Chapter 1

Introduction

Land and water are the two most vital natural resources that must be conserved and maintained carefully for survival of life and environmental protection. Agricultural sustainability invariably depends on conservation and effective management of finite natural resources like soil and water. Soil erosion is a serious threat to the preservation of quantity and quality of these resources. The problem of soil erosion stems from a combination of factors like agricultural intensification, rolling topography, soil degradation and intense rainstorms. These factors are more pronounced in hilly and mountainous ecosystem like eastern Himalaya where high amount of runoff and concomitant losses of soil and nutrients are fast degrading the land resources on-site and causing siltation of water bodies and reservoirs off-site.

Some studies in the past revealed that 99% of the food consumed by human being comes from the land (Pimentel and Pimentel, 2003). The productive land resource of the world is finite, non-renewable over the human time frame, and prone to degradation due to unscientific and improper management. Thus, the precious land resource must be safeguarded against degradation. About 12% of the world's total land surface is utilized for cultivation and total global degradation is estimated at 1964.4 million ha, of which 38% is categorized as light, 46% as moderate, 15% as strong and the remaining 1% as extremely degraded. Available arable land of the world is only 1463 million ha, which is less than the total area of degraded land (Koohafkan, 2000). Soil degradation is responsible for making 4 to 12 million ha or 0.3–0.8% of the world's arable land unsuitable for agricultural production every year, with wind and water erosion alone accounting for 84% of the soil degradation (den Biggelaar et al., 2004a). According to an assessment of the Food and Agricultural Organization, an additional 200 million ha of cropped area would be required over next 30 years to feed the increasing population. Thus, good management practice to protect the soil against erosion to sustain long-term productivity is imperative for meeting the world's future demand for food and fiber (den Biggelaar et al., 2004b; Lafond et al., 2006).

Increasing global attention is devoted to issues of sustainable agriculture and natural resource management. Among these issues, soil conservation plays a major role, because soil is unarguably the most important resource for agricultural production (Gijsbers et al., 2001). With the increase in global population, arable and fertile land will become scarcer, and land use will tend to be intensified resulting in soil degradation. One of the most important phenomena leading to soil degradation is water erosion in croplands. Soil erosion is the process that causes loss of fertile topsoil, and sedimentation as well as pollution of surface water bodies. It causes serious agricultural and environmental problem in many parts of the world (Brown and Wolf, 1984).

India, with a population density of seven times that of the world average, faces a stiffer challenge to feed its population. Out of total geographical area of 329 million ha, approximately 145 million ha is subjected to various degrees of wind and water erosion, which cause a loss of about 5.3 million Mg of soil every year. Besides, about 29 million ha area is degraded due to problems like water logging, sodicity, salinity, shifting cultivation, ravines and gullies, reverine and torrents. Out of the country's total net cultivated area of about 143 million ha, 96 million ha that is, 67% is under rainfed farming (Sehgal and Abrol, 1994; Paul, 2004).

In eastern Himalayan region of India, soil erosion by water is a major factor causing land degradation and environmental deterioration. The degradation process is often triggered and accelerated by inappropriate land use and/or poor management. Traditional slash-and-burn agriculture on steep slopes, rainfall of high magnitude and intensity, compounds the problem many folds. The region receives an average annual rainfall ranging from 1242 to 11409 mm, with the number of rainy days having 2.5 mm or more rainfall being more than 100. The average annual erosion index in the mid hills of the region was estimated as 1218.77 m–Mg cm ha^{-1} h^{-1} (Satapathy et al., 1999).

The region is typical with diversified climatic conditions, ranging from subtropical to alpine, favourable for growing a wide variety of crops. However, in spite of its total geographical area of 18.4 million ha, which is 5.6% of the total area of the country, the region contributes only 1.5% to the country's food production. Practice of slash-and-burn agriculture on steep slopes and expansion of agriculture to erosion prone land results in as high as 76.6 Mg ha^{-1} yr^{-1} of soil loss (Satapathy, 1996). Consequently, 80% of the cultivated area is under threat of moderate to severe erosion (Vilayutham, 1999) threatening ecological balance and food security for future generations.

Soil loss to the tune of 40.9 Mg ha^{-1} and the corresponding nutrients loss of 702.9 kg ha^{-1} organic carbon, 7.1 kg ha^{-1} phosphorous and 145.5 kg ha^{-1} potassium from shifting cultivation plots on 45–53% slopes have been reported by previous researchers (Sharma, 1998). Under fallow condition, the loss of nitrogen was estimated at 600 kg ha^{-1} and recovery was less than half (Ram and Singh, 1993). The soil erosion from hillslope (60–70%) with a cropping sequence consisting of shifting cultivation during the first year, followed by upland paddy in the subsequent year and fallow during the third year was estimated as 147, 170 and 30 Mg ha^{-1} yr^{-1} respectively (Singh and Singh, 1981; Prasad et al., 1986; Singh et al., 1996).

To combat the problem of resource degradation and ecological imbalance, there is a need to adopt appropriate land use and conservation measures particularly in upland situations. Watershed being a natural drainage unit should form the basis for planning various land uses and conservation measures to optimize the use of soil and water resources for enhanced and sustained production. The watershed based farming system coupled with vegetative and structural conservation measures at appropriate locations can retain maximum rainfall within the slope and help dispose off excess runoff to foothills with non-erosive velocity. In case of most of the watersheds in the region consisting of mixed land use, all the areas do not contribute equally to non-point source (NPS) pollution. Numerous studies have indicated that for many watersheds, a few areas are responsible for disproportionate amount of NPS pollutant yield (Mass et al., 1985; Dillaha, 1990). In order to develop a comprehensive conservation plan to reduce or minimize the negative effects of sedimentation, accurate estimation of runoff, sediment and nutrient loss is essential.

Remotely sensed data provide the synoptic view of a large area with near real time spatial information on natural resources and physical terrain parameters, which are very useful for watershed management. Accurate characterization of land use/land cover, critical areas and soils in the study area, which are required for watershed simulation studies, can be done with less cost and time using remote sensing data (Tiwari et al., 1997). The geographic information system (GIS) is a computer-based design tool to collect, integrate, store, analyze, retrieve and display spatial geographical data to solve complex planning and management problems. Analysis of satellite imageries in GIS environment provides easier and quicker extraction of watershed parameters. When available spatial data are geo-referenced and put in the form of maps, GIS provides an alternative way of manipulating the input data by overlaying different layers and preparing input files for hydrologic models (Amore et al., 2004; Singh et al., 2006). Conceptual models which are also often called as “semi-physical model” like USLE, MUSLE and RUSLE provided fairly good estimate of potential sediment yield of small agricultural watersheds based on the parameters extracted using remote sensing and GIS techniques (Zhou and Wu, 2008; Tripathi et al., 2001; Terranova et al., 2009). Watershed response is the result of interaction among vegetation, management, soil, topography and climate. Therefore, the response of a watershed can be very well understood through application of a physically based distributed parameters hydrologic model using input parameters extracted from integration of remotely sensed imageries and GIS. In recent hydrological studies in India (Pandey et al., 2005; Tripathi et al., 2005; Behera and Panda, 2006; Jena and Tiwari, 2006), remotely sensed data and GIS technique were successfully used for watershed characterization and model parameterization. In the last two decades, inputs of remotely sensed data analyzed in GIS environment have proved to be effective in watershed development and management.

Evaluation of alternate management strategies only through field experiments is not feasible as it is time and cost intensive. Therefore, simulation modelling is one of the most effective techniques for developing and testing management options (Behera and Panda, 2006). In recent years, a large number of physical process based runoff and soil erosion models such as the WEPP (Flanagan and Nearing, 1995), SWAT (Arnold et al., 1998), AGNPS (Young et al., 1989), ANSWERS (Beasley et al., 1980), EPIC (Sharpley and Williams, 1990) were tested at field as well as at watershed scales. These physical process based models, often with an explicit attempt to describe runoff and erosion processes, are better equipped to evaluate the impact of management interventions and environmental change at a range of temporal and spatial scales (Yu and Rosewell, 2001). These models offer an up-to-date prediction technology to help make land and crop management decisions aimed at preserving land productivity and environment quality (Zhang et al., 1996). In this connection, the WEPP represents a new generation of erosion prediction technology (Yu and Rosewell, 2001), which is capable of handling complex hillslope and estimate soil erosion and deposition along the hillslope and channel. The model predicts runoff, erosion and sediment yield from areas ranging from a plot of a few m^2 to a small watershed.

The WEPP model was developed in United States of America (USA) but its performance has been tested worldwide. Most of the studies on the WEPP were related to evaluation of crop growing techniques and suggestions of vegetative measures for control of runoff and soil loss. However, studies on its applicability in high rainfall and high slope conditions, in watersheds treated with structural measures and also in Indian conditions are very limited. For application of the model in Indian conditions, its parameters are to be calibrated properly with local measured data to give reliable and accurate estimates. Considering these facts, one untreated small watershed, two micro watersheds treated with graded bunds and water harvesting tank, and eight research plots with different land uses were monitored during the monsoon seasons of the years 2003 and 2004, under the reported study.

With these facts in mind, the reported study was undertaken with the following specific objectives:

1. To perform calibration, validation and sensitivity analysis of the WEPP model for simulating runoff and sediment yield from hilly catchments under high rainfall and steep slope conditions
2. To assess the capability of the WEPP model for simulating runoff and sediment yield from the treated watersheds
3. To develop regression models for quantification of nutrients loss from the study watersheds
4. To develop vegetative and structural management practices for a typical hilly watershed affected by severe soil and nutrient loss due to traditional methods of cultivation.