Abstract

The vadose zone is the unsaturated zone between the ground surface and water table. This zone is of much importance as it acts as a link between surface water and ground water. Knowledge of soil moisture in this zone is very much essential to understand the meteorologic, hydrologic and agronomic process. Flow and transport in the unsaturated zone are more complex compared to saturated medium, as the pores in unsaturated zone are partly filled by air and partly by water. Most of vadose zone studies are done on agricultural plots where anthropogenic activities govern the vadose zone flows. Vadose zone studies in natural pristine conditions such as in forested areas where no anthropogenic activities are present are very limited that too in Indian conditions are rare.

The present research work deals with understanding of the flow behavior in the vadose zone in a small experimental forested watershed called Mule Hole. Mule Hole watershed is 4.5 km² and located in Bandipur National Park in Chamrajnagar District of Karnataka state, in the southern part of India. The forest is of deciduous type with 3 to 4 months of leafless dry period. The watershed has mean annual 25 years rainfall of 1120 mm and mean yearly temperature is 27°C. The rainfall pattern is bimodal i.e. it receives rainfall during South West Monsoon (June –
Abstract

September) and North East Monsoon (October – December) with dominant rainfall occurring during South West Monsoon. Human activity is minimal as watershed is a part of Bandipur National Park, dedicated to wildlife and biodiversity preservation. The watershed consists of around 80% of red soils, and black soil and saprolite covering the rest. The first part of the study involves soil moisture measurements by neutron probe and electrical resistivity measurements by geophysical method and their linking, i.e. developing volumetric soil moisture vs electrical resistivity relationship. The second part of the study involves application of neutron probe soil moisture measurement in identifying relationship between soil and erosion in the watershed. The third part involves development of two dimensional (2D) vadose zone model for watershed and validating it with measured data. The last part involves development of three dimensional model of watershed and validating it with observed data.

Vadose zone is briefly described in chapter 1 along with its governing equations. Different soil moisture measurement techniques including invasive and non-invasive ones are also discussed. Different vadose zone modeling software which are public domain as well as commercial ones are also discussed. The chapter ends with organization of this thesis.

Chapter 2 reviews relevant literature related to this study with focus on soil moisture measurement techniques and vadose zone flow modeling. Different soil moisture measurement techniques, their applications and limitations are reviewed. In the soil moisture measurement techniques, invasive and non-invasive types are reviewed. In the modeling part, different vadose zone models for 2D and 3D flow along with its applications and limitations are reviewed. Also a brief review about application of HYDRUS 2D/3D model is done which is used for the vadose zone modeling in this thesis.
Chapter 3 introduces study area Mule Hole watershed, which is a forested watershed located in Bandipur National Park, Karnataka, India. The watershed has mean annual 25 years rainfall of 1120 mm and mean yearly temperature is 27°C. The watershed has average regolith thickness or vadose zone of 17 m with roots of the trees able to penetrate up to groundwater. A toposequence T1 is identified in the watershed which has red soil – black soil confluence where soil moisture measurements and electrical resistivity measurements are carried out. The toposequence consists of 8 layers with organic layer forming the top layer followed by 3 red soil layer with 2 black soil layers intruding from stream into red soil layers and sandy weathered horizon at base of red and black soil. Also a sandy horizon at the top of black soil. Soil moisture measurements with neutron probe and electrical resistivity measurements with electrical logging tool which are done on toposequence periodically for two years are explained and the data are presented in this chapter. These data are used for validation of vadose zone models.

Chapter 4 discusses in detail about comparison of electrical resistivity by geophysical method and neutron probe logging for soil moisture monitoring in a forested watershed. The electrical resistivity data and soil moisture data are compared for different soils and existence of relationship between them are studied and discussed in this chapter. For the red soil, existence of relationship between volumetric soil moisture content and electrical resistivity is found.

Chapter 5 discusses soil moisture measurements as a tool to study erosion processes in forested watershed. Hydrodynamic behavior of the red soil – black soil system at toposequence T1 is studied using neutron probe soil moisture measurements. Two distinctive types of erosional landforms have been identified at T1 viz, rotational slips (Type 1); seepage erosion (Type 2),
which are highlighted by neutron probe soil moisture measurements. Based on the observations relative chronology of formulation of different soil horizons are studied, which guided in developing four-stage model showing the relative chronology in the recent formation of the soil cover at downslope.

Chapter 6 discusses application of 2D vadose zone modeling using HYDRUS – 2D model at two experimental sites in forested watershed where soil moisture monitoring and groundwater monitoring have been conducted. At the first site, which is toposequence T1 in the forested watershed, where soil moisture measurements are done, three case studies for comparison of daily scale data with hourly scale data and effects of internal layering by clubbing red soil layers and black soil layers to equivalent red soil and black soil layers respectively are performed. The model is run for two years. In that, first year results are used for calibrating the model where measured soil moisture content data are used to get soil hydraulic parameters for all the three cases by inverse modeling using Marquardt – Levenberg algorithm which is a part of HYDRUS 2D. The parameters thus obtained fall under particular soil range and performed efficiently in predicting soil moisture content. The second year results of model run is used for validation of the model in all the three cases where simulated soil moisture content is compared with measured soil moisture content. It is found that model is performing well and match between measured and simulated soil moisture contents is good in all the three cases. It can be said that having hourly scale data with detailed layering information is always advantageous in modeling soil moisture content. But, in absence of hourly scale data or finer scale data and absence of detailed layering information, the soil moisture model can also perform well. The scale of data and detailed layering information has minimal effect on soil moisture modeling. At the second
site ERT profile near the watershed outlet has five monitoring wells are available and all layering information regarding regolith and hard rock layer distribution profiles. The soil hydraulic parameters obtained at toposequence T1 for soil and sandy weathered horizon are used and tested at this site to simulate the groundwater levels. The parameter for rock layer is estimated by testing different hydraulic parameters from HYDRUS database. The results are validated using observed groundwater levels at the site. The results show significant match between observed and simulated groundwater levels.

Chapter 7 discusses 3D modeling of Mule Hole forested watershed using HYDRUS – 3D model. A three layer model of Mule Hole along with its topographic details is modeled. The layering information is derived from geophysical study done at 12 Electrical Resistivity Tomography (ERT) profiles distributed in the watershed. The three layers considered are top soil layer followed by sandy weathered layer and bottom rock layer. Anisotropy in hydraulic conductivity, root water uptake and sloping water table are introduced to make the model more realistic. Soil hydraulic parameters obtained during 2D vadose zone modeling of toposequence T1 are used initially for soil and sandy weathered layers and are subsequently tuned to make model more efficient. Different scenarios are considered to test flux as well as constant head boundary conditions and effect of different porosities for rock layer. The model is run for 7 years and model simulations are validated with observed groundwater levels from monitoring wells across the watershed. The result shows good fit between simulated and observed groundwater levels especially for monitoring well which has shallow groundwater level. It is found that porosity in the rock layer is not uniform and there exist different porosities for the rock layer across the watershed. Also the distribution of sandy weathered zone requires improvement. The model is
also able to predict ET closer to ET predicted by COMFORT model which was developed earlier. Also the model shows rise in groundwater fluxes as groundwater starts replenishing. Over all, the 3D model of Mule Hole watershed in HYDRUS – 3D worked well with satisfactory results and HYDRUS – 3D can be used for modeling small forested watersheds.

Chapter 8 concludes the study and discusses the further scope of the work.