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Water for everyone

Biniam Ashagre, Cranfield University and University of Exeter; Sue White, University of Cranfield; Andrew Balmford; Neil Burgess; Felix Mtalo, University of Dar es Salaam; Shadrack Mwakalila; Philip Platts; Marije Schaafsma; Celina Smith, Cranfield University; Ruth Swetnam; and Patrick Valimba, University of Dar es Salaam.

Around one in ten Tanzanians source their water from rivers originating in the Eastern Arc Mountains (EAM). In Dar es Salaam, the main water source is the Ruvu River, flowing from Uluguru Nature Reserve, from which around 300 million litres are extracted daily. Moreover, at least half of Tanzanian hydroelectricity is generated from EAM rivers.

The EAM contain moist forest assemblages as well as large areas of miombo woodland at lower elevations and on drier leeward aspects. These biomes are believed to play significant roles in the regulation of hydrological flow, flood mitigation and soil conservation. Despite this hypothesised importance, the interactions between river flow, habitat type and land use are not well understood. To explore these complexities, the Valuing the Arc programme (VTA) parameterised a detailed, daily water model called SWAT to model the hydrology of two focal catchments: the Sigi in Tanga Region and the Ruvu in Morogoro region. In addition, we developed a broader scale, monthly model (WatR) to tentatively explore hydrological flow across the wider VTA region.

Detailed model

The Soil and Water Assessment Tool (SWAT) is a physically-based watershed model, operating on a daily time-step. SWAT implements two phases in the simulation of hydrology: the land phase and the routing phase. The model describes the hydrological response of each land parcel according to detailed information on local climate, topography, soil and land cover. Plant growth, rooting depths and agricultural practices were also considered, in order to determine the relative proportions of water reaching the river channel via surface runoff, movement through the soil column or baseflow (via ground water). The second modelling phase routes water though the river network, based on what is contributed by each sub-basin, subject to local abstraction and irrigation for cash-crops such as rice, sugar and vegetables.

In the Ruvu catchment (14,000 km^2), SWAT was calibrated using daily rainfall data from sixteen weather stations spanning the years 1995-2004, as well as information on river flow from two points along the Ruvu river for the same time period: Kibungo (gauge 1H5) and Morogoro Bridge (1H8, the watershed outlet). Model performance was good at 1H8 and moderate at 1H5. Independent testing in the Sigi catchment, which is much smaller (<1000 km^2) and subject to different land use and rainfall patterns, suggested a stable parameterisation, able to cross-predict between catchments. This in turn suggested a stable parameterisation, able to cross-predict between catchments and under scenarios of land cover change.

Broad-scale model

The broad-scale model ('WatR') uses similar principles to SWAT, but is less rigorously process-based, has larger sub-basins, and uses a monthly – rather than daily – time-step. Direct overland runoff, which leaves the sub-basin within one month, is a function of soil type and land cover. If the remaining water is insufficient to meet the transpiration requirements of plants, then moisture is absorbed from the soil. Conversely, if transpiration requirements are fulfilled, then water infiltrates the soil column. When soils are fully saturated, surplus water is either discharged through the soil (leaves the sub-basin within two months), or infiltrates the soil to recharge groundwater, discharging more slowly to the main river channel. As in SWAT, the contribution of each sub-basin is routed through the river network, adjusting for local abstraction and irrigation.

This WatR procedure was implemented using widely available spatial datasets, allowing for rapid assessment of hydrological flow across the entire watershed region of the EAM (Figure 1). The model was calibrated in the Ruvu catchment, favouring accuracy in dry season flow at the expense of some over-prediction (still within the observed range) during the wet season. Annual flow at Morogoro Bridge was estimated at 1.7-1.9 × 10^9 cubic metres per year (mean observed, 1995-2004: 1.6 × 10^9 cubic metres per year). Independent testing in the Sigi catchment found that the same model parameters again estimated annual flows reasonably well (1.6-1.7 × 10^8 cubic metres per year), but that seasonal flow was more uncertain.

The role of forest and woodland

The Ruvu catchment covers an area of 14,000 km^2, of which 2-3% is forest and 32% is open or closed woodland (miombo). To determine the role of these woody habitats in the regulation of hydrological flow, we modelled the response of Ruvu river flow at Morogoro Bridge (1H8) to scenarios of uncontrolled agricultural expansion, whereby forests and/or woodlands were converted entirely to cropland (maize and beans). Uluguru Nature Reserve, which contains the majority of forests in the catchment, has recently been established and governance is strong. In the absence of this protected area, uncontrolled encroachment may well have occurred; forests outside reserve boundaries have already been cleared. As elsewhere in the EAM, woodland habitats are largely unprotected; we estimate that 43% were lost between 1975 and 2000.

Forest ecosystems have high transpiration rates compared with maize or bean fields. Consequently, conversion to cropland was predicted to result in a 6% (SWAT) or 5% (WatR) increase in total annual flow volumes towards Dar es Salaam. Both modelling approaches predict that the much of this additional water would be discharged rapidly after falling as rain, mainly in the wet season, and so reach the main river channel within a matter of days (SWAT; <1 month, WatR). Conversely, during the dry season when there are fewer rainfall events and water shortages are most acute, both models predict that forest removal would result in a reduction in flow (Figures 2 and 3).

This is because interception of rainfall is higher in forests than in cropland (less water reaches the ground), and because more water infiltrates forest top soils due to

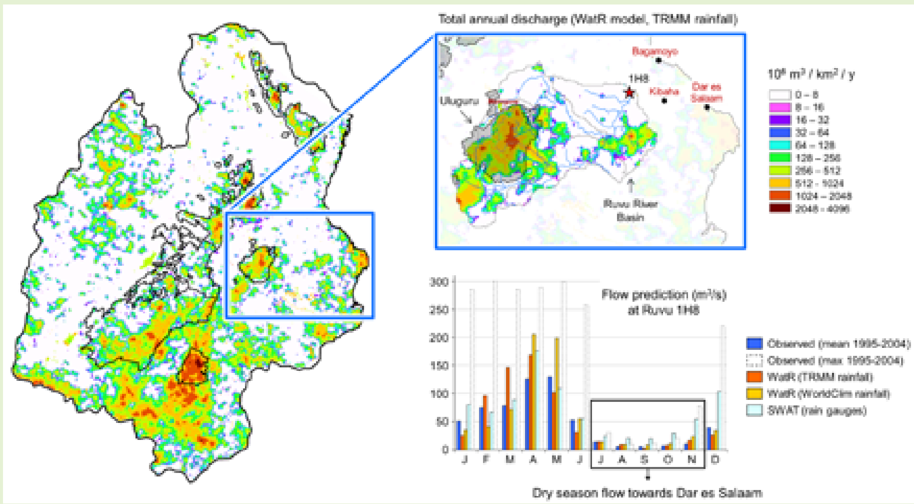


Figure 1. Broad-scale model (WatR) predictions for total annual in the Ruvu catchment (left) and the wider Valuing the Arc study region (right). Bar chart compares WatR results (rainfall from TRMM or WorldClim climatologies) against observed flow at Morogoro Bridge (gauge 1H8), as well as against the more detailed SWAT results (aggregated from daily to monthly values).

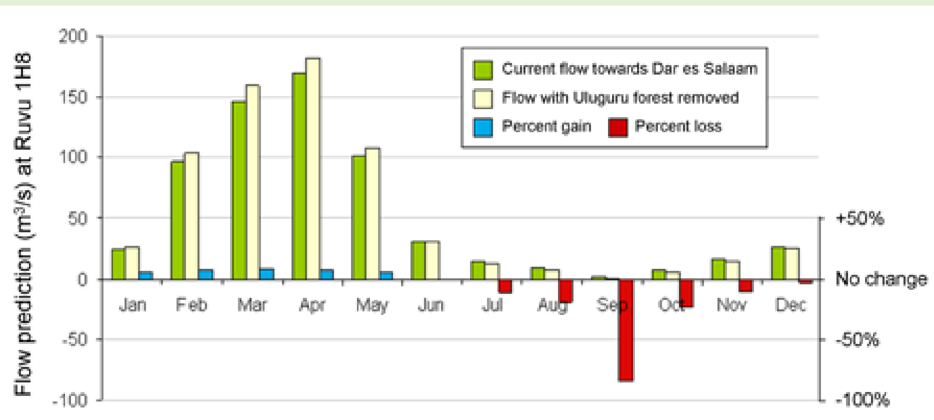


Figure 2. Broad-scale model (WatR) predicts that conversion of forest to cropland in Uluguru would result in reduced Ruvu River flow towards Dar es Salaam during the driest months of the year potentially leading to water shortages, whilst increasing peak flow during the wet season potentially leading to erosion and flooding

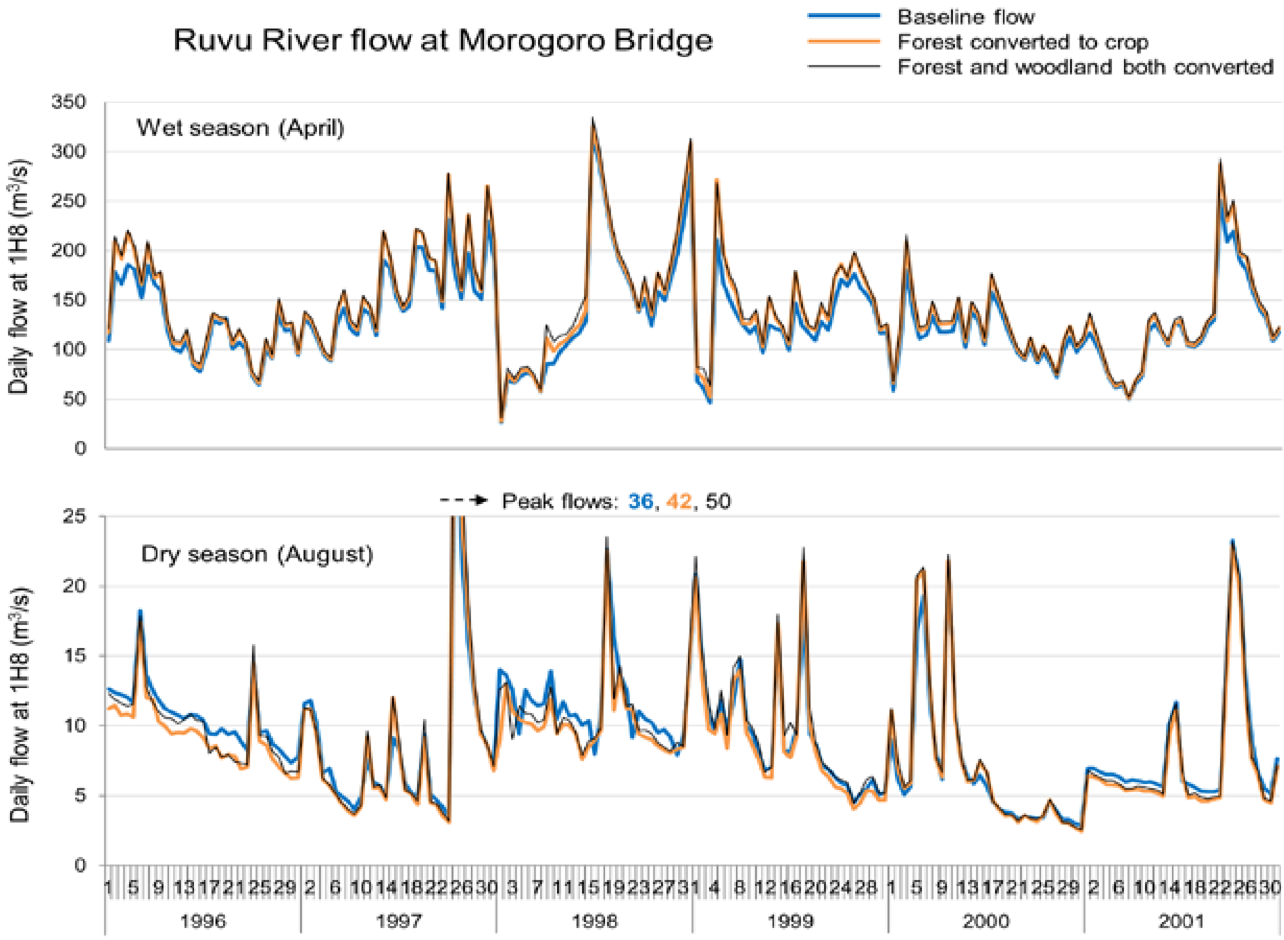


Figure 3. Daily SWAT model prediction of Ruvu River flow towards Dar es Salaam for two representative months in the wet (upper) and dry (lower) seasons. Forest and/or woodland clearance results in higher peak flow during the rainy season and lower flow during dry season.

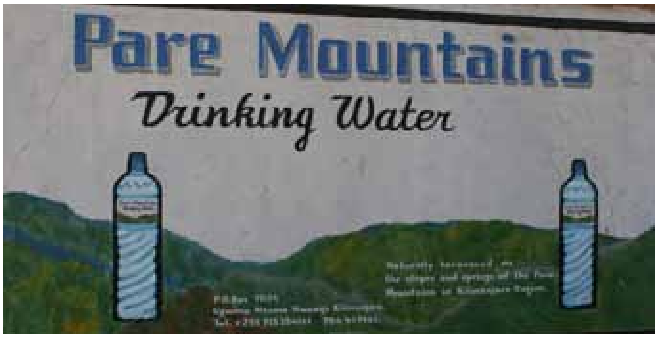
their higher porosity, combined with lower evaporation rates from the soil surface compared with cropland. Thus, without forest vegetation, less water infiltrates the soil to recharge ground water, reducing baseflow throughout the year. The amount of water reaching the ground water is, however, limited in forest ecosystems by higher transpiration rates and the fact that subsoil can be accessed by the deep-rooted trees.

A qualitatively similar phenomenon was observed in the case of woodland conversion (Figure 3). The removal of woodlands, however, had a slightly lesser impact on dry season flow, despite the large difference in land area involved (~4500 km^2 for woodland versus just ~300 km^2 for forest), highlighting the importance of mountain forests in the regulation of hydrological flow.

Conclusions

The complexities outlined above show that the role of forests and woodlands in hydrology is not straight forward, and that understanding this relationship is heavily reliant on detailed and site-specific datasets. Nonetheless, both our broad-scale water model and SWAT suggest that, on balance, the loss of woodland and, especially forest, results in more extreme flow patterns. The people most acutely affected are communities immediately downstream of the conversion, but changes in flow would also be felt in more distant towns and cities.

During periods of increased peak flow, as a result of forest or woodland loss, potential impacts include flooding, top soil erosion, loss of soil fertility, declines in fish populations, increased sedimentation in rivers and reservoirs, and power cuts due to reduced hydroelectric power generation. Impacts during the dry season(s), when already scarce water resources are further reduced, are clear: less potable water from both taps and streams, reduced crop yield (less water



for irrigation) and increased pressure to abstract from deep aquifers using bore-holes, compromising the long-term sustainability of the water resource.

These findings corroborate a widely held belief in Tanzania that deforestation, combined with increased abstraction by agriculture and people, has contributed significantly to reduced dry season flows toward Dar es Salaam. Furthermore, the cloud forests of the Uluguru and elsewhere in the EAM are known to intercept mist and fog, adding more water to the local system, which then infiltrates the soil for slow discharge through the soil and rocks. Since this process is poorly represented in the models described above, the forests of the EAM are likely to play an even greater role in enriching and regulating water resources than shown here.

Sanje falls, Uzungwa, Kilombero catchment

Uluguru, Ruvu catchment

Uluguru, Mgeta River, Ruvu catchment

Uluguru Mountain near Mgeta

Small vegetable farm near Kilombero: lettuce growing in raised beds under irrigation (above); water abstraction using a pump from the nearby river (below)

Further information about this research can be found in Philip Platt's PhD thesis on 'Spatial Modelling, Phytogeography and Conservation in the Eastern Arc Mountains of Tanzania and Kenya.'