CHAPTER 1

INTRODUCTION

1.1 Background

Land and water form the two crucial and complementary resources that influence the regional development and also directly affect the quality of human life. Due to overexploitation as well as unscientific use, the quality and quantity of the available land and water resources have been subdued around the world. It necessitates for optimal and conjunctive use of these two vital resources. This in turn gave birth to the concept of watershed, a natural organizing unit, for implementation of management practices for conserving the land and water resources. The basic tenet of watershed management is the relationship between watershed processes and spatially distributed watershed properties. Geographic Information System (GIS) based hydrological models are useful tools for investigating interactions among the various watershed properties and watershed response i.e. runoff and sediment yield. The basic data required for hydrologic modeling such as topography, land use land cover (LULC), soil type and rainfall intensity can easily be stored and analyzed within GIS (Devantier and Feldman, 1993). But, there is currently a paucity of information regarding the characteristics of the errors involved in using different models. A large proportion of the total error introduce while processing of raw data, and the subsequent modeling with and analysis from it (Smith et al., 2004).

1.2 Problem statement

The spatial data characterizing the factors that govern the watershed functions and processes are always of immense significance for proper management of watershed. The three primary factors governing hydrologic variability in the form of rainfall-runoff response and erosion are soil, topography and LULC. These are also the basic input for many GIS based hydrological models, which can easily be analyzed therein to generate various hydrologic parameters. While representing the actual topography is a real challenge, variation in watershed scale hydrologic response through time is primarily due to land use and land cover dynamics. Therefore, the output of any hydrological model hugely depends on how does one deal with these two factors i.e. topography and LULC.

1.2.1 Topography and hydrological modeling

Topography represented in the form of digital elevation model (DEM) has profound application in hydrological modeling. A DEM is a computer representation of the earth's surface and is defined as "any digital representation of the continuous variation of relief over space" (Burrough and McDonnell, 1998). Often DEM is represented in raster form as a two-dimensional array of cells where each grid cell has an elevation value.

Raster DEM that drives surface flow is arguably one of foremost data used by numerous hydrological models for deriving hydrological parameters. It facilitates the easy computation of surface flow networks and their topology critical for modeling soil moisture, runoff accumulation, stream flow, and flood response (Tarboton, 1997). It is also used as a controlling variable for the interpolation of other hydrologically important variables such as temperature, rainfall, soil properties including soil depth, and vegetation characteristics. Moreover, DEM derived flow networks allow the delineation and calculation of catchments and stream properties, routing of lateral flows of water etc.

The relative eases with which DEM analysis can be performed points to numerous opportunities, but obtaining a quality DEM for a large area is a daunting task. Like other models and spatial datasets, DEMs are not error free and uncertainty on DEM’s ability to represent the true topography exists. However, DEM users rarely account for uncertainty in the DEM representation of terrain through elevation and derived topographic parameters (Wechsler, 2003). Therefore, accounting DEM uncertainty is of great significance for hydrological application. These uncertainties are often linked to issues such as terrain data quality (Krupnik, 2000); DEM interpolation algorithm reliability (Florinsky, 1998); DEM scale as imposed by grid cell resolution (Gertner et al., 2002) and terrain surface modification used to generate hydrologically viable DEM surfaces (Lindsay and Creed, 2005). Each of these topical areas contributes to DEM uncertainty and potentially influences results of distributed parameter hydrologic models that rely on

DEMs for the derivation of input parameters (Wechsler, 2007). Thus, there must be a quantitative evaluation of DEM uncertainty before it put into subsequent use.

1.2.2 LULC and hydrological modeling

Land use land cover (LULC) is an important factor that determines spatial and temporal variation of the watershed's hydrological characteristics. Different LULC have different interception and evapotranspiration rates because different plants have different vegetation cover, leaf area indices, root depths and albedo. Land use also influences the infiltration and soil-water redistribution process through saturated hydraulic conductivity (Ragab and Cooper, 1993). Moreover, LULC influences the soil erosion and surface roughness which in turn affects the overland flow velocity. The major changes in land use that affect hydrology are vegetation change, agricultural intensification, the drainage of wetlands and urbanization. The hydrological effects of land use changes have been thoroughly described by Calder (2003).

However, both composition and spatial configuration of LULC classes affect the hydrological responses of a watershed. For example, as the vegetation density increases, the average infiltration rate will increase, thus leading to a reduction in discharge while more fragmented vegetation implies a greater number of pathways from the runoff source areas to the channel base. This increase in connectivity consequently increases hill slope discharges. A number of studies have shown strong relationships of water quality and quantity and sediment loss with landscape characteristics such as spatial arrangement of vegetation patch and bare soil (Ludwig et al., 2007a); effect of LULC pattern on water yield in a forested watershed (Lorz et al., 2007) and importance of LULC pattern on sediment yield (Bakker et al., 2008). Understanding the relationship between landscape characteristics and watershed response can provide important clue on how spatial configuration of hydrological variable controls hydrological response (Xiao and Ji, 2007). Distributed hydrological models classify the structural heterogeneity of landscape into functional unit viz. hydrotopes, hydrological response unit (HRU) to represent catchments. Their composition and spatial configuration strongly govern the hydrological connectivity and hence control the catchment response. This kind of classification can strongly improve catchment response prediction if sophisticated methods of pattern description accounted for connectivity as imparted by LULC configuration can be incorporated into the hydrologic model. Landscape ecology and catchment hydrology, both disciplines deal with patterns and processes as well as their interactions and functional implications on a variety of scales. Thus, quantitative landscape ecology may greatly contribute towards deeper understanding of the pattern-process relationship at catchment scale and research effort to make better predictions in ungauged basin (Schroder, 2006).

1.3 Objective

The present study aims at improving the way one deals with spatial data for analyzing the catchment hydrological response. This research study also attempts to integrate the concept from terrain analysis and landscape ecology with hydrologic modeling to provide better watershed management option and improved understanding of pattern process relationship at watershed scale by using Soil and Water Assessment Tool (SWAT). Broadly, the purpose of the research is to perform two major tasks i) to characterize the DEM error/uncertainty and its impact on hydrological model output, and ii) to determine how the land use changes have affected the hydrologic response of the catchments using a pattern descriptor of watershed characteristics. The watershed response estimates in the form of runoff and sediment yield are the focus of study. The following specific sub-objectives have been framed for the present research work.

a) To evaluate the effect of different interpolation techniques, resolution and hydrologic conditioning on DEM quality.

b) To compare SRTM DEM and contour derived DEM for hydrologic study.

c) To model DEM error and its propagation in terrain analysis and hydrologic modeling.

d) To predict the change in catchment response for future land use scenarios.

e) To explore the underlying mechanism responsible for change in catchment response.

1.4 Organization of thesis

This thesis consists of six chapters that describe all the major components of this research including definition of problems, gaps in current state of knowledge, theory behind various modeling and analysis, methodological approach and the major findings etc.

Chapter 1: This chapter serves as a prologue to present research work and covers the general background of the study, the problem statement, objectives, research questions and structure of thesis.

Chapter 2: This chapter deals with critical review of literature on DEM quality issue, DEM uncertainty and its propagation, LULC in hydrological modeling and effect of its spatial pattern in modeling exercise. Finally, identified research gaps in current state of knowledge are presented.

Chapter 3: The chapter presents the detailed description of theory behind the various interpolation algorithms, DEM preprocessing algorithms, models, indices and statistics, used in the present research work.

Chapter 4: In this chapter, a detail description on the study area, data used and methodology adopted to achieve the research goal are presented.

Chapter 5: This chapter covers the presentation of results of various spatial analyses and modeling output. The scientific significances of those outputs are critically discussed in this chapter.

Chapter 6: This chapter summarizes the work carried out. It also contains the scientific contribution made and conclusions derived out of the present study. Finally, it outlines the limitations and scope for further research.

In addition to these chapters, the thesis includes a comprehensive list of references and appendices for supporting the study. At the end of the thesis, a compact disc is attached which contains the portable document format (.pdf) of the thesis.