## Watershed Hydrology

*a) Water Balance Studies in Small Experimental Watersheds*

In order to characterize the geometry of the regolith as well as the directions of the fractures or fissures in the protolith, a combination of two surface geophysical methods: electrical resistivity tomography (ERT) and magnetic resonance soundings (MRS) were made in a small experimental watershed set up in a sub-humid tropical climate (~1200 mm of yearly rainfall) in the western Ghats (Kabini river basin), south India with gneissic substratum. These methods have helped in characterizing the thickness of these layers and spatial variability, favorable locations for indirect recharge in the fractured-fissured zone and hydraulic conductivity variations.

The presence of spatial variability of stratification (variation of the thickness of the subsurface layers) and the variation of hydraulic conductivity within the fissure zone of protolith were found to be important for assessing the uncertainty in the groundwater flux in this zone. Studies were made to: (i) develop a method to generate the non-Gaussian random fields, which are conditioned to the 2-D profile data available from ERT inversion, (ii) analyze the effect of the topological uncertainty and the conditional modeling of the random field on the probabilistic behavior of the groundwater flux through the fissured zone in a sub-zone of the watershed. The results indicated that the effective steady seepage flux is reduced due to the spatial variability of the layering. The prediction uncertainty of groundwater flux was not as high as the uncertainties in the thickness of the layers.

Further, field experiments were conducted in small experimental Moolehole watershed, located in the Bandipur national park, which is mainly a semi deciduous forest. The area of the watershed is 4.5 sq km and the annual average rainfall is about 1200 mm. 'All parameter' weather station has been setup to gather the weather data. Stream gauging and also the water sample data were collected for 3 years covering monsoon, non-monsoon and also low and high rainfall years. The gathered data was analyzed using the SWAT model to build the rainfall-runoff relationships and also different components of the water balance (Figure 65). Also the water samples were analyzed for their chemical signature so that it could be useful for hydrograph analysis.

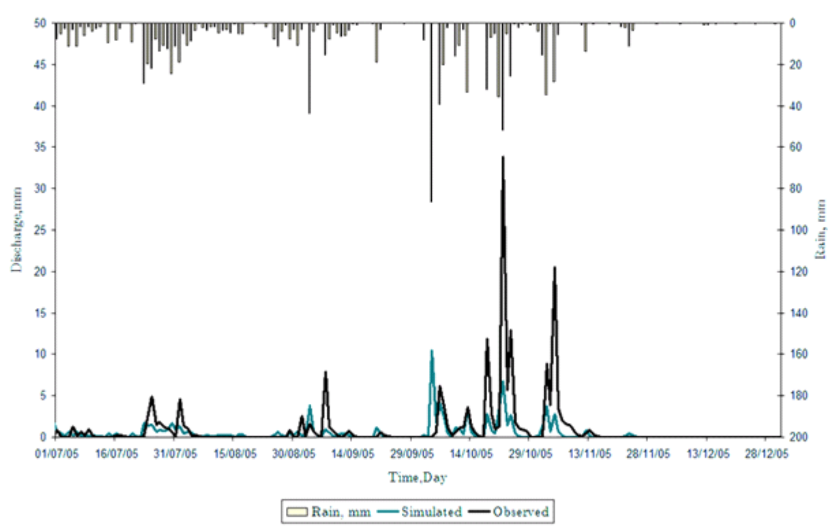


**Figure 65: SWAT: observed vs. simulated discharge**

*b) Root Zone Soil Moisture Estimation at Watershed Scale using Satellite Retrieval, Assimilation and Modeling*

Soil moisture in the top few meters of the earth's surface is widely recognized as a key parameter in numerous environmental studies, including meteorology, hydrology, agronomy and climate studies. It is this soil water that controls the success of agriculture and regulates partitioning of precipitation into runoff, evapotranspiration and groundwater storage. Near-surface soil moisture (i.e. in the top 50 mm of the soil profile) is particularly complex and highly variable. The main factors controlling the spatial and temporal dynamics of soil moisture include topography, soil, land use, vegetation, and solar radiation. Satellite remote sensing and ground point measurements present two techniques for obtaining soil moisture observations. While point measurements allow for the collection of high resolution data through the soil profile, it is limited to a local scale due to instrument and logistic constraints. On the other hand satellite remote sensing is limited to the top few centimeters but yields good spatial information over large areas. The only satellite systems that currently meet the spatial resolution and coverage required for watershed management are active microwave sensors. The magnitude of the SAR backscatter coefficient is related to surface soil moisture through the contrast of the dielectric constants of bare soil and water. The perturbing factors affecting the accuracy of surface soil moisture estimation are soil surface roughness and vegetation biomass. Studies, particularly in the past decade, have resulted in a multitude of methods, algorithms, and models relating satellite-based images of SAR backscatter to surface soil moisture. However, no operational algorithm using SAR data acquired by existing space borne sensors exists.

To fully meet the requirements for soil moisture information for watershed management, it is necessary to combine the horizontal coverage and spatial resolution of remote sensing with the vertical coverage and temporal continuity of a soil moisture simulation model. Such models are generally called Soil Vegetation Atmosphere Transfer (SVAT). The advantage of SVAT models is that profile soil moisture is estimated to several meters depth on hourly, daily or monthly time steps. One disadvantage of SVAT models for monitoring regional soil moisture condition is that they are one-dimensional, and without remotely sensed inputs, they are rarely capable of producing a distributed map of soil moisture. There is a potential to retrieve root zone soil moisture from SAR products by combining the SVAT models with remote sensed data through assimilation approaches.

Using an extensive ground based monitoring system in a watershed the soil moisture can be measured at watershed scale, which offers spatially and temporally consistent ground truth information coincident with Envisat and Radarsat overpasses to test the many existing retrieval algorithms for the effects of soil, topography, roughness, various types of vegetation. As part of the ongoing research project funded by ISRO-IISc STC, an experimental watershed (7 $km^2$) in the southwest of Karnataka is being monitored and modeling studies along with assimilation approaches are being carried out. Future scope includes combining the remote sensing data sets from multiple satellites (ENVISAT & RADARSAT) for modeling the catchment scale soil moisture in vegetated semi-arid landscape (Figure 66). India is in the process of launching RISAT-SAR for soil moisture mapping. The calibration and validation experiments would lead to development of an effective operational algorithm for retrieval of surface soil moisture and modeling the root zone soil moisture at watershed scale.

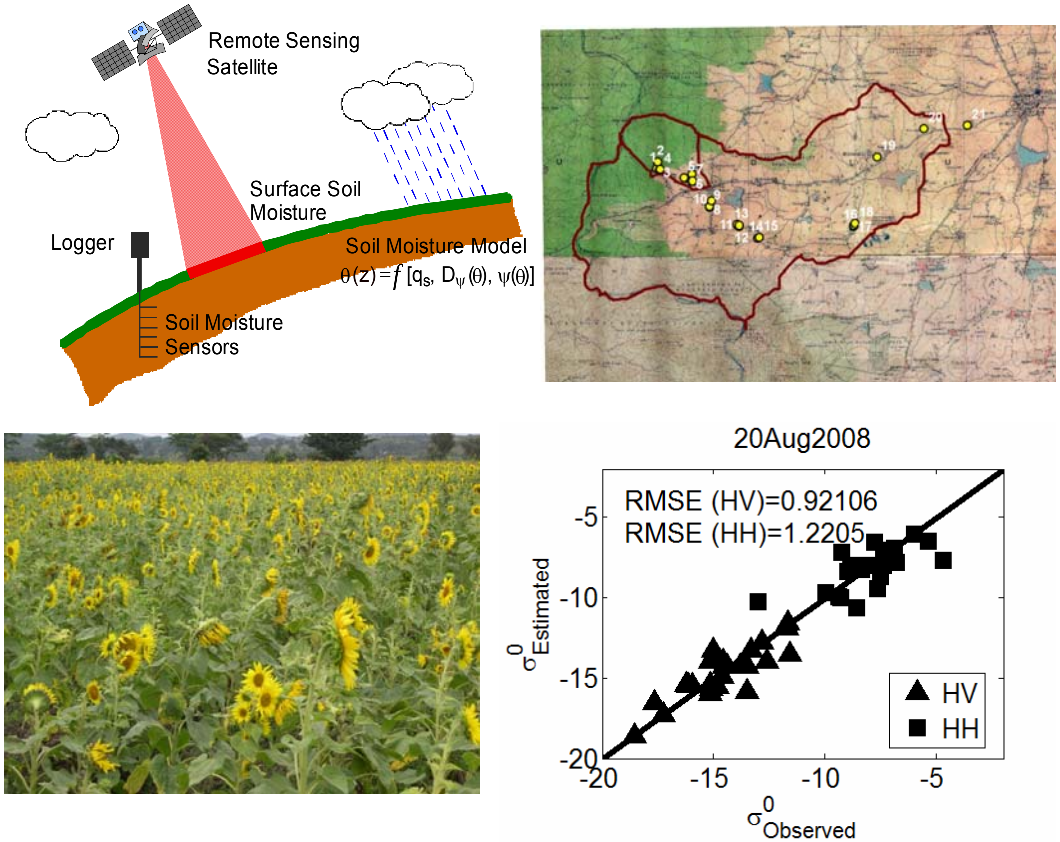


**Figure 66: Soil moisture retrieval experiments using ENVISAT and field experiments in the Maddur watershed (~7 Km$^2$).**

*c) Groundwater Recharge Estimation*

Understanding of climate variability and anthropogenic change impacts on groundwater resources – related to availability, vulnerability and sustainability – is critical. Studies have been carried out in understanding the various controls on the dynamics of groundwater recharge and discharge in the watersheds in the Cauvery basin, located in South India to understand some of these effects and their sensitivity in this basin to the type of climatic regimes viz. humid, transition or semi-arid. The parts of this basin provide a unique study areas comprising of the various climatic zones. Dominant patterns of climate and land use controls in groundwater for a semi-arid sub-basin are investigated for assessing inter- year and decadal variations in rainfall. The distributed groundwater model (MODFLOW) is used for the simulation of the groundwater system in the Gundal sub-basin (~1000 km$^2$), which is intensively cultivated through groundwater in the recharge and intermediate zones. Using the remotely sensed data a methodology is evolved, which is used for conditioning the parameterization of the regional groundwater system in this structurally controlled sub-basin. Simulation approach is used for recharge and groundwater balance over three decades. The modeling also helped in assessing the boundary fluxes due to intense use of groundwater for irrigation in the last decade. Remotely sensed data combined with SWAT model is used for evaluating water balance in the semi-arid catchment of Arkavati sub-basin in the Cauvery river, South India during last two decades under changing land use practices. The applicability of combining SWAT and MODFLOW models for regions with groundwater irrigation is tested.

*d) Sustainable Groundwater Use Under Climatic Variability and Land Use Change*

In the last two decades, significant changes have taken place in India on the use of groundwater for irrigation, and currently large part of irrigated agriculture depends on groundwater pumping. This has resulted in systematic changes in land use practices especially in the upland areas (recharge areas of river basin), which were not part of the green revolution. An examination of the spatial trends in groundwater level variations, in several regions indicate that groundwater is declining in spite of recharge occurring after post-monsoon season, which is attributed to anthropogenic pressures. The impact of land use/land cover (LU/LC) changes in certain settings is found to be much stronger than the climate variability and hence studies have been initiated to characterize dominant patterns of climate and land use controls on the groundwater system for developing sustainable groundwater resource programs. The geology of central and peninsular India is different and far more complex. The water-bearing and conveying properties of these aquifers vary greatly even over small distances, making scientific resource management critical and difficult at the same time. Groundwater data are still often inaccessible or unavailable at the smaller scale to alleviate the current constraints impeding the planning and decision.

Studies have been initiated through two research projects in the last few years. The focus of these projects is to characterize the fractured rock aquifers for recharge & discharge behavior. Taking further the models developed it is envisaged to develop a science-based decision support tool for planning and decision that can provide groundwater balance at village/ small watershed scale due to climatic, geomorphological and land use controls. Figures 4.67 and 4.68 give the spatial and temporal variations of groundwater balance components at village scale as modeled using the village-wise sustainable ground water assessment model, which considers the climatic and land use effects. The developed tool would be extensively tested for regions with varied climatic, soil, geological and land use settings, in various places in the Karnataka state.

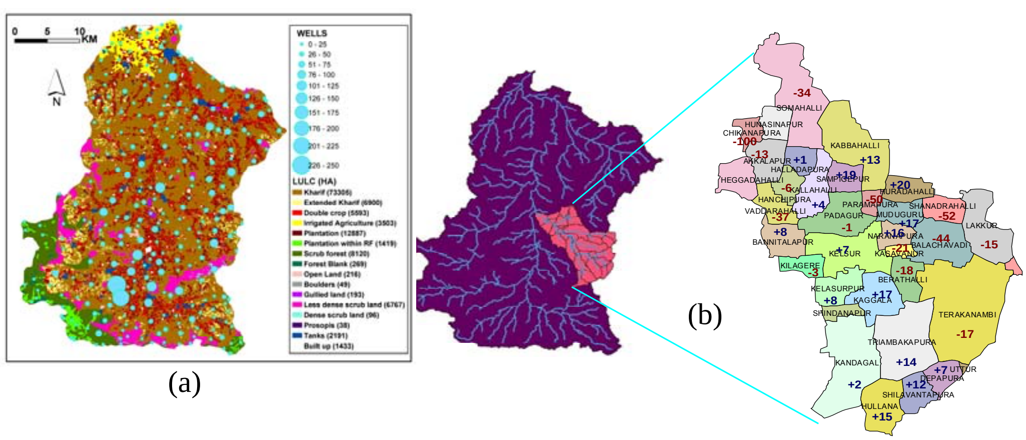


**Figure 67: (a) Land use and land cover map from multi-season imagery of IRS-1C with bore wells in villages in 2008 of Gundal basin (~ 1000 Km$^2$) in the Chamarajanagar district, Karnataka. (b) Spatial distribution of groundwater balance (mm) modeled in each village of the Terakanambi watershed (~80 Km$^2$) for 2008.**

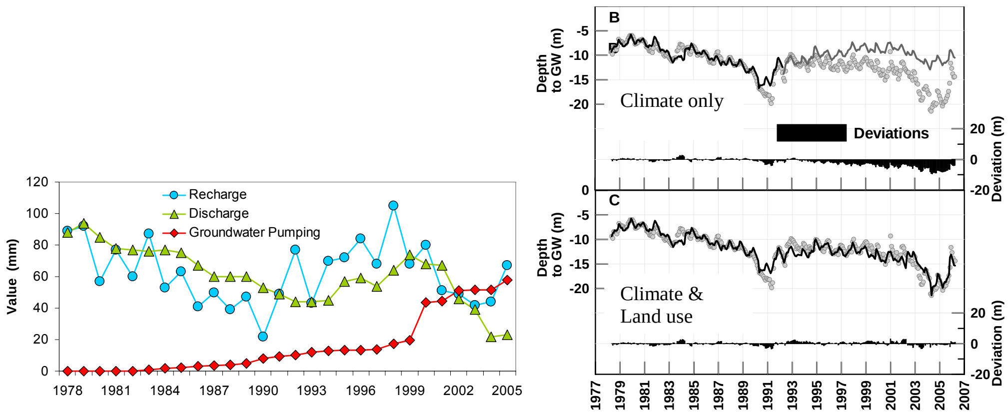


**Figure 68: (A) Temporal patterns of recharge, discharge (baseflow & underflow) and pumping in the Terakanambi village (~25 $Km^2$) during 1978-2005. (B) Simulations of groundwater levels using the model due to climatic variability alone during 1991-2005. (C) Simulations of groundwater levels using the model due to climatic variability and land use changes during 1991-2005.**