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Hydrological and water allocation modelling for PES evaluation in the Malaprabha catchment in Karnataka, India

Technical Briefs are short summaries of research results aimed at a non-technical audience. The aim of the PES India project is to assess feasibility criteria for schemes for payments for environmental services (PES), particularly watershed services. In order to test such feasibility criteria the project is carrying out a number assessments on different issues regarding watershed services in the Malaprabha river basin. This includes land use scenario analysis using hydrological and water allocation models; evaluation of water conservation measures by upstream land users, and the legal and institutional feasibility of PES schemes.

In this Technical Brief we report from modelling of Malaprabha river basin both in the hydrological model AVSWAT and in the water allocation model MIKE BASIN.

Catchment characteristics

Malaprabha River is one of the tributaries of the Krishna River in Karnataka, India. The Navilutheertha dam was built across the river and was commissioned in 1976 with a live storage capacity of 870 Mm^3. The catchment area of the reservoir is mainly agricultural areas, largely depended on rainfall. Apart from the significant variation in rainfall distribution within the watershed, the area is characterized by the large heterogeneity in the land use characteristics, agricultural and irrigation practices, soil characteristics and geology.

For the hydrological analysis the catchment area is divided into three zones as shown in Fig. 1. Zone 1 is characterized with an annual average rainfall of approximately 2000 mm and dense to moderate forest coverage extending as much as 38% of the total zone area. On the other hand the annual average rainfall received in zones 2 and 3 is approximately 1000 mm and 500 mm respectively. From the hydrological data analysis, it has been found that much of the stream flow is generated from zone 1. Zones 2 and 3, which are mostly agricultural areas, contribute much less to the stream flow. In addition to this the groundwater recharge occurs in the upper catchment zones 1 and 2 only.

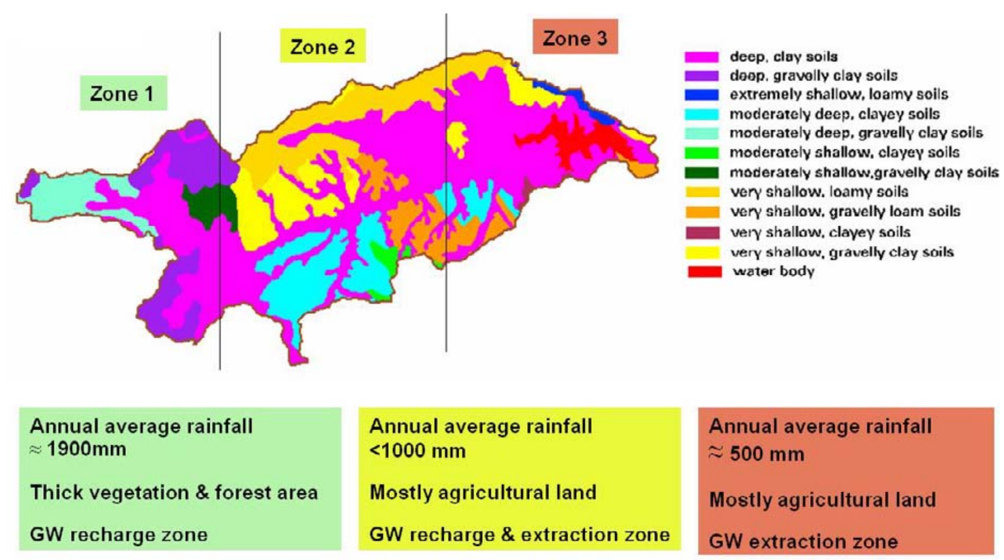

Fig. 1 Hydrological zones in the upper Malaprabha River basin

Development of Tools and Methodologies to Implement the Payment for Environmental Services Concept in Watersheds in India (PES India Project)

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Water scarcity problem in the catchment

Agricultural intensification, over extraction of the surface and ground water resources for irrigation, and the unsustainable changes in the land use pattern have resulted in resource depletion in the catchment. The same is observed in the study area in the form of reduced flow in the river and drastic depletion of the groundwater table and drinking water scarcity at the major settlements within the catchment. However, from the hydrological data analysis, the rainfall pattern and the changes in the forest density or coverage have not been identified as the major reason for the reduced flow in the river. Stream flow generated from zone-1, which contributes to almost 80% of the monsoon river flow, has not changed significantly over the last 3 decades. The increased extraction for irrigation in zone-2 and zone-3 is identified as one of the major reason for the water scarcity in the area. Fig 2 shows the increase in the irrigation since 1970 in the Belgaum district (The entire catchment comes under Belgaum district in Karnataka, India).

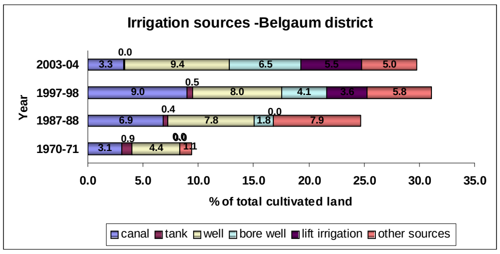

Fig 2. Area under irrigation and sources of water supply in Belgaum district, Karnataka (source: District at a glance, Gov. Karnataka)

Modelling requirement

Within the larger framework of PES feasibility analysis, hydrological modelling of the catchment is required to understand the water availability and demand in the area. Modelling optimal water allocation can be used to identify the most productive way of allocating the water resources among various users. In addition, various watershed service scenarios, in the form of land use change and irrigation cut off, can be built in the model to study the effectiveness of each service in improving the water availability. The results from the hydrological model can be used in the PES analysis to identify the potential service providers and beneficiaries as well as to identify the feasibility of PES in the watershed. The Decision Support tool therefore consists of two components: model for the estimation of the water availability and model for identifying the optimal allocation of water between various users. A large number of models are available for the above mentioned function.

Soil and Water Assessment Tool integrated with Arc View (AVSWAT) (Di Luzio et al., 2002) and MIKE BASIN (www.dhigroup.com) are selected in this study for hydrologic process simulation and the water allocation respectively. These Models are briefly explained in the following sections.

Hydrological model - AVSWAT

AVSWAT is one of the most robust tools that are capable of simulating the complex hydrological processes taking place in an agricultural watershed. Starting from the runoff simulation, the model is efficient in estimating various components of the hydrological cycle in different layers down to the ground water storage. Using Digital Elevation Model (DEM), land use information, soil characteristics and hydro-meteorological data as input, the model estimates stream flow, evapotranspiration, percolation and ground water recharge (Fig. 3).

The model is integrated with the Geographic Information System (GIS) platform using ARC VIEW developed by ESRI (www.esri.com). This gives AVSWAT the adequate flexibility to assimilate large amount of spatially distributed data. This simplifies the scenario building with temporal changes in the land use conditions, as well as to simulate possible future scenarios in the direction of watershed services. Using the topographical characteristics, the model identifies small watershed units andsub-basins within which the water allocation between different users can be best achieved. For more information about the use of AVSWAT in India PES project see the Technical Brief-2

Water allocation model - MIKE BASIN

MIKE BASIN is a GIS-based decision support tool for integrated water resources management and planning. MIKE BASIN is developed by Danish Hydrologic Institute, DHI and use Arc GIS developed by ESRI as a platform (www.esri.com).

Mike Basin is designed to address water allocation, conjunctive use, reservoir operation, or water quality issues. To set up a MIKE BASIN model for one geographic area, geographic information like catchments, rivers, lakes, reservoirs and water users are needed. Hydrological information is also required, like input water discharge to the different sub-catchments. Depending on what type of water users that have been implemented in the model different types of input data are required. Modelling domestic and irrigation water use requires input of timeseries on demand for the respective users.

Water allocation results can be derived in every geographic element in the model, meaning for every river, lake or wateruser. For this project results as surplus water discharge and water deficit are the most policy relevant. For more information about the use of MIKE BASIN in India PES project see the Technical Brief-1

Integration of the models as a decision support tool

The figure below shows how AVSWAT and MIKE BASIN work together in this India-PES project.

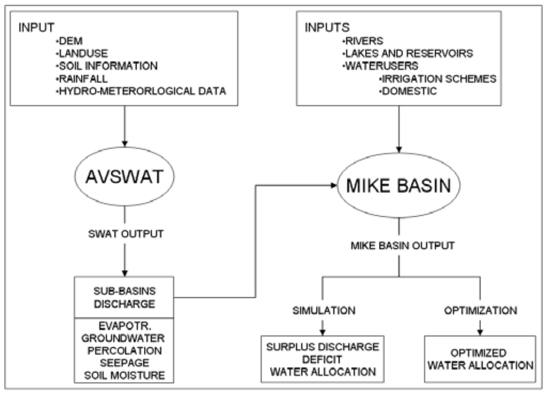

Fig. 3 Relation between AVSWAT and MIKE BASIN

AVSWAT calculates the stream flow at different time periods with the existing as well as the possible land use scenarios. The time series discharge data are used directly as the input to the MIKE BASIN. When this is implemented in the water allocation model, the corresponding water deficit and surplus water will be found. In addition MIKE BASIN can be used to assess economically optimal allocation. For this type of analysis MIKE BASIN will allocate water and until its marginal economic value is the same across water users. This includes an implicit water allocation to landuses modelled in AVSWAT. However in the latest version of Mike Basin lack an economic optimization tool that suites the Malaprabha basin where the economic analysis should be done among the same type of users. AVSWAT is the run “backwards” to find the land-use configurations that correspond to the optimal water allocation determined by MIKE Basin. The combination between the two models can therefore be of major importance for decision makers.

Issues addressed

The following issues can be addressed by the use of this integrated decision support tool.

Land use changes

Land use changes will always be an important issue for decision makers. The simulation possibilities that lies in AVSWAT and MIKE BASIN makes the decision makers able to see

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the water availability according to these changes.

Water deficit
Water allocation will in many situations result in water deficit in the lower parts of basins. The combination of the two models will simulate the best possible water allocation in basins. Simulation can be done according to minimize water deficit for the prioritized water users or according to economic optimization.

Water availability
To better understand the availability of water in a basin the different kinds of losses must be investigated. By the use of hydrological model evaporation and seepage from the river can be obtained. This in addition to water discharge will give the availability and can be translated to water values.

Main challenges / limitations in the modelling
In all models the quality of the output/results are determined by the quality of the input. Major challenges in the development and application of the proposed decision support tool for the Malaprabha catchment are the following.

- Data availability: Quality of the results depends on the accuracy of the input data. Though the interpretation of the remote sensing satellite imageries provides the spatial variation in the land use, the acquisition of time series imageries becomes expensive, making it unaffordable for local organizations. In addition to this, the expertise required to interpret the imageries also acts as another constraint.
- Lack of adequate field observatories to represent the heterogeneity in the hydro-meteorological characteristics.
- Groundwater component: AVSWAT proposed for the simulation of the hydrological processes in the watershed does not simulate groundwater flow from deep aquifer.
- Lack of economic optimization tool in Mike Basin.

Technical recommendations
The two models chosen in this project are robust and well tested. They have spatial distribution as a basis. The programs are easily available and the AVSWAT model is free.

The combination of hydrological and water allocation model will give the decision makers a better understanding of the water balance and the water allocation problems. It visualises the problem areas and it can present different scenarios. The model thus helps the decision makers to identify the possible impact of a scenario without actually implementing it in the field.

References
Di Luzio, M., Srinivasan, R., Arnold, J.D., Neitsch, S. L. (2002). *ArcView Interface for SWAT 2000, User's Guide,* Blackland Research & Extension Center, Texas.

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