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REPORT

Forest Cover and Stream Flow in a Headwater of the Blue Nile: Complementing Observational Data Analysis with Community Perception

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Abstract This study analyses the relation of forest cover and stream flow on the 266 km^2 Koga watershed in a headwater of Blue Nile Basin using both observed hydrological data and community perception. The watershed declined from 16% forest cover in 1957 to 1% by 1986. The hydrological record did not reveal changes in the flow regime between 1960 and 2002 despite the reduction in forest area. This agrees with the perception of the downstream community living near the gauging station. The upstream community, however, reported both decreases in low flows and increases in high flows shortly after the forest cover was reduced. The upstream deforestation effect appeared to have been buffered by a wetland lower in the watershed. This study concludes that community perception can be a complement to observational data for better understanding how forest cover influences the flow regime.

Keywords Blue Nile Basin · Community perception · Deforestation · Ethiopia · High flow · Low flow

INTRODUCTION

The influence of forests on the amount and timing of runoff is of great importance for planning sustainable land use in many regions of the world, not least in the Blue Nile Basin (BNB), Ethiopia. With an annual rainfall ranging from 800 to 2200 mm (Ministry of Water Resources 1998), the Blue Nile accounts for 49.4 G $\mathrm{m}^3\mathrm{yr}^{-1}$ flow at its outlet to Sudan. Even though this does not include all flows from the Ethiopian highlands to the Nile, it sill comprises 62% of the flow in the Nile at Aswan (Ministry of Water Resources 1998). Despite this great contribution to the Nile and abundant rainfall, there is a prolonged dry period in the headwaters of the BNB from December to May. The amount of dry season flow is a critical constraint for both water supply and agriculture in the region. During the rainy period (June–September) soil erosion associated with high flow is also a serious problem. Loss of forest in Ethiopia is popularly believed to have diminished dry season flows and increased high flows. As a result, increased forest cover has been suggested as a part of the region's integrated water resource management plan (Ministry of Water Resources 1998).

However reasonable it may seem to recommend increased forest cover as a desirable planning objective for the sake of the flow regime, the actual influence of forests on flow remains a subject of ongoing research (Andreassian 2004; Johnson 1998). One reason for this is the complex, multi-faceted nature of watershed response to changes in forest cover that can include influences on local climate and soil properties (Bruijnzeel 2004; Calder 2005). Another reason is that of scale, since forest cover change is generally confined to smaller portions of the watersheds from which flow is measured, making it difficult to accurately discern the effect of the change in forest area (Bloschl et al. 2007). There is also the issue of distinguishing between the effects of felling previously established forest and afforesting land which has been free of forests for a period of time (Bruijnzeel 2004; Malmer et al. 2009). Calder (2005), among others, has warned against land use policies being steered by myths about the benefits of forest cover for the low flow and for the hydrological cycle, in general. Despite the popular belief that forests promote dry season flows in Ethiopia, including in the Blue Nile Basin (BNB), there are many examples from other regions where forest cover is negatively correlated to dry season flow (Bruijnzeel 2004; Eisenbies et al. 2007; Robinson et al. 2003; Wilk et al. 2001). While there are some examples of forests contributing to low flow (Bruijnzeel 2004), it is difficult to predict where and how these will occur. Moreover, even though there is more general agreement that deforestation increases high flows and total annual flows in a wide range of landscapes, quantifying these influences is also difficult without regional, if not local, observational data.

The northern part of Ethiopia, including the BNB, lost much of its forest over a century ago (Bekele 2003). Current forest cover is just a few percent in large parts of the region; much of it planted *Eucalyptus* monoculture. Loss of much more diverse natural forest is popularly believed to be a cause of stream flow extremes (drought and flood). However, there are only a few studies which can be used to test this popular belief, or support the policies based on it. Hurni et al. (2005) concluded from a compilation of plot and small watershed studies conducted in the BNB and other parts of Ethiopia between 1957 and 1995 that surface runoff rates are clearly influenced by land use and soil degradation. They found 5–40 times more surface runoff during the rainy season from cultivated or degraded land than from forested test plots. Although there are no quantitative conclusions from the study about low flow, the results have been used to suggest decreases in the low flow of the highlands of the upper BNB in a historical perspective (Hurni et al. 2005). A study conducted on the 364 km^2 *Chemoga* watershed, (Bewket 2003) found that, between 1960 and 1999, the annual total, dry season and wet season flow declined by 1.7, 0.6 and 0.5 mm yr^{-1}, respectively. All these flow declines were more rapid than the decrease in annual rainfall of 0.29 mm yr^{-1}. The relative decline in stream flow on the *Chemoga* watershed occurred at the same time as there was a small absolute increase in the forest cover extent from 2.4 to 3.6%. However, the forest cover increment was attributed to *Eucalyptus* plantation, while the natural forest cover decreased. This study concluded that the observed changes in stream flow had apparently resulted from change in land use; expansion of cultivation, overgrazing and *Eucalyptus* plantation. The small change in forest area means that the other land use factors were probably more important than forest change for the observed hydrological changes.

These published studies provide rather little information for drawing conclusions from a scientific perspective that either supports or disproves the popular belief in the value of increased forest cover for sustaining dry season flows in the BNB. Thus, there is clearly a need for region-specific data to test the widespread belief that forests sustain dry season flows in this region.

This is important for both the local population and continental geopolitics. Locally, the Ethiopian highlands are one of the poorest societies in the Nile basin (FAO 2000) with a high degree of rain-fed subsistence agriculture that is vulnerable to drought and soil degradation associated with soil erosion at high flows. The Blue Nile is also a transboundary river where there is intense scrutiny of anything that will alter the downstream delivery of water to the Nile in Sudan and Egypt (Arsano 2004; Mason and 2003). Owing to the international implications of local concerns about water development and food security in the Blue Nile river basin, it is a crucial region for studying the relationship between forest cover and stream flow.

The key to a satisfactory basis for predicting the effect of forests on flow regimes is region-specific empirical data that is often lacking. In general, this means 'objective' quantitative observational data, such as measurements of runoff, climate and land use. However, community perception can also be a source of qualitative data that should not be confused with the popular beliefs of people remote from the local water resources. The belief that forests promote dry season flows should be seen as an example of popular beliefs. Community perception in this article refers to the knowledge of people living close enough to the land and water to experience the local hydrological regime. Several studies (Evelyn and Camirand 2003; Gautam 2006; Sandewall et al. 2001; Sin and Sammani 1987) used community perception to generate historical change and ongoing land resource information, which is different from popular beliefs.

In order to help us define the relationship between forest cover and the stream flow regime in the BNB with the observed hydrometric data, there are over a dozen river flow gauges that have been in operation since 1960. This study uses one of those long-term gauging records, complemented by remote sensing of land use to determine how forest cover related to the flow regime changes on the 266 km^2 Koga watershed in a headwater of the Blue Nile (Fig. 1). The observed flow record extends from 1960 to 2002, and there are remote sensing observations to define land cover in the watershed over the same period (air photos from 1957 to 1982, and thereafter satellite images).

This study also investigates community perception of how the extent of forest cover influences stream flow. Community perception was collected using Participatory Rural Appraisal (PRA) techniques, a methodology used to compile peoples' perception in planning and development activities. Many in the current generation of community elders have experienced firsthand what has been happening to the water and land resources over the same period as the observational record.

Therefore, in addition to examining region-specific observational data on the effect of forest cover on flow extremes, this article compares community perception to the observational record to determine whether either or both of these sources of knowledge confirm or contradict the popular belief that increased forest cover will better sustain dry season flow and reduce peakflow in the BNB. A further question was whether community perception is a potential complement to the observational record which

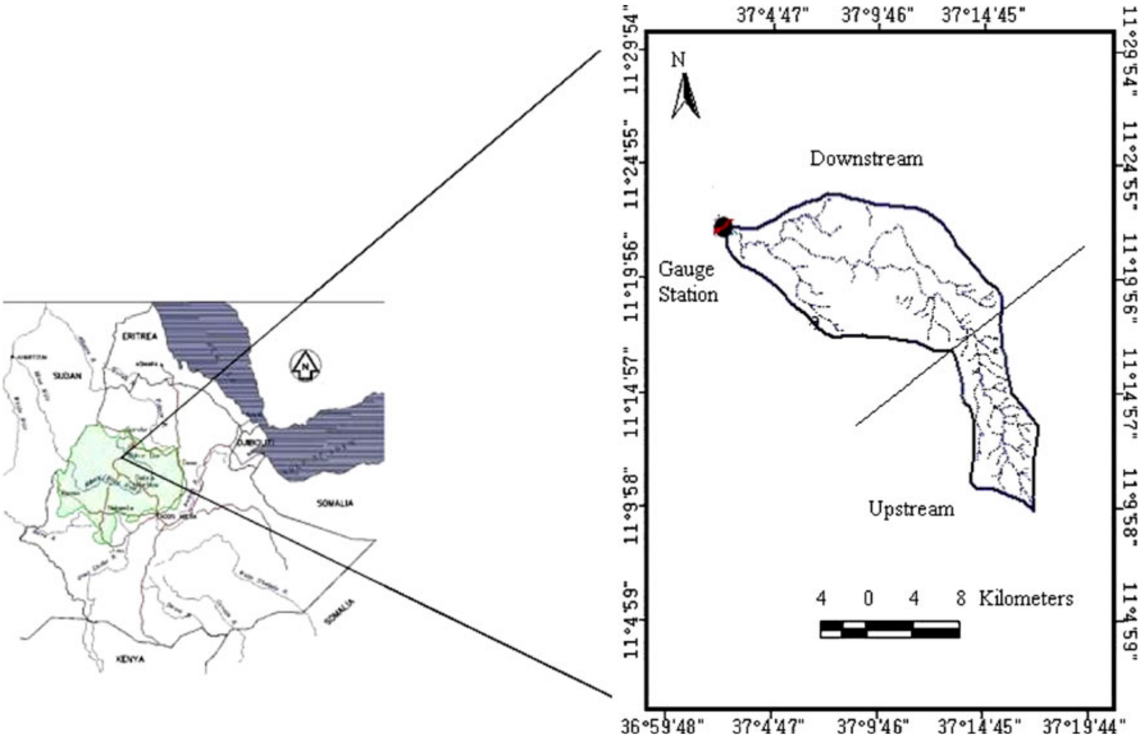


Fig. 1 Location of the Blue Nile Basin/Ethiopia; the *green* shaded area in the left figure. To the right is the 266 km^2 Koga watershed with the division into upstream (65 km^2) and downstream (201 km^2) areas

has spatial and temporal limitations in its description of the water resource relative to a community's experience of that resource.

METHODOLOGY

Study Site

The Koga watershed is located in a headwater of the Blue Nile, Ethiopia (Fig. 1). The total area of the watershed is 266 km^2. The elevation stretches from 1800 at the gauge station (11°22′12″ N latitude and 37°02′15″ E longitude) to 3000 m above sea level. On the basis of the relief, the watershed can be classified into two parts. There is a narrow hilly to mountainous upstream area, and a wide, flat to gently sloping downstream area. Based on the meteorological record of Bahir Dar 35 km away from the watershed, the mean daily temperature was 19°C, and the mean annual rainfall was 1560 mm (1960–2003) with a maximum annual rainfall of 2036 mm in 1973, and a minimum of 895 mm in 1982.

During a field inventory in 2005, the major land use/land cover features of the watershed were cultivated land, settlement, scrub-wetland, bush land and a few remnants of natural forest trees. There are also some planted *Eucalyptus* trees around settlements. The wetland is characterized by grass and scrub vegetation; more or less grazing land. However, during wet periods, parts of the wetland are submerged.

Observed Data: Remote Sensing

Aerial photos for the entire watershed were obtained from the Ethiopian Mapping Agency (EMA) for December, 1957 and January, 1982 (nominal scale ca. 1:40000); in addition, Landsat satellite images (path-170 and row-52) with 28.5-m spatial resolution in six spectral bands are available from January 1986 and 2001. The photos and images were used for land use/land cover identification and classification analysis. The identified land use/land cover classes were forest cover, open bush land, cultivated land, scrub-wetland and settlement (Table 1). Land use/land cover classification and area determination for 1957 and 1982 were conducted through manual digitization based on stereovision. The watershed boundary and drainage patterns were digitized using georeferenced topographic maps (dated 1984). Stream patterns of the watershed were delineated with the help of these topographic maps. Satellite images were resampled and georeferenced to UTM projection using tie points from the topographic maps. Enhancement was handled through band filtering, stretching and colour composite in ILWIS 3.1 Academic. The digital map and enhanced Landsat images were integrated so that land use/land cover could be classified

Table 1 Land use/land cover description and characteristics in Koga watershed

Land use	Description and characteristics
Forest cover	Land cover dominated by the natural forest. In 2005, most forest cover was patchy. At that point, closed forest was only found in mountain-gorges and around the compounds of ancient orthodox churches.
Open bush land	Sparse, low vegetation—grasses and bushes. The soil is generally marginal.
Cultivated land	Subsistence farming, mostly rainfed. In fallow time, cultivated land is used for grazing.
Scrub-wetland	Wetlands and marshy lands with sparse, low vegetation. The land is not generally used for farming due to standing water for much of the year. However, recently it has been noted that the time of inundation is decreasing to only shorter periods during the rainy season.
Settlement	Settlement indicates residential places with some garden vegetation, including *Eucalyptus* which dominates home gardens since the 1980s.

through screen digitization using the Arcview interface. The data obtained from the aerial photos were adjusted to the scale of the topographic map (1:50000), which had already been scanned and geo-referenced for GIS. The enhanced satellite images were overlaid on the delineated watershed and land use/land cover classes. The geo-referenced topographic map and the 1982 aerial photo were then used to calibrate satellite image classification.

Observed Data: Climate and Hydrometric

The observed hydrometric variables are monthly rainfall, temperature, and river flow. The monthly rainfall as well as monthly maximum and minimum temperature data were provided by the National Meteorological Service Agency from the local meteorological station in Bahir Dar located 35 km Northeast of the gauging station (Fig. 1). Maximum and minimum temperatures were used for calculating monthly evapotranspiration using Hargreaves's method (Belete 2002). The main control on rainfall over the region is the moist air coming from the Atlantic and Indian oceans following the north–south movement of the Inter Tropical Convergence Zone (ITCZ).

The flow data were provided from the central hydrological record database maintained by the Department of Hydrology in the Ministry of Water Resources. In this study, high flow refers to the maximum monthly flow over the course of the year. Low flow is the lowest monthly flow recorded in the respective year, generally occurring in February. The flow data are determined from the daily water mean level. The water level is measured manually twice daily (0600 and 1800) by a local observer. The rating curve for converting water level to flow at that site is updated regularly by the Ministry of Water Resources based on flow gauging performed on several occasions each year. The reference level for the water level measurements are re-established every year after the peak, rainy season flows by survey from the local benchmark.

Data quality is always a concern, especially for multidecadal time-series such as those used in this study. Gragne et al. (2008) found that it was possible to use a hydrological model driven by the local precipitation and temperature records to predict flows that corresponded acceptably with the observed flows (1993–2006) when averaged over a 2-week period. The correspondence of model and observations was less satisfactory at a daily level. This earlier modelling study and our own analysis of the water balance for the entire 43 year period used in this study suggest that the monthly values used are not obviously incorrect. Our water balance analysis involved comparison of monthly rainfall, discharge and evapotranspiration, as well as calculation of annual runoff coefficients and estimated water storage.

Community Perception

Community perception in this study refers to qualitative data on the local peoples' views about the changes in the forest resource, stream flow and climate. These perceptions were documented using Rapid Rural Appraisal (RRA) which is an approach to PRA for instantaneous generation of information. These are systematic techniques used for participatory collection of qualitative data (Jackson and Ingles 1998). Community perceptions from two distinct areas of the Koga watershed were documented. One area was the flatland in the downstream area near the stream gauge, and the other area was the mountainous upstream portion of the watershed. The specific PRA tools used in this study were key informants, focus group discussion, historical matrix analysis and triangulation.

Key Informants

People with valuable sources of information for a specific study are known as key informants (Jackson and Ingles 1998). Thirteen elders from the upstream community and

11 elders from the downstream community participated in the focus group discussions. These participants were identified with the help of the provincial agricultural office and Koga watershed management office experts. All the participants were at least 40 years old.

Focus Group Discussion

Key informants discussed specific topics, upon which a group consensus was sought. The group discussions were conducted in January 2006, with different dates for the upstream and downstream communities. The first topic for both the upstream and downstream areas was the classification of time periods for matrix analysis with respect to physical resources. Then, changes in land use, flows and climate were discussed. In most cases, those between 40 and 50 years old gave precedence to the views of those who were older (50–80 years old). This contributed to the attainment of consensus in the focus groups.

Historical Matrix Analysis

Historical matrix analysis is where the focus group physically places different events in specified time periods using a matrix of rows and columns. Physical resources that correspond to different events constitute the rows. Time period classes constitute the columns of the matrix. Data collected and analysed by the historical matrix tool were high flows and dry season flows, forest cover status, wetland extent, temperature, rainfall patterns, and erosion. The amount of the resource was identified by placing different numbers of pebbles in the appropriate cell of the matrix defined by a particular resource and time period.

Triangulation

This is a method used to cross-check the information extracted through different PRA tools. In this case, the method of personal observation and cross-checking the information gathered through historical matrix and group discussion was employed. Personal observation was made through field observation before and after group discussion. Cross-checking also included comparing the PRA information with the remote sensing analysis of the historical land cover.

Statistical Analysis

The methods used for data analysis were simple regression for testing the trend over time, Analysis of Variance (ANOVA), and variance homogeneity test. A simple linear regression checked for trends in the annual flows, rainfall, and evapotranspiration. ANOVA and variance homogeneity tests are used to see the difference in means and variances between different periods. These time periods were defined based on the community perception information about when major changes in land use and flow occurred.

RESULTS

Land Use/Land Cover Change

The dominant land use/land cover during the entire period of the study was cultivated land and scrub-wetland. These two alone comprised 75–82% of the total watershed area (Table 2; Fig. 2). Forest cover, open bushland and settlement comprised a smaller area of the watershed. In the first air photos from 1957, the forest area was 16%, located mostly in the upper part of the watershed. In the next set of air photos from 1982, the forest cover was 2%, and in the first Landsat satellite image from 1986, the forest area was just 1%. The wetland covered 28% of the watershed area in 1957 and 11% in 2001. Caution needs to be exercised in the interpretation of the wetland area changes from instantaneous observations since this is a feature of the landscape that may vary from year to year, and within the year, depending on antecedent precipitation. Cultivated land had the highest proportion of coverage in the watershed for the whole period. In general, forest cover and scrub-wetland declined, while settlement, cultivated land and open bushland increased (Table 2).

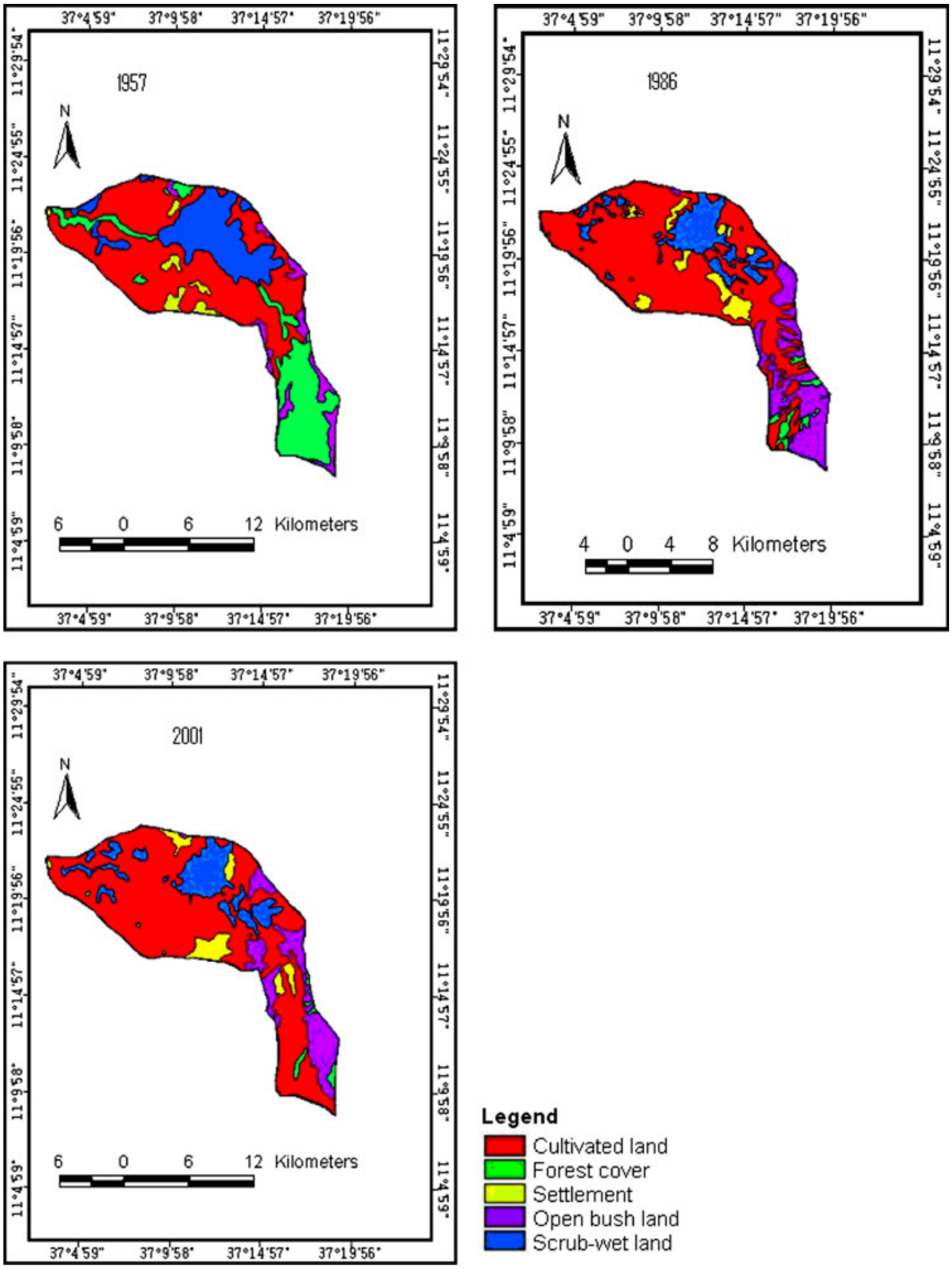
Observations of Climate and Flow

The general trend of rainfall shows a reduction of 4 mm yr^{-1} (Fig. 3). More specifically, the total amount of rainfall before and after 1976 shows a difference; with a mean of 1585 mm for 1960–1975 as compared to 1349 mm for 1976–2002 (refer to the next sections for significance of changes between these periods). The potential evapotranspiration fluctuated throughout the study period without any prolonged period of increase or decrease.

Table 2 Land use/land cover extent at different years in the Koga watershed determined from the remote sensing observations

Land use	1957		1982		1986		2001	
	km^2	%	km^2	%	km^2	%	km^2	%
Forest cover	42	16	6	2	4	1	4	1
Open bush land	16	6	33	13	28	11	35	13
Cultivated land	124	47	173	65	181	68	179	67
Scrub-wetland	76	28	41	15	38	14	30	12
Settlement	9	3	14	5	16	6	19	7

Fig. 2 Map of land use/land cover change based on remote sensing analysis



The patterns in low flow, high flow and total flow did not reveal any significant trend over time (Fig. 3). One distinctive feature of the flow record was the exceptionally large values for total and high flow in 1975, as well as low flow in 1976. Removing these from the statistical analysis does not change the conclusion that there was no consistent change in flow patterns.

Community Perception

The community identified 1975, 1985 and 1991 as benchmark dates for change in the land use and flow variables. These dates related to changes in political power (1975 and 1991), as well as major changes of land tenure policies, in 1975 and 1984/1985. The overthrow of the monarchy in 1975 was accompanied by a decree giving 'land to the tillers'. In 1984/1985 the government of the time (the Derg regime (Table 3)) implemented a national resettlement program (villagization).

The upstream and downstream communities independently reported changes in a number of parameters occurring at the same time. There was generally little difference in the starting dates of change in land use and in some flow variables. Both communities agreed that forest cover began

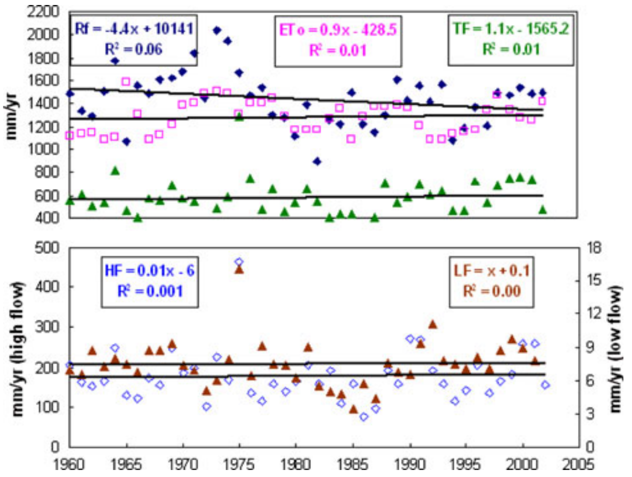


Fig. 3 Annual rainfall (Rf, *filled diamond*), evapotranspiration (ETo, *open square*) and total flow (TF, *filled triangle*) (*upper panel*) as well as, minimum and maximum monthly flows (*lower panel*) as low flow (LF, *filled triangle*) and high flow (HF, *open diamond*). Note that the low flow values correspond to the scale on the right axis

to decline in 1975. They also noted decreases in precipitation, and increase in temperature starting in the post villagization period (1985). Increased erosion had also been noticed about 1985. There were, however, differences in when the upstream and downstream communities noted decreases in low flows and increases in high flows. The upstream community noted changes in flow extremes earlier than the downstream community. For the upstream community, high flows increased starting in 1975 and low flows decreased starting around 1985. For the downstream community, increases in peak flow and decreases in base flow were first noted post-2001 (Table 3).

A diminishment of the wetland starting in 1985 was noted by the upstream community, but this subject did not come up in the downstream community focus group, so no comparison with the downstream community is possible for this. The downstream community made a point of mentioning that the colour of the water became brown since 1975 which could be an indication of erosion occurring further upstream.

Statistical Analysis of Changes in Flow Regime

Based on the community perception of when major changes in forest and flow parameters occurred, statistical tests were made to compare the behaviour of flow response of three different periods. These periods are 1960–1974; 1975–1985; and 1986–2001. The breakpoints between these periods coincide with the overthrow of the monarchy in 1975 and villagization resettlement program in 1984/1985. The means and variances of these periods were compared for these three periods (Table 4).

Rainfall showed significant differences in means between some periods, with most rain pre-1975, while there was no significant change in variances at $p \leq 0.05$. High, total and low flows showed no significant differences between the means of the periods. However, there was a

Table 3 Summary of community perception based on Participatory Rural Appraisal (PRA) results, showing the time and direction of changes for climate, hydrological and land use parameters

	Community	Monarchy (before 1975)	*Derg*[a] pre villagization (1975–1985)	*Derg*[a] post villagization (1985–1991)	During FDRE[b] (1991–2001)	Current (after 2001)
Rainfall	Upstream			–	–	–
	Downstream			–	–	–
Temperature[c]	Upstream			+	+	+
High flow	Upstream		+	+	+	+
	Downstream[d]					+
Low flow	Upstream			–	–	–
	Downstream					–
Erosion	Upstream			+	+	+
	Downstream[d]			+	+	+
Forest cover	Upstream		–	–	–	–
	Downstream		–	–	–	–
Wetland[c]	Upstream			–	–	–

[a] *Derg*, is the term for the communist regime which replaced the monarchy in 1975. This term means unity or council in the ancient *Geez* language of Ethiopia

[b] FDRE stands for Federal Democratic Republic of Ethiopia

[c] These topics were not discussed with the downstream community

[d] Though the downstream community indicated changes in high flow only post 2001, they noticed a change in the colour of river water to brown since 1975 rainy season

Table 4 Statistics of rainfall and flows in the three periods as well as tests of mean and variance differences

		Mean	SD
Rainfall	1960–1975	1581^{a}	255^{NS}
	1975–1985	$1331^{a,b}$	217^{NS}
	1986–2002	1387^{b}	165^{NS}
High flow	1960–1975	176^{NS}	43^{*}
	1975–1985	182^{NS}	97^{*}
	1986–2002	179^{NS}	59^{*}
Total flow	1960–1975	551^{NS}	110^{**}
	1975–1985	605^{NS}	250^{**}
	1986–2002	597^{NS}	130^{**}
Low flow	1960–1975	7.4^{NS}	0.11^{**}
	1975–1985	7.3^{NS}	0.31^{**}
	1986–2002	7.8^{NS}	0.18^{**}

Within columns, each value followed by ^{NS} indicates not significantly different. Means followed by different letters are significantly different at $p \leq 0.05$, SD tested with the corresponding variances followed by * are significantly different at $p \leq 0.05$, and by ** at $p \leq 0.01$

significant difference in the variances between the periods ($p \leq 0.05$).

DISCUSSION

The effect of deforestation on the flow regime is a major concern in the Upper Basin of the Blue Nile, as in many other regions. Sustaining low flows during the dry season is of particular concern since rain-fed subsistence agriculture is the mainstay of the population. Despite estimates that much forest cover loss in the BNB has occurred in the last century, the few detailed studies on land use change to date have shown relatively little loss in forest cover. Most of the dense forest cover was already gone over a century ago in the northern part of the country where Koga is located (Bekele 2003). The remote sensing analysis in this study, however, revealed substantial loss of dense forest since 1960, from 16 to 1%. This makes Koga the watershed with the largest loss of forest area since 1960 yet documented for the BNB. Much of that loss occurred in the steeper, upstream 65 km^2 of the watershed (Figs. 1, 2). The forest covered 65% of the upstream area at the start of the study period, but declined to 5% in 2001.

Compelling as the remote sensing imagery is for documenting the forest loss, the community perception is still a valuable complement to those observed data. In the era before satellites began observing the earth surface at high frequency, there were major temporal gaps between observations, as is the case of the 26 years between the first air photo survey in 1957 and the subsequent survey in 1982. Given the available observational data, it might seem reasonable to posit a continuous exponential function to describe the forest loss (Fig. 4). The community perception, however, provides a distinctly different and even more dramatic time line for the forest loss, with the deforestation focused around 1974/1975. The community perception suggests that much of the deforestation occurred in conjunction with the land tenure reform in 1975 rather than more continuously from 1957 to 1982. Based on such greater temporal resolution, the community perception provides a more likely course of forest cover changes closer to a step shift starting in 1974 (Fig. 4).

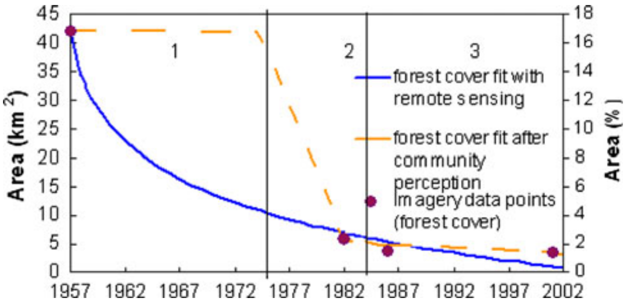


Fig. 4 Forest cover over time (*blue, curved line*) based on exponential interpolation between remote-sensing values alone (*filled circles*) and as refined by the community perception into a more linear, step-shift interpolation (*lighter, straighter dashed line*) of the Koga watershed. Absolute forest area is shown on the left-hand *side y*-axis, and the forest area as a percentage is on the right-hand side *y*-axis. Vertical lines and numbers define the periods used in ANOVA analysis

It is on the basis of this composite interpretation from remote-sensing and community perception that the statistical analysis of flow regime change was extended from looking for trends over the entire period to an ANOVA comparison of three periods. The period of relatively stable land use prior to 1974 is one period, followed by an intermediate phase of rapid forest loss, and then a new period of forest cover stability after most of the forest from 1957 was gone.

Despite the largest recorded loss of forest in the last century for any gauged watershed in the BNB, no change in total flow, high flow or low flow was evident in the monthly flow record. This lack of change is found both in terms of a linear trend analysis and the ANOVA comparison of means in the three periods before, during and after the deforestation. The lack of change in the observed flow regime occurred despite significant changes of rainfall between periods, from 1581 mm in the first period to 1331 mm in the second period. There were, however, significant changes in the variability of flows.

One possible explanation of the lack of a significant response in the observed record despite loss of forest is the presence of the large wetland above the gauge station in the lower part of the watershed. Gragne et al. (2008) compared the runoff response of Koga with the adjacent Gilgel Abbay during of the late 1990s and early2000s, when the forest cover had already largely vanished. That study found that the wetland dampened the Koga runoff response to rainfall relative to its larger neighbor, Gilgel Abbay (1660 km^2) which has negligible wetland area.

If only the observed hydro-climatological record were available, then the analysis of deforestation effects on flow would end there. However, the qualitative PRA data about community perception makes it possible to take the analysis further. While the perceptions from the upstream and downstream communities coincide on a number of points, such as rainfall and temperature, as well as the timing of forest loss, they differ with regard to the onset of increases in high flow and decreases in low flow. The downstream community noted no changes in these parameters until the last several years (after 2000), a quarter of a century after the major loss of forest in the upstream area. This perception of the downstream community is generally consistent with the observed record, even though the downstream community's perception of increased flows extremes post-2001 is not reflected in the observed flow record. This is a salutary reminder that hydrometric observations and community perception are not necessarily congruent. One possible explanation is that community perception of dry season flow and peak flow represents something more short-term or localized than the monthly average flow. It could be shorter term extremes, or the drying out of certain springs. This could be tested by comparing community perception with the daily runoff observations, or maps of water sources that have stopped flowing during successive dry seasons.

The upstream community on the other hand, noted an increase in high flow that coincided with the forest loss in 1975. Within a decade, the upstream community was also reporting decreases in low flow. This suggests that the decline in forest cover from the upstream area did have noticeable and rapid consequences for flow extremes from that upstream area. This supports the hypothesis that the wetland intervening between the upstream area, where most of the deforestation occurred, and the gauging station may have indeed obscured that hydrological response further downstream. This is also an example of the way in which observations at larger scales are difficult to relate to land-use changes focused on smaller areas of the watershed. The fact that the downstream community noted a change in the colour of the river water starting in 1975, and that both upstream and downstream communities perceived an increase in erosion starting in 1985, also suggests the importance of forests for both soil and water conservation.

The upstream community perception of declining wetland area (also noted in the remote sensing) suggests that the capacity of the wetland to buffer the flow extremes may have diminished, possibly due to lower dry season flows from the upstream area. The increased variability in the flows of the later periods may be related to this reduction of the wetland area from 74 to 29 km^2 (Tables 3, 4). It should be noted, though, that it is difficult to observe wetland extent in the limited number of images that comprise the remote-sensing record for this study, and the downstream community did not include the wetland extent in their RRA focus group discussion.

When it comes to assessing changes in flow regime, and its causes, a reliable observational record is highly desirable (Tharme 2003). The example from the Koga watershed, however, demonstrates that even with a relatively good observational record supported by remote sensing data, community perception can serve as a valuable complement in the interpretation of that record. The community living with the water regime develops its perception with a spatial and temporal resolution that can fill gaps in the observational record, even though community perception is only a qualitative data source.

The community perception of increased erosion after the major forest loss is consistent with both the scientific consensus and popular belief. This emphasizes the importance of land management in the BNB for controlling peak flows that influence the degree of soil erosion and degradation (Hurni et al. 2005). The flow regime is also vulnerable to soil degradation that can contribute to reductions in flow. Land management activities to conserve soil could help sustain low flows. The lack of a change in both the observed flow regime and the perception of the downstream community up until 2001 is not consistent with either the popular belief about the value of forests for mitigating flow extremes for the BNB or the scientific view which predicts that changes in forest cover will change the flow regime (even if the direction of the low-flow change is still subject to debate.).

Perhaps the most intriguing finding of this study though, is the decline in low flow noted by the upstream community. This is congruent with the popular belief that the presence of forests sustains low flows. In the observational analysis of the relation between flow and forest cover, this is the exception rather than the rule, since many literature examples indicate that the forest cover is negatively correlated to low flows, rather than sustaining them (Bruijnzeel 2004). Changes in soil depth and perhaps associated with the forest cover loss were not evaluated in this study. Such data would be interesting to examine as it might help explain how a decrease in forest cover could correlate to decline in dry season flow. For even though reducing tree cover will reduce transpirational demand, which might be expected to increase the amount of water in the watershed to sustain dry season flows, soil degradation could counteract this effect by reducing the water-holding capacity of the soil. That would be expected to decrease dry season flows, especially if the local climate is affected by the loss of forest cover in a way that reduces precipitation and infiltration capacity.

It would have been desirable to have had a gauge further upstream to quantify the effects of the deforestation in the 1970s. Nonetheless, the community perception that low flow declined after deforestation raises the possibility that this region may be one of the areas where there is a positive relationship between extent of the natural forest cover and dry season flows. This would also support the popular belief in the region that afforestation could help sustain dry season flows. Such qualitative community perception data, however, are not a substitute for quantitative observations of such an effect. It may seem somewhat ironic that by identifying an area that may be an exception to the generalized scientific results from other regions that increased forest cover reduces low flows; the qualitative PRA methods build a case for more quantitative observations.

CONCLUSION

Deforestation is an important part of land use history in the BNB. It is essential to investigate its implications for the flow regime. This will help future integrated watershed management plans which incorporate afforestation and conservation strategies for the country and/or BNB development. In this study, the community perception was able to help explain the perplexing results that the largest recorded deforestation in the region since 1960 appeared not to have affected the observed flow regime, including both low flow and high flow. The greater spatial resolution of the community perception was able to corroborate the speculation that the wetland in the downstream part of the watershed had obscured the effect of the upstream deforestation on the hydrological signal reaching the gauge in the downstream area at the watershed outlet. The community's ability to localize the time point of the deforestation also contributed to the interpretation of the remote sensing observations of land use change and the ability to design an appropriate statistical design for analysis of the flow regime.

This study is the first to compare quantitative observational data and qualitative community perception data with popular beliefs in the BNB about the relation of forest cover to the flow regime. More such efforts will be needed to provide a better basis than popular belief for establishing forestry's role in integrated water resource management for the region. In future study, we suggest that community perception can be used for complementing both remote-sensing and hydrological observations.

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