Location:	Krishna river basin, India
Contractor:	IWMI, Colombo, Sri Lanka
Period:	2001 - 2003

Scope of the project

Because 'losses' from irrigation can be potentially recycled and the water consumed by the various agro-ecosystems is not longer available for usage by other sectors in the basin, water use deserves to get more attention in the context of basin management. Water depletion by evapotranspiration in the rural areas is by far the largest water consumer. This is the first WaterWatch study with the new MODIS satellite that demonstrates how monthly spatially discretized water use data can be obtained at the scale of entire river basins systems. This technology was applied for the entire Krishna river basin in southern India (figure 1). The study is part of the IWMI paradigm research program on losses and recycling of water resources.

Study approach

Two seasons were analysed: the Rabi-season 2001-02 and the Kharif-season 2002. The Rabi-season is the dry season and runs from approximately November to April; Kharif covers the period May untill October and is dominated by monsoon rains. First, SEBAL was applied to calculate daily ET_{act} and biomass production on individual MODIS acquisition dates (n=15). Multiple images per month were used to exclude cloud effects to the maximum extent possible. The output composites and average monthly meteo-values were used to apply SEBAL on a monthly basis. A Digital Elevation Model (DEM) perpared by the USGS was applied to correct for elevation and slopes in the mountainous parts of the basin.

Figure 1: location of the Krishna river basin in India; the basin is situated in three Indian states: Andhra Pradesh, Karnataka and Maharashtra

For the Kharif 2002 season a different approach was followed as no cloud free (or even partially cloud-free) images could be acquired. 10-Day composite images from the French SPOT-Vegetation satellite were used to calibrate a non-linear relationship between the surface resistance to evapotranspiratoin r_s and NDVI for two MODIS images on the start (April 23) and at the end (October 29) of the Kharif season. This relation was used to calculate monthly r_s-values during the Kharif-season using the SPOT-Vegetation-based NDVI values.

For the hydrological interpretation of the ET grids, the Krishna basin was divided into 56 sub basins (red lines in Fig. 2). The DEM was used to determine a hierarchical stream flow pattern and sub basin structure. For each sub basin the yearly water balance was established according to:

$$Q_{out} = P + Q_{in} - ET$$

where, Q_{out} is the outflow of the subbasin, P the precipitation, ET the *actual* evapotranspiration and Q_{in} is the outflow of the upper 2 or more subbasins. By absence of data, the water balance does not include storage in reservoirs, groundwater extraction and changes in the soil water profile.

Results

A graph of the temporal variation of monthly ET values for forest, irrigated area and bare soil is presented in Fig. 3. Forests have high ET throughout the year, though ET is lower during winter time when less solar energy is available. From the ET-curve for irrigated areas the two seasons can clearly be distinguished: rabi (December – April) and kahrif (July – November). Between the two seasons (approx. May- August), the curve closely follows the curve of bare soil, but is slightly higher due to residual soil moisture. To view the temporal changes spatially please click here.

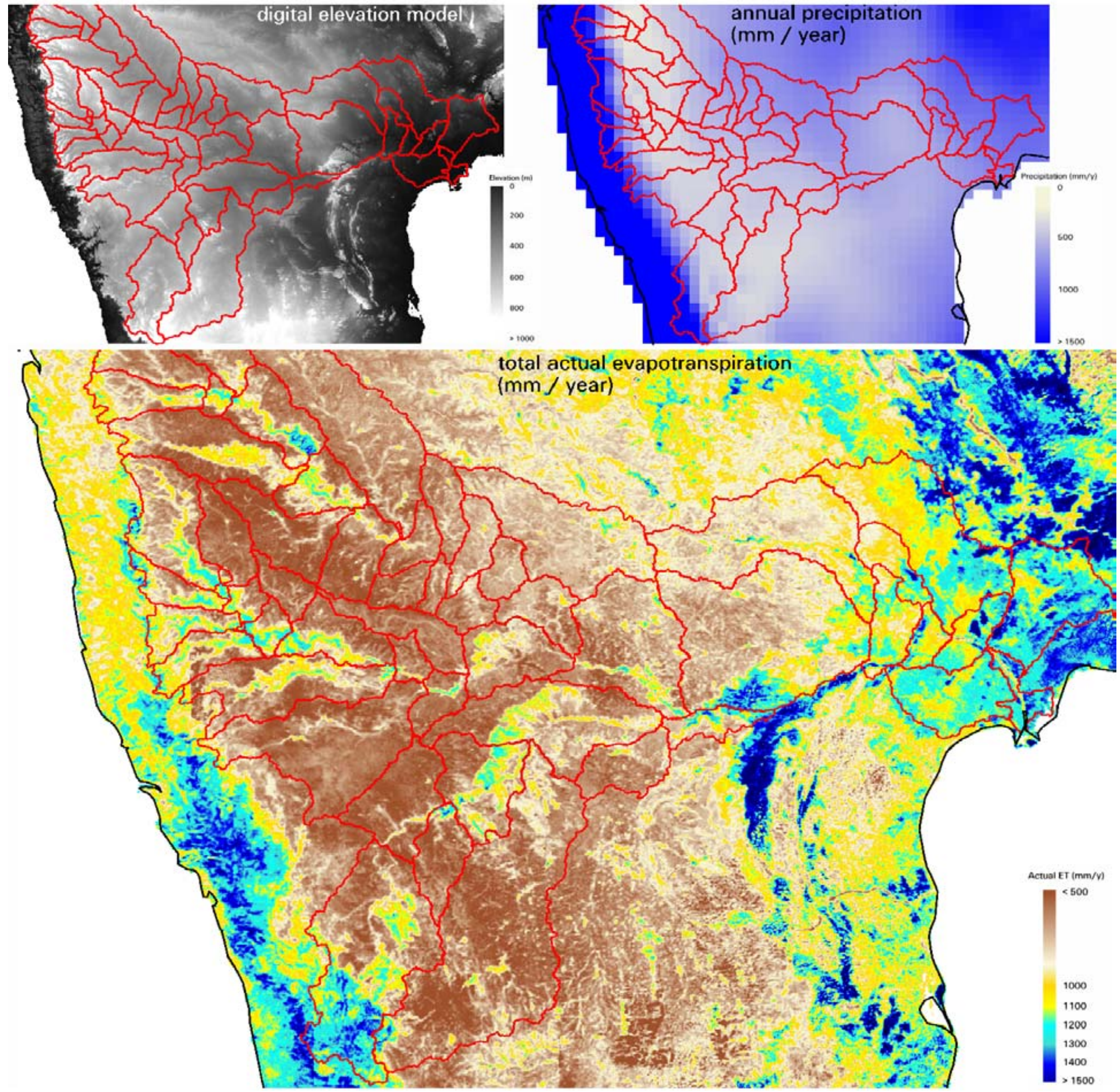

Figure 2: Digital Elevation Model (DEM), annual precipitation (IWMI Water and Climate atlas) and annual actual evapotranspiration for the period November 2001 – October 2002 (SEBAL)

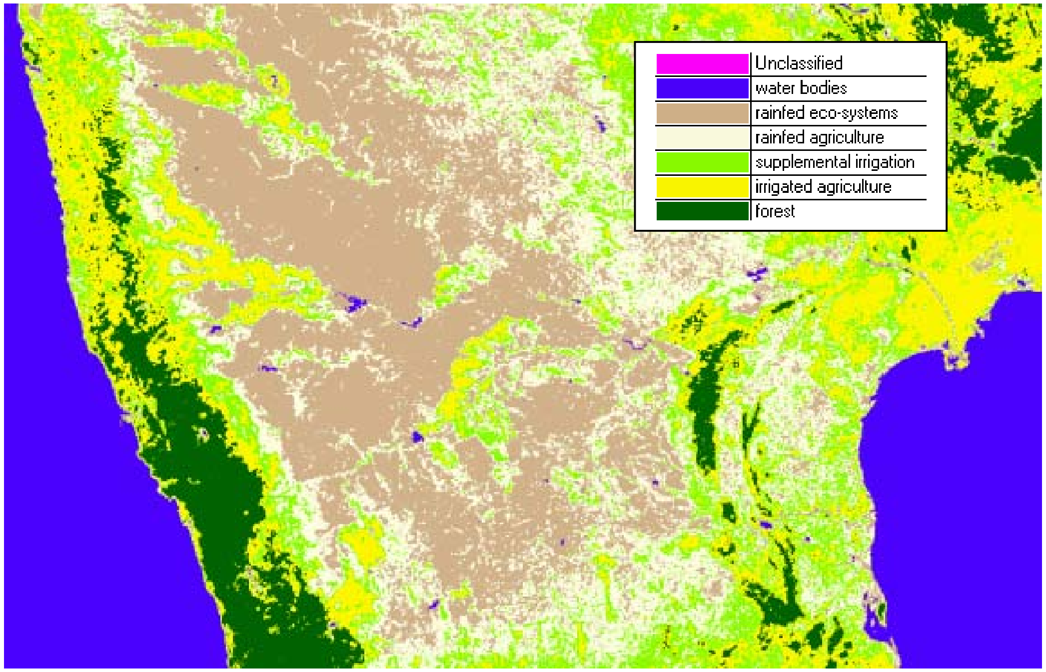

Figure 4: Land use classification based on MODIS and SPOT vegetation NDVI maps

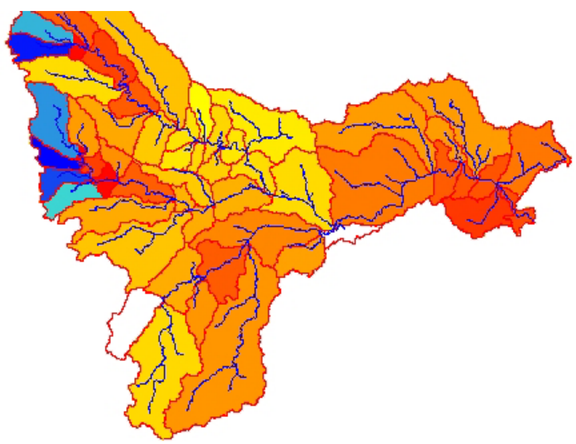

Figure 5: Rainfall surplus (gross precipitation – actual ET) for all sub-basins of the Krishna during 2001-02

The ET data can also be organized by sub-basin and by land use type. The aerial average ET for the entire Krishna basin was found to be 805 mm/yr. This is somewhat lower than the irrigated Indus Basin (955 mm/yr) and in Sri Lanka (1279 mm/yr). A lower ET value is in agreement with the large-scale presence of rainfed agro-ecosystems in the semi-arid tropics (Fig. 4 and Table 1).

The rainfall has been taken from the IWMI Water and Climate Atlas. This is

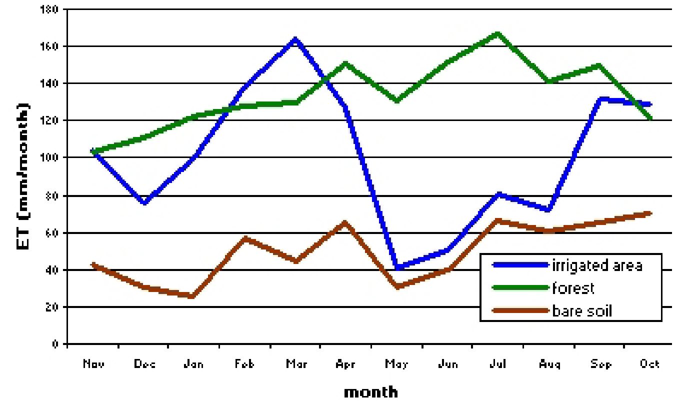

Figure 3: Temporal variability of water depletion of the major agro-ecosystems

the longer-term average rainfall across the basin. The aerial average value is 636 mm and this is less than the 805 mm of ET. The annual rainfall during the time frame 2001/02 investigated is drier than average, but the extent is not very well understood. Fig. 5 demonstrates the areas that generate runoff (surplus positive) and the areas that deplete the water resources (surplus negative). Except the Western Ghats mountainous (blue colored subbasins in Fig. 5), ET exceeded precipitation (yellow, orange and red areas), which points out that soil moisture and groundwater is exploited at a large scale. The irrigated areas, such as the Krishna basin and the Tungabhadra, have the lowest rainfall surplus (red areas).

Table 1: land use classes and area

land use class	Prec. mm	ET_{act} mm	area (km^2)
rain fed eco-systems	531	655	114,664
rain fed agriculture	668	808	67,314
supplemental irrigation	867	955	36,724
irrigated agriculture	1172	1150	37,777
forests	1759	1325	7,731

Conclusions

Information on water consumption is key for (i) relating water supply to water use at a multitude of spatial scales to quantify the recycling factor, (ii) water productivity for various agro-ecosystems, (iii) real water saving programs to achieve less water depletion at river basin scale through ET reduction programs and (iv) estimate streamflow from rainfall surplus and assess whether environmental flow requirements for water pollution and discharges to coastal zones including wetlands are met.

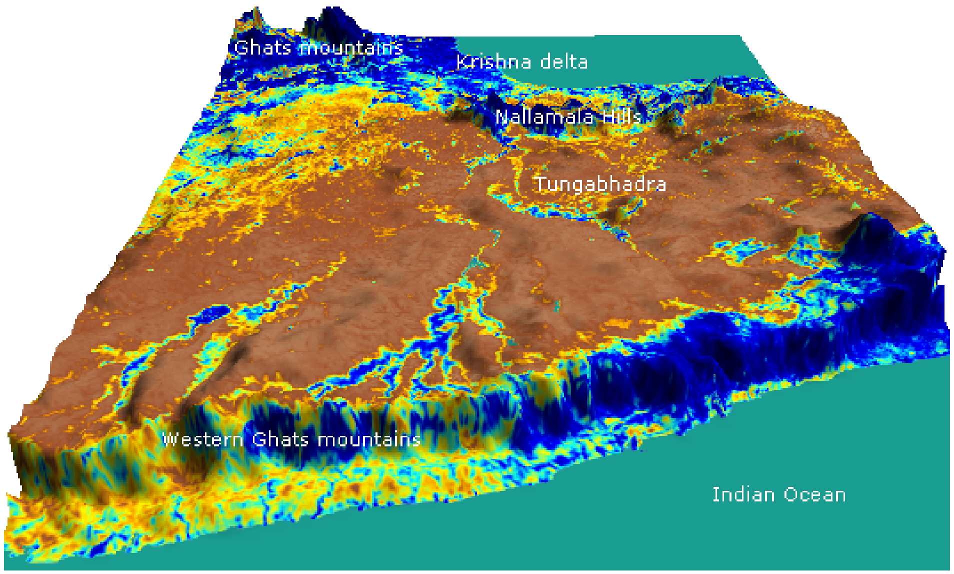

Figure 6: 3D-view of total actual evapotranspiration between November 2001 and October 2002

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