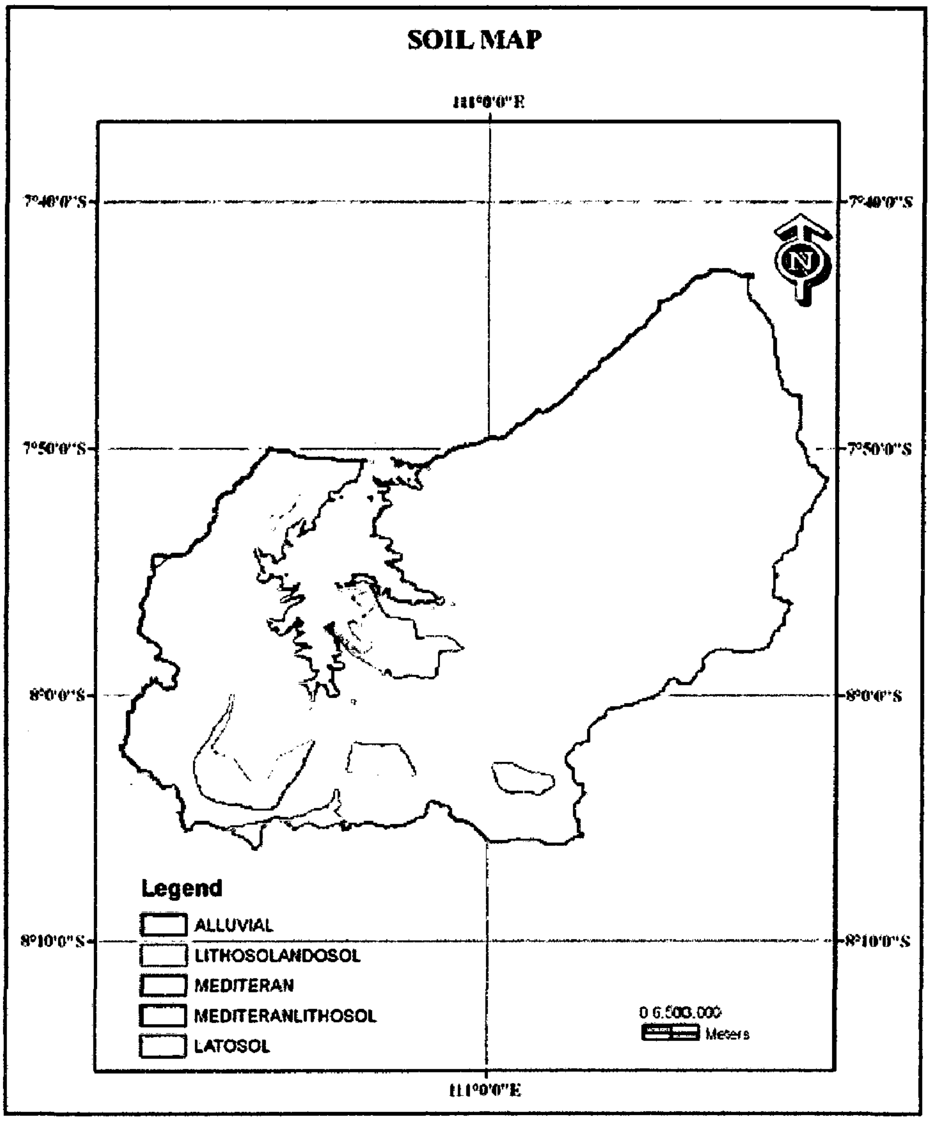

Figure 3.4 Soil map of Wonogiri watershed

3.2.3. Land use

Low-lying flat lands in the Wonogiri dam watershed have been widely developed for paddy cultivation (Figure 3.5). Upland fields with an elevation of 200-1000 m have been also developed for agricultural uses. Since the completion the Wonogiri dam, forest areas have drastically decreased and upland field have been increased. It is considered that such changes of land uses in the dam watershed might be one of main causes for the drastic increase of soil erosion within the dam watershed.

3.2.4. Hydro-meteorological data

The SWAT model require daily values of precipitation, maximum and minimum air temperature, relative humidity, solar radiation and wind speed to generate weather information. The data for all these parameters in this study from three stations locations namely Tawangmangu, Ngancar and Wonogiri with the data available for a period of 1992-1999 (Table 4.1).

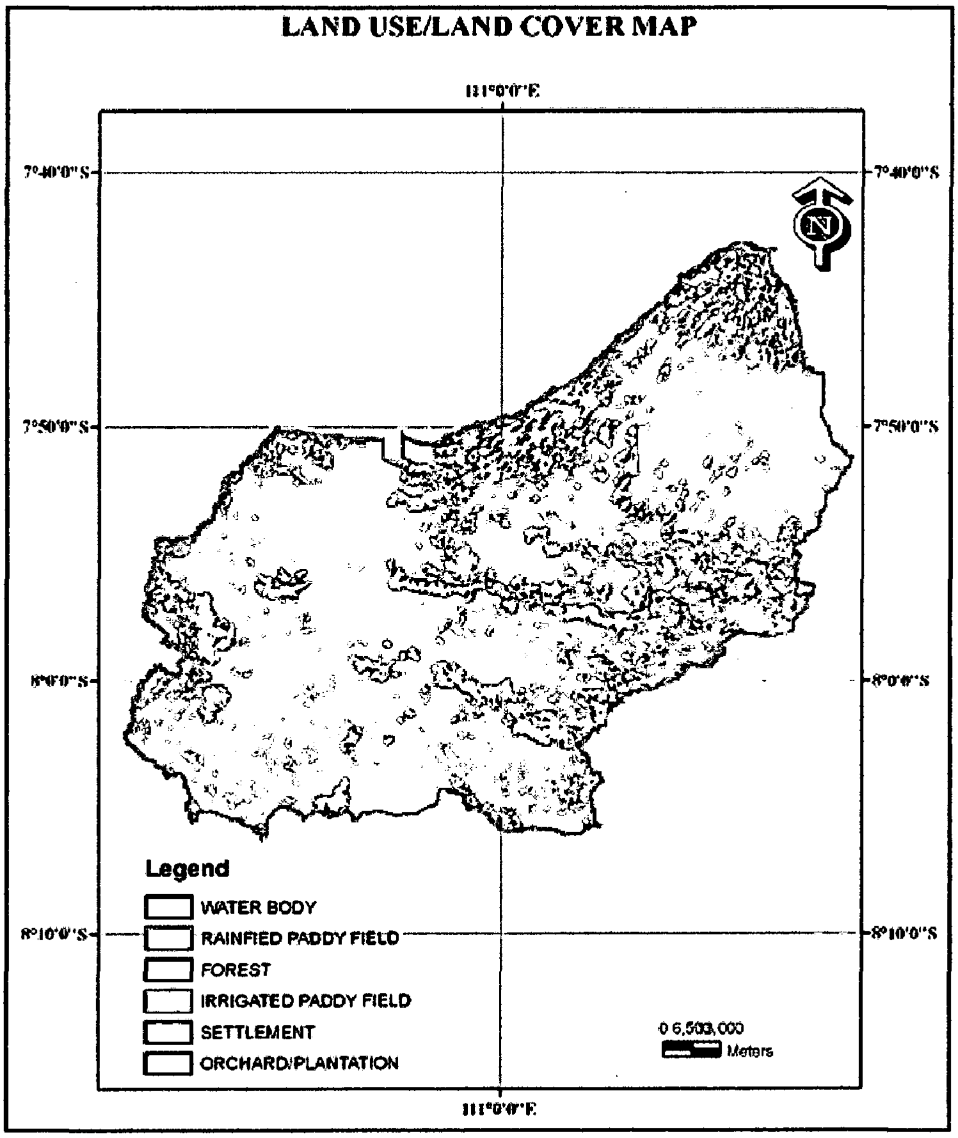

Figure 3.5. Land use map of Wonogiri Watershed

3.3. Collection of the data and description

Table 3.1 Data description

Data Type	Scale	Data Description
DEM		**Shuttle Radar Topography Mission (SRTM)**
Soil map	1:250,000	Central Soil Research Institute of Bogor Indonesia.
Land use map		**United States Geological Survey (USGS)**
Precipitation	Daily	Daily precipitation (1992-1999)
Temperature	Daily	Daily Temperature (1992-1999)
Evaporation	Daily	Daily Evaporation (1992-1999)
Discharge	Daily	Daily Discharge (1992-1999)

3.4. Hardware and Software used

The Intel (R) Xeon (R) CPU workstation was used in this study. The Arc GIS 9.3 and ERDAS 9.2 image processing software which is available at the Institute Computer Centre in IIT-Roorkee were used. Extracted data were processed with the help of Excel package of Microsoft Office XP..

3.5. Data Processing for the SWAT Model

As a part of data processing SWAT model requires a number of database files. These were prepared in the form of dBase (*.dbf) files as per procedure and format specified in User's Guide of SWAT 2009 (Winchell, et al., 2007). The specific data requirement for SWAT database is summarized below:

☑ Soil databases

☑ Land use databases

☑ Weather databases

☑ Land use look-up table

☑ Soil look-up table

☑ Location table of outlet, weather generation gauges, rain gauges, temperature gauges, relative humidity gauges, solar radiation gauges and wind gauges.

Table 3.2 Hydro-meteorological Data table at Ngancar Station.

S.No.	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
1	TMPMX	33.22	33.02	33.02	32.94	32.18	31.87	30.73	31.16	32.16	33.78	34.03	33.56
2	TMPMN	22.42	22.40	22.01	22.21	19.87	19.72	19.73	19.60	19.23	21.21	22.26	21.68
3	TMPSTDMX	1.52	1.46	1.52	1.49	1.17	1.48	1.15	1.01	0.89	0.65	0.75	0.51
4	TMPSTDMN	1.84	1.82	1.84	2.08	0.95	1.32	2.61	3.34	1.13	1.36	0.77	0.72
5	PCPMM	9.98	12.41	10.11	6.43	1.10	1.91	0.99	0.58	0.82	3.19	5.83	7.93
6	PCPSTD	17.77	18.77	16.22	13.47	4.97	7.24	4.65	5.07	5.21	7.92	12.88	13.39
7	PCPSKW	3.08	1.84	2.42	3.09	6.51	5.64	6.21	9.25	9.39	3.70	489.00	1.86
8	PR_W1	0.10	0.23	0.20	0.17	0.06	0.08	0.05	0.01	0.02	0.10	0.16	0.15
9	PR_W2	0.69	0.66	0.64	0.54	0.31	0.43	0.31	0.01	0.43	0.53	0.53	0.68
10	PCPD	19.00	16.75	17.50	12.50	3.13	4.75	3.13	0.63	1.50	7.13	9.38	15.63
11	RAINHHMX	135.23	97.00	102.00	80.00	51.00	66.00	39.00	55.00	52.00	64.00	77.00	64.00
12	SOLARAV	20.65	20.58	19.86	17.92	15.52	14.38	14.64	16.87	18.10	19.68	20.39	20.24
13	DEWPT	27.8	27.7	27.47	27.6	26.0	25.8	25.3	25.4	25.6	27.5	28.0	27.6
14	WNDAV	2.15	2.17	1.73	1.69	2.03	2.43	3.50	5.72	7.61	7.57	4.86	2.96

Table 3.3 Hydro-meteorological Data table at Wonogiridam Station.

S.No.	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
1	TMPMX	33.22	33.02	33.02	32.94	32.18	31.87	30.73	31.16	32.16	33.78	34.03	33.56
2	TMPMN	22.42	22.40	22.01	22.21	19.87	19.72	19.73	19.60	19.23	21.21	22.26	21.68
3	TMPSTDMX	1.52	1.46	1.52	1.49	1.17	1.48	1.15	1.01	0.89	0.65	0.75	0.51
4	TMPSTDMN	1.84	1.82	1.84	2.08	0.95	1.32	2.61	3.34	1.13	1.36	0.77	0.72
5	PCPMM	10.96	11.14	8.94	5.77	1.26	1.94	0.80	1.07	0.34	3.66	5.91	7.29
6	PCPSTD	20.43	17.22	15.31	12.65	5.48	6.39	4.37	3.47	2.33	10.25	13.34	15.78
7	PCPSKW	3.05	2.45	2.20	3.54	7.98	4.18	7.65	6.18	8.58	4.35	4.11	3.24
8	PR_W1	0.20	0.19	0.22	0.19	0.13	0.11	0.04	0.03	0.02	0.16	0.19	0.17
9	PR_W2	0.70	0.74	0.68	0.58	0.17	0.27	0.46	0.33	0.42	0.53	0.62	0.69
10	PCPD	21.00	21.00	19.13	13.13	5.00	5.63	3.00	1.88	1.25	9.38	14.88	17.38
11	RAINHHMX	146.00	87.50	79.40	85.50	65.50	46.50	48.00	51.00	26.00	87.00	116.00	91.20
12	SOLARAV	20.65	20.58	19.86	17.92	15.52	14.38	14.64	16.87	18.10	19.68	20.39	20.24
13	DEWPT	27.8	27.7	27.47	27.6	26.0	25.8	25.3	25.4	25.6	27.5	28.0	27.6
14	WNDAV	2.15	2.17	1.73	1.69	2.03	2.43	3.50	5.72	7.61	7.57	4.86	2.96

Table 3.4 Hydro-meteorological Data table at Tawangmangu Station

S.No.	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
1	TMPMX	29.09	28.74	28.56	28.68	25.89	25.56	25.52	25.33	24.93	27.52	28.90	28.13
2	TMPMN	21.86	21.69	21.16	21.10	19.08	18.88	18.77	18.75	18.24	20.25	21.14	20.79
3	TMPSTDMX	4.32	3.72	4.29	4.22	3.47	3.37	4.44	5.00	3.26	4.00	3.53	3.76
4	TMPSTDMN	4.18	3.76	3.82	3.97	3.60	3.25	4.40	4.61	3.23	3.79	3.60	3.73
5	PCPMM	18.92	17.64	15.14	9.07	3.58	3.34	0.10	1.50	1.54	5.14	12.71	14.54
6	PCPSTD	22.74	24.57	20.22	13.29	10.17	8.89	4.63	7.00	7.71	10.25	20.61	21.10
7	PCPSKW	1.61	2.38	1.65	1.98	4.91	4.12	7.78	7.10	7.55	2.60	2.11	1.94
8	PR_W1	0.16	0.17	0.17	0.14	0.16	0.11	0.05	0.04	0.06	0.15	0.15	0.14
9	PR_W2	0.78	0.76	0.75	0.76	0.44	0.52	0.50	0.40	0.37	0.63	0.75	0.76
10	PCPD	25.13	21.25	22.37	19.50	9.25	8.38	3.88	3.00	3.37	12.37	18.75	21.75
11	RAINHHMX	116.00	166.00	91.00	67.00	86.00	70.00	46.00	75.00	75.00	54.00	100.00	106.00
12	SOLARAV	21.18	21.12	20.41	18.43	16.13	14.97	15.19	16.89	18.72	20.25	20.88	20.76
13	DEWPT	25.48	25.22	24.86	24.89	22.48	22.22	22.14	22.04	21.59	23.89	25.02	24.46
14	WNDAV	2.15	2.17	1.73	1.69	2.03	2.43	3.50	5.72	7.61	7.57	4.86	2.96

Table 3.5 Hydro-meteorological Data table at Wonogiri Station

No.	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
1	TMPMX	30.20	29.96	29.68	29.67	26.94	26.63	26.39	26.01	26.01	28.68	30.13	29.29
2	TMPMN	21.92	21.88	21.52	21.70	19.42	19.27	19.29	19.15	18.78	20.72	21.86	21.19
3	TMPSTDMX	5.08	4.37	4.98	5.18	4.55	4.42	5.14	5.25	4.24	5.11	4.81	4.98
4	TMPSTDMN	4.30	3.71	4.23	4.05	3.57	3.36	4.30	4.75	3.21	3.92	3.61	3.83
5	PCPMM	10.77	13.05	11.41	6.82	2.05	2.51	1.20	0.97	0.53	4.87	8.17	7.10
6	PCPSTD	16.16	19.12	18.69	14.29	6.26	10.50	5.03	4.25	3.45	10.86	16.24	13.52
7	PCPSKW	2.18	2.12	2.16	3.17	3.51	6.75	4.97	7.61	7.70	3.05	3.69	2.75
8	PR_W1	0.21	0.22	0.19	0.18	0.10	0.08	0.04	0.02	0.02	0.10	0.22	0.17
9	PR_W2	0.61	0.57	0.59	0.54	0.15	0.29	0.23	0.35	0.40	0.53	0.50	0.56
10	PCPD	17.13	16.38	16.38	11.87	4.62	4.37	2.50	1.62	1.25	9.25	13.75	12.63
11	RAINHHMX	87.00	115.00	96.00	105.00	39.00	99.00	37.00	55.00	36.00	68.00	136.00	94.00
12	SOLARAV	20.59	20.38	19.83	18.17	15.99	14.93	15.10	16.66	18.26	19.57	20.06	19.85
13	DEWPT	26.06	25.92	25.60	25.68	23.18	22.95	22.84	22.58	22.39	24.70	25.99	25.24
14	WNDAV	2.15	2.17	1.73	1.69	2.03	2.43	3.50	5.72	7.61	7.57	4.86	2.96

Table 3.6 Hydro-meteorological Data table at Nawangan Station

No.	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
1	TMPMX	33.22	33.02	33.02	32.94	32.18	31.87	30.73	31.16	32.16	33.78	34.03	33.56
2	TMPMN	22.42	22.40	22.01	22.21	19.87	19.72	19.73	19.60	19.23	21.21	22.26	21.68
3	TMPSTDMX	1.52	1.46	1.52	1.49	1.17	1.48	1.15	1.01	0.89	0.65	0.75	0.51
4	TMPSTDMN	1.84	1.82	1.84	2.08	0.95	1.32	2.61	3.34	1.13	1.36	0.77	0.72
5	PCPMM	9.98	12.41	10.11	6.43	1.10	1.91	0.99	0.58	0.82	3.19	5.83	7.93
6	PCPSTD	17.77	18.77	16.22	13.47	4.97	7.24	4.65	5.07	5.21	7.92	12.88	13.39
7	PCPSKW	3.08	1.84	2.42	3.09	6.51	5.64	6.21	9.25	9.39	3.70	489.00	1.86
8	PR_W1	0.10	0.23	0.20	0.17	0.06	0.08	0.05	0.01	0.02	0.10	0.16	0.15
9	PR_W2	0.69	0.66	0.64	0.54	0.31	0.43	0.31	0.01	0.43	0.53	0.53	0.68
10	PCPD	19.00	16.75	17.50	12.50	3.13	4.75	3.13	0.63	1.50	7.13	9.38	15.63
11	RAINHHMX	135.23	97.00	102.00	80.00	51.00	66.00	39.00	55.00	52.00	64.00	77.00	64.00
12	SOLARAV	20.65	20.58	19.86	17.92	15.52	14.38	14.64	16.87	18.10	19.68	20.39	20.24
13	DEWPT	27.8	27.7	27.47	27.6	26.0	25.8	25.3	25.4	25.6	27.5	28.0	27.6
14	WNDAV	2.15	2.17	1.73	1.69	2.03	2.43	3.50	5.72	7.61	7.57	4.86	2.96

3.5.1. Soil Data Base

The soil databases defining the physical properties of the soil layers was created directly using the SWAT interface, by filling the data in specified columns.

3.5.2. Land Use Databases

Land use databases were also created using the SWAT interface.

3.5.3. Weather Generation Table

Weather generator databases contain the statistical data required to generate representative daily climate data for the sub basins. SWAT model require daily values of precipitation, maximum and minimum air temperature, relative humidity, solar radiation and wind speed to generate weather information. The data for all these parameters in this study from three stations locations namely Tawangmangu, Ngancar and Wonogiri with the data available for a period of 1992-1999. Weather station parameters categories under two categories are given below.

3.5.3.1. Weather Station Parameter

- ☑ TITLE (Title of the file): This is not processed by model.

- ☑ WLATITUDE (Latitude of the weather station used to create statistical parameter): The value of latitude was given as **8.05** degrees, **7.82** degrees, **7.66** degrees, **8.01** degrees and **7.81** degrees for Nawangan, Wonogiridam, Tawangmangu, Ngancar and Wonogiri stations respectively.
- ☑ WLONGITUDE (Longitude of the weather station): This value of longitude was given as **110.90** degrees, **110.91** degrees, **111.12** degrees, **111.03** degrees and **110.93** degrees for Nawangan, Wonogiridam, Tawangmangu, Ngancar and Wonogiri stations respectively.

Table 3.7 Longitude and Latitude of the station locations

NO	STATION	WLATITUDE (degree)	WLONGITUDE (degree)
1	Nawangan	-8.05	110.90
2	Wonogiridam	-7.82	110.91
3	Tawangmangu	-7.66	111.12
4	Ngancar	-8.01	111.03
5	Wonogiri	-7.81	110.93

- ☑ XPR (X projected coordinate of the weather station location): The values of coordinate were given as **513552.23**, **503464.03** and **491762.30** for Tawangmangu, Ngancar and Wonogiri stations respectively.
- ☑ YPR (Y projected coordinate of the weather station location): The value of coordinate were given as **9142453.98**, **9115116.49** and **9136615.02** for Tawangmangu, Ngancar and Wonogiri stations respectively.
- ☑ RAIN_YRS (Number of years of maximum monthly 0.5hr rainfall data used): Daily rainfall recorded at five rain gauge station for the period of 1992 to 1999 has used to generate different variables of this weather generation database.
- ☑ WELEV (Elevation of weather station in meter): This value of elevation gives as 1000m, 275m and 136m for Tawangmangu, Ngancar and Wonogiri stations respectively.

Table 3.8 Projected coordinate and elevation of the stations location

NO	STATION	XPR	YPR	ELEVATION (m)
1	Nawangan	489064.58	9110448.80	230
2	Wonogiridam	490310.56	9135279.48	141

3	Tawangmangu	513552.23	9142453.98	1000
4	Ngancar	503464.03	9115116.49	275
5	Wonogiri	491762.30	9136615.02	136

3.5.3.2. Monthly Weather Parameter

- ☑ TMPMX (Average daily maximum air temperature for the month in ^{0}C): These values were computed by summing the daily maximum air temperature for each month for all years of record and dividing by the number of days summed.
- ☑ TMPMN (Average daily minimum air temperature for the month in ^{0}C): These values were computed by summing the daily minimum air temperature for each month for all years of record and dividing by the number of days summed.
- ☑ TMPSTDMX (Standard deviation for daily maximum air temperature in the month): This parameter quantifies the variability in maximum temperature for each month.
- ☑ TMPSTDMN (Standard deviation for daily minimum air temperature in the month): This parameter quantifies the variability in minimum temperature for each month.
- ☑ RAINHMX (Maximum 0.5hr rainfall in entire period of record for month): These values represent the most extreme 30 minute rainfall intensity recorded in the entire period of record.
- ☑ SOLARAV (Daily average solar radiation for month in MJ/m^2/day). These values were calculated by summing the total solar radiation for everyday in the month for all years of record and divided by the number of days summed.
- ☑ DEWPT (Average daily dew point temperature in the month in ^{0}C): These values were calculated by summing the dew point temperature for everyday in the month for all years of record and divided by the number of days summed.
- ☑ WNDAV (Daily average wind speed in the month in m/s): These values were calculated by summing the average wind speed values for daily data in the month for all years of record and divided by the number of days summed.

3.5.4. Precipitation Data Table

Daily precipitation (mm) data for the simulation period from 1992 to 1999 was used for running the model. Precipitation data is required in dBase (.dbf) format as specified in the above SWAT manual.

3.5.5. Temperature Data Table

Temperature data table were used to store daily maximum and minimum air temperatures. These temperatures can either be used to read by the model or they may be generated by the model for simulation. Temperature data (^{0}C) table for above simulation period was prepared in dBase (.dbf) format as specified in the User's Guide.

3.5.6. Weather Generation Gauges

Location table for outlet of watershed, weather gauge, rain gauge, temperature gauge, relative humidity gauge, solar radiation gauge and wind gauge were prepared in dBase format as per User's Guide. Coordinates have been provided in term of X and Y projected coordinates for all gauging stations and watershed outlet.

3.5.7. Land Use Look Up Table

This table is used to specify the SWAT land cover plan/urban land code to be modeled for each category in the land use map grid. It was prepared in dBase format table as per User's Guide. SWAT codes to be assigned for each land use type was written against each category appearing in the land use grid map to link the grid with land use database.

3.5.8. Soil Look up Table

This table is used to specify the SWAT. It will be prepare in dBase format table as per User's Guide. SWAT codes to be assign for each soil type will write against each category appearing in the soil map to link the grid with soil data base .This table is used to link the soil map attributes with the soil database in dbase format.

According to the reconnaissance surface soil map of the Bengawan Solo River basin, which was prepared as the second edition by the Soil Research Institute in 1973, the ground surface soils found in the basin was classified into five soil groups (lithosolandosol, mediteranlithosol, alluvial, mediteran and latosol) as shown in the following table.

Table 3.9 Soil Look up Table

VALUE	NAME
0	LITLAN
1	MEDTL
2	ALL
3	MEDT
4	LTSL

3.6. The SWAT Model Description

The Soil and Water Assessment Tool (ArcSWAT 2009.93.4) having an interface with ArcGIS 9.3 software was selected for hydrological modeling of Wonogiri watershed, located in Wonogiri, Central of Java Province, Indonesia. The SWAT model is the continuation of a long-term effort of nonpoint source pollution modelling by the USDA-Agricultural Research Service (ARS) at Temple Texas (U.S.A.). The SWAT model allows considerable flexibility in watershed decomposition. The watershed can be divided into a number of Hydrological Response Unit (HRU) or grid cells or sub-watersheds. Different parts of the watershed can be divided differently. The new routing structure of the SWAT model routes and adds flows down through the basin reaches and reservoirs. Apart from this, changes were incorporated to simulate lateral flow, ground water flow, reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams and valleys. The SWAT model is capable of simulating hundreds of sub-watersheds for the periods of 100 years or more. The major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agricultural management.

3.6.1. Model Operation

SWAT is a distributed parameter model that operates on a daily time step. The major goal of the model development was to predict the impact of management measures on water, sediment and agricultural chemical yields in large ungauged basins. The merits of the model are as follows (Arnold *et al.*, 1998):

1. It is comparatively simple, user friendly and physically based distributed model which uses readily available inputs.
2. It is computationally efficient to operate on large basins in a reasonable time.
3. It is a continuous time scale model, capable of simulating long term effects of management change.
4. It has got high potentiality to integrate with GIS.

The SWAT model uses a command structure for routing runoff and chemicals through a watershed (Williams and Hann, 1973). Specific commands are there for routing flows through streams and reservoirs, adding flows and inputting measured data or point sources. Using a routing command language, the model can simulate a basin sub divided into grid cells or sub-watersheds. Additional commands have been developed to allow measured and point source data to be input to the model and routed with simulated flows. Also, output data from other simulation models can be input to the SWAT model.

3.6.2. Capabilities of SWAT model

The SWAT model is a continuation of nearly 30 years of modeling efforts conducted by the USDA Agricultural Research Service (ARS). The worldwide application of SWAT reveals that it is a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decisions.

- SWAT is capable of simulating number of different physical processes occurring in a watershed.
- For the model purpose, a watershed may be partitioned into a number of sub-watersheds.
- The use of sub-watershed in a simulated is particularly beneficial when different areas of the watershed are dominated by land use or soil dissimilar enough in properties to impact hydrology.
- To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed.

3.6.3. Model limitations

The following are the limitations of the model (Arnold *et al.*, 1998):

1. Daily precipitation is input to the model and curve number equation is applied to daily rainfall without accounting for its intensity for runoff estimation.
2. One of the major limitations of large area hydrologic modelling is the spatial variability associated with precipitation. Precipitation can cause considerable errors in runoff estimation if only one rain gauge is used to represent an entire sub-watershed or even if an attempt is made to 'spatially weight' precipitation for a watershed.
3. SWAT does not simulate detailed event based flood and sediment routing. It was developed to predict agricultural management impacts on long term (100 years) erosion and sedimentation rates. The model operates on a daily time step, although a shorter and more flexible time increment would be a major enhancement to the model.

4. The sediment routing equations are relatively simplistic and assume that channel dimensions are static throughout the simulation period. This may be unrealistic since simulation may be made even for 100 years or more.
5. Another limitation is the simplistic way the channel bed is described. The erodibility factor should be replaced with more detailed models that account for cohesive, noncohesive and armored channels.

Reservoir routing was originally developed for small reservoirs and assumes well-mixed conditions. The reservoir outflow calculations are not accounted for controlled operation. To adequately simulate large reservoirs, these items need to be addressed.

3.7. The methodology of study

The detailed methodology for SWAT modeling is presented in figure 3.6

3.8. SWAT model setup

The model setup involved seven steps and spatial data sets (DEM, Land use/Land cover map, soil map and slope map) were projected to UTM 49 South and WGS84 datum. Reprojection was done using ArcGIS 9.3 raster and vector standard world reproject tool. ArcSWAT requires all data to be in the same projection before any GIS processing can take place. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. We have used DEM mask that was superimposed on the DEM since the model uses only the masked area for stream delineation. The Land use/Land cover spatial data were reclassified into SWAT land cover/plant types. A user look up table was created that identifies the SWAT code for the different categories of land cover/land use on the map as per the required format. The soil map was linked with the user soil data-base. The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, land use, slope and weather data.

3.8.1. Modeling/simulation

- ☑ After preparing input data, an initial run of model were made using default model parameters.
- ☑ Available hydrological data were split into two parts, the calibration period and the validation period.
- ☑ The parameters of the model were calibrated in order to get better match between runoff and computed runoff hydrograph. Due to use of large number of

parameters in SWAT model, it is better to find sensitivity of parameters to understand the model and also to arrive at suitable value of parameters during calibration of the model.

☑ There were 6 basic steps in the modeling work using ArcSWAT program:

- ☞ Watershed Delineation, this process is aimed to develop site boundary modeling limits. Boundary modeling based on the concept of geo-hydrology science, namely the limit resulting from the formation of a region catchment area / watershed. Then the user of this application software must provide data: altitude map in grid format (DEM / Digital Elevation Model),
- ☞ Parameterization Landuse and Soil Type on ArcSWAT modeling analysis is using GIS system base, that is system with one interface between an image map and table attributes. Because it was necessary to determine the parameters of watershed, land use map, and soil type and its data properties.
- ☞ Calculating boundary map modeling and parameter values and catchment land use or soil type is called processing HRU (Hydrologic Response Unit)
- ☞ Input Data Base
- ☞ Edit data base was listed as the properties of land, location modeling studies.
- ☞ Run Simulation.

3.8.2. Calibration and validation of SWAT model

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The flow was calibrated manually using the observed flow gauged at the outlet of the watershed. First of all, the surface runoff flow components of gauged flow are balance with that of the simulated flow. The manual calibration was done based on the procedures recommended in SWAT user manual.

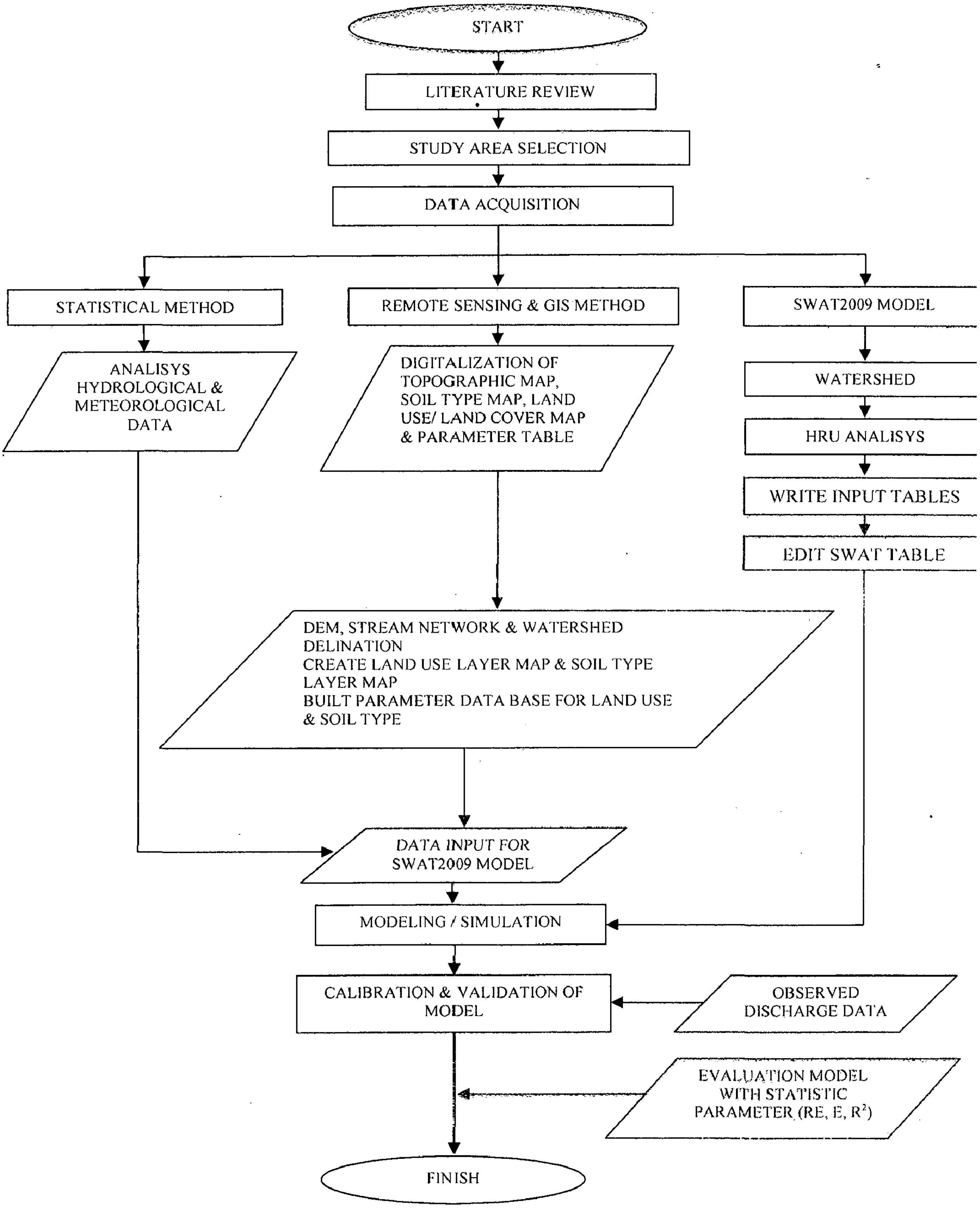

Figure 3.6. Flow chart of Methodology of the study

- ☑ The calibration process is primarily aiming at obtaining a set of model parameters which provide a satisfactory agreement between model computed runoff and field observations.
- ☑ Statistical Calibration

  In SWAT model, three statistical measures (RE, NSE & R^2) are including to evaluate the goodness of a calibration. SWAT model calibration was performed by minimizing the Relative Error (RE in percent) and maximize Nash-Sutcliffe coefficient (E) and coefficient of determination (R^2).

  Relative Error RE (%) is calculated as:

$$RE(\%) = \sum_{i=1}^{n} \left| \frac{(O_i - P_i)}{O_i} \right| x100$$

  where O is the measured value, P is the predicted output and n is number of values.

  Nash – Sutcliffe coefficient (E), which is defined as:

$$E = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

  where, O is measured values, P is predicted outputs, and $\overline{O}$ equals the mean of observed values (Nash and Sutcliffe, 1970). Monthly coefficient of determination (R^2) was calculated since E is sensitive to outliers (Kirsch *et al.*, 2002). A significance test can be performed when conducting a linear regression analysis with a null hypothesis that the coefficient of determination is equal to 0.

  The R^2 statistic is calculated as:

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\left[\sum_{i=1}^{n} (O_i - \overline{O})^2 \sum_{i=1}^{n} (P_i - \overline{P})^2 \right]^{0.5}} \right)^2$$

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter presents the results of calibration and validation of the SWAT model. Further, effect of land use/cover changes on runoff on Wonogori catchment has also studied.

4.1 Simulation of Runoff using the SWAT model

4.1.1. Pre Calibration

Pre calibrated model results for runoff is presented in Figure 4.1. The low values of Nash Sutcliffe model efficiency (0.378) indicate pre calibrated model performance is poor. Thus, in the present study input parameter values required by the model were obtained from direct field and laboratory measurements, remote sensing, GIS or through the calibration process of the models, where selected model parameters were adjusted within an expected range and the discrepancies between the measured and model predictions could be minimized (Donigian and Rao, 1990). The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the runoff from the study area. The observed and simulated monthly runoff values of Wonogiri catchment for the pre calibrated period (1992-1996) along with 1:1 line are shown in figure 4.2. It is observed from Figure 4.2 that the simulated runoff values are not distributed uniformly about the 1:1 line for both the lower and higher values of the observed discharge. Descriptive statistics for the model results are presented in Table 4.1

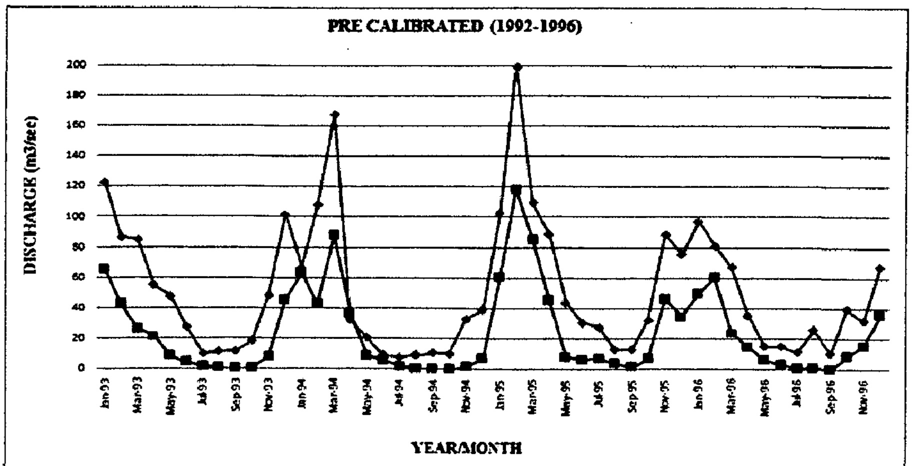

Figure 4.1 Observed monthly discharges (1992 -1996) and simulation result for pre calibrated model

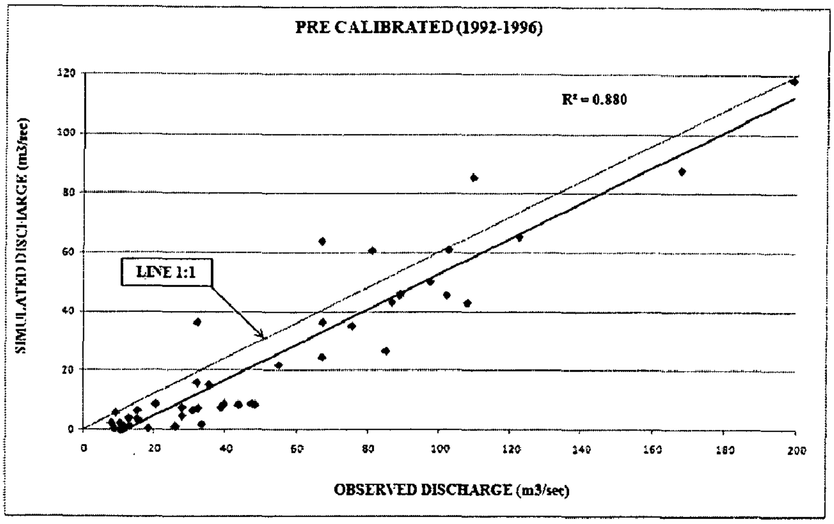

Figure 4.2 Comparison between the observed and simulated discharge for pre calibrated model

Table 4.1 Descriptive statistics for calibration and validation of SWAT output

Descriptive Statistics	Observed Discharge (1992-1996)	Calibration (1992-1996)	Validation (1997-1999)
Mean	50.026	40.709	38.404
Standard Error	6.283	5.858	5.599
Median	33.350	27.160	36.530
Standard Deviation	43.074	40.158	33.127
Sample Variance	1855.390	1612.632	1097.394
Kurtosis	2.382	1.473	-0.755
Skewness	1.451	1.197	0.549
Range	191.042	176.287	110.500
Minimum	8.081	0.013	0.000
Maximum	199.123	176.300	110.500
Sum	2351.241	1913.327	1344.154
Count	47.000	47.000	35.000
Confidence Level (95.0%)	12.647	11.791	11.379

4.1.2. Calibration

The SWAT model was calibrated with the observed daily discharge measured at the watershed outlet for the year 1992-1999. After calibration, the model was used for prediction of runoff. The results of the SWAT model are presented in figure 4.3. After calibration the coefficient of determination (R^2), Relative Error (RE %) and Nash-Sutcliffe coefficient (E) was obtained as 0.913, 17.971 and 0.868 respectively (Table 4.1). The value of Nash Sutcliffe model efficiency (0.868) indicates the calibrated model performance is very good.

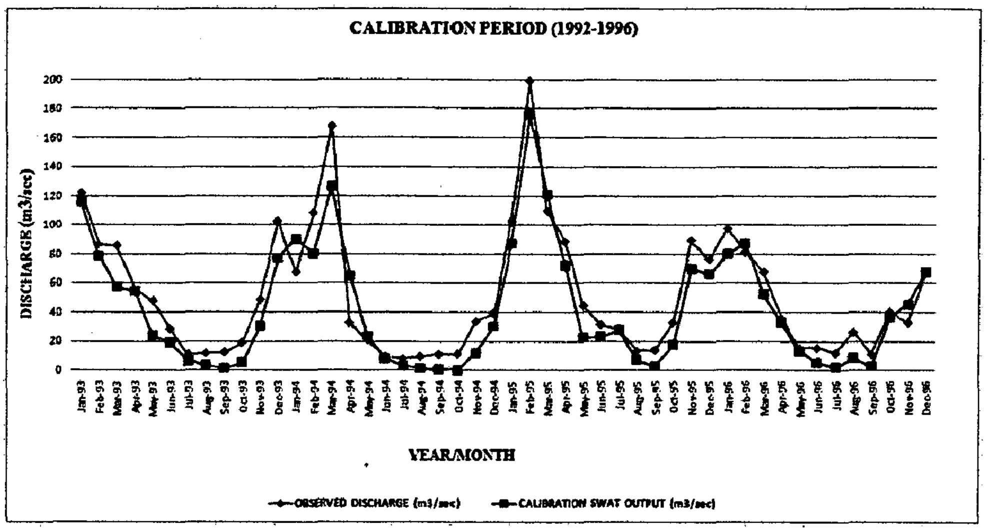

Figure 4.3 Observed monthly discharges (1992 – 1996) and simulation result for calibration period.

The observed and simulated monthly runoff values of Wonogiri catchment for the calibration period (1992-1996) along with 1:1 line are shown in Figure 4.4. It is observed from figure that the simulated runoff values are distributed uniformly about the 1:1 line for both the lower and higher values of the observed discharge. Higher values of the coefficient of determination (0.913) indicate a close relationship between the measured and simulated runoff (Table 4.1). Result of the calibration and validation of the SWAT model are also presented in Table 4.2.

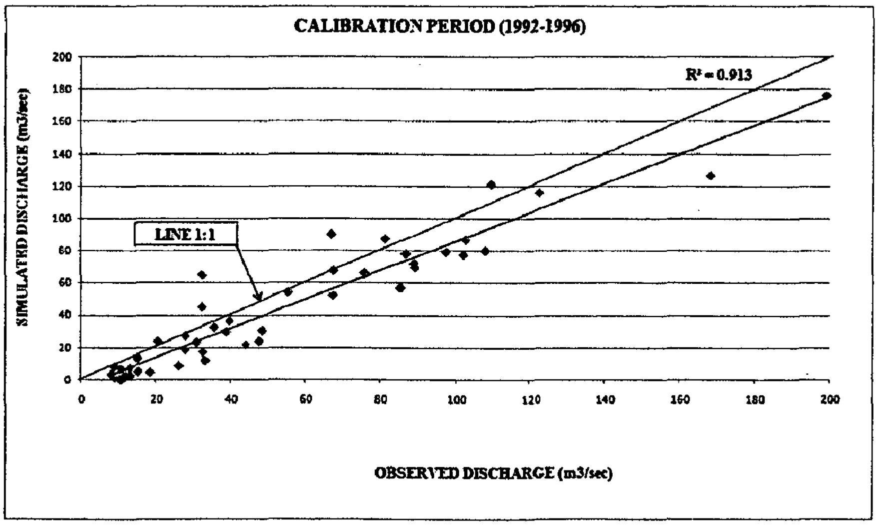

Figure 4.4 Comparison between the observed and simulated discharge for model calibration

Table 4.2 Result of the calibration and validation of the SWAT model

No	Period	Time step	Mean (m^3/sec)		Evaluation statistic		
			Observation	Predicted	**R^2**	**NSE**	**RE**
1	Preliminary calibration (1992-1996)	Monthly	51.535	23.599	0.880	0.378	54.208
2	Calibration (1992-1999)	Monthly	51.535	42.273	0.913	0.868	17.971
3	Validation (1997-1999)	Monthly	47.247	39.062	0.908	0.842	17.324

4.1.3. Validation of the SWAT Model

The SWAT model was validated with the observed daily discharge measured at the watershed outlet for the year 1997-1999. The result is presented in Figure 4.5. For the model validation the coefficient of determination (R^2), Relative Error (RE %) in and Nash-Sutcliffe coefficient (E) was obtained 0.908, 17.707 and 0.861 respectively. The value of Nash Sutcliffe model efficiency (0.908) indicates the model performance is very good. The observed and simulated monthly runoff values of Wonogiri catchment for the calibration period (1992-1996) along with 1:1 line are shown in figure 4.6. It is observed from figure that the simulated runoff values are distributed uniformly about the 1:1 line for both the lower and higher values of the observed discharge. Higher values of the coefficient of determination (0.913) indicate a close relationship between the measured and simulated runoff for the validation period.

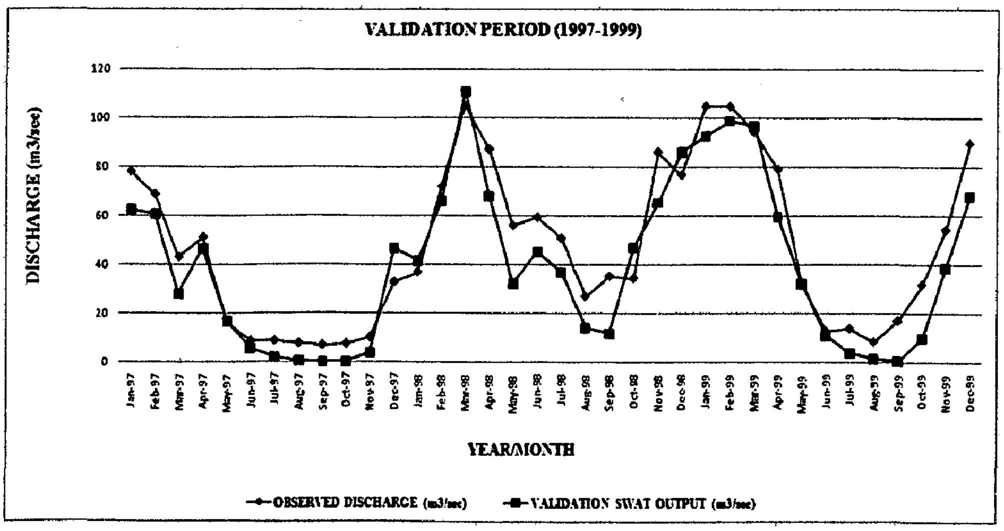

Figure 4.5. Observed monthly discharges (1992 – 1996) and simulation result for validation period.

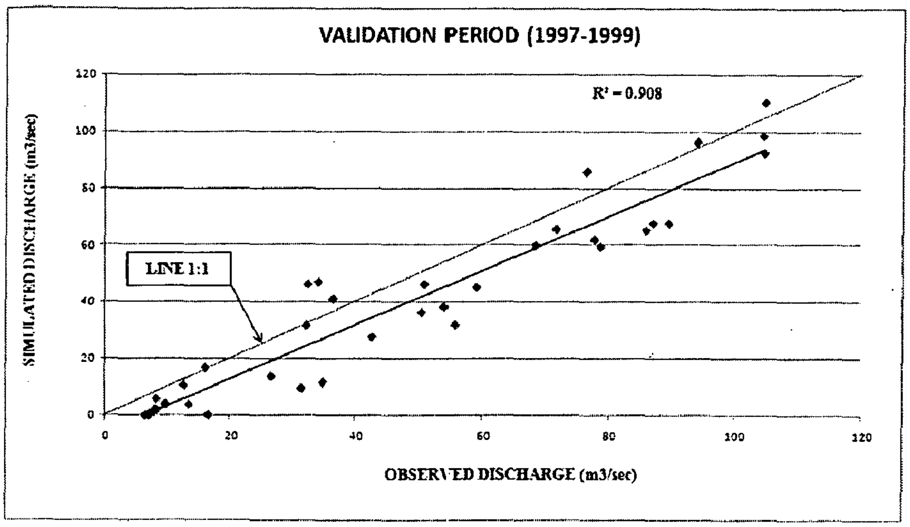

Figure 4.6 Comparison between the observed and simulated discharge for model calibration

From calibration graph shown in Figure 4.6, by adjustment of the parameters the amount of water infiltrated into the soil, become sub surface water so that the stream runoff increases. After some iterations, the stream runoff increases and the predicted graph becomes closer to the observed graph but not 100% similar because some assumption and adjustment about land and soil characteristic that used in modeling may be not same with the reality conditions in field. Final result of the SWAT model show that the Relative Error (RE %) is 17.324% (>10%), it is indicated that the model does not represent the actual condition of stream flow. In case if human error on input data may be given effect to result of the program. Thus carefully review precipitation and flow data for the particular duration to make sure that the input data was correct.

4.2. Evaluation of the SWAT model in Changing land use/land cover

In order to understand how land use/land cover influences the amount of surface runoff, figure 4.7 shows the result of the SWAT for simulation with the different land use/land cover type.

For urban land use, the lowest runoff was 0.052 m^3/s in October, 1994 and higher was 189.23m^3/sec occurred in February, 1995. And for SWAT output (after calibration), the lower runoff was 0.013 m^3/s in October 1994 and higher was 176.3 m^3/sec occurred in February, 1995 (Table 4.3). The result shows that the surface runoff varied across the catchment within the monthly time step (period 1992-1996), and the coefficient of determination R^2 was 0.994 (table 4.4). Simulation shows that the amount of runoff was increased by 1.95 % when land use was changed to urban (Table 4.5).

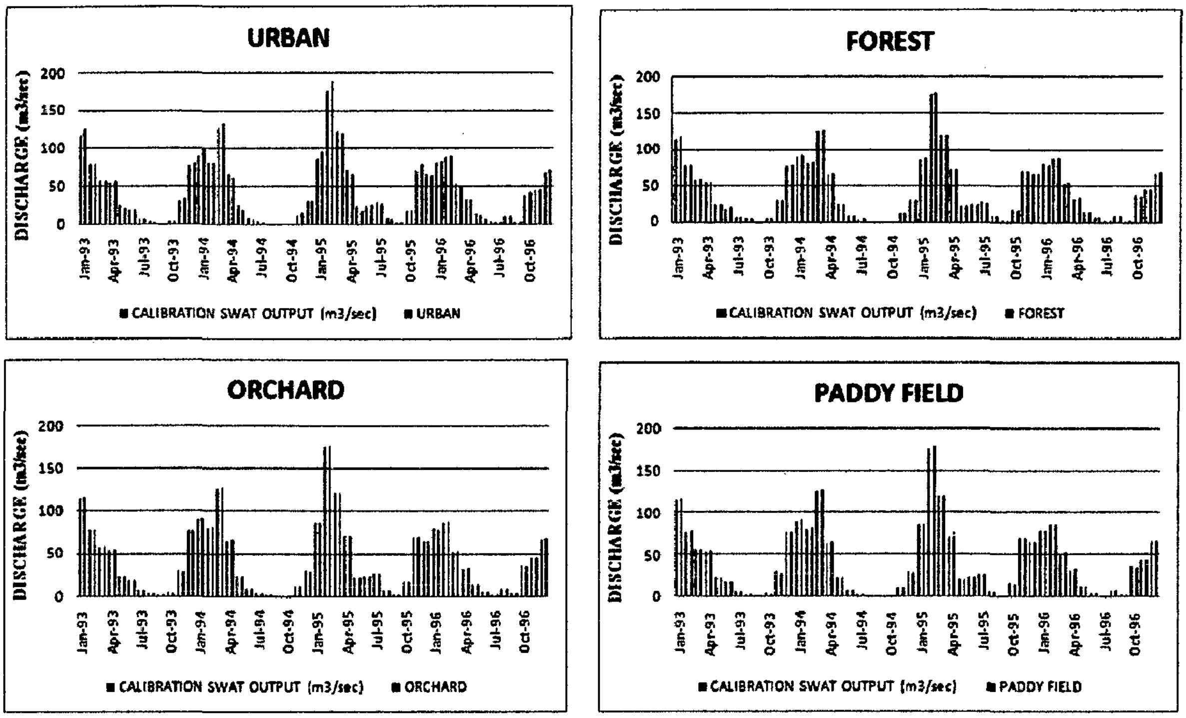

Figure 4.7 SWAT model results for each land cover simulation

For Forest, the lowest runoff was 0.023 m^3/s in October 1994 and higher was 189.3 m^3/sec occurred in February 1995. And for SWAT output (after calibration), the lowest runoff was 0.013 m^3/s in October 1994 and higher was 176.3 m^3/sec in February 1995 (Table 4.3). The result shows that the surface water runoff varied across the catchment within the monthly time step (period 1992-1996), and the coefficient of determination R^2 was 0.999 (Table 4.4). After simulation, showing that the amount of runoff was increased to 1.13 % (Table 4.5) when the type of land cover/Land use was changed to forest land.

For Orchard, the lowest runoff was 0.022 m^3/s occurred in October 1994 and higher was 178.80 m^3/sec occurred in February 1995. And for SWAT output (after calibration), the lowest runoff was 0.013 m^3/s occurred in October 1994 and higher was 176.3 m^3/sec occurred in February 1995 (Table 4.3). The result shows that the surface water runoff varied across the catchment within the monthly time step (period 1992-1996), and the coefficient of determination R^2 is 0.999 (Table 4.4). After the simulation, showing that the amount of runoff was increased to 0.64 % (Table 4.5), it means that when changing the type of land use/Land cover on Orchard was given impact on increasing the amount of the runoff by 0.64%.

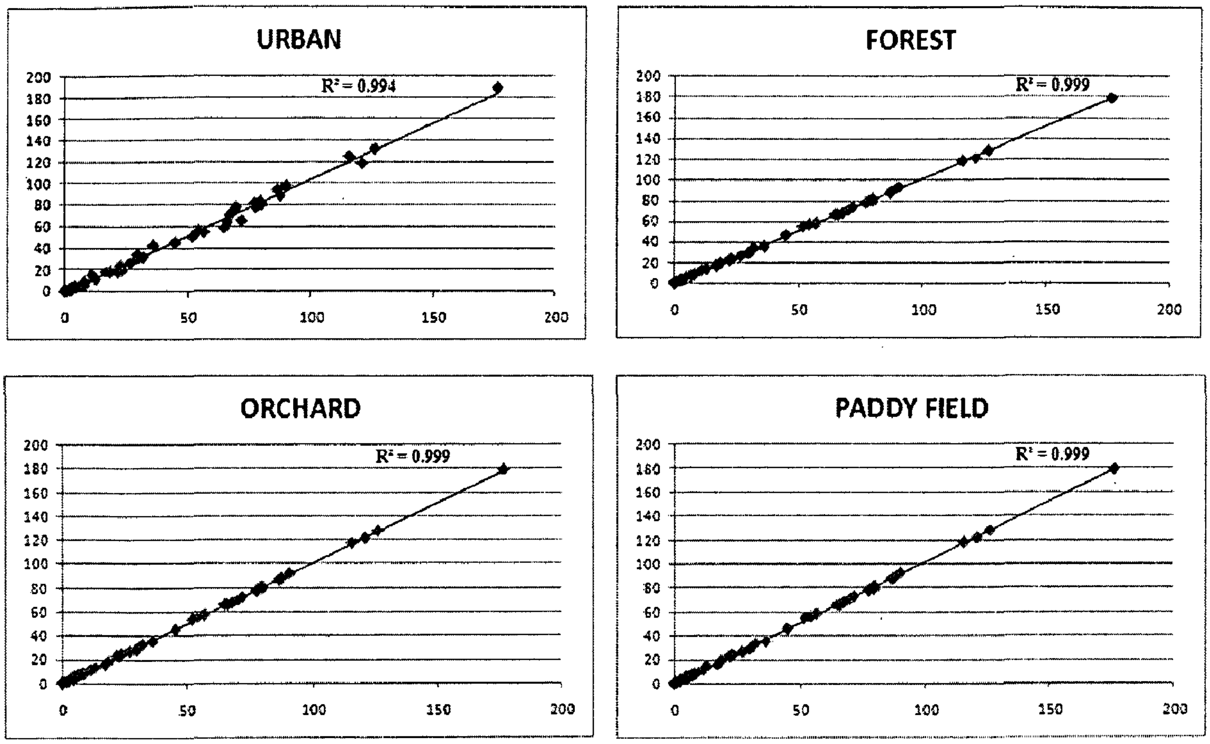

Figure 4.8 Significance test for coefficient of determination R^2 for each Land use/Land cover simulation

For Paddy Field, the lowest runoff was 0.022 m^3/s occurred in October 1994 and higher was 179.5 m^3/sec occurred in February 1995. And for SWAT output (after calibration), the lowest runoff was 0.013 m3/s occurred in October 1994 and higher was 176.3 m^3/sec occurred in February 1995 (Table 4.3). The result shows that the surface water runoff varied across the catchment within the monthly time step (period 1992-1996), and the coefficient of determination R^2 was 0.999 (Table 4.4). After the simulation, showing that the amount of runoff was increased to 1.12 % (Table 4.5), it means that when changing the type of land use/Land cover on Paddy field was given impact on increasing the amount of the runoff by 1.12%.

Table 4.3 SWAT output Land use/Land cover simulation

Year / Month	Observed Discharge (m^3/sec)	Simulated Discharge (m^3/sec)	Swat Output Runoff after Simulation (m^3/s)			
			Forest	Orchard	Paddy field	Urban
Jan-93	122.42	115.8	118	117.5	118.1	125.3
Feb-93	86.75	78.04	78.89	78.39	78.81	77.69
Mar-93	85.38	56.92	57.92	57.56	57.96	55.38
Apr-93	55.30	54.18	55.9	55.55	55.84	55.59
May-93	47.73	23.44	24.21	24.01	24.17	20.33
Jun-93	28.03	18.56	18.7	18.61	18.65	18.46
Jul-93	10.57	6.497	6.635	6.586	6.643	5.01
Aug-93	11.60	3.177	3.184	3.152	3.199	2.743
Sep-93	11.83	0.864	0.9335	0.9176	0.9314	0.6578
Oct-93	18.40	4.513	3.565	3.557	3.547	3.872
Nov-93	48.62	30.08	28.52	28.49	28.46	33.98
Dec-93	102.28	77.25	77.52	77.31	77.58	81.3
Jan-94	67.18	90.32	92.29	91.86	92.35	98.19
Feb-94	108.01	79.92	81.71	81.27	81.81	80.72
Mar-94	168.07	126.2	128.7	128	128.5	132.8
Apr-94	32.40	64.68	66.29	65.91	66.27	59.32
May-94	20.59	23.39	24.26	24.07	24.25	18.99
Jun-94	9.20	8.065	8.407	8.335	8.407	6.322
Jul-94	8.08	2.859	3.009	2.982	3.008	2.23
Aug-94	9.11	0.8947	0.9683	0.9581	0.9677	0.6806
Sep-94	10.85	0.23	0.2769	0.2728	0.2761	0.1682
Oct-94	10.48	0.01345	0.02337	0.02244	0.0223	0.0518
Nov-94	33.35	11.46	11.84	11.82	11.95	14.82
Dec-94	38.96	29.92	29.08	28.9	29.01	30.83
Jan-95	102.71	86.78	87.57	87.24	87.58	94.64
Feb-95	199.12	176.3	179.4	178.8	179.5	189.3
Mar-95	109.46	121	121.8	121.3	121.6	119.1
Apr-95	88.92	71.82	72.68	72.37	72.65	66
May-95	44.01	22.03	22.55	22.43	22.59	17.61
Jun-95	31.01	22.94	22.98	22.91	22.99	23.93
Jul-95	27.98	27.16	26.47	26.34	26.41	25.78
Aug-95	13.07	6.96	6.915	6.868	6.923	5.071
Sep-95	13.30	2.395	2.407	2.389	2.409	1.735
Oct-95	32.52	17.2	15.97	15.93	15.92	18.64
Nov-95	89.32	69.8	70.52	70.31	70.66	77.64
Dec-95	75.89	65.83	65.99	65.63	65.85	63.97
Jan-96	97.56	79.66	79.41	79.13	79.48	83.05
Feb-96	81.45	87.43	88.01	87.64	87.98	88.87
Mar-96	67.42	52.17	54	53.58	54.09	50.57
Apr-96	35.64	32.2	33.49	33.21	33.44	31.98
May-96	15.30	13.14	13.92	13.73	13.86	10.82
Jun-96	15.32	5.007	5.427	5.34	5.393	4.406
Jul-96	11.62	1.88	2.084	2.045	2.071	1.584
Aug-96	26.09	8.459	8.001	7.969	8.014	8.786
Sep-96	10.90	2.643	2.729	2.685	2.718	2.094
Oct-96	39.80	36.47	35.4	35.28	35.41	42.09
Nov-96	32.40	45.08	45.54	45.3	45.58	45.09
Dec-96	67.65	67.5	67.98	67.62	67.95	70.42
TOTAL	2473.66	2029.13	2052.08	2042.08	2051.78	2068.61

Table 4.4 Descriptive statistics for each Land use/Land cover simulation

DESCIPTIVE STATISTICS	SWAT OUTPUT	URBAN	FOREST	ORCHARD	PADDY FIELD
Mean	40.709	41.347	41.151	40.948	41.142
Standard Error	5.858	6.160	5.946	5.921	5.945
Median	27.160	25.780	26.470	26.340	26.410
Standard Deviation	40.158	42.229	40.762	40.595	40.758
Sample Variance	1612.632	1783.309	1661.504	1647.959	1661.189
Kurtosis	1.473	1.921	1.527	1.540	1.532
Skewness	1.197	1.297	1.210	1.213	1.211
Range	176.287	189.248	179.377	178.778	179.478
Minimum	0.013	0.052	0.023	0.022	0.022
Maximum	176.300	189.300	179.400	178.800	179.500
Sum	1913.327	1943.311	1934.075	1924.579	1933.680
Count	47.000	47.000	47.000	47.000	47.000
Confidence level (95.0%)	11.791	12.399	11.968	11.919	11.967

Table 4.5 Impact of change in Land use/Land cover simulation to the amount of Runoff

NO	AMOUNT OF RUNOFF (m^3/sec)		% CHANGE	REMARKS
1	SWAT output After Calibration	2029.13	--	--
2	SWAT output due to Urban	2068.61	1.95	Increase
3	SWAT output due to Forest	2052.08	1.13	Increase
4	SWAT output due to Orchard	2042.08	0.64	Increase
5	SWAT output due to Paddy Field	2051.78	1.12	Increase

Results show that the SWAT model can characterize the effects of different land cover conditions. Results show that for Wonogiri catchment, land cover changes have contributed negatively to the amount of runoff changes. The impact that occurred in the presence of Land use/Land cover change can seriously impact on the livelihoods of the region and also on the wildlife in the area. This study may help decision makers to lessen the impacts of Land use/Land cover changes; there is an urgent need to reduce vulnerability to Land use/Land cover changes in this catchment area.

CHAPTER V
SUMMARY AND CONCLUSION

5.1. Modeling of Wonogiri catchment using the SWAT model

The Wonogiri watershed is located in Wonogiri, Central of Java Province, Indonesia, which covers catchment area of 1,350 km^2 and the Wonogiri dam with reservoir area of 90 km^2. Wonogiri Multipurpose Dam is the largest dam built in the Solo River, located in Central Java Province Wonogiri with a catchment area of around 16,100 km^2 and a length of about 600 km. Exact location of the dam at the meeting of the Solo River and Keduang River. The dam was built in 1976 and completed in 1982. Wonogiri Dam is a multi function dam with the primary function as flood control. Besides, as a provider of water for irrigation, power generation, fisheries and tourism purpose. Downstream of the dam, the irrigation system has been irrigating an area of 30,000 ha of agricultural and supports the implementation of the technical agricultural system by 3 times in 1 year of planting.

In this study, the Soil and Water Assessment Tool (SWAT2009) having an interface with ArcGIS 9.3 software was selected for hydrological modeling of Wonogiri watershed, located in Wonogiri, Central of Java Province, Indonesia. Spatial data of the Wonogiri catchment (DEM, soil and land use/land cover) is used in the pre-processing phase and fed into the SWAT model through the interface. In SWAT, Wonogiri watershed was delineated into 146 Sub-basins, which were further, divided into 1417 hydrologic response units (HRUs), each of which represents a unique combination of land use, management and soil characteristics.

The SWAT hydrological model was run and the model results were compared with measured flow data. Five years of observed monthly discharge data (1992 to 1996) were used to calibrate the model, and three years of monthly discharge data (1997 to 1999) were used for model validation. Model parameters were then fine tuned based on a visual inspection of daily hydrographs and flow frequency curves. The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the runoff from the study area. The low values of Nash Sutcliffe model efficiency (0.378) indicates pre calibrated model performance is poor. After calibration the coefficient of determination (R^2), Relative

Error (RE %) and Nash-Sutcliffe coefficient (E) was obtained as 0.913, 17.971 and 0.868 respectively. For the model validation the coefficient of determination (R^2), Relative Error (RE %) in and Nash-Sutcliffe coefficient (E) was obtained 0.908, 17.707 and 0.861 respectively.

5.2. Evaluation of the SWAT model in Changing land use/land cover

The impact of land use/ Land cover change was assessed for the Urban, Forest, Orchard and Paddy field by running the calibrated model for the period from 1992 to 1996. The results shows that for the Wonogiri catchment, land cover changes have contributed negatively to the amount of runoff changes. The study reveals that the SWAT model can characterize the effects of different land cover conditions. The Land use/Land cover changes can seriously affect on the livelihoods of the region and also on the wildlife in the area.

5.3. Conclusions

The following important conclusions are drawn from this study.

1. The SWAT model simulation results showed that the amount of runoff increased when changing the type of land use/Land cover. Urban was given impact on increasing the amount of the runoff by 1.95%. For forest, orchard and paddy field were given impact on increasing the amount of the runoff by 1.13%, 0.64% and 1.12% respectively.
2. This study may help decision makers to decrease the impacts of Land use/Land cover changes.
3. The Soil and Water Assessment Tool (SWAT) model, supported by GIS and remote sensing technology can be a useful tool for modeling the impact of land cover/land use changes in Wonogiri catchment.

5.4. Future Research

Suggestions for future research are as follows:

1. Alternative crop scenarios/simulation planning in the Wonogiri catchment.
2. Simulation of Sediment yield in the Wonogiri catchment
3. Simulation of Water pollution in the Wonogiri catchment.
4. Simulation of land use land cover and its affect on water availability and cropping/ plantation in the Wonogiri catchment.
5. Simulation of climate change impact on crop production in the Wonogiri catchment.

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