

Linking the hydrological cycle and rural livelihoods: a case study in the Luvuvhu catchment, South Africa

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Abstract

The role of the hydrological cycle in contributing to the livelihoods of rural communities is often said to be important, but clear evidence of this is rarely offered. Furthermore, where such aspects are considered, they are largely focussed on the use of water from rivers, boreholes or some form of storage (blue water).

In this study, the hydrological cycle is considered in its entirety. Links between rural livelihoods, land use and the goods and services provided by the evaporation and transpiration components of the hydrological cycle (green water) are assessed through analyses of rural livelihoods in the Luvuvhu catchment, Limpopo Province, South Africa. Results highlight the importance of green water, and thus the importance of access to land and use of the natural resource base, in disaggregated rural community livelihood strategies.

Finally, we describe a methodology for linking common outputs from hydrological models to rural livelihood impacts. In this way, the potential role of land use change in disaggregated rural livelihoods can be assessed for various development scenarios, such as increases in commercial forestry and dryland agriculture.

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1. Introduction

Society depends on the integrity of natural systems to provide goods and services for production and consumption. In particular, the goods and services generated by the movement of water through the landscape are assumed to make significant contributions to the livelihoods of rural communities. However, clear evidence is rarely offered to substantiate this position; the general tendency is to focus on the use of water from rivers, boreholes or some form of water storage for irrigated crop production. The omission of the contributions of other

land uses under natural (rainfed) conditions has been emphasised as a major weakness in the analysis of land, water and development interactions.

Land use influences catchment hydrological responses by partitioning rainfall between return flow to the atmosphere as evaporation and transpiration (“green water”) and flow to aquifers and rivers (“blue water”). Increasing attention is now being paid to understanding the dynamic inter-relationships between “green” and “blue” water, as these are considered to underpin essential terrestrial and aquatic ecosystem services (FAO, 2000; Jewitt, 2002; Falkenmark, 2003). The FAO suggests that almost all “green” water and a large proportion of “blue” water are needed to sustain ecosystem structures and functions, and maintain sustainable water supplies.

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In this paper, links between rural livelihoods, land use change and the goods and services provided both green and blue water components of the hydrological cycle are assessed in the Luvuvhu catchment, Limpopo Province, South Africa. Specifically, a methodology to link the impacts of scenarios of land use change, such as, conversion of natural vegetation to commercial afforestation and irrigated agriculture on catchment hydrological functioning and rural livelihoods is illustrated in terms of green and blue water use. Furthermore, the analysis shows the impacts of land use change on poverty as a means of informing policy development (forestry, land affairs, water resources, institutional governance, compensation mechanisms, agriculture etc.) in an integrated and practical manner.

2. Land and water interactions and ecosystem goods and services

Movement of water through the landscape contributes to production (e.g., crops, timber, cattle), information (e.g., nature experiences), and regulation (e.g., formation of topsoil), functions of the environment. Several authors have highlighted the importance of dry-land crop production in rural areas and thus the importance of the water vapour phase (green water) of the hydrological cycle to rural livelihoods (e.g. Savenije, 1998, 1999; Rockström et al., 1999). Typically, communities seek to optimize the conversion of available water, in the form of rainfall or irrigation water, through crop production resulting from the movement of green water through agricultural crops. However, natural resource harvesting of non-agricultural goods and services is also an important component of rural livelihoods.

Water both sustains and constrains land use, which in turn, influences catchment hydrological functioning by partitioning incoming precipitation into runoff, ground water recharge and evaporation. Changes in upstream land use and resulting alterations in the movement of water through vegetation and air will impact on the downstream flow of water.¹ An issue that has been highlighted, particularly in arid and semi-arid regions where green water flow dominates the hydrological cycle, is the potential for change in upstream land use and a resulting impact on the downstream flow of water. However, the impact of such land use change on the goods and services generated from green water flows is rarely considered explicitly.

¹ Change the partitioning of green and blue water in the catchment and may result in changes in livelihood responses at both community and catchment scale.

3. Luvuvhu catchment

The Luvuvhu Catchment (5941 km²) is located in Limpopo Province, South Africa, and together with the Letaba Catchment forms the Luvuvhu/Letaba Water Management Area (WMA), one of 18 WMAs identified by the South African Department of Water Affairs and Forestry (DWAF). It forms part of the larger Limpopo system, which drains into the Indian Ocean in southern Mozambique. For water resources management purposes, the catchment has been sub-divided into 14 quaternary catchments² (Fig. 1). Mean annual precipitation (MAP) over the Luvuvhu catchment is 608 mm yr⁻¹, potential evaporation is estimated at 1678 mm yr⁻¹ and natural mean annual runoff (MAR) is estimated to be 520 × 10⁶ m³ yr⁻¹. However, all of these show high spatial and temporal variation with highest rainfall and lowest total evaporation (E_t) over the Soutpansberg mountain range in the southwest and the lowest rainfall and highest potential E_t in the arid areas in the northeast of the catchment adjacent to the Kruger National Park.

It is estimated that some 624,907³ people, including the populations of Thohoyandou (pop. 130,000), Louis Trichardt (pop. 88,000) (via inter-basin transfer) and Malamulele (pop. 2000) depend on the basin for their water needs. Urban and industrial use was estimated at 6% of total water demand in 1997. However, it is predicted that this could reach 13% by 2010. Water use by commercial forestry is 10%. A low confidence estimate of ecological water requirements of 105 × 10⁶ m³ yr⁻¹ or 20% of MAR means that there is no surplus yield available in the water management area and that an over commitment of resources exists. The bulk of irrigation water used in the catchment is supplied either from the Albasini Government Water Scheme or from private dams. In contrast to many other areas of the country, significant areas rely on groundwater for irrigation. DWAF (2002) report that ground water is extensively over-exploited, particularly in the vicinities of the Albasini Dam and Thohoyandou. Many small-scale irrigation schemes which utilize run-of-river flow and do not rely on an impounded water supply exist. It has been estimated that combined abstractions utilize all of the low flows in the river, particularly during the critically dry period of August to November.

Available soil surveys, indicate that 17% of the soils of the catchment (960,280 ha) are potentially suitable for afforestation. However, only 14% of this area (14,750 ha) has been planted. Rainfall constraints, as well as difficulties faced in obtaining a Stream Flow

² The SA Department of Water Affairs and Forestry sub-divides the countries catchments into quaternary catchments for water resources management purposes.

³ CSIR estimate from national census data.

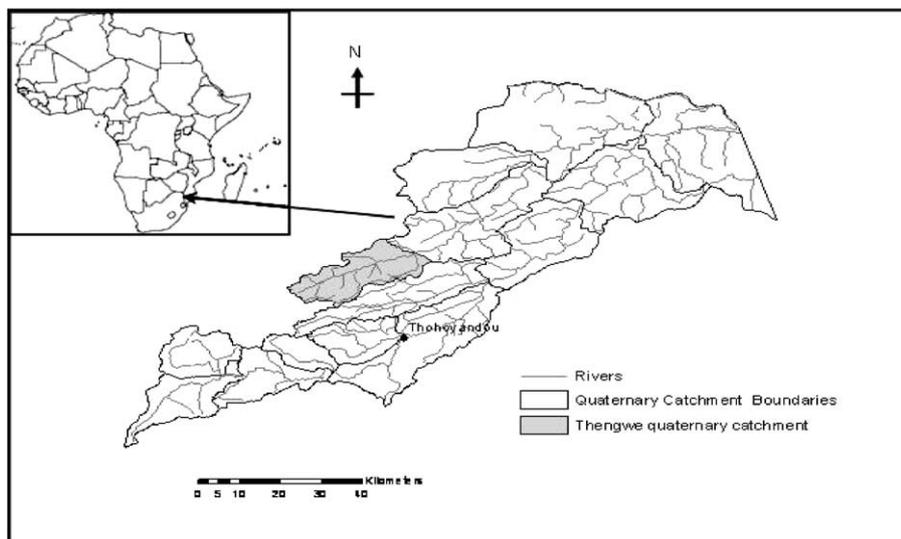


Fig. 1. Location of the Luvuvhu Basin and the Thengwe (upper-Mutale) quaternary catchment (A92A).

Table 1

Land use in the Luvuvhu catchment and land use in the study quaternary with a 'natural' state and four potential development scenarios

Land use	Luvuvhu	A92A (%)	Natural (%)	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)	Scenario 4 (%)
Commercial forestry	4	14	0	56	56	14	38
Commercial dryland agriculture	10	22	0	17	12	12	27
Commercial irrigated agriculture	3	5	0	0	15	15	0
Rangeland	50	59	100	27	17	59	35
Conservation areas	30	0	0	0	0	0	0
Urban areas	3	0	0	0	0	0	0

Reduction Activity (SFRA) water use licence are the primary reasons for this. However, the potential for additional commercial afforestation does exist, and scenarios for such expansion form an important component of this study.

The upper catchment of the Mutale River, an important tributary of the Luvuvhu, and classified as quaternary catchment A92A by DWAF, forms the focus of this study. This is a relatively high MAP catchment (879mm) and includes areas of commercial afforestation, dryland and irrigated agriculture. A summary of existing land uses for both the Luvuvhu and upper-Mutale catchments and potential scenarios of land use change are summarised in Table 1.

4. Hydrological modelling in Luvuvhu

The ACRU Agrohydrological modelling system has been configured for use in the Luvuvhu Catchment. The ACRU model is a multi-purpose and multi-level integrated physical conceptual model that can simulate streamflow, total evaporation, and land cover/management and abstraction impacts on water resources at a daily time step (Schulze, 1995). The model revolves

around multi-layer soil water budgeting: streamflow is generated as stormflow and baseflow dependent upon the magnitude of daily rainfall in relation to dynamic soil water budgeting. Components of the soil water budget are integrated with modules in the ACRU system to simulate many other catchment components including irrigation requirements and sediment yield. Spatial variation of rainfall, soils and land cover is facilitated by operating the model in "distributed" mode, in which case the catchment to be modelled is sub-divided into sub-catchments. Within these sub-catchments, units of similar hydrological response, based largely on land use zones, are designated to facilitate simulation of land use changes, or isolation of, for example, riparian zones. Land cover and land use affect hydrological responses through canopy and litter interception, infiltration of rainfall into the soil and the rates of evaporation and transpiration of soil water from the soil and the model has been shown to be highly effective in this regard (Jewitt and Schulze, 1999).

The principal applications of the model are in the assessment of environmental and land use related impacts for water resources planning. Many verification studies have been performed, both on internal state variables and final model output (Schulze, 1995). In

Table 2
Comparative development profile of Limpopo Province, South Africa and selected SADC countries

	Access to improved water source (%)	Access to sanitation (%)	Adult literacy rate (%)	Per capita income (US\$) ^a
Limpopo Province	47	58	77	2473
South Africa	70	46	85	8318
Botswana	70	55	76	6032
Kenya	53	77	80	975
Mozambique	32	21	42	797
Tanzania	49	86	73	478

Sources: World Bank (2001), SARPN and StatsSA (Southern African Regional Poverty Network (SARPN); RSA national statistics office (StatsSA)).

^a Gross Domestic Product (GDP) per capita in 1999 US\$.

particular, forest water use and the impacts on streamflows have been verified at several locations in South Africa (Jewitt and Schulze, 1999).

5. Rural livelihoods and poverty

Approximately 75% of the 1.2 billion poor live in rural areas of the developing world (IFAD, 2001). In South Africa, of the 50% rural population 72% are considered poor (May, 1999). Rural livelihoods in the extensive semi-arid and arid areas of the developing world are influenced by their access to and use of local natural resources (e.g. water, rangeland⁴ etc.). A common perception that the natural resource base is unproductive is based more on reductionism⁵ than reality (Scoones et al., 1992; Guijt et al., 1995; FAO, 2001). Understanding how livelihood strategies are mediated by access to and use of water-dependent resources will allow a better understanding of how to reduce rural poverty. Analysis that includes common water-dependent livelihood activities may provide clearer direction on the trade-offs and likely outcomes of catchment water resources management, strategies for poverty reduction, hydrological integrity and economic development.

Livelihood analysis was conducted in Limpopo Province as it is one of the poorest of the nine South African provinces (Table 2). It has an estimated 4.9 million inhabitants across 123,910 km² representing 10% of the total land mass. It is the least urbanised province with a majority black population (96%). Across a range of development indicators the provincial status is poor in the national context, though its regional standing in the Southern African Development Community (SADC) is far better.

⁴ Here, defined as communal land under Tribal Authority de facto management. Often, under mixed and complex open access, communal access and/or private tenure systems. The bulk of rangeland in the Luvuvhu falls within the former homeland/Bantustan of Venda.

⁵ The practice of analysing and describing a complex phenomenon in terms of its simple or fundamental constituents, especially when this is said to provide a sufficient explanation.

Livelihoods research in the Luvuvhu catchment is based on a household questionnaire (January, 2002; $n = 552$), informant inquiry across 4 communities (September–December, 2002) and reference to secondary data sources.⁶ Data are disaggregated by reported household income quintiles and are weighted by inverse probability of selection. Selected poverty indicators from the catchment survey are presented in Table 3.

Six water-dependent livelihood activities that conform to wider local, national and regional practices are identified for the analysis:⁷ (1) Water collection, (2) Livestock rearing (cattle and goats), (3) Kitchen garden farming,⁸ (0.04 ha; irrigated by an Improved Water Supply (IWS)), (4) Dryland farming (maize), (5) Non-Edible Woodland Products (NEWP: fuelwood, construction etc.), and (6) Edible Woodland Products (EWP: wild fruit and vegetables, herbs, worms etc.).

The research quantifies the six activities by five criteria: (1) Gross economic value (US\$ yr⁻¹), (2) Gross costs (US\$ yr⁻¹), (3) Net economic value (US\$ yr⁻¹), (4) Green water use (m³ yr⁻¹), and (5) Blue water use (m³ yr⁻¹).

The opportunity cost of fuelwood gathering, water collection, subsistence farming and other natural resource harvesting activities is often described as a constraint to livelihoods in relation to children missing school, physical hardship and livelihood vulnerability due to illness or loss of an able-bodied family member (daughter/son leaves, father dies etc.). Whilst these very real costs are borne by the poor (including women and children in wealthier households) it is important to

⁶ Shackleton et al. (1999a,b, 2001) data from Limpopo province research into livestock and rangeland resources has been adapted with inputs from the Crookes et al. (2000) study.

⁷ Other activities (orchard, beer-brewing, brick-making etc.) were considered but a limited and unrepresentative distribution across the study area limited their wider applicability.

⁸ Households with IWS (private taps in the home compound) are identified as the appropriate unit for analysis. The estimated area (0.04 ha) conforms to Perez de Mendiguren and Mabelane (2001) though is smaller than the 0.4 ha (4000 m²) used by High and Shackleton (2000). Kitchen garden water use is considered a proxy for irrigated agriculture and supplementary water application (assumed to be from IWS) is estimated from the difference between rainfall (859 mm) and irrigated agriculture evaporation (1149 mm).

Table 3
Household profiles by income quintiles (weighted catchment sample)

	Bottom 20%	40%	60%	80%	Top 20%
Mean household size	5.3	5.2	5.9	6.2	6.2
Proportion with improved water supply	0.21	0.31	0.21	0.33	0.45
Proportion with pit latrine	0.73	0.69	0.73	0.71	0.81
Proportion cooking daily with fuelwood	0.96	0.93	0.95	0.94	0.70
Mean dryland plot (ha)	0.35	0.47	1.02	0.79	0.77
Mean cattle stock	0.12	0.28	1.75	1.83	2.96
Mean number state pension	0.00	0.05	0.04	0.34	0.34
Mean number of full-time employees	0.06	0.07	0.36	0.94	1.20
Mean HH income (US\$yr ⁻¹)	167	526	778	1357	4158

Note: All economic data is reported in US\$, 2002 (US\$1 = 7 Rands).

understand how these costs are distributed (Hope and Gowing, 2003; Budlender and Brathaug, 2002; StatsSA, 2001). This study has applied an effective local wage rate (US\$0.25 per hour) for these productive activities in order to compare it (gross costs) against the estimated values from water-dependent activities (gross value). Further, due to an unequal distribution of services (electricity, IWS, etc.) in rural areas, it is highlighted which groups (here, income quintiles) have to bear the greater (opportunity) cost for a poor level of access.

6. Linking livelihood impacts and water use

The upper-Mutale case study represents an area of the Luvuvhu Catchment with a relatively high diversity of land uses and corresponding livelihood strategies. Data elicited from one of the eight sampled catchment communities located in the study quaternary catchment (Rambuda, $n = 64$) are used to represent livelihood values.

Livelihood water use is estimated according to water use relative to a “natural” baseline condition represented by 100% cover with the dominant natural vegetation of the area (here, rangeland). In addition to the current land use in the catchment, the hydrological response of four additional land use scenarios was simulated with the ACRU model. In all scenarios, except the baseline, domestic blue water use is calculated at 251capita⁻¹day⁻¹ (lcd) for the estimated quaternary catchment population of 36790. Only water collection remains unchanged in each scenario, though risk analysis of ‘blue’ water availability will assess the conditions under which dry season flow may be reduced to a level which fails to meet the specified Basic Human Needs Requirement (BHNR). These scenarios provide for a non-validated estimate of the direction and scale of water and economic impacts on the livelihood quintiles. It must be noted that complicated social, political and institutional factors that are likely to drive such land use change are not considered, as it is the management of such factors at policy level which this research is intended to inform.

Informant inquiry, secondary sources and careful deliberation are combined to assess how the land use change scenarios will affect livelihood water-dependent activities. Here, the following methodology has been followed with its inherent limitations:⁹

- Water collection remains static in each livelihood scenario analysis though a risk assessment is made within the hydrological analysis.
- Land, labour and other variables that contribute to kitchen garden and dryland agriculture are proportionally adjusted by active household and then weighted by income quintile class.
- Livestock and NEWP activities are proportionally adjusted by active household (own cattle, goat or collect fuelwood from rangeland) but labour is not adjusted as herding activities are argued to still involve similar labour demands and reductions in rangeland are likely to lead to more not less NEWP gathering effort. Active households are adjusted for each quintile.
- EWP are adjusted proportionally across all households.

It is assumed that a household with an IWS receives 25lcd and that all other households collecting water from non-IWS sources (specifically, river water) consume 14lcd.¹⁰ Increases in commercial forestry and commercial agriculture land use are assumed to result in a loss of rangeland and that the “water use” of these land uses is calculated relative to the baseline condition (i.e. baseline water use = 0%). This is consistent with the definition of SFRA in the South African NWA. Whilst there is uncertainty that water is always available in the reticulated system (IWS source), community research indicates that most households are likely to pursue a

⁹ The sustainability (ecological carrying capacity, resource availability, vegetation cover change, etc.) of both the current activities and scenarios is beyond the scope of this study.

¹⁰ The 14lcd estimate was taken from a random sample of households with non-IWS and is supported by more extensive surveys of rural water use in Africa (Thompson et al., 2001; PDG, 1996).

kitchen garden (food security) strategy given no supply constraints. The benefits of such a strategy provide insights into a potential poverty-focussed compensatory mechanism across the catchment with the relative benefits/costs calculated in water use (m^3yr^{-1}), economic units (US\$) and food security (maize yield).

7. Results and discussion

A summary of household water-dependent activities is presented in Table 4. These data present the incremental difference in water use relative to the natural rangeland state. The four activities highlighted exhibit a hydrological impact that is moderated by asset ownership (IWS, cattle, dryland, etc.). It is estimated that the bottom quintile depends on non-IWS sources for 68% of its domestic water requirements compared to 40% for the top quintile. Further the inequitable distribution of water provision disproportionately burdens the income poor both in the highest opportunity costs of sourcing non-IWS water and the associated health risks of consuming it. Analyses of daily flow volumes generated by the ACRU model shows that without significant storage associated with IWS systems, the runoff generated for Scenarios 2 and 3 will not be able to supply BHNR (25lcd) in October at least once every ten years. Kitchen garden farming, which is reliant on IWS for winter irrigation, highlights the skewed distribution of livelihood opportunities (food security) associated with IWS delivery. Analysis of mean dryland maize production illustrates the vulnerability of the bottom quintile to the FAO grain food security threshold of 0.17 ton/capita/yr (Table 5). ACRU simulations indicate that, due to climatic fluctuations, at least one in five years the maize production of the bottom quintile will fail to meet this threshold. Whilst kitchen garden farming could potentially buffer this impact, the poorest are least well-served in this regard.

Related to dependency of the poorest on non-IWS sources is the livestock Voluntary Water Intake (VWI) demand, which is mainly provided by river water. The quantity and quality of river water are connected as non-IWS households must often compete with livestock

Table 5
Household maize production estimates (ton yr^{-1})

	Bottom 20%	40%	60%	80%	Top 20%
Mean kitchen garden yield	0.52	0.58	0.54	0.50	0.59
Mean dryland yield	1.38	1.86	4.03	3.12	3.04
Maize yield per capita	0.36	0.47	0.77	0.58	0.59

Table 6
Additional estimated household value from water-dependent livelihood activities ($\text{US}\$\text{yr}^{-1}$)

	Bottom 20%	40%	60%	80%	Top 20%
Gross value	780	935	1589	1315	1427
Gross costs	506	516	601	548	582
Net value	274	419	988	767	845
Proportion of net value to combined household income	0.62	0.44	0.56	0.36	0.17

for low river flow and risk health problems associated with sharing an unhygienic water resource. It is the wealthier households with larger herds that compound the situation for the poor.

Dryland agriculture represents the dominant water impact of livelihood activities, which has the linked effect of reducing evaporation (shorter root crops, limited growing season) with a concomitant increase in runoff relative to the natural vegetation. Access to land and a sufficient rainfall regime are critical to this activity. The level of green water use is linearly related to dryland plot size, which in turn determines crop (here, maize) production. Poorer households fail to capture the opportunity (income-generating or expenditure-saving) of dryland farming activities in comparison to wealthier households. The explanatory variables of community-level dryland distribution is beyond the scope of this paper but are broadly identified within the socio-cultural context of a patriarchal Tribal Authority system that is organised on kinship networks across generations and/or the ability to both overcome entry barriers (financial, in-kind, other) to land (size, location, fertility, etc.) and the resources to fund land development (traction, labour, market produce, etc.). Dryland farming

Table 4

Household-level green water (evaporation) incremental impact of livelihood activities in relation to the natural hydrological condition (rangeland) by income quintiles in the study quaternary catchment (m^3yr^{-1})

	Bottom 20%	40%	60%	80%	Top 20%
Water collection	31	33	35	39	43
Kitchen gardens (irrigated maize)	46	58	46	60	74
Dryland (rainfed maize)	-214	-287	-622	-482	-470
Livestock (cattle/goats)	2	6	32	32	52

Note: NEWP and EWP are considered hydrologically neutral. Positive green water values are balanced by an equivalent reduction in blue water and vice versa, e.g. $-100\text{m}^3\text{yr}^{-1}$ is a reduction in evaporation in comparison to rangeland with an equivalent $+100$ increase in runoff (blue water).

Table 7

Scenario analyses of land use change impacts on study quaternary catchment outflow (blue water) and contribution of livelihood activities on rangeland hydrology (million m^3yr^{-1})

		Rangeland (natural condition)	Commercial dryland agriculture	Forestry	Commercial irrigation	Livelihood impact as % of rangeland	Catchment outflow $\text{Mm}^3\text{yr}^{-1}$
Baseline	$\text{Mm}^3\text{yr}^{-1}$ (area %)	200 (100%)	0	0	0	0	85
Current land use	$\text{Mm}^3\text{yr}^{-1}$ (area %)	118 (59%)	49 (27%)	30 (14%)	0	2	89
Scenario 1	$\text{Mm}^3\text{yr}^{-1}$ (area %)	34 (17%)	49 (49%)	119 (56%)	0	1	84
Scenario 2	$\text{Mm}^3\text{yr}^{-1}$ (area %)	34 (17%)	22 (12%)	119 (56%)	57 (15%)	1	53
Scenario 3	$\text{Mm}^3\text{yr}^{-1}$ (area %)	118 (59%)	22 (12%)	30 (14%)	57 (15%)	2	59
Scenario 4	$\text{Mm}^3\text{yr}^{-1}$ (area %)	70 (35%)	49 (27%)	81 (38%)	0	1	86

Table 8

Economic impact of land use change on livelihoods at household level ($\text{US}\$ \text{yr}^{-1}$; gross values with net values in brackets)

	59% rangeland	35% rangeland	17% rangeland
	Current and Scenario 3	Scenario 4	Scenarios 1 and 2
Bottom 20%	780 (274)	427 (149)	293 (−19)
40%	935 (419)	503 (221)	361 (57)
60%	1589 (988)	779 (444)	550 (182)
80%	1315 (767)	655 (354)	448 (105)
Top 20%	1427 (845)	715 (400)	501 (150)

generates the highest economic return for all income groups.

A summary of the scenarios analysed, and upper-Mutale catchment green and blue water flows for each scenario are provided in Table 7. The scenarios (Table 1) illustrate the baseline condition under natural vegetation (no human modification), the current land use, and four land use change permutations that highlight the hydrological impact of maximum commercial forest cover and/or increased commercial irrigation. The impact of livelihood activities within the rangeland land use on the flow regime (blue water) is presented as water use relative to the baseline condition for all scenarios.

The scenarios used have been selected in order to isolate one particular land use's hydrological influence within the case study area. The most significant hydrological impact occurs when commercial irrigation is increased to 15% land cover with commercial forestry at its maximum potential land use (Scenario 2). However, commercial forestry's contribution to a reduced catchment outflow is only limited in comparison to commercial irrigation (Scenario 3). The economic value generated from the resource base by each income quintile for each scenario is presented in Table 8.

Intuitively, the economic impacts on livelihoods reflect the proportional change in land availability. It is land availability per se rather than neighbouring land uses which determine the livelihood outcomes from this analysis. The impact that increased commercial irrigation has on hydrological functioning appears to have

no direct ramification on livelihood outcomes.¹¹ However, in Scenarios 2 and 3 where commercial forestry is at its maximum cover or present level with increased irrigation, non-IWS households will face the risk of river water flow being unable to supply the BHNR. The poorest quintile will face a more critical situation under Scenario 2 as it will record a net loss in the identified livelihood activities with the additional risk of failure of the river to supply the BHNR.

Evidence from this research suggests two policy implications that link land resources change, water use and livelihoods. First, two of the scenarios will result in a significant reduction in the level of streamflow (blue water), leading to households without IWS facing a water crisis approximately once in every ten years. However, commercial forestry expansion (to 56%) has significantly less hydrological impact than commercial irrigation (to 15%). Scenario 4 makes this position clear with an increased forestry cover to 38% from 14% having only a limited impact on catchment outflow (reduced by $3 \text{Mm}^3\text{yr}^{-1}$). However, the associated impact of an increase in forest cover (or commercial irrigation) would be to reduce the rangeland area and concomitant values harvested from the resource base by local communities. Under Scenario 4 (35% rangeland), there is a proportional reduction in gross values harvested by livelihood activities but the net effect (counting labour) is felt hardest by the poorest as their asset endowments (IWS, land, livestock) are lower than any other quintile. The poorest are more vulnerable to shocks from land use change due to their higher dependency on the resource base. Combining reported household income with water-dependent livelihood activities (non-market) (Table 6) reveal a significant dependency on the natural resource base for the bottom quintile (62%) in comparison to the top quintile (17%).

Analysis of water-dependent livelihood activities has indicated both the hydrological, economic and food

¹¹ Forward and backward economic/employment linkages are likely to occur but are not captured here.

security significance of dryland agriculture within rangeland. The green water use (evaporation) of dryland crops is the most significant hydrological component of rural livelihoods subject to access to land and a sufficient rainfall regime. The high rainfall in the upper-Mutale catchment provides opportunities to develop income-generating and expenditure-saving food production strategies. Table 3 indicates how access to the dryland resource base is skewed in favour of wealthier quintiles, which are thus better able to exploit the resource. A more equitable distribution of dryland within communities (under de facto Tribal Authority management) could significantly reduce the vulnerability of the poor to food security and, potentially, create surpluses to increase incomes that are less than US\$1 per day. The connection between dryland food production and livelihood security mirrors the forestry situation in that rainfall is captured and converted into biomass, which then has value. Whilst land and water are prerequisites in this configuration, the negotiated process of land acquisition, land management and surplus marketing for dryland produce in communal areas are equally important.

8. Conclusions

The findings from this study suggest that small-scale dryland food production offers a tenable path to poverty reduction (here, increased food security) given relaxation of the identified constraints. However, upstream land use change that reduces the resource base must be weighed against the significant impacts it has on rural livelihood diversified value production systems. The impact of the two most likely land use changes reveal a significant difference in catchment hydrology that have both legal implications (Reserve) and very real human impacts. Land use change in the upper, water-endowed upper-Mutale catchment has the potential for economic growth (employment, production) but any land use change should have an equitable and compensatory mechanism for the negative impacts (externalities) that it is likely to trigger on downstream communities.

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