Probe - Water Conservation and Sustainability

Analysis of Ecosystem Service Value Dynamics in Sub-Sahara Africa

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Abstract: Dwindling ecological service value (ESV) is a key challenge in Ethiopia and Hare River Catchment (HRC). As studies made about ESV of HRC were rare, it was vague to understand the supply and threats of the services in the area. So, this study was aimed at analyzing magnitude, trend and drivers of ESV change in HRC. Data were captured from remote sensing sources, survey, questionnaire, etc. LULC data and valuation coefficients of Costanza et al., (1997) and Kindu et al., (2016) were used for estimating ESV dynamics. Sensitivity analyses were run to verify accuracy of the estimated ESV changes. HRC, with an area of 23,432.7ha, revealed net ESV loss by US$ 6.035 million within 1967 - 2015. The lion share of ESV loss was triggered by land use/land cover change and farm expansion at the cost of forest, woodland, etc. So, gov't policy should be targeted on resilience of ecological services and on agro-forestry options to curb farm expansion-led ESV loss in HRC, Southern Ethiopia.

Keywords: services, value, net gain, net loss, magnitude, trend, sensitivity analysis, etc.

1. Introduction and Statement of the Problem

Ecosystems are basically linked to the welfare of humans since they satisfy livelihood needs of people. An ecosystem is a distinct area where living entities interact each other and also with the non-living elements of nature (MEA, 2005); whereas, goods (being concrete products) and services (being largely intangible ones) are benefits manufactured through functions of ecosystems (Egoh et al., 2012). Sustaining ecological services is a critical challenge worldwide (MEA, 2005) as the flow of services is often impacted by Land Use/Land Cover (LULC) dynamics (Costanza et al., 2014). Most ecosystem services are not marketed and have no market values (Boyd, 2012; Czajkowski et al., 2017; Muller et al., 2019). Design of "value coefficients" about services of the different ecosystems (Costanza et al., 1997) and use of "benefit transfer" technique (Czajkowski et al., 2017) eased measuring values of marketed and non-marketed services at a time and also, analysis of ESV dynamics overtime (Kreuter et al., 2001; Kindu et al., 2016). Especially, non-marketed services are most frequently measured by benefit transfer technique (Czajkowski et al., 2017). Thus, benefit (value) transfer can be used for valuing forest, woodland, bush/shrub and grassland services since most services (especially supportive, regulatory and cultural services) of these ecosystems are non-marketed ones (Muller et al., 2019).

Studies that have measured magnitudes of ESV gains/losses in response to LULC dynamics were several (Kreuter et al., 2001; Yuan-wang et al., 2006; Li et al., 2007; Chanhda et al., 2009; Tian-hong et al., 2010; Yun-guo et al., 2011; Costanza et al., 2014; Kindu et al., 2016) even if this kind of studies seemed to have not been fairly distributed across the globe. Cumulative effect of the value of ES dynamics in a locality could be positive/net gain (Chanhda et al., 2009) or negative/net loss (Kindu et al., 2016). The changes (ES) could be triggered by *negative drivers* (De-Groot et al., 2010) such as poverty, overuse of resources (Kideghesho et al., 2006; Shackleton et al., 2008), expansion of farming and infrastructure, deforestation (Geist and Lambin, 2002; Binyam, 2015), chemical farm inputs, invasive species, climate variability (Newcome et al., 2005; Heathwaite et al., 2012; Egoh et al., 2012), etc.; it could also be caused by *positive drivers* (afforestation, area-closure, agro-forestry, etc.,) and *neutral drivers* (like LULC change) - the effect of which can be positive or negative depending on circumstances where the drivers act (De-Groot et al., 2010). But, nature, magnitudes and drivers ESV changes could not be similar and equally significant everywhere, globally. Measuring such issues is valuable for setting policies on sustainable management of ecosystems upon concrete evidences in monetary terms (Boyd, 2012).

The procedures used for data acquisition and analyses are known to play pivotal roles for the validity of results of any research work (Creswell, 2009). In this regard, a number of studies aimed at measuring LULC dynamics–led ESV gains/losses revealed limitations in applying the "change matrix" model and hence, quantifying the magnitudes of net ESV gains/losses was not possible by the studies (Kreuter et al., 2001; Zou et al., 2005; Yuan-wang et al., 2006; Li et al., 2007; Chanhda et al., 2009; Kindu et al., 2016). Evidences obtained upon the "change matrix"-based estimations are also good indicators of the drivers of ESV gains or losses triggered by LULC changes overtime (Yun-guo, 2011).

Several researches were conducted about the impact of LULC dynamics in Ethiopia (Badege, 2001; Wondamlak, 2002; Meles et al., 2008; Abate, 2011; Binyam, 2015, etc.), and also in the study area/HRC (Abren and Daniel, 2007; Yechale, 2012; Assefa and Bork, 2016); most of these and other studies revealed that LULC changes have led to the depletion of ecological resources largely in highlands of Ethiopia where population pressure is high (Belay, 2002; Wondamlak, 2002). For instance, forest cover was indicated to have declined from two-fifth of country's area in the 1st half of the 20th C to 2.5% (EFAP, 1993) before it grew to 9% in the recent past (Alemu and Kidane, 2014);

increasing soil loss rate or depletion of valuable nutrients (Binyam, 2015), declining land productivity (Zewdu et al., 2014), destruction of forest (Badege, 2001; Yechale, 2012), loss of habitat (Meles et al., 2008), etc., were among the impacts of LULC changes in Ethiopia. But, none of these studies (except Kindu et al., 2016) quantified magnitude of LULC change-led ESV loss and its impact on climate in Ethiopia and HRC. Measuring ESV losses is useful for setting resource management options (Muller et al., 2019) and mobilizing stakeholders towards resilience of degraded resources as the response to such a challenge is thought to be vibrant whenever people are told in terms of money (Boyd, 2012).

2. Objectives of the Study

This study was targeted to: **(1)** assess ESV of HRC for six periods within 1967 – 2015; (**2**) analyze the magnitude and trend of ESV changes within 1967 – 2015, **(3)** measure net ESV gain/loss in six periods within 1967 – 2015, and **(4)** explain the main change drivers of ecosystem services in the Catchment.

3. Study Area and Research Methods

3.1 Study Area

HRC (with 23,432.7ha) is located within $6^0$02’13’’ – $6^0$17’55’’ N and $37^0$27’09’’ – $37^0$37’51’’ E (Figure 3.1). Its greater part is in Gamo highland and smaller part is in the Rift-Valley, Ethiopia. It is 1170 – 3484m high above sea level. The Middle Catchment (MC) and Upper Catchment (UC) of HRC is largely rugged and steep to very steep landscape with interlocked spurs/ridges. But, the Lower Catchment (LC) being within the Ethiopian Rift-Valley is largely plain. Hare River has a dendritic drainage pattern; that is, the main river and its tributaries appear like a tree with its branches (Figure 3.1). Agro-ecology of HRC varies from *Kola* (tropical) to *Wurch* (alpine). Mean annual temperature of the area ranges from 16.7 ^{0}C in the MC and UC to 24 ^{0}C in the LC; and, its annual rainfall varies from 883.7 mm of the LC to 1406.5 mm in the MC and UC (MAE, 2016; Table 4, Appendix).

HRC consisted of six LULC classes in 2015 (Table 5, Appendix), which are described contextually below: (1) *Forest* is composed of trees with minimum height of 5m (FAO, 2000) and having nearly interlocked canopies, largely confined to inaccessible areas. Its area was 2.6% (609.2ha). (2) *Riverine vegetation,* covering 4.8% (1124.8ha), consists of varieties of trees, woody and herbaceous plants along banks of Hare River, its tributaries and adjacent to Abaya Lake. (3) *Cropland (and settlement)* refers to land used for rain-fed and irrigation-based crop farming including homestead with largely scattered trees. It was 63.2% of HRC. (4) *Bush/shrub-land* has more of short, hard woody stem trees (bushes), limited herbaceous plants (shrubs), mixed with grasses and less dense than forests. It was 12.4% (2905.6ha). (5) *Woodland* consists of trees where the physiognomy varies up to 20m depending on composition and density of the undergrowth-more of shrubs and grasses (Yachale, 2012). Its extent was 11.3%. (6) *Grazing-land* is composed of grasses and herbs intermingled with trees and shrubs having canopy cover of < 20% and including barren land (Ibid). Its extent was 5.7% (1335.7ha).

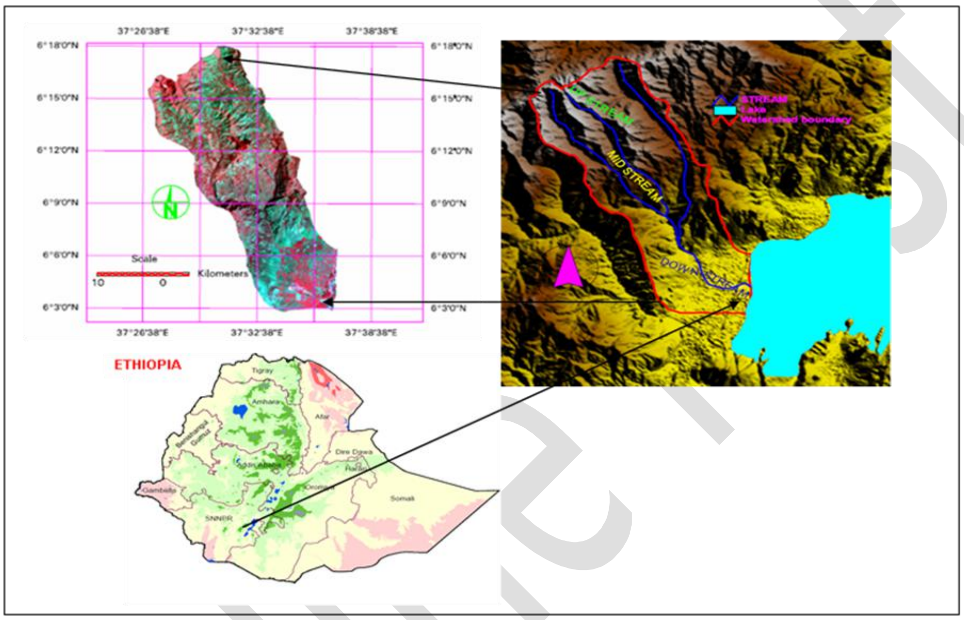

Figure 3.1 Location of HRC (**Source**: Yechale, 2012)

Forest, woodland and bush/shrub in lower HRC are composed of acacia (*albida*), desert-date (*balanites aegyptiaca*), flamboyant (*delonic regia*), bitter-leaf (*vernonia amygdalina*), *moringa oleifera*, *eucalyptus camaldulensis, acacia senegal (kontir)*, etc.; whereas, trees such as croton (*croton macrostachyus*), flat-top acacia (*acacia abyssinica*), olive (*cuspidate olea africana*), *tid* (*juniperus procera*), cypress (*cupressus lusitanica*), hop-bush (*dodonaea viscosa*), *koshim* (*dovyalis abyssinica*), *kosso* (*hagenia abyssinica*), *eucalyptus citriodora*, mountain bamboo (*arundinaria alpine*), reed-grass (*arundo donax*), etc., are components of forest, woodland and bush/shrub in the middle and upper catchments of HRC (Table 9a and Table 9b, Appendix).

3.2 Research Methods

3.2.1 Research Approach, and Sources and Methods of Data Acquisition

This study was conducted upon the quantitative approach (Creswell, 2009) since sensitivity analysis was used for statistical-based inferences about ESV dynamics (Yun-guo et al., 2011). Data were acquired from aerial photos (1967), Landsat MSS (1976) and TM of 1985, 1995, 2003 and 2015 (http://glovis.usgs.gov) records of temperature (1987 - 2015) and rainfall (1982 - 2015) (MAE, 2016). Field survey, questionnaire and interview were also used to gather data about provisioning and other services of HRC, and the threats or change drivers of the ES.

3.2.2 Sampling Techniques

Sampling design was required for environmental and household (HH) surveys. The 1km^2 grid square on the 1:50,000 topo-sheet of HRC was used as a basis for sampling LULC classes. Three (3) grid sample sites were identified from the lower, middle, and upper catchment each for data collection via check-lists. The grid sample sites were selected through purposive sampling, that is, from sites where sampling for two, three or more of the LULC classes (forest, cropland, woodland, etc.,) was possible. Evidences about existing LULC classes of each grid sample site, were described and recorded using camera and GPS. About 465 HH (19.3%) were selected upon systematic sampling (every 5th HH) for questionnaire administration; meaning, sample HH were taken proportionally from the lower (37.4%), middle (28.8%) and upper (33.8%) catchments of Hare (DANRP, 2015).

3.2.3 Techniques of Data Analysis

The 1:50,000 scale topo-sheets were scanned, geo-referenced and digitized to acquire base-map of HRC (with an area of 23,432.7ha). Aerial photos and Landsat images were also geo-referenced. Aerial photographs (20 stereo pairs) were scanned with a resolution of 600 dots per inch, and saved in Tag Image Format File (TIFF) for further processing. Aerial photo resampling process (at 30m resolution) was run to avoid the resolution differences between aerial photos and Landsat images (MSS and TM). The multi-temporal remote sensing data were imported to image processing software, and hence, image enhancement, rectification and classification were made (Li et al., 2007; Yechale, 2012); LULC classes were identified upon supervised maximum likelihood classification technique using ERDAS and Arc-GIS 9.3 (Chanhda et al., 2009; Yechale, 2012). Attributes such as pattern, shape, size, texture, tone, association and sites were used for identifying LULC classes of HRC within 1967 – 2015 (Lillesand and Kiefer, 2000; Yeachale, 2012).

LULC dynamics data were extracted via "change matrix" procedure for all the periods considered. It was assumed that the probability of transition (Pij) for each class in the matrix was proportional to the surface area of the corresponding class that remained unchanged throughout the periods considered (Chanhda et al., 2009; Yechale, 2012). Mathematically: $P_{ij} = S_{ij}(t_1)/ Sj(t_2)$; where: Sij is the surface area of the "ij" element of the LULC transition matrix during each initial year and "Sj" is the surface area of the "j" LULC class in the next year; thus, for any "j" class: SPij =100% (Yechale, 2012). Areas of six LULC classes and Valuation Coefficients (VC) of Costanza et al., (1997) and Kindu et al (2016) were used for measuring ESV of HRC for six periods within 1967 – 2015. VC of Kindu et al (2016) were adapted from van der Ploeg and de Groot (2010), and Knoke et al. (2011). Decisions were made on the LULC classes of HRC, which could be surrogates for local LULC classes of Munessa–Shashemene area of Ethiopia (Kindu et al., 2016) and the corresponding global biome categories (Costanza et al., 1997); and, VC of each LULC class was assigned using "value/benefit transfer" technique (Table 3.1).

Table 3.1 LULC of HRC Equivalent to Global Biome Classes and "Valuation Coefficients" (VC): (i) Adapted for Estimating ESV of HRC (from Kindu et al., 2016), (ii) of Costanza et al., (1997)

N0	LULC of HRC	(i) VC ($/ha/Year)	Global Biomes	(ii) VC ($/ha/Year)
1	Forest	986.69	Tropical forest	2007
2	Riverine vegetation	986.69	Tropical forest	2007
3	Cropland and settlement	225.56	Cropland	92
4	Bush/shrub-land	293.25	Grass/rangeland	232
5	Woodland	986.69	Tropical forest	2007
6	Grazing-land	293.25	Grass/rangeland	232

Source: Set upon Costanza et al., (1997); Yun-guo et al., (2011); Kindu et al., (2016); Table 7 (Appendix)

Scholars reveal that value transfer is likely to be less relevant for valuing ES where there are no significant similarities in bio-physical and socio-economic attributes between the proposed study site and the area from which values are going to be transferred (Czajkowski et al., 2017; Muller et al., 2019). However, "value transfer" is used in this study as it has been employed for similar purpose by various studies (Kreuter et al., 2001; Zou et al., 2005; Yuan-wang et al., 2006; Li et al., 2007; Chanhda et al., 2009; Tian-hong et al., 2010; Yun-guo et al., 2011; Kindu et al., 2016); this technique is also preferred due to shortage of funds for original valuation study, and availability of inadequate evidences that support function transfer for all affected services (Johnston et al., 2015). Due to the difficult of determining GDP and human population at catchment level, VC of Kindu et al (2016) were used for this study: (a) since VC of the original study were determined on account of inflation rate of US$, (b) as both the original study site (Munessa–Shashemene area of Kindu et al., 2016) and our study area (HRC) are located within 6 – 8^0 N, and both are situated partly in the Rift-Valley of Ethiopia, (c) as both study sites are dominated by agrarian economy, and (c) assuming the difference in the study period between the original study (1973 – 2012) and this study (1967 – 2015) is insignificant.

Total ESV of HRC (in each period) was estimated using (Kreuter et al., 2001; Li et al., 2007): $\mathrm{ESV} = \sum_1^n (\mathrm{Ak} * Vk)$; where: "ESV" is Ecosystem Service Value, "Ak" and "V_k" refer to the "Area" and "Value" coefficient of LULC class "k," and "n" is the number of LULC classes. ESV gain and/or loss was measured upon this model (Yun-guo et al., 2011): $G_{xy} = (V_y - V_x) * A_{xy}$; where "$G_{xy}$" = the gain and/or loss of ESV after the initial LULC class "x" is changed into class "y" in the next study period, "V_x" and "V_y" represent the value coefficients for LULC class "x" and "y," respectively, and "A_{xy}" is the area change from LULC "x" to "y" (that is, values obtained via the change matrix model). As there is no absolute match between local LULC classes and the global scale biomes, applying sensitivity analysis is of great worth (Yun-guo et al., 2011; Pannell, 2013; Kindu et al., 2016). Sensitivity analysis is assessment of possible errors that may originate from a model and the effects on inferences drawn upon use of the model (Pannell, 2013). It is used to prove accuracy of ESV changes estimated upon existing and/or modified VC. Its formula is (Yun-guo et al., 2011; Kindu et al., 2016):

$$\mathrm{CS} = \frac{(\mathrm{EV}a - \mathrm{EV}i)/\mathrm{EV}i}{(\mathrm{VC}a_k - \mathrm{VC}i_k)/\mathrm{VC}i_k}$$

Where, CS is coefficient of sensitivity, EV is the estimated service value, VC is the value coefficient, "a" and "i" refers to the "adjusted" and "initial" values, respectively, and "k" is the land use class. In fact, VC of all the six LULC classes was adjusted by 50% for the sake of sensitivity analysis even if some of the LULC classes have good fit with definitions in literature (Costanza et al., 1997). Values of the 2015 ES of HRC such as crop and fuel-wood (firewood and charcoal) products were quantified [in ETB (Ethiopian Birr)] using the market price technique. Then, value of the products (in ETB) was converted to US$ upon the 2015 average exchange rate of US$ to ETB, which was 1/21.5 (or approximately 0.046512).

3.2.4 Assumptions:

The following assumptions were set pertaining to assignment of VC used for analysis of ESV dynamics of HRC within 1967 – 2015: **(1)** Local level LULC classes of HRC were assumed to be surrogates of the global scale biome categories (Yun-guo et al., 2011; Kindu et al., 2016) given by Costanza et al., (1997); **(2)** Even if HRC is located within 6^{0}02'13'' – 6^{0}17'55'' N, its *forest* and *woodland* resources are assumed to have a VC of US$ 986.69/ha/year each (instead of US$ 2007) that is allocated for "tropical forest or woodland" by Costanza et al., (1997); but, US$ 2007/ha is assumed to be service value of rainforest of Congo and Amazon where mean total annual rainfall is high (1500 - 2500mm) unlike HRC where rainfall is 883.7 – 1406.5 mm (MAE, 2016); (**3**) Riverine vegetation of HRC is assumed to provide a value equivalent to "forest" (US$ 986.69/ha/year) upon the believe that this LULC class (being largely evergreen) is assumed to supplant services of an average forest (US$ 986.69/ha/year), which was allocated by Costanza et al., (1997).

4. Results

4.1 Status of ESV of HRC within 1967 – 2015

HRC provides multiple ecosystem services to people and nature. Forest, riverine vegetation and woodland in the study catchment provide provisioning (such as water supply, food, raw materials and genetics), regulatory (like water, gas, climate and disturbance regulation, waste treatment, erosion and biological control, etc.,), supportive (nutrient cycling, habitat and soil formation) and cultural (like recreation, aesthetics, etc.) services (Table 7, Appendix). Food production, biological control and pollination services are obtained from cropland, bush/shrub and grazing-land of the Catchment. Bush/shrub-land and grazing-land also provide regulatory (water and gas regulation, erosion control and waste treatment), supportive (like soil formation) and cultural (recreation) services (Table 7, Appendix). The goods and services listed here (in this paragraph) are the only benefits about which valuation was made using "value transfer" technique (see Table 7 in the Appendix). Based on this valuation technique, ESV of HRC was estimated to be the largest (US$ 14,977,000) in 1967 when the share of woodland (US$ 6,759,000 or 45.1%) was the highest, followed by that of forest (2,808,000 or 18.7%) and riverine vegetation (2,502,000 or 16.7%). However, the 1995 estimated ESV of the area

(US$ 8,318,000) was the smallest; ESV of the area for years 1976, 1985, 2003 and 2015 was estimated at US$ 10,287,000, 8,834,000, 8,834,000 and US$ 8,912,000, respectively (Table 8, Appendix).

Result of the field survey revealed that residents of HRC obtain multiple specific goods and services from natural and managed ecosystems. The inhabitants generate fuel-wood (for energy), construction materials [(like logs/timber, lianas, etc., for building houses, fences and chicken-home), and production of HH furniture (bench, chair, spoon, hair-comp, etc.,), farm-tools (hoe, plow, etc.)] and simple boats (for fishing) from *sokie* tree, acacia, eucalyptus, tid (*juniperus procera*), Mexican cypress, croton, hop-bush, highland bamboo, reed-grass, etc., trees of forest, riverine vegetation, woodland, bush/shrub and agro-forestry; food like vegetables (from *moringa oleifera)* and fruits (from ambeshok or *annona muricate*, desert-date or *balanites aegyptiaca,* etc*.)*, bio-chemicals or medicines from *moringa oleifera* (for malaria and blood pressure), leaves of mango (for diabetic treatment), shoots of banana (for stomach-ache), leaves of bitter-leaf and seeds of papaya (for treating gastric disease), etc., provisions are also obtained from the ecological classes listed above; inhabitants of the area use *natra/aritti* (a grass) for treating breast-feeding problems of mothers; that is, this grass species is used by women in the form of tea so as to enhance milk production during breast-feeding (see Table 10b, Appendix).

For instance, annual fuel-wood (firewood and charcoal) consumption by residents of HRC was about 1,630.1 kg/HH in 2015; and, the corresponding value of the fuel-wood service was US$ 182/HH/year; similarly, HH of HRC generate fruits, cereals, pulses, vegetables, tuber and root, etc., products from croplands; that is, where the estimated harvest was 20.6 quintal/HH for 2015, and estimated value of the crop harvest was US$ 695.3/HH/year (Table 10a, Appendix). Hare River with mean annual flow of 59.166 million m^3 (1980-2006) (Table 4, Appendix) supply irrigation water for 92.5% of the agrarian people in lower catchment where agro-forestry (banana, mango, avocado, …) is a dominant practice.

4.2 Magnitudes, Trends and Drivers of ESV Dynamics within 1967 – 2015

Environmental services undergo change overtime. Tables 4.2a and 4.2b illustrate magnitude and rate of ESV dynamics of HRC within 1967 – 2015. Figures about "gross ESV gain/loss" (2nd row from bottom in Tables 4.2a and 4.2b) were computed without considering "change matrix" data; whereas, figures about "net ESV gain/loss" were calculated upon change matrix data of LULC dynamics.

Table 4.2a: Magnitude (M) of Change, Annual Rate (AR) of Change, Gross and Net Gain/Loss of ESV of HRC within 1967 – 1976, 1976 – 1985 and 1985 – 1995:

N0	Ecological (LULC) Classes	ESV Change (Gain/Loss) in US$ '000'								
		1967 – 1976			1976 – 1985			1985 – 1995		
		M	%	AR (%)	M	%	AR (%)	M	%	AR (%)
1	Forest	-1619	-57.9	-6.4	-231	-19.6	-2.2	46	4.9	0.5
2	Riverine vegetation	-994	-39.8	-4.4	208	13.8	1.5	-439	-25.7	-2.6
3	Cropland and settlement	856	68.1	7.6	915	43.3	4.8	-376	-12.4	-1.2
4	Bush/shrub-land	508	42.5	4.7	-550	-32.3	-3.6	262	22.7	2.3
5	Woodland	-3653	-54.1	-6.0	-1664	-53.7	-6.0	-509	-35.5	-3.6
6	Grazing-land	241	52.4	5.8	-137	-19.5	-2.2	494	87.6	8.8
	Gross ESV gain/loss	**-4661**	**-31.1**	**-3.4**	**-1459**	**-14.2**	**-1.6**	**-522**	**-5.9**	**-0.6**
	Net ESV gain/loss	**-4729**	**-31.6**	**-3.5**	**-1419**	**-13.8**	**-1.5**	**-475**	**-5.4**	**-0.5**

Source: Own Computation upon Table 8 in the Appendix

During 1967 – 1976, HRC revealed high magnitude of ESV loss from woodland (by US$ 3,653,000 or 54.1%), forest (by US$ 1,619,000 or 57.9%) and riverine vegetation (by US$ 994,000 or 39.8%); and the annual rate of ESV decline of woodland, forest and riverine vegetation was estimated at 6.0% (US$ 405,889), 6.4% (US$ 179,889) and 4.4% (US$ 110,444), respectively, on average. However, the area experienced service value growth through increase in bush/shrub-land (by US$ 508,000 or 42.5%), cropland and settlement (by US$ 856,000 or 68.1%) and grazing-land (by US$ 241,000 or 52.4%) in the same period (1967 – 1976). The effect of LULC change within 1967 – 1976 was a net ESV loss by about US$ 4,729,000 (31.6%), and this indicates that ESV of HRC had declined by 3.5% (US$ 525,444) per year during this period (Table 4.2a). Such a high magnitude and rate of net ESV loss of HRC was triggered largely by expansion of cropland (plus settlement) and bush/shrub into woodland, forest and riverine vegetation in the nine-year's duration (Table 1a, Appendix).

Woodland, bush/shrub and forest had experienced a huge ESV loss by about US$ 1,664,000 (53.7%), 550,000 (32.3%) and US$ 231,000 (19.6%), respectively, during 1976 – 1985; and, the annual rate of ESV loss due to transformation of the respective LULC classes was about 6% (US$ 184,889), 3.6% (US$ 61,111) and 2.2% (US$ 25,667), then. Grazing-area change-induced loss of ESV was about US$

137,000 (19.5%) in 1976 – 1985. Whereas, cropland (US$ 915,000 or 43.3%) and riverine vegetation of HRC (208,000 or 13.8%) revealed an increase (gain) in ESV within 1976 – 1985; that is, where service value of the respective LULC classes had grown by 4.8% (US$ 101,667) and 1.5% (US$ 23,111) annually in the period. The net ESV loss due to LULC change (1976 – 1985) was about 13.8% (US$ 1,419,000) of the total ESV of the area; meaning, ESV of HRC had declined by about US$ 157,667 (1.5%) annually in almost a decade (Table 4.2a). Change of woodland, forest, riverine vegetation and bush/shrub resources into cropland and settlement was the main reason for the high magnitude of net ESV loss of HRC within 1976 – 1985 (Table 1b, Appendix). Establishment of the irrigation-based State Farm in the fertile lower catchment in the 1950s (according to an elder, 64) and in-migration of people from highlands of Gamo and Wolayta areas into the same sub-catchment (by 52.9% of the HH) was the root cause of ESV loss in 1967 – 1976 and 1976 – 1985.

Evaluation was also made about the status of ESV of HRC for a decade within 1985 – 1995 (Table 4.2a above). A significant ESV decline, by 25.7% (US$ 439,000), 12.4% (US$ 376,000) and 35.5% (US$ 509,000), was observed in response to changes of riverine vegetation, cropland and woodland, respectively; in other words, ESV loss triggered by change of the respective LULC classes was US$ 43,900 (2.6%), 37,600 (1.2%) and 50,900 (3.6%) per year within 1985 – 1995. A seemingly unique experience during this period was the raise of forest ESV by 5.4% (US$ 46,000) as a result of slight increase in its area; here, rise in ESV of forest had emanated mainly from the transformation of bush/shrub into forest, underlain by restriction of illegal exploitation of forest during 1985 – 1995 (that is, by the socialist gov't of Ethiopia at large) (Table 1c, Appendix). ESV gain was also observed from the change of grazing-land (US$ 494,000 or 87.6%) and bush/shrub (US$ 262,000 or 22.7%). Increasing grazing-land and bush/shrub induced growth of ESV, respectively, was about 8.8% (US$ 49,400) and 2.3% (US$ 26,200) per annum in 1985 – 1995. Overall effect of the 1985 – 1995 LULC dynamics on ESV of HRC was also negative (US$ - 475,000) even if its magnitude of service value loss was by far smaller than that of 1967 – 1976 and 1976 – 1985; that is, net ESV loss triggered by LULC change was about US$ 475,000 (5.4%); this means, ESV of the area had dropped by about US$ 47,500 (0.5%) annually within 1985 – 1995 (Table 4.2a).

Table 4.2b: Magnitude (M) of Change, Annual Rate (AR) of Change, Gross and Net Gain/Loss of ESV of HRC within 1995 – 2003, 2003 – 2015 and 1967 – 2015:

N0	Ecological (LULC) Classes	Change (Gain/Loss) of ESV (US$ '000')								
		1995 – 2003			2003 – 2015			1967 – 2015		
		M	%	AR (%)	M	%	AR (%)	M	%	AR (%)
1	Forest	-115	-11.6	-1.5	-278	-31.6	-2.6	-2197	-78.5	-1.6
2	Riverine vegetation	-463	-36.4	-4.6	301	37.2	3.1	-1387	-55.6	-1.2
3	Cropland and settlement	312	11.8	1.5	375	12.7	1.1	2082	165.5	3.5
4	Bush/shrub-land	-564	-39.8	-5.0	0	0.0	0.0	-344	-28.8	-0.6
5	Woodland	1433	154.9	19.4	255	10.8	0.9	-4138	-61.3	-1.3
6	Grazing-land	-96	-9.1	-1.1	-570	-59.3	-4.9	-68	-14.8	-0.3
	Gross gain/loss	**507**	**6.1**	**0.8**	**83.0**	**1.0**	**0.1**	**-6052**	**-40.5**	**-0.8**
	Net gain/loss	**508**	**6.1**	**0.8**	**84.0**	**1.0**	**0.1**	**-6035**	**-40.3**	**-0.8**

Source: Own Computation upon Table 8 in the Appendix

The level of dynamics of ESV of HRC was also measured for periods 1995 – 2003, 2003 – 2015 and 1967 – 2015 (Table 4.2b). During 1995 – 2003, significant decline of ESV had been experienced as a result of the change in bush/shrub (US$ 564,000 or 39.8%), riverine vegetation (US$ 463,000 or 36.4%) and forest cover (US$ 115,000 or 11.6%). The rate of ESV loss (effected by the declining area size of the respective LULC classes) was about 5% (US$ 70,500), 4.6% (57,875) and 1.5% (14,375) annually within 1995 - 2003. Expansion of cropland and settlement into bush/shrub, riverine vegetation, forest and grazing-land was the main cause for the decline of ESV from these environmental resources (LULC classes) (Table 1d, Appendix). An estimated ESV loss by about 9.1% (US$ 96,000) was also observed due to shrinkage of grazing-land in the same period.

On the contrary, a huge gain of ESV (by US$ 1,433,000 or 154.9%) was observed from the raise in the area extent of woodland within 1995 – 2003. That is, increasing area of woodland had resulted in a rise of ESV by about 19.4% (US$ 179,125) per year within 1995 – 2003. Transformation of large area of cropland and bush/shrub into woodland had greatly contributed to the huge growth of ESV of woodland in HRC, then (Table 1d, Appendix); and, the increase in woodland extent, in turn, have emanated from the expansion of tree-(fruit) crops such as mango in LC (Abren and Daniel, 2007) and apple in the UC (Seifu et al., 2014). A service value gain of about 11.8% (US$ 312,000) was also observed as a result of increasing area of cropland (plus settlement). Unlike the three earlier periods

(1967 – 1976, 1976 – 1985 and 1985 – 1995), the cumulative impact of LULC dynamics within the eight-year duration (1995 – 2003) was a net gain/rise in the overall ESV of HRC by about 6.1% (US$ 508,000); this means, level of ESV of HRC grew by 0.8% (US$ 63,500) annually (Table 4.2b).

On the other hand, ESV of grazing-land and forest has dropped by about 59.3% (US$ 570,000) and 31.6% (278,000), respectively, during 2003 – 2015; that is, grazing-land and forest shrinkage–induced ESV loss was about 5% (US$ 37,500) and 2.7% (US$ 23,167) annually in the twelve-year duration, respectively. However, riverine vegetation, cropland and woodland ESV of HRC have revealed growth by the respective proportions of US$ 37.2% (301,000), 12.7% (US$ 375,000) and 10.8% (US$ 255,000); and where the estimated annual increase of ESV due to the change of the three LULC classes (in their order) was about 3.1% (US$ 25,083), 1.1% (US$ 31,250) and 0.9% (US$ 21,250). Anyway, HRC revealed a limited net ESV increase by about 1% (US$ 84,000) within 2003 – 2015; that is, where the overall ESV of the Catchment has grown by 0.1% (US$ 7,000) per/year (Table 4.2b). Alike the period 1995 – 2003, the net ESV gain/growth of HRC (in 2003 – 2015) was largely triggered by the change of cropland [perhaps, conversion to tree/fruit crops like mango, avocado, etc., (Abren and Daniel, 2007)] and bush/shrub into woodland in the same period (Table 1e, Appendix).

HRC experienced the largest amount of ESV loss by 61.3% (US$ 4,138,000) and 78.5% (US$ 2,197,000) due to dwindling supply of woodland and forest, respectively, within 1967 – 2015, where ESV of the respective LULC classes has diminished by 1.3% (US$ 86,208) and 1.6% (US$ 45,771) annually. ESV of riverine vegetation (55.6% or US$ 1,387,000) and bush/shrub (28.8% or US$ 344,000) have also exhibited decline (loss) within forty-eight years; that is, where the rates of ESV loss of the respective resource classes were estimated at 1.2% (US$ 28,896) and 0.6% (US$ 7,167) per year. During 1967 - 2015, a gross ESV gain/increase (by 165.5% or US$ 2,082,000) was experienced in response to cropland expansion in HRC in four-five decades. The overall effect of LULC dynamics within HRC was a net ESV loss by about 40.3% (US$ 6,035,000); meaning, ESV of the area has been decreasing, on average, by about 0.8% (US$ 125,729) each year within 1967 – 2015 (Table 4.2b). Expansion of cropland (plus settlement) and bush/shrub at the cost of forest, woodland and riverine vegetation was the principal cause for the huge amount of ESV loss of HRC within 1967 – 2015 (Table 1f, Appendix). Improvement of ESV within 1995 – 2015 was a result of actions like area-closure, afforestation, forest protection, etc., by the current gov't of Ethiopia (to some level) and, also due to agro-forestry practices (mango, banana, avocado, apple, etc.,) by farmers. Households (%) also revealed that exploitation of firewood (99.6%) and charcoal (28.2%), building materials (53.6%), and over-browsing and overgrazing (35.1%) were other causes for alteration of forest, woodland, etc., into bush/shrub and the associated ESV loss (see Figure 1, Appendix).

4.1.3 Sensitivity Analysis about the Estimated ESV Changes

Results about the effect of adjusting VC on the estimated ESV gains/losses and also the Coefficient of Sensitivity (CS) associated with the adjustments were summarized below (Table 4.3). Values of the CS for grazing-land were as low as 0.03 and 0.04 in 1967 and 2015, respectively; this means, ESV of HRC was found to raise by 0.03% and 0.04% for 1% increase in the VC of grazing-land in 1967 and 2015, respectively (Table 4.3). Relatively larger coefficients were computed for woodland and cropland (except 0.08 in 1967), where the coefficients range within 0.11 (in 1995) – 0.45 (in 1967) and 0.21 (1976) – 0.38 (2015) for the respective LULC classes in all the periods; in other words, ESV of HRC was proved to have increased in proportions of 0.11 – 0.45% and 0.08 – 0.38% for a 1% raise in the respective VC of woodland and cropland. Cropland revealed the smallest CS (0.08) in 1967 and the largest CS (0.38) in 2015 (Table 4.3); similar interpretation holds for CS of others LULC. The study indicated that the CS of all LULC classes was < 1.0 (Table 4.3); it means, the estimated ESV change of HRC was relatively inelastic with respect to the VC used for estimation. This, in turn, confirms the veracity of estimations made about ESV dynamics of HRC upon adjusted VC of Costanza et al (1997) and Kindu et al (2016).

Table 4.3 Effect of Changing Valuation Coefficient (VC) and the Coefficient of Sensitivity (CS) Associated with the Adjustments

LULC	1967		1976		1985		1995		2003		2015	
	%	CS	%	CS	%	CS	%	CS	%	CS	%	CS
F_VC ±50%	±9.4	0.19	±5.7	0.12	±5.4	0.11	±6.0	0.12	±5.0	0.10	±3.4	0.07
RV_VC ±50%	±8.4	0.17	±7.3	0.15	±9.7	0.19	±7.7	0.15	±4.6	0.09	±6.2	0.13
CS_VC ±50%	±4.2	0.08	±10.3	0.21	±17.1	0.34	±16.0	0.32	±16.8	0.34	±18.8	0.38
B/S_VC ±50%	±4.0	0.08	±8.3	0.17	±6.5	0.13	±8.5	0.17	±4.8	0.10	±4.8	0.10
W_VC ±50%	±22.6	0.45	±15.0	0.30	±8.1	0.16	±5.6	0.11	±13.4	0.27	±14.7	0.29
G_VC ±50%	±1.5	0.03	±3.4	0.07	±3.2	0.06	±6.4	0.13	±5.5	0.11	±2.2	0.04

Source: Computed upon Kreuter et al., 2001, Li et al., 2007 and Yun-guo et al., 2011; (F=Forest, RV=Riverine Vegetation, CS=Cropland & Settlement, B/S=Bush/Shrub, W=Woodland, and G=Grazing-land)

Again, ESV (US$ '000') of HRC was estimated after adjusting VC, and the magnitude of changes and effect of changing VC were also measured for all the periods studied (Table 3a & Table 3b, Appendix). However, ESV measured upon adjusted VC and the corresponding ESV changes presented, here, were results of the 1967 and 2015 only just for the sake of illustrating the results briefly. Adjusting VC is found to have its own effect on the estimated ESV change of each LULC class and also the overall ESV of the Catchment. A reduction of total ESV of HRC by about 43.7% (US$ 7,150,000) was the result of increasing VC of forest by 50% for the duration 1967 – 2015, which is a bit larger than the initial proportion of decline, 40.3% (the figure before adjustment of VC); but, the overall ESV of the study area dropped by about 36.5% (US$ 4,953,000) when the VC of forest is reduced by 50% (Table 3b, Appendix). Increasing or decreasing VC of forest by 50% affected more the estimated ESV of 1967 (by ±9.4%) than that of 2015 (by ±3.4%) (Table 4.3 above).

Estimated ESV of HRC was found to decrease by 32.1% (US$ 5,011,000) and 49.5% (US$ 7,093,000) when VC of cropland was raised by 50% and reduced by 50%, respectively, in 1967 – 2015. But, adjusting VC of cropland by ±50% impacted more the estimated value of 2015 (by ±18.8%) than that of 1967 (by ±4.2%). ESV changes of the Catchment impacted by adjustment of VC by ±50% were within 34.4% to 44.3% for LULC classes other than forest and cropland; and these values were relatively around the proportion of ESV change (40.3%), which was estimated before adjusting VC of each LULC category (Table 3a and Table 3b, Appendix).

5. Discussion

HRC experienced a net ESV loss in response to LULC changes within 1967 – 2015, which was similar with results of other studies (Kreuter et al., 2001; Li et al., 2007; Yun-guo et al., 2011; Kindu et al., 2016); in fact, studies with positive ESV changes/net gain (Chanhda et al., 2009) were rare. The net ESV loss of HRC was drastic within 1967 – 1985 due to reasons attributable to: (i) the dramatic cropland expansion at the cost of woodland, forest, bush/shrub and riverine vegetation within 1967 – 1985, which was largely similar to the experience of Borena area (Northern Ethiopia) within 1972 – 1985 (Abate, 2011); (ii) the high VC of forest, riverine vegetation and woodland (US$ 986.69/ha/year)

(Kindu et al., 2016); and (iii) the low VC of cropland services (US$ 225.56/ha/year) (Kindu et al., 2016); that is, a value that couldn't compensate ESV of forest, woodland, etc., (Yun-guo et al., 2011).

The net ESV gain of HRC during 1995 – 2003 was due to high magnitude of change of cropland and bush/shrub into woodland, and bush/shrub into riverine vegetation, that is, a change from LULC classes with small VC to those with too large VC (Costanza et al., 1997; Kindu et al., 2016)-which made the net ESV change positive. Decline of ESV of forest, bush/shrub, woodland, riverine vegetation and grazing-land in HRC was triggered largely by increasing crop farming, which was more or less similar to the situation in some areas of Ethiopia (Meles et al., 2008; Abate, 2011; Hiywot, 2014). That is, crop farming has long been a major cause of ESV loss by depleting products, species diversity, habitat provision, carbon sink, erosion control, etc., services of forest and woodland (Zhang et al., 2007; Maeda et al., 2010) in HRC, underlain by population pressure (Belay, 2002). Generally, ESV dynamics of HRC (1967 – 2015) was triggered by *negative* (farm expansion, fuel-wood and timber extraction-led deforestation, over-browsing, etc.,), *positive* (afforestation, area-closure, resource protection, etc.,) and *neutral* (LULC change) drivers, which is a scenario of De-Groot et al., (2010).

6. Conclusion and Management Options

HRC experienced LULC dynamics-led net ESV loss by US$ 6.035 million within 1967 –2015. ESV of the area revealed a decreasing trend within 1967 – 1995 due to expansion of crop farming and settlement largely to the fertile lower catchment - an area where malaria and tsetse-fly challenges have gradually been mitigated). However, HRC experienced an increasing trend of ESV within 1995 - 2015 largely due to growing agro-forestry practices (like banana, mango, papaya, avocado, etc.,) in lower catchment following the pollical change of Ethiopia within 1991 – 1995, that is, a change that promoted private land use options. Depletion of key services of forest, riverine vegetation and woodland such as food and raw materials, air/gas and climate regulation, nutrient cycling, erosion control, waste treatment, etc., services contributed to the largest share of the ESV loss in the area.

ES dynamics of HRC is triggered by *negative*, *positive* and *neutral drivers* of change. Growing population-led clearing of land covers for farming and settlement, extraction of fuel-wood and timber, and over-browsing and overgrazing are the main *negative drivers* of ESV loss from forest, riverine vegetation, woodland, bush/shrub and grassland in HRC. Whereas, actions such as afforestation, control of illegal tree-cutting, agro-forestry practices of farmers and area-closure are the main *positive drivers* of ESV changes; but these actions are limited in coverage. LULC dynamics, exerting negative and positive impacts on ES, is the main *neutral driver* that had contributed to the high magnitude of net ESV loss within 1967 – 1985, and to the net ESV gain within 1995 - 2015.

Ethiopian gov't should direct its policy towards resilience of degraded resources of HRC, perhaps, through payments for ecosystem services by integrating options below: **(i)** structural (bench terraces, check-dams/gabion, micro-basins, etc.,) and vegetative (afforestation, agro-forestry, planting valuable grasses, etc.,) measures should be intervened by the coordinated efforts of stakeholders (local to national); these actions should be supported by "area-closure" for effective restoration of degraded lands. **(ii)** The gov't (national and local) should provide renewable energy options (say solar energy, biogas, hydro-power) to HH of HRC so as to curtail fuel-wood exploitation-induced burden on forest, woodland, etc., for energy consumption. **(iii)** The gov't (national and local) should integrate objectives of ecological resilience actions with other national and regional development goals such as improving income, food security, poverty reduction, employment creation, etc.; this could enhance commitment of the local people (the poor, youth, women, etc.,) in the efforts towards sustainable restoration of degraded resources. **(iv)** The gov't, investors and farmers should also focus on agro-forestry options (banana, mango, apple, *enset*, etc.,) so that cropland expansion-driven ESV loss could be mitigated.

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Appendix:

Table 1a: Area Change Matrices (in ha) among LULC Classes of HRC within 1967 – 1976

1976 / 1967	Forest	R. Vegetation	Cropland & Settle't	Bush/Shrub	Woodland	Grassland
Forest	136.6	148.0	1360.4	577.8	233.4	389.9
R. Vegetation	124.2	185.1	803.7	765.6	580.6	70.1
Cropland & settle't	334.0	384.1	2521.9	823.9	378.6	1124.6
Bush/shrub	175.1	224.0	1172.8	1718.5	598.6	183.3
Woodland	328.8	486.4	2767.4	1650.9	1157.7	458.9
Grassland	112.5	107.8	776.3	195.2	87.5	282.7

Source: Analysis via ERDAS 8.6 and Arc GIS 9.3 (Yechale, 2016)

Table 1b: Area Change Matrices (in ha) among LULC Classes of HRC within 1976 – 1985

1985 / 1976	Forest	R. Veg	Cropland & Settle't	Bush/Shrub	Woodland	Grassland
Forest	325.4	286.3	306.4	183.4	65.1	16.6
R. Vegetation	173.0	475.1	551.0	107.8	138.1	72.8
Cropland & settle't	75.0	290.8	7260.4	844.2	422.1	487.8
Bush/shrub	273.6	209.6	2730.2	2445.0	139.7	23.3
Woodland	84.8	282.6	1670.3	345.4	643.6	113.0
Grassland	40.6	193.6	843.8	31.1	66.9	1214.3

Source: Analysis via ERDAS 8.6 and Arc GIS 9.3 (Yechale, 2016)

Table 1c: Area Change Matrices (in ha) among LULC Classes of HRC within 1985 – 1995

1995 / 1985	Forest	R. Vegetation	Cropland & Settle't	Bush/Shrub	Woodland	Grassland
Forest	423.1	95.5	51.6	182.4	107.0	95.5
R. Vegetation	152.9	722.8	330.1	125.1	151.2	255.4
Cropland & settle't	147.8	349.3	9767.8	1464.5	215.0	1491.4
Bush/shrub	189.3	31.5	879.3	2673.4	157.7	11.8
Woodland	111.6	39.1	581.2	375.4	324.7	17.4
Grassland	1.9	61.2	126.2	1.9	9.6	1711.6

Source: Analysis via ERDAS 8.6 and Arc GIS 9.3 (Yechale, 2016)

Table 1d: Area Change Matrices (in ha) among LULC Classes of HRC within 1995 – 2003

2003 / 1995	Forest	R. Vegetation	Cropland & Settle't	Bush/Shrub	Woodland	Grassland
Forest	399.5	104.6	131.8	119.7	214.3	36.2
R. Vegetation	212.5	305.9	221.4	7.7	325.1	207.4
Cropland & settle't	58.8	105.9	9733.1	647.3	741.5	482.5
Bush/shrub	101.5	164.3	1763.8	2019.9	686.2	96.7
Woodland	78.7	99.5	292.9	126.1	286.3	64.5

Grassland	32.4	28.8	1021.6	3.6	154.7	2356.2

Source: Analysis via ERDAS 8.6 and Arc GIS 9.3 (Yechale, 2016)

Table 1e: Area Change Matrices (in ha) among LULC Classes of HRC within 2003 – 2015

2015 / 2003	Forest	R. Vegetation	Cropland & Settle	Bush/Shrub	Woodland	Grassland
Forest	351.5	130.2	77.6	101.7	230.1	0.9
R. Vegetation	22.1	355.3	205.5	98.2	131..8	5.7
Cropland & settle't	26.3	170.8	11485.2	683.3	709.6	65.7
Bush & shrub	34.9	130.9	1233.5	1445.9	61.1	2.9
Woodland	158.5	225.8	595.6	502.0	910.3	9.6
Grassland	29.4	121.0	1193.6	68.7	598.5	1259.0

Source: Analysis via ERDAS 8.6 and Arc GIS 9.3 (Yechale, 2016)

Table 1f: Area Change Matrices (in ha) among LULC Classes of HRC within 1976 - 2015

2015 / 1967	Forest	R. Vegetation	Crop & Settle	Bush/shrub	Woodland	Grassland	Total
Forest	96.8	128.1	1758.9	241.9	404.1	216.3	2846.1
R. Vegetation	27.9	**88.7**	1774.6	438.6	190.2	12.7	2535.2
Crop & settle	222.7	250.5	**3139.8**	233.8	946.4	773.8	5567.1
Bush/shrub	61.1	187.3	2716.2	**769.7**	272.8	65.2	4072.3
Woodland	150.7	404.1	4438.8	1089.1	**623.4**	143.9	6850.0
Grassland	70.3	56.2	948.1	31.3	245.2	**210.9**	1562.0

Source: Analysis via ERDAS 3.8 and Arc GIS 9.3 (Yechale, 2016)

Table 2a: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 1967-1976

1976 / 1967	Forest	R. Veg	Crop & Settle	Bush/Shrub	Woodland	Grassland	**Total (1967)**
Forest	0.0	0.0	-1,036	-401	0.0	-270	**-1,707**
R. Vegetation	0.0	0.0	-612	-531	0.0	-49	**-1,192**
Crop & settle	254	292	0.0	56	288	76	**966**
Bush/shrub	121	155	-79	0.0	415	0.0	**612**
Woodland	0.0	0.0	-2,106	-1,145	0.0	-318	**-3,569**
Grassland	78	75	-53	0.0	61	0.0	**161**
Total (1976)	**453**	**522**	**-3,886**	**-2,021**	**764**	**-561**	**-4,729**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011

Table 2b: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 1976-1985

1985 / 1976	**Forest**	**R. Veg.**	**Crop & Settle**	**Bush/Shrub**	**Woodland**	**Grassland**	**Total (1976)**
Forest	0.0	0.0	-233	-127	0.0	-12	**-372**
R. Vegetation	0.0	0.0	-419	-75	0.0	-51	**-545**
Crop & settle	57	221	0.0	57	321	33	**689**

Bush/shrub	190	145	-185	0.0	97	0.0	**247**
Woodland	0.0	0.0	-1,271	-240	0.0	-78	**-1,589**
Grassland	28	134	-57	0.0	46	0.0	**151**
Total (1985)	**275**	**500**	**-2,165**	**-385**	**464**	**-108**	**-1,419**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011

Table 2c: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 1985 – 1995

1995 / 1985	Forest	R. Veg.	Crop & Settle	Bush/shrub	Woodland	Grassland	Total (1985)
Forest	0.0	0.0	-39	-127	0.0	-66	**-232**
R. Vegetation	0.0	0.0	-251	-87	0.0	-177	**-515**
Crop & settle	113	266	0.0	99	164	101	**743**
Bush/shrub	131	22	-60	0.0	109	0.0	**202**
Woodland	0.0	0.0	-442	-260	0.0	-12	**-714**
Grassland	1	42	-9	0.0	7	0.0	**41**
Total (1995)	**245**	**330**	**-801**	**-375**	**280**	**-154**	**-475**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011

Table 2d: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 1995 – 2003

2003 / 1995	Forest	R. Veg.	Crop & Settle	Bush/shrub	Woodland	Grassland	Total (1995)
Forest	0.0	0.0	-100	-83	0.0	-25	**-208**
R. Veg.	0.0	0.0	-169	-5	0.0	-144	**-318**
Crop & settle	45	81	0.0	44	564	33	**767**
Bush/shrub	70	114	-119	0.0	476	0.0	**541**
Woodland	0.0	0.0	-223	-87	0.0	-45	**-355**
Grassland	23	20	-69	0.0	107	0.0	**81**
Total (2003)	**138**	**215**	**-680**	**-131**	**1,147**	**-181**	**508**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011

Table 2e: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 2003 – 2015

2015 / 2003	Forest	R. veg.	Crop & Settle	Bush/shrub	Woodland	Grassland	Total (2003)
Forest	0.0	0.0	-59	-71	0.0	-1	**-131**
R. Vegetation	0.0	0.0	-156	-68	0.0	-4	**-228**
Crop & settle	20	130	0.0	46	540	4	**740**
Bush/shrub	24	91	-84	0.0	42	0.0	**73**
Woodland	0.0	0.0	-453	-348	0.0	-7	**-808**
Grassland	20	84	-81	0.0	415	0.0	**438**
Total (2015)	**64**	**305**	**-833**	**-441**	**997**	**-8**	**84**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011

Table 2f: ESV Gain/Loss of HRC (US$ '000') Estimated upon Change Matrices of LULC in 1967 – 2015

2015 / 1967	Forest	R. Veg.	Crop & Set	Bush/shrub	Woodland	Grassland	**Total (1967)**
Forest	0.0	0.0	-1,339	-168	0.0	-150	**-1,657**
R. Veg.	0.0	0.0	-1,351	-304	0.0	-9	**-1,664**
Crop & set	170	191	0.0	16	720	52	**1,149**
Bush/shrub	42	130	-184	**0.0**	189	0.0	**177**
Woodland	0.0	0.0	-3,379	-755	0.0	-100	**-4,234**
Grassland	49	39	-64	0.0	170	0.0	**194**
Total (2015)	**261**	**360**	**-6,317**	**-1,211**	**1,079**	**-207**	**-6,035**

Source: Own Computation (2017) upon Costanza et al., 1997 and Yun-guo et al., 2011;

Table 3a: Level of ESV of HRC after Adjusting VC and Change Magnitude (CM) of the Service Value

LULC	**ESV (US$ '000')**				**Magnitude of ESV Change (US$ '000')**					
	1967	**1976**	**1985**	**1995**	**1967-1976**		**1976-1985**		**1985-1995**	
					CM	%	CM	%	CM	%
Forest VC ±50%	16359	10889	9314	8815	-5470	-33.4	-1575	-14.5	-499	-5.4
	13561	9710	8366	7821	-3851	-28.4	-1344	-13.8	-545	-6.5
R. Vegetation VC±50%	16209	11051	9696	8954	-5158	-31.8	-1355	-12.3	-742	-7.7
	13712	9548	7985	7682	-4164	-30.4	-1563	-16.4	-303	-3.8
Cropland & set VC±50%	15589	11356	10355	9645	-4233	-27.2	-1001	-8.8	-710	-6.9
	14331	9242	7326	6992	-5089	-35.5	-1916	-20.7	-334	-4.6
Bush/shrub VC±50%	15558	11151	9417	9026	-4470	-28.3	-1734	-15.6	-391	-4.2
	14362	9447	8263	7610	-4915	-34.2	-1184	-12.5	-653	-7.9
Woodland VC±50%	18336	11848	9557	8781	-6488	-35.4	-2291	-19.3	-776	-8.1
	11585	8750	8123	7856	-2835	-24.5	-627	-7.2	-267	-3-3
Grazing-land VC±50%	15190	10650	9122	8847	-4540	-29.9	-1528	-14.4	-275	-3.0
	14730	9949	8558	7789	-4781	-32.5	-1391	-14.0	-769	-9.0
***Total[a]**	**14,960**	**10,299**	**8,840**	**8,318**						

*Total[a] = Total ESV before adjustment of VC of LULC classes by ±50% (**Source:** Own Calculation upon Kreuter et al., 2001; Yun-guo et al., 2011; Kindu et al., 2016)

Table 3b: Level of ESV (US$ '000') of HRC after Adjusting VC and Change Magnitude (CM) of the Service Value

LULC Class	ESV (US$ '000')				Magnitude of Change of ESV (US$ '000')					
	1967	**1995**	**2003**	**2015**	**1995-2003**		**2003-2015**		**1967-2015**	
					CM	P (%)	CM	P (%)	CM	P (%)
Forest VC ±50%	16359	8815	9265	9209	450	5.1	-56	-0.6	-7150	-43.7
	13561	7821	8386	8608	565	7.2	222	2.7	-4953	-36.5
R. Vegetation VC±50%	16209	8954	9230	9463	276	3.1	223	2.5	-6746	-41.6
	13712	7682	8421	8353	739	9.6	-68	-0.8	-5359	-39.1
Crop & settle VC±50%	15589	9645	10308	10578	663	6.9	270	2.6	-5011	-32.1
	14331	6992	7343	7238	351	5.0	-105	-1.4	-7093	-49.5
Bush/shrub VC±50%	15558	9026	9251	9334	225	2.5	83	0.9	-6224	-40.0
	14362	7610	8399	8482	789	10.4	83	1.0	-5880	-40.9
Woodland VC±50%	18336	8781	10004	10215	1223	13.9	211	2.1	-8121	-44.3
	11585	7856	7646	7602	-210	-2.7	-44	-0.6	-3983	-34.4
Grazing-land VC±50%	15190	8847	9306	9104	459	5.2	-202	-2.2	-6086	-40.1
	14730	7789	8344	8712	555	7.1	368	4.4	-6018	-40.9
***Total**	**14,960**	**8,318**	**8,825**	**8,908**						

***Total** = total ESV of HRC before Valuation Coefficients (VC) were adjusted by 50%; **[Source:** Own Computation upon Kreuter et al., 2001; Yun-guo et al., 2011; Kindu et al., 2016];

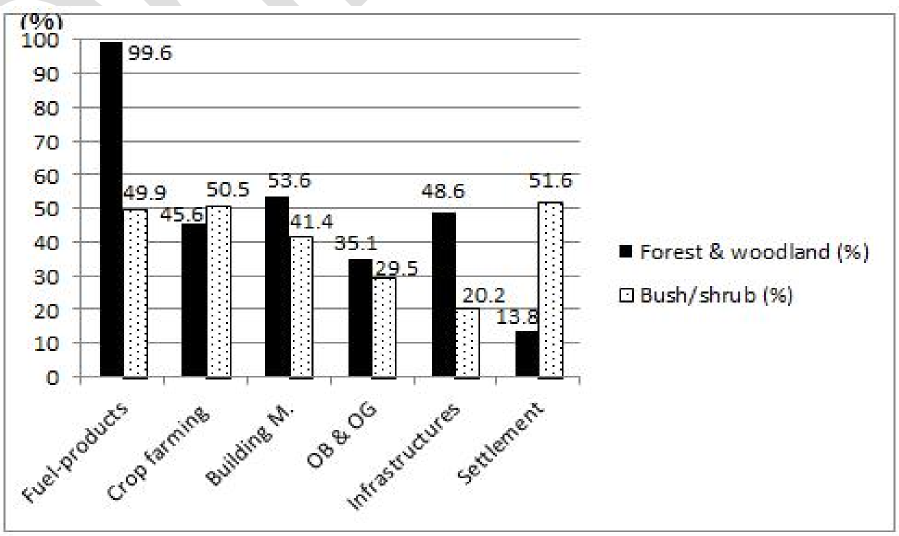


Figure 1: Causes for Decline of: **(a)** Forest & Woodland (i.e. the Black Bars), and **(b)** Bush/Shrub (i.e. the Grey Bars); [i.e. OB = Over Browsing; OG = Over Grazing]

Table 4b: Temperature (1987 – 2015), Rainfall (1982 – 2015) & Discharge (1980 – 2006) of HRC

N0	Variable	Measurement of Variable	LC		MUC	
			Value	Period	Value	Period
I	Temperature	Maximum mean annual (^{0}C)	25.1	2009	17.3	2008/2014
		Minimum mean annual (^{0}C)	23.3	1998/2007	16.2	1998
		Average of mean annual (^{0}C)	24.0	”	16.7	”
		Standard deviation (^{0}C)	0.41	”	0.30	”
		Coefficient of variation (^{0}C)	0.0171	”	0.0179	”
		Change/rise in mean annual (^{0}C)	0.6	1987-2015	0.5	1987-2015
II	Rainfall	Maximum total annual (mm)	1253.9	1997	1897.5	2007
		Minimum total annual (mm)	580.1	1986	1135.2	1986
		Mean total annual (mm)	883.7	”	1406.5	”
		Standard deviation (mm)	160.6	”	168.7	”
		Coefficient of variation (mm)	0.18	”	0.12	”
		Change/rise of total annual (mm)	214.8	”	104.1	”
III	Discharge of Hare River	Mean total annual (million m^3)	59.166	-	-	-
		Standard deviation (million m^3)	16.280	-	-	-
		Coefficient of variation (million m^3)	0.275	-	-	-

Source: Own Computation upon Data from MAE (2016) [LC=Lower Catchment; MUC=Middle & Upper Catchment]

Table 5: Area (ha) of the Six LULC Classes of HRC in Six Periods within 1967 – 2015

N0	LUC	1967 Area (ha)	1976 Area (ha)	1985 Area (ha)	1995 Area (ha)	2003 Area (ha)	2015 Area (ha)
1	Forest	2846.1	1183.1	955	1006.2	892.0	605.1
2	Riverine vegetation	2535.2	1517.8	1737.5	1280.0	818.6	1135.3

3	Cropland & settlement	5567.1	9380.3	13435.7	11769.1	13140.9	14808.2
4	Bush/shrub	4072.3	5821.4	3943.0	4832.4	2909.2	2907.4
5	Woodland	6850.0	3139.7	1449.4	948.0	2401.8	2646.7
6	Grazing-land	1562.0	2390.4	1912.4	3597.2	3270.2	1330.0
	Total	23,432.7	23,432.7	23,432.7	23,432.7	23,432.7	23,432.7

Source: Analysis via ERDAS Imagine 3.8 and Arc GIS 9.3

Table 6a: Agro-climate Categories of HRC

N0	Agro-climate	Altitude (m)	Area (ha)	P (%)	Sub-catchment
1	*Wurch* (afro-alpine)	3200 - 3484	937.2	4.0	UC
2	*Dega* (temperate)	2300 - 3200	1,1318.0	48.3	UC (38.6%) MC (9.7%)
3	*Woina-Dega* (sub-tropical)	1500 - 2300	5,553.6	23.7	MC
4	*Kolla* (tropical)	< 1500	5,623.9	24.0	LC
	Total		23,432.7	100.0	

Source: Based on Own Field Survey data, and Evidences from Hurni (1998) and Yechale (2012)

Table 6b: Landscape Configuration Categories of HRC in 2015

N0	Landscape Configuration (Slope)	Area (ha)	P (%)
1	Gently sloping to sloping, < 5˚ (8.3%)	7,475.0	31.9
2	Strongly sloping to moderately steep, 5 - 15˚ (8.3 - 25%)	13,075.5	55.8
3	Steep (15 - 30˚ or 25 – 50%) to very steep (> 30˚ or 50%)	2,882.2	12.3
	Total	23,432.7	100

Source: Analysis via Arc GIS 9.3 (2017) upon Slope Gradient Classes of FAO (1990)

Table 7: "Value Coefficients" Adapted for Estimating ESV of Six LULC Categories of HRC (1967 - 2015)

Ecosystem Service		ESV (US$/ha/Year) of each LULC Class					
Broad Classes	**Specific Classes**	**Forest**	**Riverine V.**	**Cropland**	**Bush/shrub**	**Grazing**	**Woodland**
Provision	Water supply	8	8	-	-	-	8
	Food production	32	32	187.56	117.45	117.45	32
	Raw material	51.24	51.24	-	-	-	51.24
	Genetic resource	41	41	-	-	-	41
Regulatory	Water regulation	6	6	-	3	3	6
	Water treatment	136	136	-	87	87	136
	Erosion control	245	245	-	29	29	245
	Climate regulation	223	223	-	-	-	223
	Biological control	-	-	24	23	23	-
	Gas regulation	13.68	13.68	-	7	7	13.68
	Disturbance regulation	5	5	-	-	-	5
Supportive	Nutrient cycling	184.4	184.4	-	-	-	184.4
	Pollination	7.27	7.27	14	25	25	7.27
	Soil formation	10	10	-	1	1	10
	Habitat	17.3	17.3	-	-	-	17.3
Cultural	Recreation	4.8	4.8	-	0.8	0.8	4.8
	Cultural	2	2		-	-	2
Total		986.69	986.69	225.56	293.25	293.25	986.69

Source: Set upon Costanza et al., 1997; "value/benefit transfer" from Kindu et al., 2016-which was allocated largely upon "Economics of Ecosystem and Biodiversity Valuation Database (van der Ploeg & de Groot, 2010) and Knoke et al. (2011)"

Table 8: ESV (US$ '000') of HRC upon LULC Classes in 1967, 1976, 1985, 1995, 2003 and 2015

LULC Class	Annual ESV in US$ ('000')											
	1967		1976		1985		1995		2003		2015	
	ESV	P (%)	ESV	P (%)	ESV	P (%)	ESV	P (%)	ESV	P (%)	ESV	P (%)
Forest	2,808	18.7	1,167	11.3	942	10.7	993	11.9	880	10.0	597	6.7
River.vegetation	2,502	16.7	1,498	14.6	1,714	19.4	1,263	15.2	808	9.1	1,120	12.6
Cropland & settle*	1,256	8.4	2,116	20.6	3,031	34.3	2,655	31.9	2,964	33.6	3,340	37.5
Bush/shrub	1,194	8.0	1,707	16.6	1,156	13.1	1,417	17.0	853	9.7	853	9.6
Woodland	6,759	45.1	3,098	30.1	1,430	16.2	935	11.3	2,370	26.8	2,612	29.3
Grazing	458	3.1	701	6.8	561	6.4	1,055	12.7	959	10.9	390	4.4
Total	**14,977**	**100**	**10,287**	**100**	**8,834**	**100**	**8,318**	**100**	**8,834**	**100**	**8,912**	**100**

Source: Own Computation (2017) based on Table 5 and Table 7 above (*Settle = Settlement)

Table 9a: Tree Species of Forest, Woodland, Riverine Vegetat. and/or Agro-forestry in Lower Catchment HRC

N0	Sub-catchment	N0	Names of Trees	
			English/Amharic	**Scientific**
I	Lower Catchment	1	Acacia	*Acacia albida*
		2	Bitter-leaf (*grawa*)	*Vernonia amygdalina*
		3	Desert-date (*bedeno*)	*Balanites aegyptiaca*
		4	Flamboyant (*diredawa-zaf*)	*Delonix regia*
		5	Cabbage tree (*shiferaw)*	*Moringa oleifera*
		6	Eucalyptus (*key-bahir-zaf*)	*Eucalyptus camaldulensis*
		7	*Kontir*	*Acacia senegal*
		8	Avocado tree	*Persea Americana*
		9	Mango tree	*Mangifera indica*
		10	Lemon tree	*Citrus aurantifolia*
		11	*Woybeta*	-
		12	*Ambeshok*	*Annona muricata*
		13	*Sockie* tree	-

Source: Own Field Survey (2015 – 2017)

Table 9b: Tree Species of Forest, Woodland and Riverine Vegetation in Middle and Upper Catchment, HRC

N0	Sub-catchment	N0	Name of Trees	
			English/Amharic	**Scientific**
II	Middle and Upper Catchments	1	Broad-leaved croton (*bisana*)	*Croton macrostachyus*
		2	Flat-top acacia	*Acacia abyssinica*
		3	Olive (*woira*)	*Cuspidata olea Africana*
		4	*Tid*	*Juniperus procera*
		5	Mexican cypress (*yeferenji-tid*)	*Cupressus lusitanica*
		6	Hop-bush *(kitkita)*	*Dodonaea viscosa*
		7	Bitter-leaf (*grawa*)	*Vernonia amygdalina*

	8	*Embus*	*Allophylus abyssinicus*
	9	*Koshim*	*Dovyalis abyssinica*
	10	*Kosso*	*Hagenia abyssinica*
	11	Grevillea	*Grevillea robusta*
	12	Eucalyptus (*nech* or *shito bahir-zaf*)	*Eucalyptus citriodora*
	13	*Gumero*	*Capparis tomentosa*
	14	Peach *(kock)*	*Prunus persica*
	15	Mountain bamboo	*Arundinaria alpine*
	16	Reed-grass (*shembeko*)	*Arundo donax*
	17	Apple tree	*Malus domestica*
	18	Cactus	*Euphorbia abyssinica*
	19	Cape-fig (*shola*)	*Ficus sur (F. capensis)*
	20	*Enset*	*Ensete ventricosum*
	21	Manna (ribbon) gum	*Eucalyptus viminalis*

Source: Own Field Survey (2015 – 2017)

Table 10a: Average Gross Income (GI), Net Economic Value (NEV), Per Capita GI and Per Capita NEV Derived from Crop and Fuel-wood (Firewood and Charcoal) Products by HH of HRC in 2015

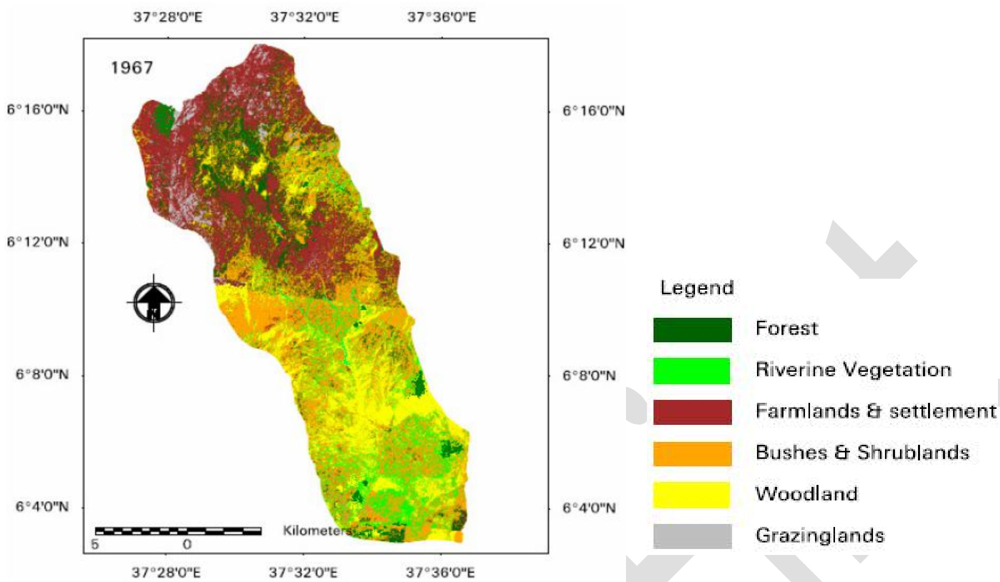
N0	Service	N0	Measurement	LC	MC	UC	HRC
I	Crop harvest	1	Average gross income (US$)	971.4	499.3	556.5	695.3
		2	Average NEV (US$)	893.1	445.0	496.6	630.1
		3	Per capita gross income (US$)	194.3	99.9	111.3	139.1
		4	Per capita NEV(US$)	178.6	89.0	99.3	126.0
II	Fuel-wood	5	Average gross income (US$)	180.5	188.5	178.2	182.0
		6	Average NEV (US$)	180.5	188.5	178.2	182.0
		7	Per capita gross income (US$)	36.1	37.7	35.6	36.4
		8	Per capita NEV (US$)	36.1	37.7	35.6	36.4
III	Crop and fuel-wood services	9	Average gross income (US$)	1,151.9	687.8	734.7	877.3
		10	Average NEV (US$)	1,073.6	633.5	674.8	812.1
		11	Per capita gross income (US$)	230.4	137.6	146.9	175.5
		12	Per capita NEV (US$)	214.7	126.7	134.9	162.4
		13	HH size	5 (5.4)	5 (5.2)	5 (5.1)	5 (5.3)
		14	Sample HH	174	134	157	465

Source: Own Computation (2018) upon Own Survey Data (2016 – 2017). **Recall**: LC = Lower Catchment; MC = Middle Catchment; UC = Upper Catchment; HRC = Hare River Catchment.

Table 10b: Some Provisions Generated from Forest, Woodland, Riverine Vegetation, Bush/shrub, Grazing-land and Agro-forestry of HRC by Its Inhabitants upon Responses of Sample Households (HH) in 2015

N0	Tree/bush/grass	Service Type	Purpose of Service	HH Respondents	
				N0	P (%)
1	*Sokie* tree	Timber/log	Make bench, chair & simple boats (in lower catchment)	142	30.5
2	Eucalyptus	Logs, fuel-wood	Furniture, energy, building houses & cash	319	68.6
3	Acacia (*albida* and *abyssinica*)	Logs, fuel-wood	Farm tools, HH energy	245	52.7
4	Croton	Logs, fuel-wood	Fencing, HH energy	167	35.9
5	*Tid (Juniperus procera)*	Logs/timber	Building houses	111	23.9
6	Bitter-leaf	Fuel, (medicine)	Treat gastric, HH energy	305 (56)	65.6 (12)
7	Mexican cypress	Logs, fuel-wood	Construction, HH energy	153	32.9
8	Reed-grass	Log/timber	Build houses & fences, and generate cash	231	49.7
9	*Natra/aritti* (grass)	Bio-chemical	Boost milk production during breast-feeding	268	57.6
10	Highland bamboo	Timber/log	Houses, chicken-home, fences, chairs, weaving tools & for cash	289	62.2
11	Cape-fig, *ambeshok* & desert-date	Fruits	Food for humans	149	32.0
12	Banana	Medicines	Shoots are used to treat stomach-etch	124	26.7
13	Mango	Medicine	Leaves are used to treat diabetics	117	25.2
14	Papaya	Medicine	Fresh seeds are used (chewed) to treat gastric disease	236	50.8
15	Hop-bush (*kitkita*)	Logs, fuel-wood	Furniture (hoe, hair-comp, spoon, etc.), HH energy	226	48.6
16	Avocado (*Persea americana*)	Medicine	The fruit flesh is used to medicate hair-fungi & smoothen skin	134	28.8
	Total sample HH			**465**	**100.0**

Source: Own Data Gathered through Field Survey (2015 – 2017) **Recall:** Table 10b above is organized from multiple responses options; and in row #6, the N0/P (%) values outside and (inside) the bracket indicate HH who replied "fuel" and "medicine," respectively.



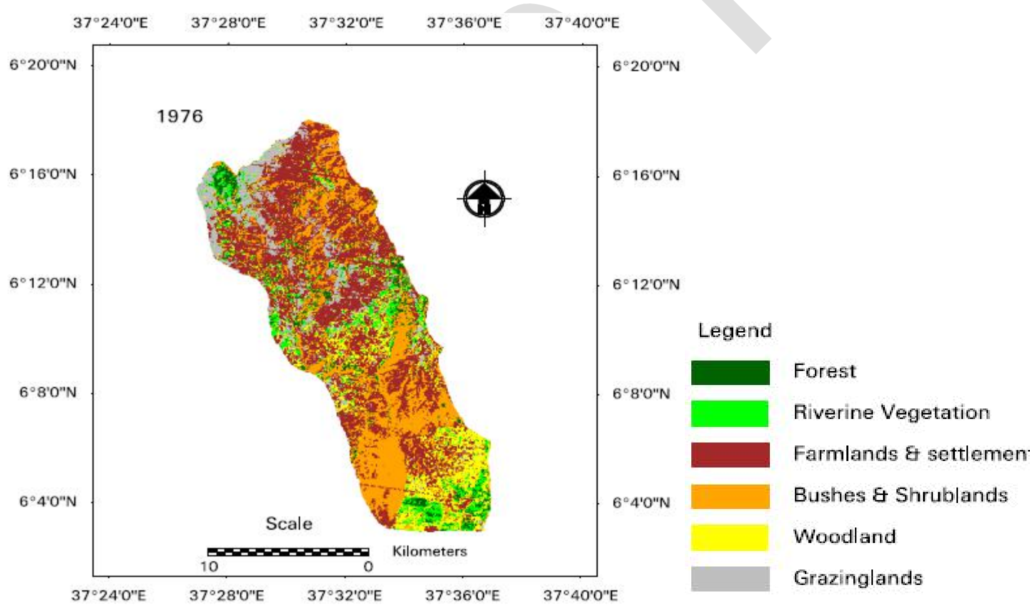
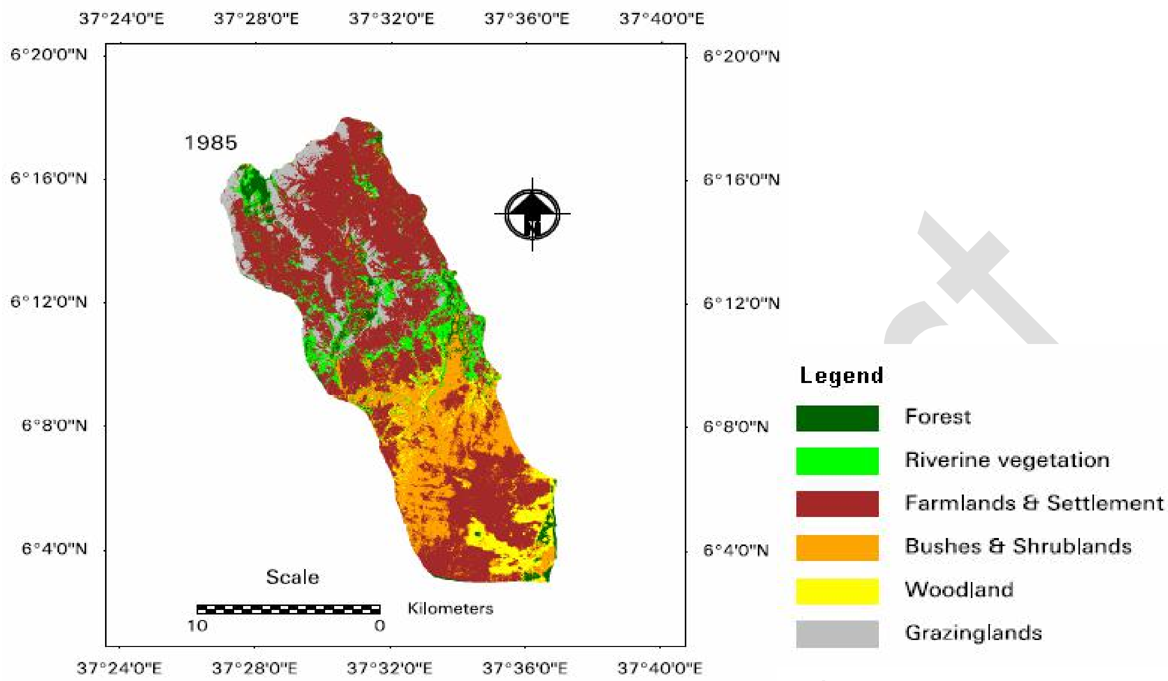


Figure 4a: LULC Classes of HRC in: **(i)** 1967 (Top) and **(ii)** 1976 (bottom) **[Source**: Analysis via ERDAS 3.8 and Arc GIS 9.3, Ychale, 2016]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6°20'0"N
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6°8'0"N
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1985
Scale
10
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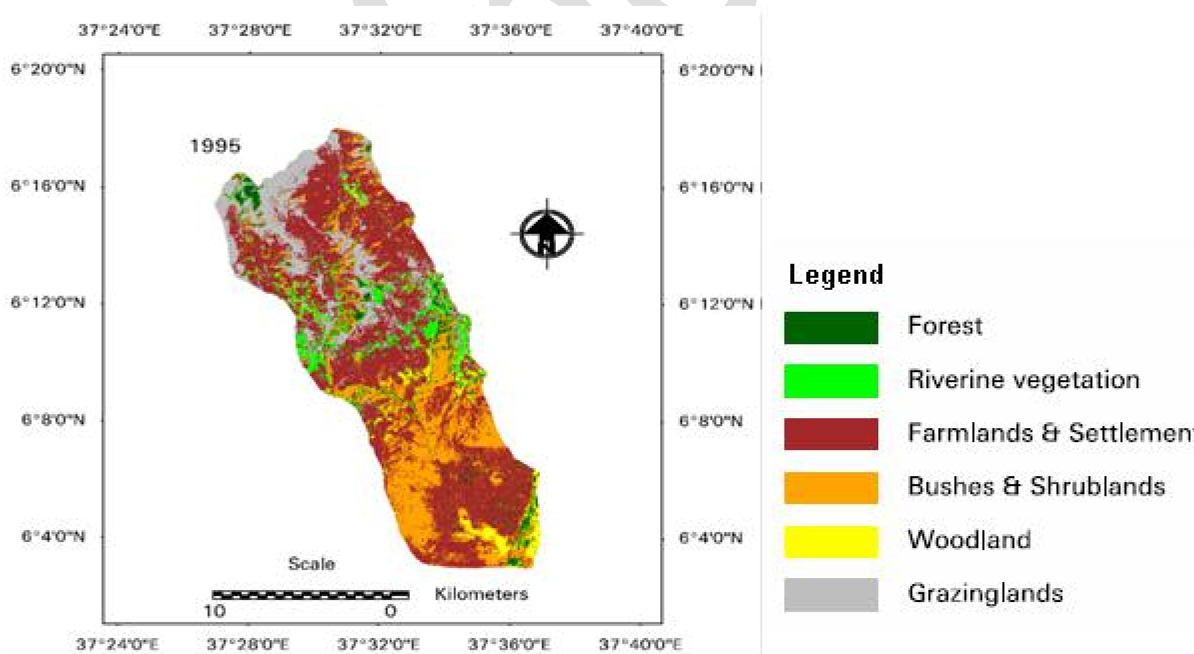
Kilometers
Legend
Forest
Riverine vegetation
Farmlands & Settlement
Bushes & Shrublands
Woodland
Grazinglands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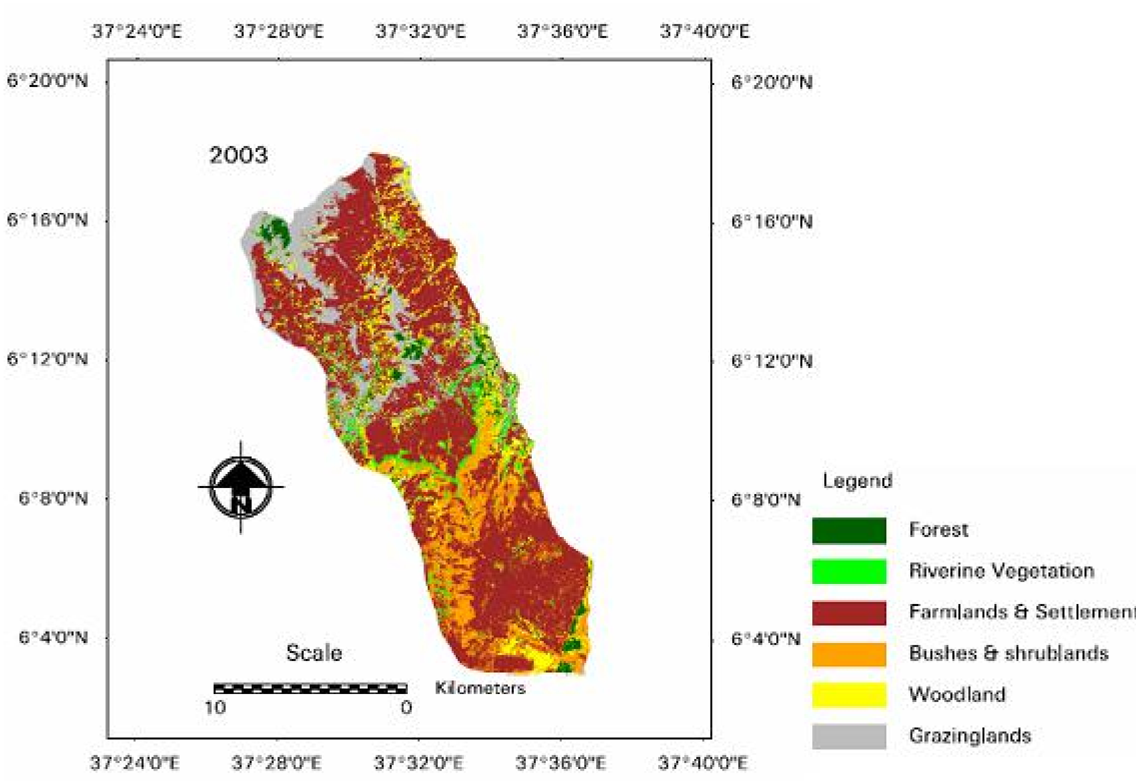
6°8'0"N
6°4'0"N
1995
Scale
10
0
Kilometers
Legend
Forest
Riverine vegetation
Farmlands & Settlement
Bushes & Shrublands
Woodland
Grazinglands

Figure 4b: LULC Classes of HRC in: **(i)** 1985 (top) and, **(ii)** 1995 (bottom) **[Source**: Analysis via ERDAS 3.8 and Arc GIS 9.3, Ychale, 2016]



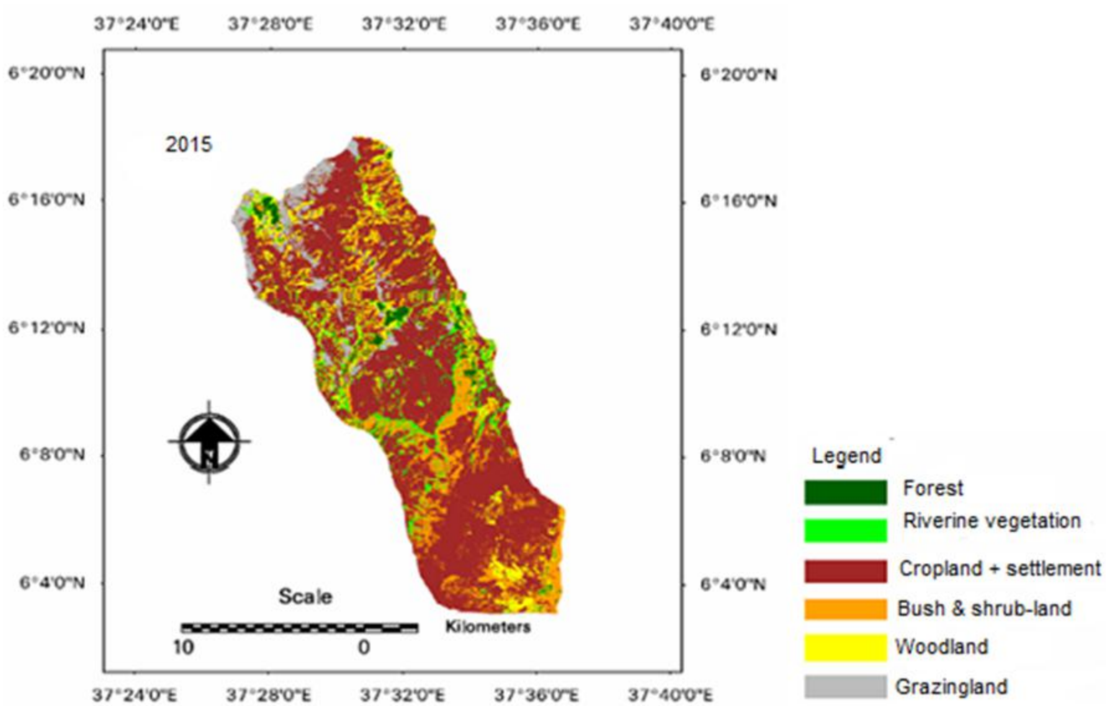


Figure 4c: LULC Classes of HRC in: **(i)** 2003 (top) and, **(ii)** 2015 (bottom) **[Source**: Analysis via ERDAS 3.8 and Arc GIS 9.3, Ychale, 2016]