

# Modelling social and environmental impacts of watershed development in Andhra Pradesh, India.

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**Abstract:** Rural communities in the dryland agricultural regions of Andhra Pradesh, India, have been the focus of watershed development (WSD) programs intended to both improve people's livelihoods and achieve sustainable use of natural resources. The effectiveness of WSD at achieving these objectives has been questioned in recent decades. Issues of inequitable distribution of benefits between and within villages as well as negative environmental impacts downstream of WSD have been reported in the literature (Reddy et al. [2004], Calder et al. [2008]). The Australian Centre for International Agricultural Research (ACIAR) has funded a project that is quantifying the socio-economic and environmental outcomes of WSD programs implemented in six villages in Andhra Pradesh to examine societal issues associated with these programs. A component of the project is the development of an integrated model to explore spatial impacts of WSD including upstream-downstream differences between villages and issues of equity and resilience within villages.

Bayesian networks (BNs) are being used to implement the sustainable livelihoods approach (Reddy et al. [2004]) within an integrated biophysical-socioeconomic model (Merritt et al. [2011]). This paper focuses on the representation of health in the human capital component of the integrated model. Household health is an important determinant of human capital which affects how a household can use other capitals to improve their livelihood. Analysis of the first round of survey data using BNs found that household health is most sensitive to the adequacy of drinking water – a function of both the quality of and access to common pool drinking water resources. The effect of WSD on drinking water adequacy and household health varies across the study villages with some showing reduced reliance on common pool resources under WSD and/or improved adequacy of drinking water resources both of which correspond to better household health.

**Keywords:** Bayesian networks, watershed development, sustainable livelihoods.

## 1 INTRODUCTION

Water is critical in drought prone areas of India for human consumption, irrigation and livestock supplies and for sanitation (Wani et al. [2008]). Watershed development (WSD) has been promoted as a way of improving livelihoods of the rural poor whilst protecting the land and water resources which support rural communities. Rural poverty is prevalent in some areas despite large scale investment in WSD by the Indian government and non-government organisations

(NGOs). Similar programs have been applied widely in the developing world; a common shortcoming is the lack of rigorous evaluation of the biophysical and socio-economic impacts within, and outside of, the implementation area. For example, Barron and Noel [2011] note that the impact of past watershed management interventions on poverty alleviation is poorly documented.

Funded by the Australian Centre for International Agricultural Research (ACIAR), the 'Impacts of meso-scale Watershed Development in Andhra Pradesh (India) and their implications for designing and implementing improved WSD policies and programs' project (the 'meso-scale project') is evaluating the biophysical and socio-economic impacts of WSD across the landscape.

## **2 WATERSHED DEVELOPMENT AND SUSTAINABLE LIVELIHOODS**

Poor populations in the rural dry inland regions of the Indian state of Andhra Pradesh are highly vulnerable to drought and other shocks. WSD in Andhra Pradesh largely reflects the sustainable livelihoods (SL) approach whereby WSD aims to improve livelihoods of the rural poor through technical and social interventions designed to increase the capabilities of a household and improve their access to the material and social resources needed for a household to gain a living (Reddy et al. [2004]). Livelihoods are improved (more resilient) if interventions enable a household to better cope with stresses (e.g. drought) and maintain or increase their capabilities and assets whilst maintaining natural resources for future generations (e.g. Plummer and Armitage [2007]).

The SL approach has been proposed as a way to design and operationalise development programs by explicitly recognising (a) the need for intervention programs to be focused on the issues or concerns of the people targeted by the program, (b) the highly participatory nature of effective programs, (c) the balance between economic, institutional, social and environmental sustainability and (d) the dynamic character of livelihood (e.g. Baumann [2000]). More often, however, the SL framework has been used to assess the positive and negative impacts of intervention programs (e.g. Reddy et al. [2004]). This is often achieved using the five capitals approach where it is recognised that people use different types of capital assets in order to meet desired livelihood outcomes. Capital assets are typically grouped as financial, human, natural, physical, and social although Baumann and Sinha [2001] and other authors define political capital as a distinct form of capital. Links exist between all forms of capital and one form can be used to increase another form. Financial capital, for example, could be used to attain political capital so as to access entitlements available through various policies and institutions (Baumann and Sinha [2001]). In rural communities, access to good quality land, water and common pool resources is critical in determining human, physical and financial capital and therefore livelihoods (e.g. Baumann [2000]).

## **3 APPROACH**

The meso-scale project has four interlinked research components: crop modelling, surface water and groundwater modelling, socio-economic analysis and integration. In the integration component, Bayesian networks (BNs) are being used to implement the sustainable livelihoods framework in a socio-economic model (Merritt et al. [2011]). This paper reports on the representation of household health in the human capital component of the socio-economic model.

### **3.1 Social Survey**

The impacts of WSD are examined in the meso-scale project for six villages in two hydrological sites in Andhra Pradesh. The upstream village in each study site occurs on the mountain slopes while the downstream villages are located in the

valley. A village located nearby each hydrological site that is not covered by a WSD program is used as a control for comparative analysis. Selection criteria for the study villages are detailed in Reddy et al. [2011].

The BN model developed in this paper uses data from structured household surveys designed to develop socio-economic and demographic understanding of the villages and to elicit the impacts and perceptions of WSD on the sample households. In parallel with the development of the BN, the survey data is being analysed using a range of analytical and statistical tools (e.g. logit/probit models, econometric regression analysis).

The surveys consist of open as well as close ended questions covering qualitative and quantitative aspects. The first round of household surveys was undertaken from November 2010-April 2011. 564 households were interviewed across the six WSD villages and the two control villages. A stratified sampling approach was applied to allow analysis of the impacts of WSD on households with different farm sizes: landless, small and marginal (<5 acres) and medium and large (> 5 acres) farmers. Using the same approach, a second round of surveys was completed in March 2012, interviewing 570 households of whom about 50% were questioned in the first round of surveys. The sampling approach is detailed in Reddy et al. [2011].

The meso-scale project is aiming to identify the nature and magnitude of changes in biophysical (e.g. drinking water quality, crop yield) and socio-economic (e.g. employment or resilience) indicators in response to WSD. WSD programs in the villages were not implemented simultaneously. To assess the impact of WSD, two analysis periods are defined: the 'before' period refers to the 5 years previous to WSD in the treated villages and 2006 to 2010 in the control villages. The 'after' period is 2011 to 2012 for all villages. The different implementation periods in the treatment villages requires discrimination of the impact of WSD from the influence of rainfall patterns and hydrology regime prevalent in the two analysis periods. The results presented in this paper will need to be re-visited once the hydrological analyses undertaken in conjunction with this work are further developed.

### 3.2 Representation of Household Health in the Human Capital BN

The structure of the Human Capital BN in Figure 1 is based on the research experience of social researchers in the meso-scale project team who have studied the impacts of WSD in India using the sustainable livelihoods framework. The BN has been populated with data from the first survey conducted in the study villages.

In the BN, the *Human Capital* variable is linked to livelihood variables which measure whether or not the education, health and skills level of the households meets their self-assessed livelihood requirement. These livelihood variables are linked to summary variables (*Vocational Skills*, *Education*, and *% of Household Healthy*) which are determined by one or more explanatory variables (e.g. access to drinking water) linked to the input variables (*Analysis Period*, *Name of Village*, and *Watershed Development*). The *Location*, *Social Category*, and *Economic Category* variables are included in the BN to allow discrimination of differences in human capital and other network variables between and within villages. All variables in the BN with the exception of *Location* and *Human Capital* correspond directly to questions in the household surveys. For each household, responses were entered into a case file which was used to 'learn' the conditional probability tables in the BN. The probability distributions for a variable reflect the proportion of survey households who fall within each state of that variable.

The health of rural communities in India is affected by a number of factors including nutrition, sanitation, hygiene and access to safe drinking water (Pal [2012]). In the Human Capital BN, the *% of Household Healthy* variable is linked to four variables: *Adequacy (Drinking Water)*, *Health Expenditure*, *Education*, and *Household Over-50's*. The adequacy of drinking water is a function of both a households' access to,

and quality of, common pool drinking water resources. *Household Over-50s* is the number of people aged over 50 years of age in a household. Household annual expenditure (in Rupees [Rs]) on health (*Health Expenditure*) is used as an indicator of access to health services (and their utilisation) and the households' self-assessed level of household education (*Education*) is used a surrogate for hygiene under the assumption that people with higher levels of education will be more aware of the links between good hygiene and good health. In the BN, the % of *Household Healthy* variable is populated based on the percentage of the household who are healthy (i.e. report no illness during the analysis periods). Currently, there is no variable representing nutrition.

#### 4 RESULTS

Hierarchical sensitivity analysis ranks the sensitivity of the dependant variable (e.g. % of *Household Healthy*) to its parent variables. Sensitivity to findings is measured using mutual information (variance reduction for continuous variables) which measures the extent to which the joint probability of two variables (e.g. *Health Expenditure* and % of *Household Healthy*) diverges from what it would be if the variables were independent. A value of 0 indicates that the two variables are independent of one another. The % of *Household Health* variable is most sensitive to the adequacy of drinking water followed by education, household over-50's and the household's annual health expenditure (Table 1). The variable is relatively insensitive to *Household Over-50's* and *Health Expenditure*.

**Table 1.** Sensitivity of the % of *Household Healthy* variable to its parent variables.

Adequacy (Drinking Water)	Education	Household Over-50s (%)	Health Expenditure
149.4	49.5	9.1	6.2

In Figure 2, the probability distribution of the % of *Household Healthy* variable is shown for each state of the parent variables. When the *Adequacy (Drinking Water)* variable is set to 'low' nearly 80% of households have less than 25% of people in the household who have no sickness in a year (Figure 2a). This percentage drops to 60% and 18% when the *Adequacy (Drinking Water)* is set to 'enough' and 'good', respectively. For the next most influential variable (*Education*), 'bad' and 'average' education have a similar impact on the *Household Over-50's* variable with the majority of households falling in the poorest state. With 'good' education, the likelihood of being in the healthiest state increases to over 50% (Figure 2b). Neither of the *Household Over-50's* or *Health Expenditure* variables have a large impact on % of *Household Healthy*.

The sensitivity of the drinking water (quality and access) and expenditure variables to the input variables (*Village, Watershed Development* and *Analysis Period*) shows the importance of the three variables in determining

**Table 2.** Sensitivity of the drinking water and expenditure variables to *Village, Watershed Development (WSD)* and *Analysis Period*.

State	Sensitivity <sup>1</sup>
<i>Education Expenditure</i>	Period > Village > WSD
<i>Health Expenditure</i>	Period >> Village > WSD
<i>Access (Drinking Water)</i>	Village >>> WSD > Period
<i>Quality (Drinking Water)</i>	Village >>> WSD >>> Period

<sup>1</sup> Order of magnitude greater sensitivity (>>>); more than 50% (>>) and less than 50% (>) greater sensitivity

differences in the two analysis periods. The *Village* variable is much more influential on the drinking water variables than the analysis period and *Watershed Development* (Table 2). The analysis period most influences the expenditure variables although *Village* and *Watershed Development* do influence health expenditure. *Watershed Development* is generally the least influential variable although has an influence on the drinking water variables.

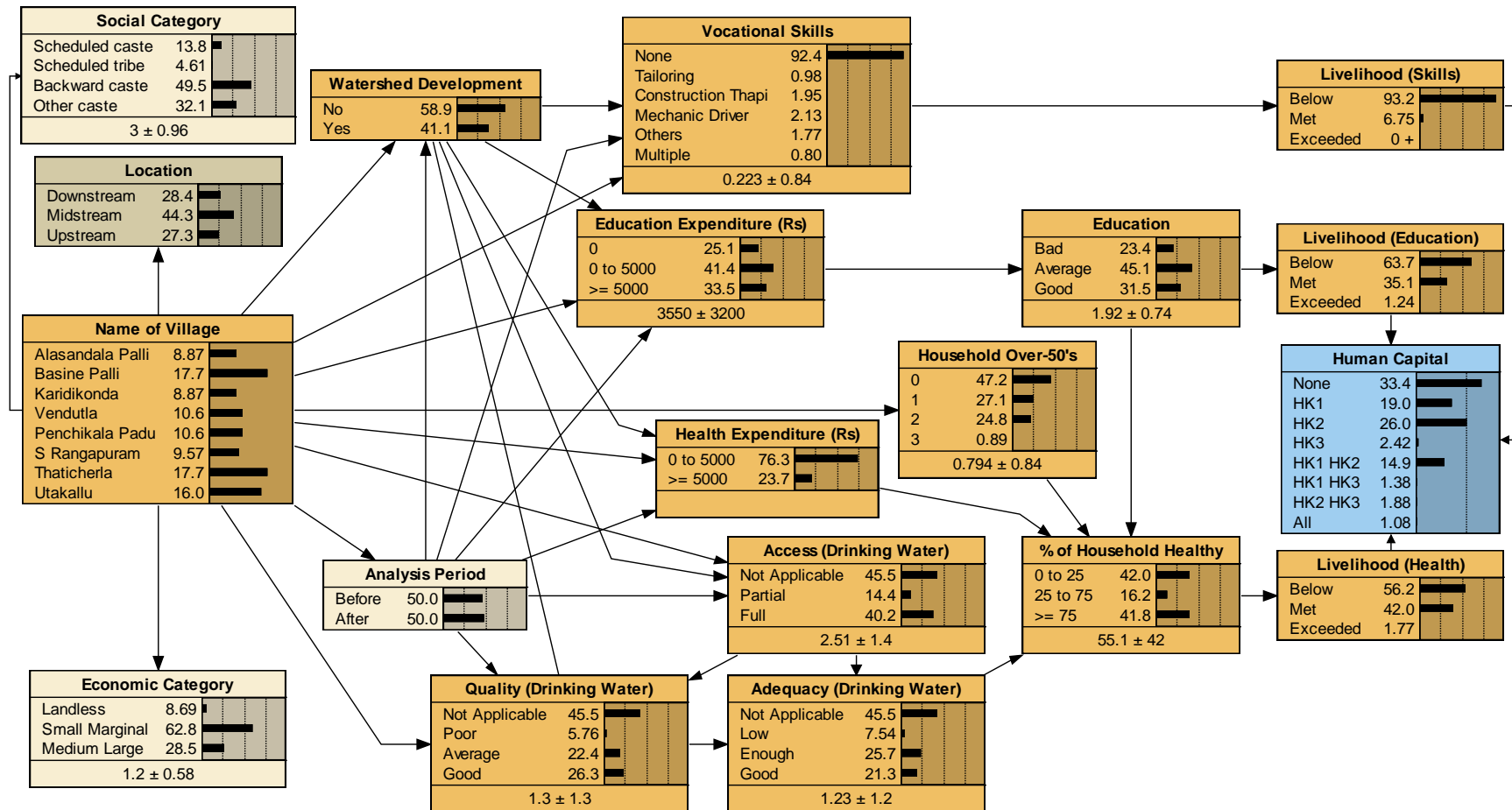
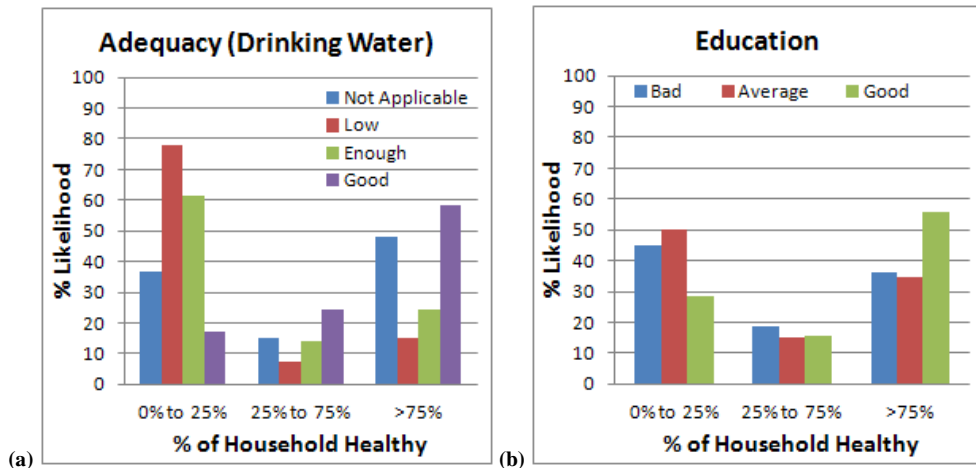


Figure 1. The human capital BN.



**Figure 2.** Impact of parent variables on the % of Household Healthy: (a) Adequacy (Drinking Water) and (b) Education.

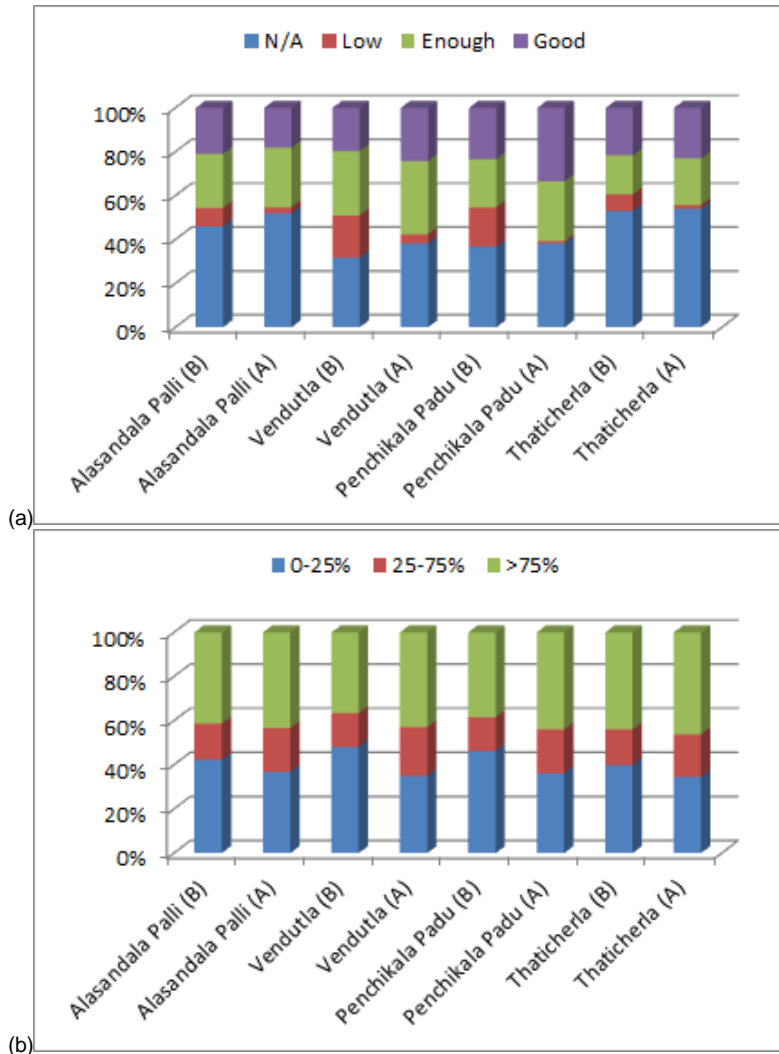
The change in the Adequacy (Drinking Water) and % of Household Healthy variables for the control village (Alasandala Palli) and WSD villages at one hydrological site are shown in Figure 3. The upstream, midstream and downstream villages are Thaticherla, Penchikala Padu and Vendutla, respectively. In each of the villages there is an improvement in the household assessed adequacy of common pool drinking resources in the 'after' analysis period (A) from earlier (B) (Figure 3a). The improvement is larger in the villages that have received WSD. An almost 5% reduction in the poorest state of health is for both the control village and the downstream village, Thaticherla (Figure 3b). Larger improvements occurred in Penchikala Padu and Vendutla where there had been higher proportion of 'low' drinking water adequacy in the 'before' analysis period. In both the control village and Vendutla, there is reduced reliance on common pool drinking water resources in the 'after' analysis period which also correspond with improvements in household health.

## 5 DISCUSSION

This paper introduced the human capital component of a Bayesian network socio-economic model being developed to explore the impacts of WSD across the landscape and between segments of the community. While it is not the focus of the meso-scale project to model it in detail, household health is a key determinant of human capital which is used to access other forms of capital. The link between health and financial capital was demonstrated by Krishna [2006] who identified that the interactive effects of health and debt are strongly related to the descent of households into poverty in rural villages in Andhra Pradesh.

The health component of the human capital BN currently links household health to the adequacy of drinking water, education, household age and health expenditure. No measure of nutrition is currently included in the BN which is a limitation of the model given links between nutrition and health. However, survey respondents were asked to quantify household consumption of specific types of food (e.g. meat, vegetables, pulses, etc) and this data could be used to develop an indicator of household nutrition. Palanisami et al. [2009] noted that an increase in drinking water availability is 'one of the important expected outputs of WSD'. The results presented in this paper demonstrate the importance between the quality and access to common pool drinking water resources and household health. Also influential in the model was the Education variable supporting the assumption that people with higher levels of education will be more aware of the links between good hygiene and good health. Health Expenditure was included as a surrogate for access to health services and their use by households. There is a positive (although weak) relationship between expenditure and household health which may indicate that households that access health services are able to recover more

quickly from illness. This relationship may need to be explored further to look at expenditure as a function of household income to try and detect different relationships between expenditure and health for different economic groups. However, household health is relatively insensitive to both of the *Household Expenditure* and *Household Over-50's* variables suggesting that the model could be simplified by removing these variables.



**Figure 3.** Impact of WSD and analysis period on *Adequacy (Drinking Water)* (a) and *% of Household Healthy* (b) at one hydrological site.

The results presented in this paper suggest that WSD may have some impact on drinking water resources and therefore health and human capital. However, the analysis period is important indicating that there are other factors influencing human capital. Reddy et al. [2004] discuss the difficulty in attributing the changes to WSD given that there could be a number of other programs or influencing factors over the analysis periods that could affect, for example, educational and health status. The changes in the adequacy of drinking water resources reported in this paper could arguably be due primarily to rainfall and hydrology regimes over the period of analysis with WSD having a lesser impact. These issues are being explored further with the second round of survey data and also the biophysical modelling being undertaken in the meso-scale project in conjunction with this work.

BNs are well suited to implementing the sustainable livelihoods approach namely because they allow relatively simple representation of cause and effect connections and can use a range of qualitative and quantitative data to develop relationships between variables. A large socio-economic survey is enabling the development of

BNs that can demonstrate the complexity of issues and impacts associated with WSD programs that have been implemented across Andhra Pradesh in India. A critical issue in the model development will be ensuring the BNs are robust and adequately represent the impact of WSD and other factors on the five capitals and resilience whilst minimising model complexity.

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