LINKAGES BETWEEN KENYA'S FOREST REGULATING SERVICES AND THE REST OF THE ECONOMY

7 February 2012

Preamble

This Report evaluates the importance of montane forest dependent regulating ecosystem services to the economy of Kenya.

The Report forms part of a larger study that builds upon the 2009 UNEP report on the forest related regulating ecosystem services of Kenya, through valuation of the priority regulating services.

The key objectives of the larger study are:

1. To link regulating services associated with the montane forests of Kenya, to the economy of Kenya;
2. To construct hybrid physical and monetary Input-Output models that will feed into the activities below as part of the process to build resource accounts for Kenya;
3. To estimate the value of the regulating services of the montane forests of Kenya;
4. To construct resulting monetary resource accounts;
5. To strengthen national institutional capacities ; and
6. To write a paper to make a case for montane forests in Kenya's linkages and contribution to the UN-REDD Programme Global Framework Document 2011-2015 and its work area 6 "Green economy transformation processes catalyzed as a result of REDD+ strategies and investment".

This Report addresses objectives 1, 3 and 6 above.

The outputs of this report are to be incorporated into the Input-Output models in order to assess the economy-wide effects of deforestation in Kenya.

The first six chapters portray the essence of the report. More detailed literature reviews and analyses on each aspect of the report are presented in the appendices from which large sections were also used in the main report. This may appear as repetition, but serves the purpose of completeness.

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Executive Summary

Kenyan economic growth is intrinsically linked to three highly variable economic characteristics. Firstly, Kenya is poorly endowed with energy resources, and thus the economy is sensitive to increases in international crude oil prices. Secondly, the economy is vulnerable to inflationary pressures when the Kenya Shilling weakens against the currencies of its major trading partners. Thirdly, inflationary pressure arises during periods of drought when the water dependent economic sectors come under pressure.

Kenya's water is highly dependent on Kenya's five Water Towers, which together encompass more than a million hectares of montane forests. The total water yield from the Water Towers could be more than 15,800 million m^3 /yr, which is more than 75% of the renewable surface water resources of Kenya.

Kenya's Water Towers are highly vulnerable to deforestation (DRSRS 2004, DRSRS 2006). Timber, fuelwood and charcoal harvested thus harvested provides poor people with immediate and significant cash incomes, as well as productive land. These constitute significant economic incentives favouring deforestation.

However, deforestation also incurs severe economic costs on the economy of Kenya. Not only does it adversely affect Kenya's water yield and thus water dependent sectors, but it also affects a range of other economic sectors. These sectors are the *Agriculture, forestry and fishing* sectors, the *Electricity and water* sectors, the *Hotels and accommodation* sector and the *Public administration and defense* sector.

Deforestation in the Water Towers affects the economy through a set of ecosystem services defined by the Millennium Ecosystems Assessment (MEA, 2005) as regulating services. In 2005, the United Nations-led Millennium Ecosystem Assessment (MA) proposed a radical new framework for the analysis of the interface between ecosystems and the economy, and thus provided a framework to structure the quantification of the value of ecosystem services from natural assets to the economy. The MA defines four categories of ecosystem services: provisioning services, cultural services, regulating services, and supporting services.

Provisioning services cover the renewable resources that are mostly directly consumed and that generally have well-defined property rights. Cultural services capture many of the non-use (or passive use) values of ecological resources such as spiritual, religious, aesthetic, and inspirational wellbeing. In Kenya irrigation agriculture, forestry, fishing, hydropower, and tourism are economic sectors that depend upon ecosystem services such as fresh water, forest products, fish stocks and the aesthetic appeal of the Kenyan landscape. These are examples of provisioning and cultural services. These services are highly tangible and their economic importance is easily recognizable.

Regulating services are indirect services that determine the capacity of ecosystems both to regulate the impact of external shocks, and to respond to changes in environmental conditions without losing functionality. Regulating services are a special category of ecosystem services which are intermediate to the production of the provisioning and cultural services. They are not directly consumed in the economy but rather, their value is determined by the value of the final consumption services they protect. Regulating services reduce risk to the economy and thus provide an insurance value to the economy. This insurance value is important, not only to maintain economic resilience to seasonal environmental and economic changes, but also to long term economic hazards, such as climate change. It is therefore important that the country manages its natural assets with a view to increasing the country's economic resilience.

Kenya can manage the supply of its regulating services by carefully managing its natural assets. Hazards that put natural assets and regulating services at risk include severe population pressure, poor farming methods, water pollution and deforestation. These hazards may result in changes in water runoff, flash flooding, reduced water infiltration into soil, soil erosion, siltation and loss of biodiversity, which in turn negatively affects the economic sectors discussed above.

This report focuses on the role that Kenya's indigenous montane forests play in producing regulating services, and on their input into the economy of Kenya. The montane indigenous forests of Kenya that fall within Kenya's five Water Towers, produce several regulating services of importance. These include local climate regulation, water flow regulation, erosion regulation, and water purification and waste treatment. These services are further closely associated with other regulating services including disease regulation and natural hazard regulation.

The regulating services of Kenya's montane forest ecosystems are thus important production factors to the *Agriculture, forest and fishing* sectors, the *Electricity and water* sectors, the *Hotels and accommodation* sector, and the *Public administration and defense* sector. These sectors, together, contributed between 33-39 % to GDP between 2000-2010. In addition, these sectors have a very significant multiplier effect on the rest of the economy's GDP.

This report presents a valuation of the regulating services produced by the Water Towers of Kenya. It is thus a step towards integrating regulating services into the national accounting framework. In 2009, Kenya Forest Services (KFS) and Kenya National Bureau of Statistics (KNBS), in collaboration and Miti Mingi Maisha Bora, developed an Environmental Economic Account for Forestry in Kenya (KFS 2009). This account focused on the provisioning services, the timber and non-timber forest products, produced by the forests of Kenya. Thereafter, the United Nations Environmental Programme (UNEP) produced a preliminary report on the role of forest-related regulating services (UNEP, 2009). This report is a continuation of the 2009 work by KFS, KNBS and UNEP.

The World Banks' WAVES[1] initiative intends to address the matter of accounting for regulating services. It identifies accounting for the regulating services as a challenge. This is because regulating services' value derives indirectly from their use as inputs to production process. Thus, most often, there are no markets for these services and their value is already included, implicitly, in the value of other assets for which markets exist (Lange 2011, World Bank 2011). In addition, regulating services is of value because they ensure the delivery of final consumption services over a range of environmental conditions (Perrings, 2006). Thus, regulating services reduce risk to the economy, which is why it has an insurance value.

In order to estimate the value of the montane forest regulating services of Kenya, this study develops a case study of the effects of deforestation that occurred between 2000 and 2010 on the Kenyan economy, for the 2010 fiscal year. The case study is evidence-based and makes use of official economic data, environmental indicators, experimental results and peer reviewed publications to

[1] Wealth Accounting and the Valuation of Ecosystem Services

develop a bio-economic model for the regulating services of Kenya. In a subsequent phase of the study, these effects will be incorporated into the national accounts of Kenya.

In the 10 year period, 2000-2010, deforestation in Kenya's Water Towers amounted to an estimated 28,427 ha. By 2010 such deforestation of montane forests yielded a timber and fuelwood volume of 210 m^3/ha with a cash value of 272,000 KSh/ha. At an estimated deforestation rate of 2,762 ha in 2010, this was equivalent to a revenue of KSh 796 million in 2010. This is a considerable economic incentive for illegal loggers.

However, the indirect costs of deforestation are borne by sectors and households elsewhere in the economy, through the reduction in the value of regulating services. Whereas the cash value of timber and fuelwood has a once-off value, the consequences of deforestation in preceding years continue to be felt in the economy in every subsequent year. By 2010, the cumulative negative effect of deforestation on the economy through reduction in regulating services was an estimated KSh 2,231 million/yr.

The largest component of this was attributable to changes in river flows in the form of a reduction in dry season river flows, which reduced the assurance of water supply to irrigation agriculture. This reduced irrigation area by 5,287ha and reduced agriculture output by KSh 1,499 million in 2010. Reduced river flows also reduced hydropower generation by KSh 8 million. Although this is relatively not a very high value, the multiplier effect of hydropower on the rest of the economy is considerable.

Reduction in water quality due to siltation and elevated nutrient levels running off degraded land into fresh water systems reduced inland fish catch by KSh 86 million and increased the cost of water treatment for potable use by KSh 192 million.

Deforestation increases malarial disease prevalence. Incidence of malaria under an exposed population of approximately 150,000 people is estimated to have been KSh 237 million by 2010. This is in the form of additional health costs to the Government of Kenya, and through losses in labour productivity.

Forest loss is also detrimental to the global carbon cycle. The above-ground carbon storage value forgone through deforestation was estimated at KSh 210 million in 2010.

Thus, in 2010, the total net cumulative effect of deforestation on the economy of Kenya was a loss of KSh 1,435 million. This loss in output has a considerable multiplier effect on the rest of the Kenyan economy.

Whereas the immediate cash benefit of deforestation through timber and fuelwood sales is KSh 272,000/ha, the total effect of regulating services lost is estimated to be KSh 763,283/ha. The cumulative loss to the economy in 2010 outweighed the cash benefits by at least 2.8 times. This ratio will increase into the future as the cumulative effect of deforestation endures.

Of particular interest is the implication for the UN's REDD+ initiative. A carbon value of US$ 6/ton provides insufficient economic incentive (KSh 71,768/ha) to compensate for deforestation (KSh 272,000/ha). However, this analysis shows that the total ecosystem service value of the montane forests far exceeds the carbon storage value. Carbon, as a proxy for regulating ecosystem services, has a regulating service multiplier effect of 10.6. In practice this means that for every KSh1 that illegal loggers earn through deforestation, various sectors in the rest of the economy, by 2010, lost USD 2.81 in terms of total output per sector.

The key policy implications for the Government of Kenya lies in (1) sustainable use of the forest resources (mainly timber en wood) through selective thinning regimes, instead of clear-felling of large area; (2) the protection of the forests against uncontrolled settlement; (3) adequate allocation and policing of water withdrawals; (4) improved management of degraded land. This can be achieved through:

- proper road and path planning, design, and maintenance;
- establishment on crop systems that protect the soil and create microclimatic condition resembling forest conditions as close as possible (shamba-system for example);
- terracing on steep upstream cropped areas to reduce surface runoff and increase infiltration;
- mulching bare areas to protect the soil, avoid weed growth to reduce soil water loss through evaporation from the soil and through transpiration by weeds;
- tied ridges are very effective in controlling surface runoff and improving soil moisture conditions;
- payments for ecosystem services schemes related to the REDD+ initiative.

The cost of these mitigation measures is expected to be far less than the value of regulating services lost.

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Acronyms and abbreviations

CEBC	Centre of Evidence Based Conservation
DRSRS	Kenya’s Department of Resource Surveys and Remote Sending
EEA	Environmental Economic Accounts
FAO	Food and Agriculture Organisation
FRA	Forestry Resources Account
GHG	Global greenhouse gas
KFS	Kenya Forest Services
KFMP	Kenya Forest Mater Plan
KNBS	Kenya National Bureau of Statistics
KSh	Kenya Shilling
MEA	Millennium Ecosystems Assessment
REDD	Reducing emissions from deforestation and forest degradation
SAR	Strategy for Revitalizing Agriculture
UN	United Nations
UNEP	United Nations Environmental Programme
USD	United States Dollar
WAVES	Wealth Accounting and the Valuation of Ecosystem Services

1 The role of water resources in the economic resilience of Kenya between 2000 and 2011

The size of the Kenya economy, as measured by Gross Domestic Product (GDP), is forecast at KSh 3,200 billion or approximately US$ 35.8 billion for 2011 (source: International Monetary Fund). This makes Kenya the 5th largest economy in Sub-Saharan Africa after South Africa and the crude oil producing economies of Nigeria, Angola and Ghana.

Kenya's economy grew at an average GDP growth rate of 5 % per year over the period 2000-2010 (Figure 1). However, this growth was highly variable due to various structural vulnerabilities in Kenya's economy. Economic resilience, as measured by inflation rate, is the ability of an economy to maintain its function and growth under the influence of external effects (Briguglio et al, undated).

Kenya's economic resilience is affected by three economic characteristics. Firstly, Kenya is poorly endowed with energy resources, and thus the economy is sensitive to increases in international crude oil prices. Secondly, Kenya traditionally has a negative trade balance, and this makes the country's economy vulnerable to inflationary pressures when the Kenya Shilling weakens against the currencies of its major trading partners. Thirdly, inflationary pressure arises during periods of drought when the water dependent economic sectors come under pressure.

These three economic characteristics primarily affect agricultural output and hydropower generation. The agriculture sector of Kenya is by far the largest contributor to the GDP of the country. Agriculture sector contribution to GDP varied between 25 – 30 % between 2000 and 2010. Hydropower comprises 46% of Kenya's power supply. During periods of drought, economic output from both these sectors decrease, and have to be substituted by imports. When droughts coincide with global economic crises, imports become very expensive, especially when crude oil prices increase while the Kenya Shilling devalues against the United States Dollar. As a result, inflation increases, and Kenyan households become poorer.

Such events happened on four occasions during the period 2000-2011, as evidenced when inflation rates exceeding 10% (Figure 2). In 2000 Kenya experienced a recession resulting from a severe drought in 1999-2000. In 2004-2006, crude oil prices increased and droughts occurred. The third slowdown occurred in 2008, when the global financial crises again followed the 2006 drought, although this time coupled with post-election violence (2007) to reduce GDP growth to nearly 1 %. By 2010, GDP growth had increased again to 5.6 % as a result of recovery of the global economy (KNBS, 2011), as well as due to favorable weather conditions. The World Bank attributed this recovery to the recovery of the agricultural sector and a more reliable energy supply, which in turn had an immediate positive impact on the manufacturing sector (World Bank, 2010). The fourth event took place in 2011, when another severe drought, combined with the United States' and European financial crises resulted in GDP growth slowdown and extreme inflation levels.

The Kenyan economy is thus highly vulnerable to water availability. It is therefore important for Kenya, perhaps more so than for many other African countries, to manage its water resources with a view to increasing the country's economic resilience. Kenya's water largely comes from the five Water Towers, which are under threat from excision and clearance (World Bank, 2006; GOK, 2005).

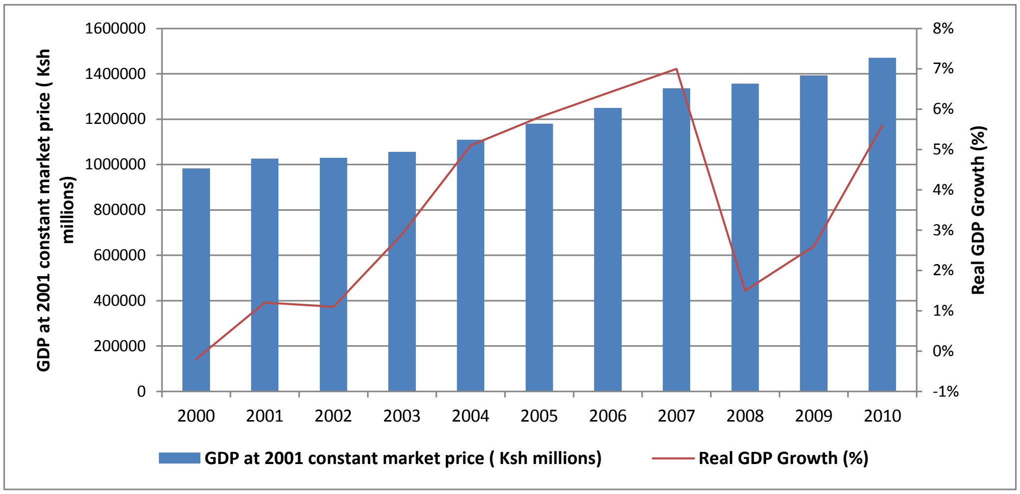

Figure 1: Kenyan GDP and real GDP growth for the past 10 years (data source CBS 2003; 2005 and KNBS 2008; 2010; 2011).

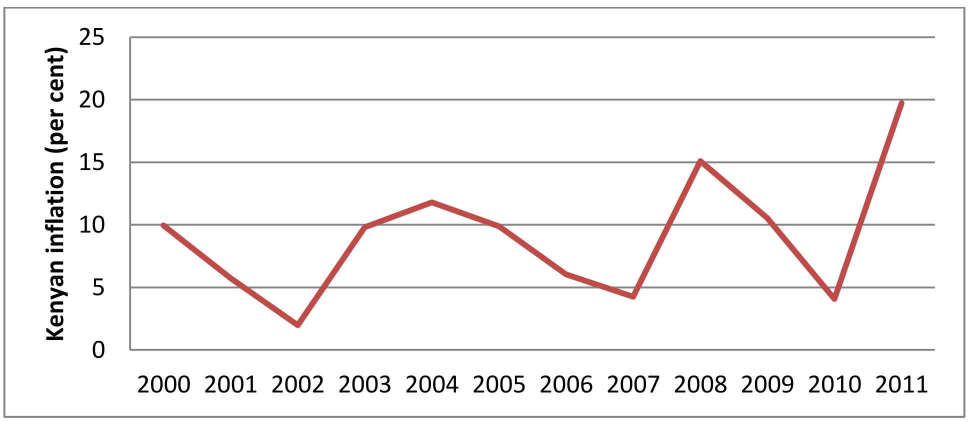

Figure 2. Inflation is an indicator of economic resilience. Inflation in Kenya exceeded 10% on four occasions since 2000. In all these instances, inflationary pressure resulted from droughts, combined with increasing crude oil prices and weaker exchange rates. The Kenyan economy is thus highly vulnerable to water availability.

2 Kenya's five Water Towers provide various benefits to the economy of Kenya

The headwaters of Kenya's five primary catchment areas all arise in five indigenous mountain (montane) forest areas. These five forest areas are commonly referred to as Kenya's five Water Towers. The five Water Towers comprise the Mau Forest Complex, Mount Kenya, the Aberdares, Mount Elgon and Cherangani (Figure 3).

Montane forests are the indigenous forests occurring in the montane belt between *1,500 m to 3,500 m (m a.s.l.) in the five "Water Towers".* Typically these are closed broadleaved forests with the following dominant species Camphor (*Ocotea spp*); (*Aningers spp*, *Albizia spp*, *Olea spp*); Pillarwood (*Cassipourea spp*); *Croton spp; Diospyros spp*; riparian species, and others. But may include open broadleaf forests: Wet upland (Hagenia spp); and Coniferous forests: *Podocarpus spp*; Cedar (*Juniperus spp*), and bamboo forests.

The Mau Forest Complex is the source of Mara, Sondu and Njoro rivers. The Mara River supports the Masai Mara Game Reserve and is key to the survival of wildlife in Masai Mara Game Reserve and Serengeti National park in Tanzania. The Sondu River has the Sondu Miriu Hydropower complex. The Njoro River flows into Lake Nakuru which is an important wildlife refuge and centre of tourism. Mt. Kenya is the source of Tana River, which provides water supply to Nairobi and generates 70% of hydropower in Kenya. It also supports agricultural development along the Tana Basin. Mt. Kenya supports numerous streams and springs that support commercial and subsistence farming on the lower slopes. Aberdare Ranges and Mt. Kenya water towers provide water to the significant horticultural and floricultural industries, which generate high export revenue. The Nzoia River, which drains into Lake Victoria, originates on Mt. Elgon (World Bank, 2006).

The montane forests of Kenya not only protect the headwaters of these river systems, but they also provide a range of other benefits to the economy. These benefits are defined by the Millennium Ecosystems Assessment (MEA, 2005) as ecosystem services.

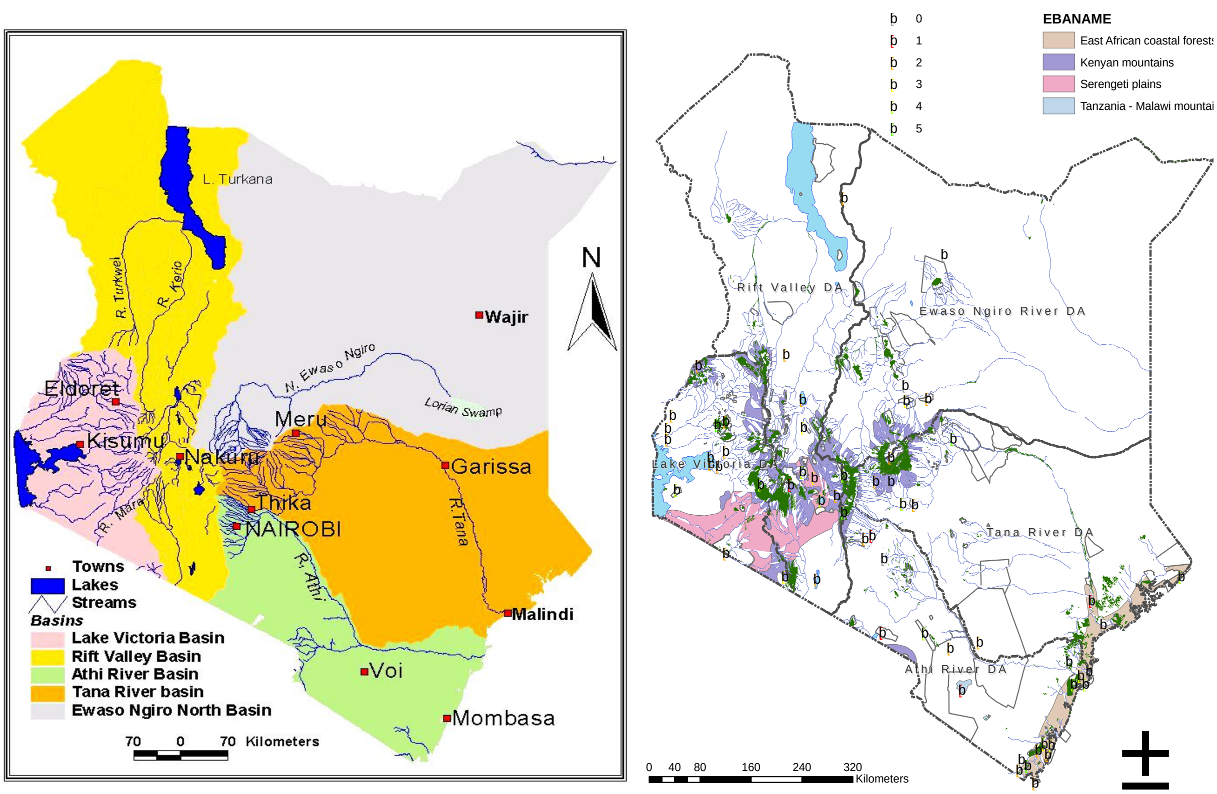

Figure 3. The montane forests of Kenya are also referred to as the five Water Towers of Kenya (seen here as dark green patches in the mountainous areas on the right-hand map). These forests lie at the source of the five major drainage basis of the country (left-hand map).

3 The ecosystem services provided by Kenya's Water Towers

The Millennium Ecosystems Assessment (MEA, 2005) defines four categories of ecosystem services: provisioning services, cultural services, regulating services and supporting services.

Provisioning services cover the renewable resources that are mostly directly consumed and that generally have well-defined property rights. The cultural services captures many of the non-use (or passive use) values of ecological resources such as spiritual, religious, aesthetic and inspirational wellbeing.

Regulating services are indirect services that determine the capacity of ecosystems both to regulate the impact of external shocks, and to respond to changes in environmental conditions without losing functionality. The regulating services affect the distribution of outcomes, and in particular they affect both variation about the mean response and the likelihood of extreme responses. (Please see the Table 1 for a detailed definition of regulating services.) Supporting services capture the main ecosystem processes that support all other services. Much of the value of biodiversity is embedded within the regulating services.

In Kenya, irrigation agriculture, forestry, fishing, hydropower, and tourism are economic sectors that depend upon ecosystem services such as fresh water, forest products, fish stocks and the aesthetic appeal of the Kenyan landscape. These are examples of provisioning and cultural services. These services are highly tangible and their economic importance is easily recognizable.

Often less recognisable are the regulating services. Regulating services are a special category of ecosystem services which are intermediate to the production of the provisioning and cultural services. Regulating services are not directly consumed in the economy. Rather, the value of the regulating services derives from the value of the final consumption services they protect (Simonit and Perrings, 2011).

Regulating services ensure the delivery of final consumption services over a range of environmental conditions (Perrings, 2006). Thus regulating services reduce risk to the economy. Regulating services can thus also be considered as providing an insurance value to the economy. This insurance value is important, not only to maintain economic resilience to seasonal environmental and economic changes, but also to long term economic hazards, such as climate change.

The montane indigenous forests of Kenya that comprise Kenya's five Water Towers produce several regulating services of importance (Table 1). These include local climate regulation, water flow regulation, erosion regulation, and water purification and waste treatment. These services are further closely associated with other regulating services including disease regulation and natural hazard regulation (UNEP, 2009).

Table 1. Regulating services produced by Kenya's five indigenous montane forest areas (Kenya's five Water Towers), defined according to the Millennium Ecosystems Assessment (MEA) framework of ecosystem services. The regulating services provide intermediate to the production of the provisioning and cultural services

Regulating services defined in the MEA	Description
Local climate regulation	Ecosystems may influence climate both locally and globally (e.g. locally, land cover changes can affect temperature and precipitation; globally, ecosystems play an important role in the carbon cycle).
Water regulation	The timing and magnitude of runoff and flooding can be strongly influenced by changes in land cover, including in particular changes in the water storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.
Water purification and waste treatment / Water pollution sink	Ecosystems can help to filter out and decompose wastes introduced into inland waters and coastal and marine ecosystems. In many cases the waste removal capacity of the ecosystem may be exceeded. In such cases the ecosystem serves as a water pollution sink
Disease regulation	Changes in ecosystems can directly change the abundance of human pathogens such as cholera and can alter the abundance of disease vectors such as mosquitoes.
Natural hazard regulation	Flood control, storm protection.

4 Deforestation, regulating services and economic benefits

Despite their economic and environmental importance, forests in Kenya continue to be under threat of conversion to other land-use types. The main hazards are: charcoal production; logging of indigenous trees; marijuana cultivation; cultivated fields in the indigenous forest; shamba-system practices; livestock grazing; quarries; landslides; human settlements. Various reports point to the extent and devastating effects of such practices on erosion, sedimentation, water quality, etc. (UNEP, 2006; Ongwenyi et al., 1993; Brakel, 1984; World Bank, 2006).

Forest clearing is reaching dramatic proportions in some areas. The World Bank (2006) show that forests in the Lake Nakuru catchment has almost completely been converted to agricultural land. Clearings in the eastern Mau Forest Complex amounted to 35,301.01 ha in one year. The Molo forest was similarly cleared of 901.62 ha. Nabutola (2010) also mentions that during the past 15 years, more than 100,000 ha - one quarter of the protected forest reserve in the Mau Forest - have been settled and cleared. Nkako et al. (2005) in a status report on the Masaai Mau Forest report forest cover losses inside and outside the forest boundaries of 39,969 ha, representing about 39% of the total forest cover. A survey of degraded land into the indigenous forest of Mt Kenya by Vanleeue et al. (DRSRS 2003) showed that encroachment of the forest was quite extensive in 2000 amounting to 11,021 ha, but that it decreased substantially by 2002.

Kenya's Department of Remote Sensing and Resource Surveys (DRSRS) conducted a number on intensive deforestation studies by aerial survey in the early 2000s (DRSRS, 2004 and DRSRS, 2006). Deforestation rates for the periods 2000-2003 and 2004-2005 were estimated at 2,427 ha/yr and 3,666 ha/yr respectively (Table 2). Based on the estimates provided in Table 2, 28,427 ha of forest cover were lost to deforestation in the period 2000-2010. This is equivalent to 2.7% of the 2000 forest cover.

Table 2. Deforestation between 1990 and 2005 based on data sourced from DRSRS (2006) and DRSRS (2004). Deforestation rates for the periods 1990-1999, 2000-2003 and 2004-2005 were 2,681 ha/yr, 2,427 ha/yr and 3,666 ha/yr respectively. The estimated deforestation for the period 2006-2010 is based on the average rate of deforestation for the period 2000-2005.

	2000	2003	2005	2010
Mau Complex	415,977	408,893	399,413	Not available
Mt Kenya	200,871	206,885	209,032	Not available
Mt Elgon	73,706	73,521	73,521	Not available
Cherangano Hills	120,842	120,995	120,995	Not available
Aberdares	251,077	244,896	244,896	Not available
Total	1,062,473	1,055,190	1,047,857	1,062,473*
Deforestation rate (ha/yr)	-2,682	-2,428	-3,666	-2,923

*Estimate based on the average deforestation rate between 2000-2005.

The economic benefit of deforestation lies principally in the immediate availability of woody biomass in the form of timber, fuelwood and polewood; and the opportunity to acquire land for free. The Kenya Forest Master Plan (1994a) reports volumes for timber, fuelwood and polewood of 61, 149 and 45 m^3/ha respectively in indigenous forests. Cash values for the timber and fuelwood are determined by market prices which were 3,000 KSh/m^3 for roundwood in 2010. Assuming polewood is used primarily for own use, the revenue generated by deforestation was approximately 270,000 KSh/ha in 2010. This is a considerable economic incentive.

The costs of deforestation are however borne by sectors elsewhere in the economy. The regulating services of Kenya's natural ecosystems are important production factors to the *Agriculture, forest and fishing* sectors, the *Electricity and water* sectors, tourism (*Hotels and accommodation* sector), the *Public administration and defense* sector, and households (Table 3). These sectors, together, contributed between 33-39 % to GDP between 2000-2010. In addition, these sectors have a very significant multiplier effect on the rest of the economy's GDP.

Thus, deforestation reduces the value of the regulating services provided by Kenya's Water Towers. The sections below analyses and discusses each of the resulting services affected by deforestation of the Water Towers, and their effects on the economy of Kenya.

Table 3. The regulating services provided by Kenya's five Water Towers, provide indirect benefits to several economic sectors, as well as to households.

Regulating services of Kenya's five Water Towers	Economic sectors that benefit indirectly
Local climate regulation	Agriculture Forestry Fishing Electricity (hydropower) Water services Public administration and defense Tourism (Hotels and accommodation) Households that benefit indirectly
Water regulation	
Erosion regulation	
Water purification and waste treatment / Water pollution sink	
Natural hazard regulation	
Disease regulation	

5 Regulating services of Kenya's five Water Towers

5.1 Local climate regulation and water yield regulation - the effects of forests on water availability

At macro-scale, the rainfall in Kenya is driven by global processes such as the seasonal northward and southward movements of the low pressure belt around the equator known as the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is influenced by macro factors such as the sea surface temperatures of the Atlantic and Indian oceans. Forest's influence on the macro-climate depends largely on the extent of the forests relative to the extent of governing weather systems. Since montane forests constitute less than 3% of Kenya's area, it is unlikely that partial deforestation will have an effect on the macroclimate over the whole of Kenya.

At a meso-scale, the annual rainfall and its distribution during the year are influenced by land characteristics, such as topography and land cover. This is evidenced by large differences in annual rainfall in Kenya between two areas that are only 50 kilometres apart (Kabat et al., 2004). Forests thus have an influence on the meso-climate through their moisture interaction with the atmospheric boundary layer. Their physical structure effects the movement of air masses and interception of moisture in the atmosphere. A key reason for example for potential increased local rainfall is that tall forests may intercept fog or moisture from clouds as a result of their higher leaf area, larger canopies, and higher aerodynamic roughness than shorter crops. Bruijnzeel (2001) presents a comprehensive and detailed review of cloud interception by tropical rain forests. Hamilton and Bruijnzeel (1997) and Bruijnzeel (2001) suggest that cloud deposition can be as high as 5% to 20% of annual rainfall. Forests also provide a slight orographic lift and concomitant cooling of air masses resulting in precipitation.

At micro-scale, climate is regulated primarily by ground cover (type of vegetation). Forests protect the soil (and thus also surface hydrological processes) in many ways and create an ecosystem conducive to such protective functions. Such ecosystems are dependent on the temperature and moisture conditions resulting from forest cover protection.

Water yield from high elevated, high rainfall areas is high. At an average annual rainfall of 2,300 mm and a potential rainfall-runoff ration of 65%, it means that total water yield from the Water Towers could be more than 15,800 million m^3 /yr, which is more than 75% of the renewable surface water resources of Kenya.

The evidence from experimental results (Bosch and Hewlett, 1980) is that deforestation and conversion to shorter vegetation types will generally increase water yield (See also Appendix 4 for discussion). However, in the case of Kenya's montane forests it is most likely that the gains in water yield as a result of deforestation will be off-set by the loss in cloud water interception in these forests occurring at such high elevations.

The Water Towers also regulate the seasonal flow of water in rivers, and deforestation can severely reduce dry season river flows. Rainfall in Kenya occurs mainly during two rain seasons. The long rains are typically from March to May while short rains are typically from October to November. Rainfall distribution and the associated need for water management to meet water needs towards the end of the dry seasons or during droughts is therefore of crucial importance to the Kenyan economy. Although human interventions, such as large dams, contribute to increasing water yield during dry seasons, the Water Towers also contribute to such management.

Forests create soil protective and infiltrative conditions conducive to the water holding capacity and slow release of water from a catchment, which will result in a more even distribution of flow throughout the year. Generally the higher the overall water yield from a catchment the higher the flow in all seasons and the more sustainable the flow during prolonged periods of drought.

Bruijnzeel (1988) in a discussion on the effects of vegetation changes on dry season flow in the tropics concluded that if infiltration opportunities after forest removal decrease to the extent that the amount of water leaving an area as quick flow, exceeds the gain in baseflow associated with decreased evapotranspiration, then diminished dry season flows will result. If surface infiltration characteristics are maintained, the effect of reduced evapotranspiration after clearing will show up as an increase in baseflow. The unfortunate reality is that uncontrolled forest conversions in Kenya result in poorly managed replacement land-use with detrimental effects on infiltration and overland flow processes, and there is evidence that dry season flows have decreased significantly in a number of Kenyan rivers after clearance and settlement of large parts of their catchments. Such reductions are all related to the land-use subsequent to clearing of indigenous forest. Poor land management causing compaction and degradation will result in lower infiltration and higher levels of overland flow. Conversion of forest to annual cropping or grazing is almost inevitably followed by increases in amounts of surface runoff as a result of either over grazing or other means of compaction (Bruijnzeel, 1990). So secondary aspects related to forest conversion are mainly the cause of disrupted seasonal flow.

In addition, where areas have been cleared for settlements and associated planting of annual crops, water is abstracted from rivers to support the settlements. Such abstractions are likely to severely influence seasonal flows. The World Bank (2006) notes that "*if extensive abstraction is allowed to occur, then flows can decrease by (in the case of the Ewaso Nyiro North catchment) a factor of 10 in dry months*". The World Bank (2006) also mentions that there was a 300% increase in water use in the Laikipia District which was mainly due to increased human settlement and an expansion of irrigated agriculture.

An important further consequence of increased wet season flow is the fact that less water thus infiltrates and so reduces the water holding capacity of the catchment, either as ground water or soil water. This may result in gradual depletion of groundwater storages.

What therefore is the effect of deforestation on seasonal flow in Kenya? The seasonal streamflow distributions before and after deforestation can be estimated from work done in Kenya by Brakel (1984) and Decurtins and co-workers (1988). As a result of Kenya's "long rains" (March to May) and "short rains" (November), dry or low flow seasons occur in January-February and June-October. Intact montane forests in the Water Towers moderate the water yield from the Water Towers, by producing somewhat lower flows during the rain seasons, and higher dry (low flow) season flows (Figure 4).

This has two consequences: During the rain seasons (March to May, and November), increased runoff from deforested areas result in elevated sediment loads and reduced water quality in fresh water systems. During the low flow seasons, especially the 5-month period from June-October, reduced water availability becomes a limiting factor to economic activities.

Total annual renewable surface water in Kenya, that is available for use, is estimated at about 19,700 millionm^3/yr (World Bank, 2006). The reduction of dry season flows, reduces the long term total availability of water. By 2010, the deforestation of the Water Towers between 2000-2010 of 28,427 ha thus resulted in a reduced water availability of approximately 62 million m^3 per year (Figure 5). This reduction in water availability will affect the irrigation sector most severely, as it is the sector which has the lowest assurance of water supply (Table 4). Hydropower generation will also be negatively affected as streamflow reduces. These effects are discussed in the sections below.

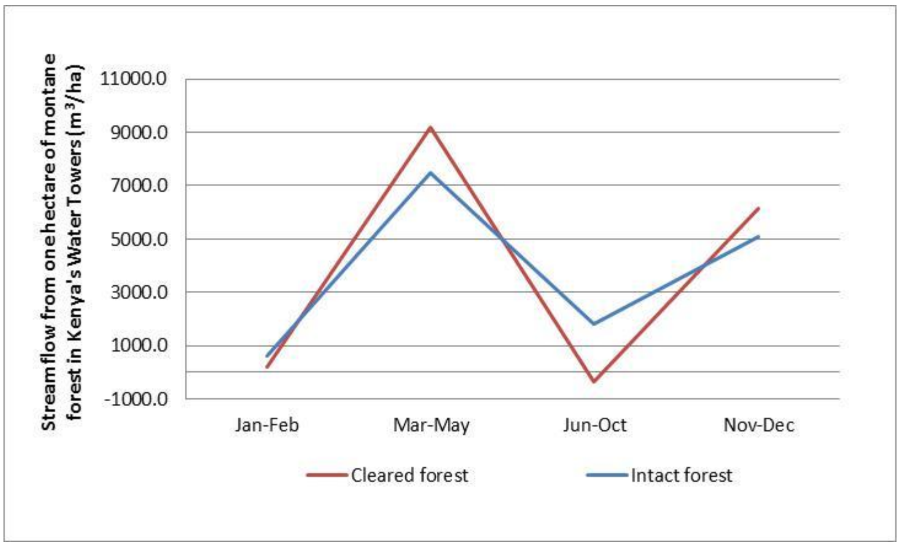

Figure 4. Changes in long term seasonal flow distribution off one hectare of intact and cleared montane forest areas in Kenya's Water Towers (adapted from Brakel (1988) and Decurtins (1984)). During the rain seasons (March to May, and November), increased runoff from deforested areas result in elevated sediment loads and reduced water quality in fresh water systems. During the low flow seasons, especially the 5-month period from June-October, reduced water availability becomes a limiting factor to economic activities.

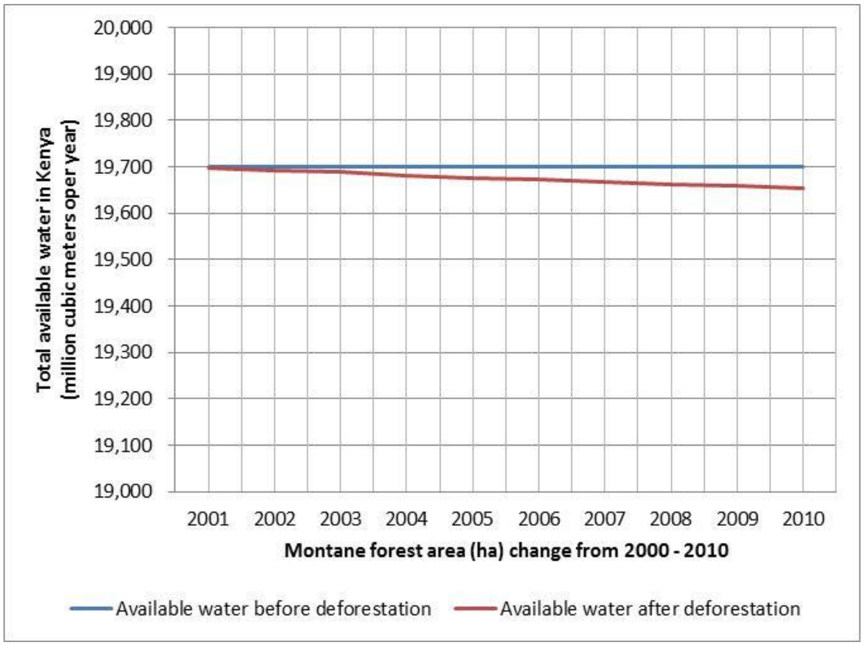

Figure 5. Based on the reduction in dry season flow resulting from deforestation of montane forests in the Water Towers, the long term water yield in Kenya had decreased by 62 million m^3 per year, by 2010.

Table 4. Estimated water demand in Kenya for 2010.

Demand by Category	Water demand projected by the Kenya Water Master Plan (1992) as reported in World Bank 2006 (million m^3/year)			Estimate of actual water demand based on actual irrigation area in 2010 and an estimate of hydroelectricity consumptive use* (million m^3/year)
Year	***1990***	***2000***	***2010***	***2010***
Domestic water				
Urban	209	427	696	696
Rural	194	273	424	424
Industrial	80	138	180	180
Hydro-electricity				109*
Irrigation	1,447	2,851	2,957	1,434*
Livestock	119	156	227	227
Inland fisheries	16	22	28	28
Wildlife	8	8	8	8
Total	**2,073**	**3,874**	**4,519**	**3,107**

5.2 Water regulation and erosion regulation

Experiments in many parts of the world suggest that any undisturbed natural or well managed vegetation cover will control overland flow or surface runoff and thus peak flows (see for example Hewlett and Helvey, 1970; Hewlett and Bosch, 1984; Kirby et el., 1991; Taylor and Pearce, 1982). Conversely, vast areas of poorly managed vegetation cover can be conducive to surface runoff and some degree of flooding. The section above has shown that wet season flows is likely to be increased by forest conversion of significant magnitude in Kenya.

These increased wet season flows, accompanied by cleared land areas leads to large-scale erosion and sedimentation. Erosion results in loss of productive soil resources. This in turn increases nutrient content in fresh water systems, cause siltation of channels, reservoirs and dams and increase turbidity of water supplies. Evidence from Kenya is that the activities that replace previous forest areas in the Water Towers are degrading to the environment (DRSRS 2004, 2006).

Deforestation degrades soil structure in two ways: firstly the soil organic carbon (SOC) content decreases resulting in the breakup of micro-aggregates and secondly, macro-aggregates breakup as a result of poor land use practices after land conversion. The results are compacted soils with increased bulk densities, decreased infiltration rates (increased penetration resistance) and decreased water-holding capacities. The water holding capacity typically decreases with between 25% and 63% with deforestation.

Cation exchange capacity (CEC) represents the degree to which basic plant nutrients (Ca, Mg, K, Na) are retained in the soil rendering them unavailable for loss through leaching and maintaining a preferable basic soil pH. Deforestation results in CEC decreases, plant nutrients are no longer retained and they leach from the soil resulting in salinization of receiving waters. Due to the decrease in plant nutrients, soil fertility decreases resulting in crop failures.

The effects of increased sediment loads on water systems and the subsequent water pollution include decreased storage capacity due to siltation with severe financial and social implications.

It is very difficult to provide an accurate overall estimate of erosion regulation provided by montane forests, because erosion is very site specific and the consequence of interaction between many physical terrain factors such as slope, rain intensity, soils, vegetation cover, but also of land-management practices such as road making, burning and cultivation. Most experimental results from plot studies are also not applicable for up-scaling. Hamilton and Bruijnzeel (1997) quote a figure of 1t/ha/yr erosion rate for intact indigenous forest in the Ethiopian Highlands.

Similarly, considering the complexity of interaction of specific local condition and a host of external factors, it is very difficult to get a precise estimate of erosion and sediment yield increase as a result of forest clearing. The World Bank (2006) notes: "*The majority of eroded material is usually deposited en route, with only a small fraction reaching downstream storages. Consequently, the abundant literature on erosion and sediment loss from plot-scale studies cannot be used to estimate a measure of sedimentation unless coupled with studies in the water storage itself*". Ongwenyi et al. (1993) reviewed data on sediment loss in Kenya and showed the high variation between regions. They summarised sediment yield over the period 1948 to 1965, calculated from suspended sediment samples and discharge records. Sediment yields ranged from as low as 0.08t/ha/yr in the Sagana basin above Kiganio, consisting mostly of forests on steep slopes, to as high as 31t/ha/yr in the Kambure, Nzoia basin between Kindaruma and Uaso Nyiro, under agriculture and grazing. They underscore the fact that sediment yields from undisturbed forests are "extremely low" and note that: "*The highest rates of soil loss are encountered in an area of very steep slopes on the eastern sides of Mt Kenya where cultivation is practised in the steep valley slopes in the upper parts and cultivation and grazing are occurring in the gentler but drier hillslopes in the lower marginal parts*".

Brakel (1984) gives an account of the distribution of sediment pulses in rivers throughout the year. They coincide with the wet season flows in Figure 4. Thus, taking results from various small scale studies it can be assumed that poor management collectively will result in higher peak flows (see previous section) and on average cause additional sediment (and thus nutrient losses) of about 20 to 25t/ha/yr. The World Bank (2006) quote a figure of 15 tons/ha of sediment per year originating in the Masinga Dam catchment area on the Tana River. KenGen (2005) estimates that up to 300 million m^3 (or 22%) of the storage capacity of Masinga Dam has been lost in 25 years due to siltation. Please also see Figure 6.

Based on the evidence reviewed, erosion and sedimentation from cleared forest may thus initially proceed at a rate of 45t/ha/yr, and thereafter reduce at a declining rate (Figure 7). At this rate of erosion, the cumulative effect of deforestation in the Water Towers for the period 2000-2010, was 1,990,000 tons of sediment. The rate of sediment production is displayed in Figure 8. Assuming that all the additional sediment would be deposited in reservoirs and dams at a sediment density 1.95 tons/m^3, the cumulative loss in water storage capacity due to deforestation exceeds 1 million m^3 (Figure 8).

Figure 6. Google Earth image of the outflow of the Masinga Dam and the Masinga Power Station, on the Tana River, in November 2003, during the short rain season. The Masinga Dam has been well documented to suffer from severe siltation resulting from deforestation activities upstream (Wanyonyi 2002).

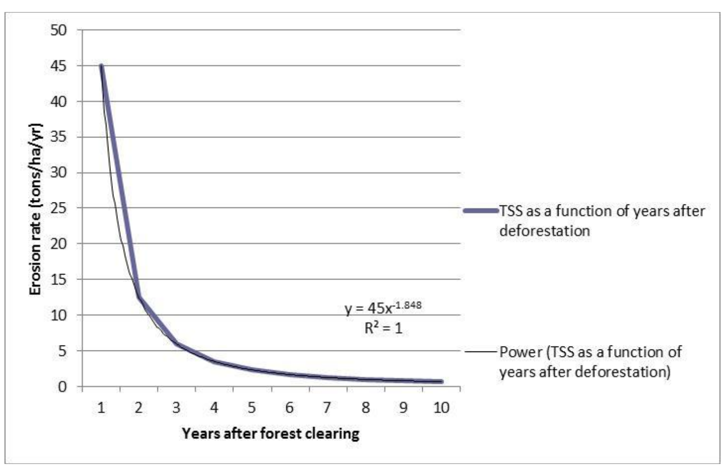

Figure 7. Lal (1985) conducted extensive studies on the effects of deforestation on erosion and siltation in Nigeria.

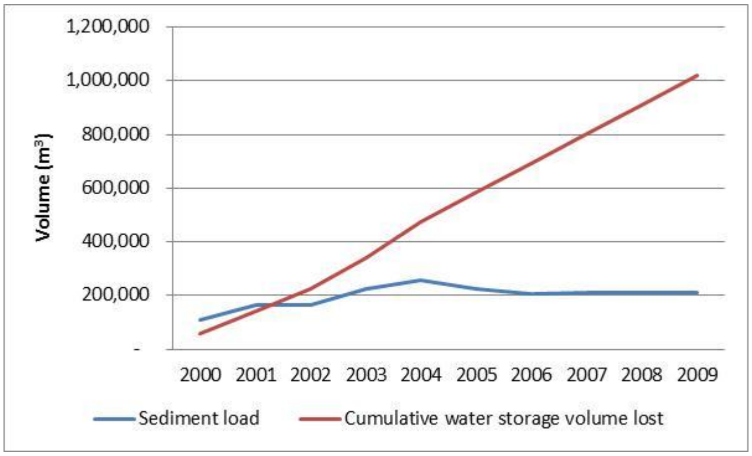

Figure 8. Deforestation in the Water Towers for the period 2000-2010 produced a cumulative sediment load of 1,990,000 tons. Assuming that all the additional sediment would be deposited in reservoirs and dams at a sediment density 1.95 tons/m^3, the cumulative loss in water storage capacity due to deforestation exceeded 1 million m^3.

5.3 Water purification and waste treatment

Under natural conditions, freshwater ecosystems have the ability to self-regulate water quality. Deforestation induced erosion and sedimentation results in water quality degradation in the downstream catchment area, to levels that exceed the ability of the natural systems to purify and treat water. This is the result of both increased sediments loads and nutrients loads. Elevated sediment loads and nutrient levels reduce water storage capacity, and thus reduces water yield, reduces fish production and increases the cost of water treatment.

Sedimentation affects fisheries in a number of ways. It results in elevated levels of suspended solids in water and this causes increased water turbidity. Increased turbidity results in decreased light penetrability in the water, which in turn inhibits phytoplankton growth. Phytoplankton is an important element in the food chain for fisheries. Increased turbidity results in increased water temperatures due to the heat adsorbing characteristics of sediment particles, and this adversely affects aquatic biota by decreasing the amount of dissolved oxygen available and also by increasing the rate of biochemical reactions, which require more oxygen by fish. Fish therefore become oxygen derived. Turbid water also results in the abrasion of gill membranes and interferes with the feeding of visual feeders.

Deposited sediments can also be harmful to fish habitats. Some of the impacts of increased sediment deposits on lake floors include the destruction of habitat of bottom-dwelling organisms such as crayfish and insects on which fish rely for food, the elimination of sheltered areas between boulders and gravel particles which young fish need for survival and the clogging of spaces between gravel particles that prevent the free flowing of oxygenated water and the removal of waste products from developing egg deposits in the gravel. The prevention of the exchange between oxygenated water and waste containing water often suffocates eggs resulting in their death and may even make gravel beds unsuitable for the future incubation of eggs[2]. The re-suspension of sediments from lake bottoms due to temporal stratified layer mixing or by flash flood incidences may re-introduce contaminants into the water system. These contaminants include adsorbed pollutants and nutrients that attached to deposited sediments.

[2] http://www.dfo-mpo.gc.ca/regions/central/pub/fact-fait-mb/mb6-eng.htm

Deforestation directly results in the increase of nutrients into receiving water bodies due to the degradation of soil properties. The main implications are the release of adsorbed basic cations, nitrates and phosphates due to decreased SOC and the transport of the soil particles and adsorbed nutrients due to the destruction of soil structure.

Increased nutrient loading in water systems increases the risk of eutrophication. Eutrophication is a result of algal blooms (biomass increase) from the plant growth limiting nutrients (NO_3-N and especially PO_4-P) now present in excess within the water system. Eutrophication results in decreased dissolved oxygen concentrations, due to the greater oxygen demand of the primary producers (algae), which result in fish kills. The formation of the algal mats on the water surface results in decreased light penetrability. Increased primary production will also result in increased hyacinth growth. Increased hyacinth growth will further decrease the water quality by the increase in organic material content of by plant material degradation and the resulting toxic conditions. Hyacinths also influence the accessibility of water as resource and negatively impacts on the fishing communities due to increased hiding places for fish and decreased sites of extraction. Cyanobacteria also flourish in the presence of increased accessible nutrients. Cyanobacteria produce toxic substances resulting in secondary water quality degradation.

Lal (1995) performed a study on the effects of deforestation on soil and nutrient loss from the watershed years after deforestation. From the data a percentage decline in sediment delivery could be calculated for years after deforestation. This study is based on the continuous deforestation over a period of 10 years (2000-2011) resulting in sediment loss of 45 ton/ha/yr with a total land clearance of 28,427 ha (Figure 8). Transport of nutrients by suspended solids will increase the nutrient loading of receiving water bodies as erosion and surface runoff increases. The nutrient load increase (nitrogen and phosphorous) in Kenyan rivers as a result of deforestation are shown in Figure 9.

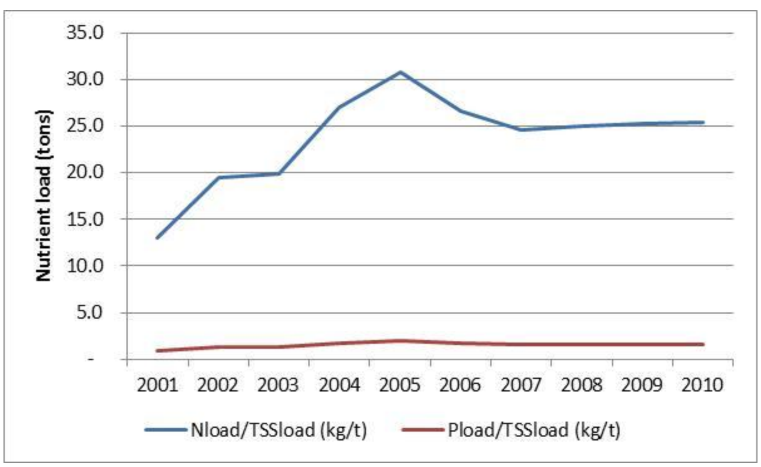

Figure 9. Increased nutrient loads (nitrogen and phosphorus) resulting from deforestation in Kenya between 2000 and 2010.

5.4 Natural hazard regulation - flooding

There is a commonly held view that forests moderate extreme flood events, but there is no evidence that forests are more effective in surface runoff moderation than any other well established undisturbed cover. Extreme flood events are usually caused purely by extreme rain events which take their own course without being influenced much by land-use. Hamilton and Bruijnzeel also point out that extreme rain and flood events will cause flooding irrespective of particular land-use patterns. So it is not possible to quantify the attribution of Kenya's forest per se in controlling extreme flooding.

Experiments in many parts of the world suggest that any undisturbed natural or well managed vegetation cover will control overland flow or surface runoff and thus peak flows (see for example Hewlett and Helvey, 1970; Hewlett and Bosch, 1984; Kirby et el, 1991; Taylor and Pearce, 1982). On the other hand, vast areas of poorly managed vegetation cover can be conducive to surface runoff and some degree of flooding. Wet season flow is likely to be increased by forest conversion of significant magnitude in Kenya.

5.5 Disease Regulation

Deforestation has been linked to a change in a number of vector-borne diseases, largely due to changes in the vector-insect groups which transfer these diseases (Molyneux, 1997).

Deforestation can change the micro-climate of an area, resulting in an increase in vector-borne disease (Zhou et al., 2004; Afrane et al., 2006; Minakawa et al., 2006; Zhou et al., 2007; Afrane et al., 2008). Through the process of clearing forests and subsequent agricultural development, deforestation alters every element of local ecosystems including the microclimate, soil, and aquatic conditions and, most significantly, the ecology of local flora and fauna, including human disease vectors (Yasuoka and Levins, 2007). Deforestation exposes areas to greater sunlight, increasing the ambient temperature in the area and increasing the temperature of stagnant pools of water which may act as breeding sites for vector insects.

The malaria carrying mosquito is the vector-insect which has been shown to be most sensitive to change in forest cover (Yasuoka and Levins, 2007). There is significant clinical evidence from Kenya that a deforestation induced change in micro-climate has significant impact on the mosquito vectoral capacity by increasing the number of new mosquito infections from one infected individual by 77.7% (Afrane et al., 2008).

Evidence shows that a change in ambient temperature and water temperature of breeding sites due to deforestation can increase the vectorial capacity of mosquitos in a number of ways. Female mosquito density and reproductive rates increase (Afrane et al., 2006; Zhou et al., 2007) with an increase in ambient temperature. The number of daily mosquito person-biting events increase as the higher ambient temperature speeds up the blood meal digestion in the mosquito and thus increasing the blood feeding frequency (Afrane et al., 2006). Finally, a small increase in water and ambient temperature due to deforestation has been shown to speed up the mosquito development process and thus the malaria risk to humans (Afrane et al., 2006; Minakawa et al., 2006; Zhou et al., 2007; Afrane et al., 2008).

The prevalence and distribution of other vectors carrying the diseases leishmaniasis (vector: sand fly), onchocerciasis (river blindness) (vector: black fly), schistosomiasis (bilhazia) (vector: fluke) and loaiasis (vector: deer fly) have all been shown to be increased by deforestation. The malaria carrying mosquito however, is the vector-insect which is most sensitive to change in forest cover, with their density and distribution significantly influenced by small changes in environmental conditions (Yasuoka and Levins, 2007).

Since the late 1980s, a series of malaria outbreaks has occurred in the western Kenya highlands where malaria incidence previously was low (Zhou et al., 2007). These highland areas, with an altitude greater than 1,500 m, were generally considered to have marginal climate conditions for malaria transmission due to the lower ambient temperatures in forested high altitude areas (Afrane et al., 2006). In the last 10 years malaria has also been reported from residents on the west side of Mount Kenya, an area historically malaria free (Chen et al., 2006). Chen et al. (2006) attributes this recent increase to topography and changing microclimate, but also to a 25% increase in population over the past 20 years. With the increasing population on the highlands, enhanced human activities including deforestation, farming and livestock rearing could create more vector habitats.

Deforestation of these areas resulted in small increases in ambient temperature and changed the vectoral capacity of misquotes, increasing the risk of humans contracting malaria in an area which was previous malaria-free or a low-risk area. Of particular interest to deforestation and the disease regulations services of forest are the highland epidemic prone areas. Malaria in this area is seasonal, with considerable year-to-year variation. Climate conditions need to be favourable for malaria transmission, with a minimum temperature of around 18°C required (Malakooti et al., 1998), usually occurring during the long rains of March-May every year.

The economic consequences of increased malaria infections are assessed and discussed in section 6.8.

6 The consequences of deforestation on the economy of Kenya

6.1 Case study and environmental economic evidence used

This section presents the results of a case study on the effects of deforestation on the economy of Kenya. The case study modeled the effects of deforestation in the agriculture, fishery, hydropower, water services, tourism and public administration sectors in Kenya.

The study used best available environmental economic evidence.

Evidence relating to the forest water and erosion regulating services, as discussed above, is based on extensive international and local scientific experimentation conducted during the 1970s, 1980s and 1990s. This evidence remains valid as the basic interaction between forests and hydrology remains unchanged. However, a weakness in the evidence used is the absence of a country-wide hydrological model for Kenya. In the absence of such a model, the study estimated several hydrological parameters, and these are discussed in the Appendix.

Closely related to the absence of a hydrological model, is the absence of a water environmental economic account. Such an account is especially important for estimation of irrigation, hydropower, commercial and household water use. In the absence of such an account, irrigation water use data was inferred from actual agricultural production data from KNBS, whilst commercial and household water use was projected from the World Bank (2006), which in turn used data from the Kenya Water Master Plan published in the early 1990s.

The last deforestation survey in Kenya was conducted in 2005 (DRSRS 2006), and thus deforestation rates post 2005 was estimated based on the 2000-2005 rate of deforestation.

The study sourced all other evidence from recent publications or actual data, as referenced in the sections below.

A key recommendation for further work relates to the improvement of these data sources, and in particular, it is advisable to (1) develop a water environmental economic account, and (2) conduct another deforestation survey.

6.2 The effects of deforestation on irrigation

The agriculture and forestry sector of Kenya is by far the largest economic sector and contributed between 25% and 30% to GDP in the period 2000-2010 (Figure 10) (KNBS, 2010).

Although agricultural output in Kenya is dominated by rainfed agriculture, the irrigation sector still plays an important role, and has the potential to grow significantly in future. Of the total land area under agriculture, irrigation accounts for only 1.7% but provides up to 18% of the value of all agricultural produce (Republic of Kenya, 2010).

Irrigation is principally practiced along the lower reaches of Tana River and in Elgeyo-Marakwet, West Pokot and Baringo district. Irrigation agriculture in Kenya consists of three types of irrigation based on the size, management and ownership of the farming unit: smallholder irrigation schemes; private irrigation schemes; and public irrigations schemes (Table 5).

Irrigation crops include rice (22% of the irrigated area); food crops (25% of the irrigated area) and horticulture crops (53% of the irrigated area) (Republic of Kenya, 2009). Horticulture crops are more common in Mt Kenya region in central and eastern provinces and in the coast province.

Various publications (World Bank, 2006) report irrigation water requirements for 2010, but these are all based on estimates done in 1990, at the time of development of the Kenya Water Master Plan. Data from various sources suggests that the 2010 irrigation area comprises 121,411 ha with a total water requirement of 1,434 million m^3 (Table 6). The output of irrigation was approximately KSh 28,672 million, which was 9.3% of total agricultural output.

Deforestation at a rate of 2,762ha per year between 2000 and 2010 would reduce the available water (as a result of reduced low flows) by 62 million m^3 per year by 2010. Irrigation usually has the lowest assurance of supply of all water users and it can thus be assumed that this reduced available water will directly reduce irrigation agriculture. Thus due to deforestation between 200 and 2010, Kenya had forgone the opportunity to cultivate 5,287 ha of irrigation agriculture.

By applying an agricultural production function for 2010 (please see Appendix 8 for more detail), it can be concluded that irrigation output in 2010 had reduced by KSh1,499 million as a result of decreased water availability due to deforestation (Figure 11).

Agricultural output in Kenya is largely dependent upon rainfed agriculture, and the irrigation sector is relatively poorly developed. As a result, a number of policies (i.e. Vision 2030; Medium Term Plant 2008-2012, Irrigation and Drainage Master Plan) have identified future irrigation expansion as important to unlocking the agricultural potential of the country (Republic of Kenya, 2009). The consequences of reduced water availability and poor water quality can therefore be significantly more detrimental to agricultural output in future.

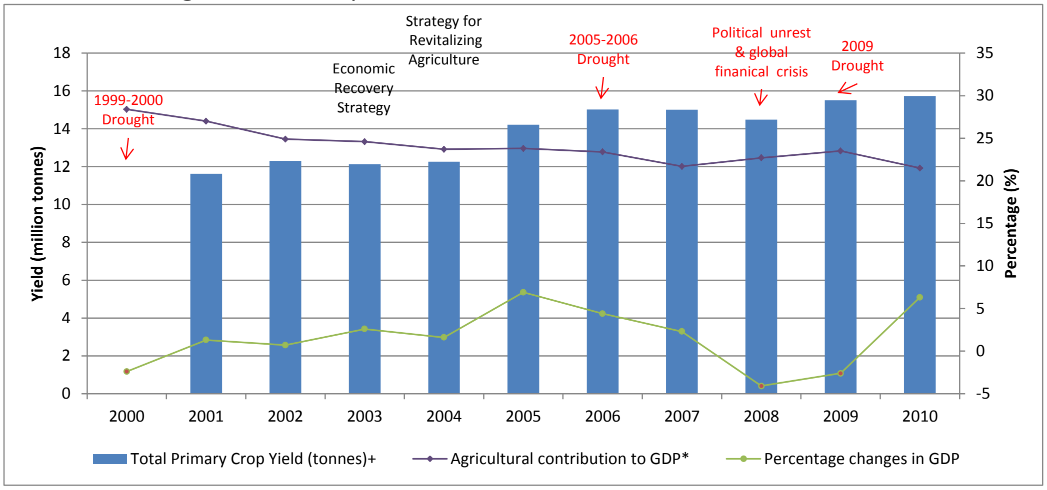

Figure 10: Agricultural statistics and changes/shocks to the sector between 2001 and 2010 (data source CBS 2003; 2005 and KNBS 2008; 2010; 2011)

Table 5. Types of Irrigation Schemes in Kenya (Source: Republic of Kenya, 2009; Thairu, 2010)

Type of irrigation scheme	Features
Smallholder (community based) irrigation scheme	They are owned and managed; The general management of these schemes is done by the Ministry of water and Irrigation.
Private Schemes	These scheme are located mostly in close proximity to the Thika River, Lake Naivasha, Athi basin and Nanyuki. Generally individual medium to large-scale farms growing export-oriented crops such as coffee, pineapples and flowers. Input cost are generally high and this type of farming requires intensive management. These private irrigation schemes account for 70% of the drip and sprinkler irrigation systems in the country
Public or 'national' Schemes.	Developed, and are managed by the Government, mostly via the National Irrigation Board (NIB). Two categories of public scheme exist, namely (1) centrally controlled, tenant-based schemes manage by the government, with plots allocated to the tenants and inputs provided to them; and (2) regional authority owned and managed schemes. There are seven public irrigation schemes in Kenya namely: • Mwea (in Central province growing rice), • Ahero and West kano (in Nyanza province growing rice), • Bunyala (in Western province growing rice), • Bura (in Coast province growing cotton), • Hola (in Coast province growing cotton) and • Perkerra (in Rift valley province growing horticulture that is chillies/onions and maize)

Table 6. The estimated irrigation water use in Kenya in 2010 was 1,434 million m^3. This was estimated based on irrigation areas for smallholder, national, and private schemes and estimating average water use per ha for crops as set out below.

Irrigation water use	Irrigated area (2010)	Ave water use	Total Water Use		
	ha	m^3/ha	million m^3	**Commodities**	**Irrigation type***

				grown*	
Smallholder schemes	54,800	10,000	548	Rice, Maize, Horticulture	88% surface; 9% sprinkler; 3% drip
National schemes	17,611	22,500	396	Cotton, Rice, Horticulture, Seed Maize	surface irrigation
Private schemes	49,000	10,000	490	Coffee, pineapples, cut flowers	drip irrigation and sprinkler
Total	**121,411**	**11,813**	**1,434**		

Sources:
Republic of Kenya 2009. Irrigation and drainage master plan
Thairu (2010) Agricultural Production and Irrigation Management: The Case of Irrigated Rice Production in Kenya
Republic of Kenya (2007) Vision 2030
KNBS Various Economic Surveys (2003; 2008; 2011)
Ministry of Water and Irrigation - Department of Irrigation and Drainage – 2010

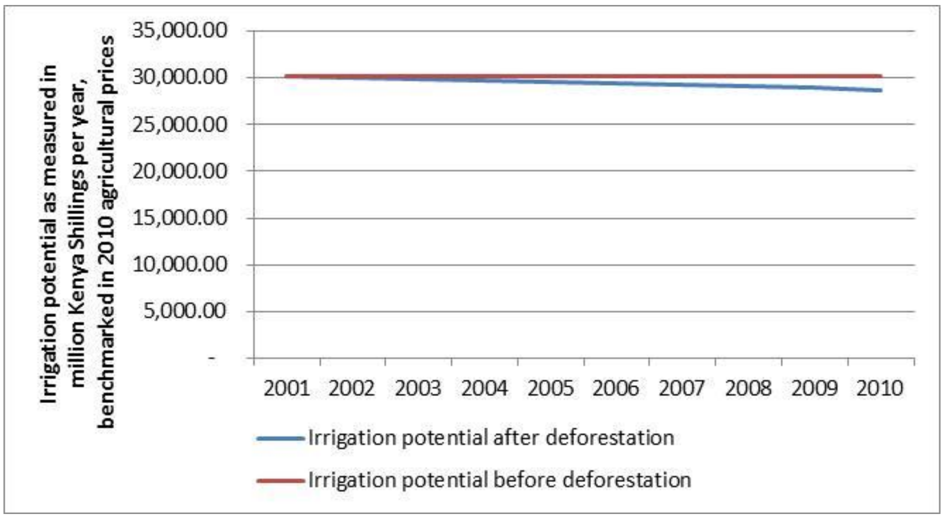

Figure 11. Irrigation potential in Kenya reduces as a result of deforestation. This is because of lower assurance of water supply to irrigation, due to low season reduced runoff from the Water Towers. The irrigation sector output lost in 2010 is estimated at KSh 1,499 million.

6.3 The effect of deforestation on inland fisheries

Inland fish production in Kenya has grown dramatically since the introduction of the Nile perch (Lates niloticus) in the early 1960s. The fishing sector contributes between 0.4 - 0.6% to the Kenya GDP annually (Simonit and Perrings 2011). The quantity of freshwater fish landed constitute 94% of the total fisheries output in Kenya (Table 7).

Table 7: Quantity and value of freshwater fish landed in Kenya, by source, between 2000-2010 (data source CBS 2005; KNBS 2010 and 2011).

Fresh Water Fish	Value to Fishermen Kshs '000										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009*	2010*
Lake Victoria	7444620	7245196	8122669	7131293	7101473	6948611	7766074	7451781	9429765	9834716	to be inserted
Lake Turkana	75140	51086	53858	60592	268983	99245	120783	245366	229171	288545	
Lake Baringo	11060	2838	6937			2285	2079	4872	10065	9682	
Lake Naivasha - Commercial	16500	215	2666	4730	4118	5738	6396	12416	13384	12998	
Lake Jipe	2780	2442	2367	3607	4891	3932	3998	5636	6470	5867	
Rivers and Dams	17260	17850	16905	14133	38160	50474	52447	23455	62205	62515	
Fish Farming	93000	102773	104316	114089	63642	55627	58577	226259	917860	971120	
Others	19210	16471	14883	18534	57979	41707	45891	13842	48729	47723	
Total	**7679570**	**7438871**	**8324601**	**7346978**	**7539246**	**7207619**	**8070557**	**7983627**	**10717649**	**12274000**	**16905000**

Annual quantities of freshwater fish landed in Kenya have displayed a long term decline since 2000 (Figure 12). The majority of freshwater fish caught in Kenya is from Lake Victoria. Fishing from this lake provides over 80% of the quantity of freshwater fish caught in Kenya annually. Fish catch from Lake Victoria has declined in the past 10 year from 192,738 tonnes in 2000 to 135,784 tonnes in 2010 (Figure 12).

These declines are mostly due to declining catches of Nile perch. Declining catches have been attributed to overfishing and eutrophication. Eutrophication results from increased nutrient loads in freshwater systems, which in turn result from slash and burn land practices, erosion and sedimentation, and fertiliser run-off and discharges from urban settlements. A reduction in nutrient absorption by wetlands on the lake margins, largely caused by the conversion of wetlands to other uses, also contributes to elevated nutrient levels (Simonit and Perrings, 2011).

The quantities for freshwater fish caught in Kenya therefore, generally closely follows the Lake Victoria catch (Figure 12). From 2007, growth of fish production in Kenya has increased relative to catches in Lake Victoria. This is attributable to a significant growth in the freshwater fish farming (Figure 12). The Kenya government’s policy in this sector is to maximise production from farmed fish, with 2009-2010 seeing an increase of 20 000 fish ponds constructed in 160 constituents in the country (KNBS, 2011).

In Lake Victoria there is evidence that total phosphorus concentration seems to be the key element influencing phytoplankton growth in inshore waters (Mugidde, 2001 as quoted in Simonit and Perrings, 2011). Increasing in chlorophyll-a concentration (a measure of water quality and eutrophication) are the result of nutrient loading from the catchment. With increasing phosphate levels due to deforestation (see section 5.3 above), a bio-economic fish production model developed by Simonit and Perrings (2011) can be adapted to estimate the effect of deforestation on inland fish catch.

To capture this effect this study adapted a bio-economic model (Simonit, Perrings 2011) of the fishery that explicitly includes the impact of water quality in relation to deforestation, water quality and fish stock biomass. Following Simonit and Perrings (2005), the study included a damage function that depends on nutrient loading from the watershed.

Total freshwater catch in 2010 was 135,784 tons, with a total output of KSh 16,905 million in 2010. Bio-economic modeling estimates that freshwater fish catch were reduced by 690 tons or KSh 86 million in 2010, as a result of elevated phosphate loads resulting from deforestation between 2000 and 2010.

Figure 12: Quantity of fish caught annual from Lake Victoria and in Kenya (KNBS, 2010, 2011; CBS 2005)

6.4 The effect of deforestation on hydropower generation

Kenya generated 6,976 million kWh of electricity from various sources in 2010. The majority of this power was generated from hydropower (46%) and thermal (37%) sources. Hydroelectricity production has historically been lower during periods of drought (Figure 13).

Most of Kenya's hydropower capacity (70%) is situated in 10 hydropower stations on the Tana River. The remainder is supplied from the Turkwell station (20%) and the rest from three smaller stations in the vicinity of Lake Victoria (Figure 14). Hydropower in Kenya is derived indirectly from the forested catchments of Kenya's Water Towers, and principally the Aberdares and Mount Kenya.

Hydropower generation is entirely dependent on river water flow. An index of lagged monthly rainfall data[3] for the Eldoret, Kakamega, Kisii, Kisumu, Kitale, Nakuru and Nyeri weather stations, in the catchments that serves the hydropower stations, correlate very closely with hydropower generation data (Figure 15). Thus, although hydropower generation is not a highly consumptive water use, it is highly sensitive to decreases in water availability and river flow. Dry season flows especially severely limits hydropower generation.

At an average selling price of 20KSh/kWh, the reduced hydropower production as a result of reduction in water yield in 2010 was estimated at KSh 8 million. Although the quantum of this number is small, the economy-wide effect of this loss is significant. Due to the importance of hydropower in the economy of Kenya, reduced dry season flows makes the economy of Kenya especially vulnerable to deforestation.

[3] http://www.tutiempo.net/en/Weather/Kenya/KE.html

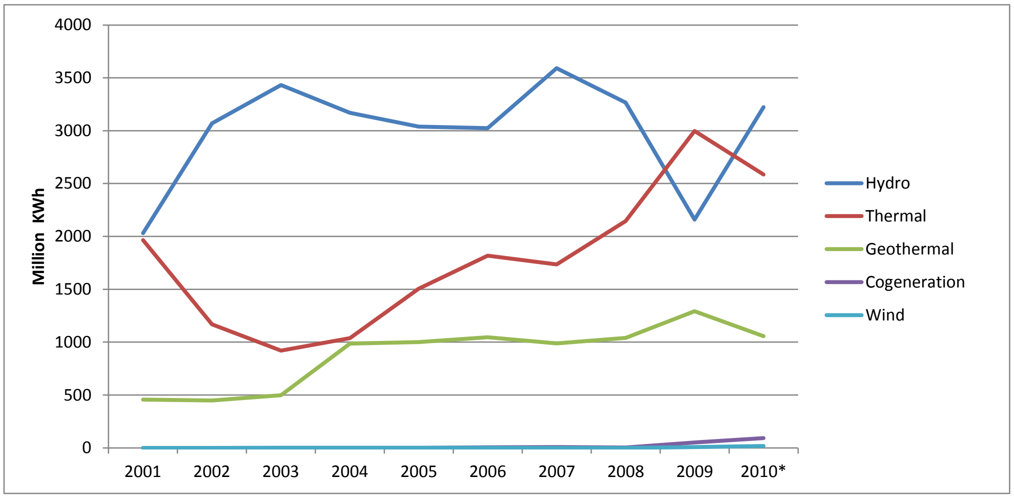

Figure 13: Trends in kilowatt hours of electricity generated in Kenya, by source, between 2000 and 2010. Reductions in hydropower generation correspond to drought periods.

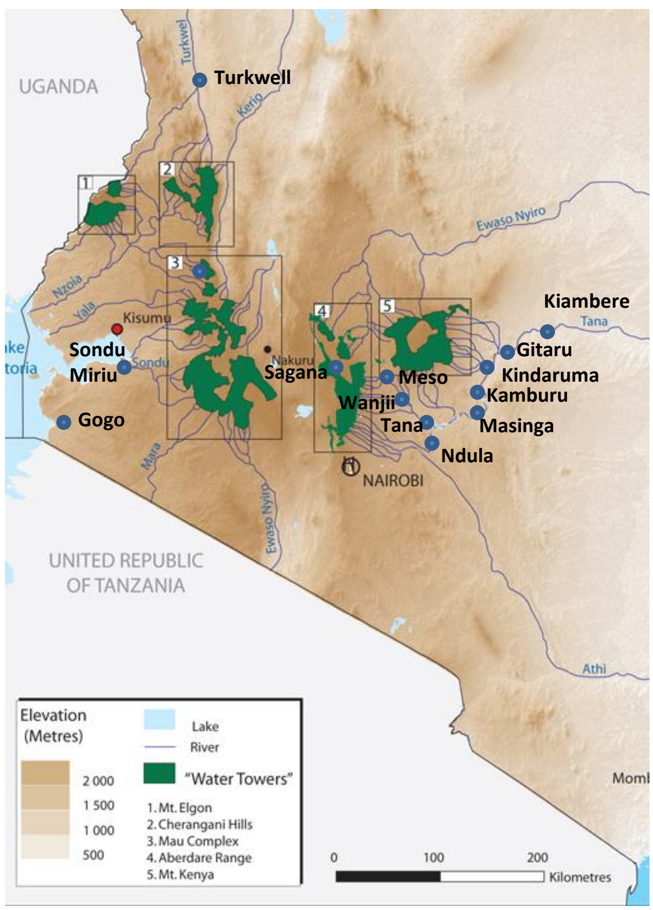

Figure 14: Hydro-electricity power plants in relation to the five Water Towers of Kenya (map sourced from UNEP, 2009a)

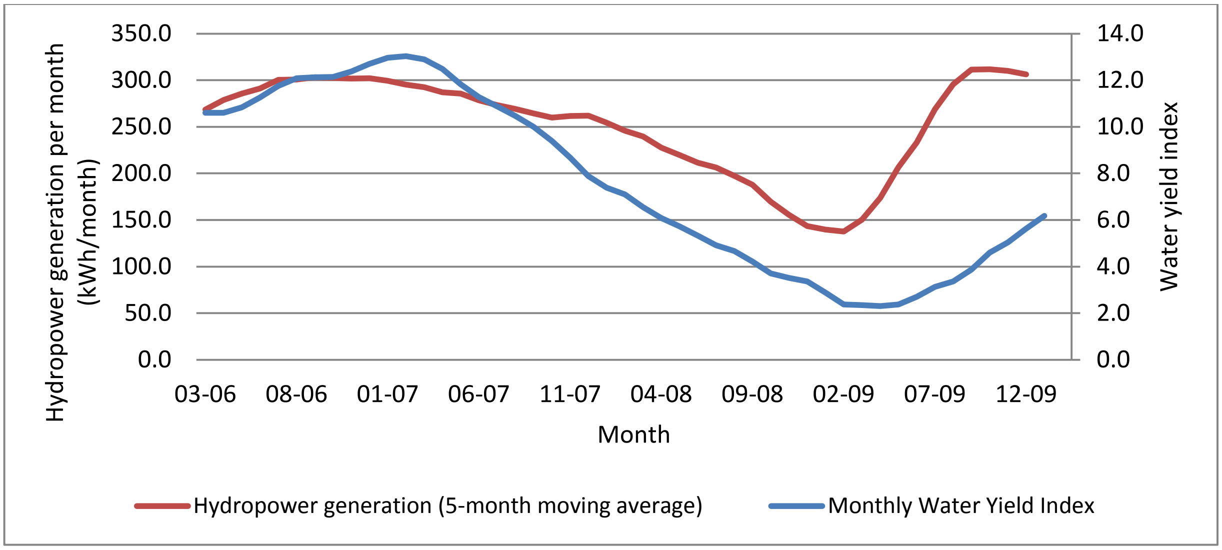

Figure 15. The relationship between the lagged monthly water yield index and the 5-month hydropower moving average indices. Data from weather stations was converted to a lagged monthly water yield index combined with hydropower generation data describes the relationship between water availability and actual hydropower generation. An ordinary least squares regression analysis of these data sets indicates that monthly water yield explains 67% of the variation in hydropower generation.

6.5 The effect of deforestation on water services

Poor water quality resulting from increased nutrient content increases the cost of water treatment for urban and domestic use. These costs are borne by water treatment works operated by the Government of Kenya. Reduced water quality increases the costs of removing sediment and nutrient loads from treated water.

Nutrients in the form of nitrogen and phosphorous are removed from waters by employing treatment processes such as primary sedimentation, bio-filters and biological nutrient removal (BNR) processes which remove suspended solids, nitrogen (as NO_3-N) and phosphorous (as PO_4-P).

The cost of nutrient removal is estimated through a marginal abatement cost curve (MCA). An (MCA) consists of two parts, the cost of wastewater treatment with pollution loadings within the normal range of wastewaters (C_{ww}); and the cost of with pollutant load exceeding the normal pollution load (C_{N},) (Equation 1).

Pollution load needs to be reduced for the total volume of water used by urban, rural and industrial water users. The resultant cost increase is KSh192 million in 2010, which is a 0.55% cost increase compared to the pre-deforestation scenario (Figure 16).

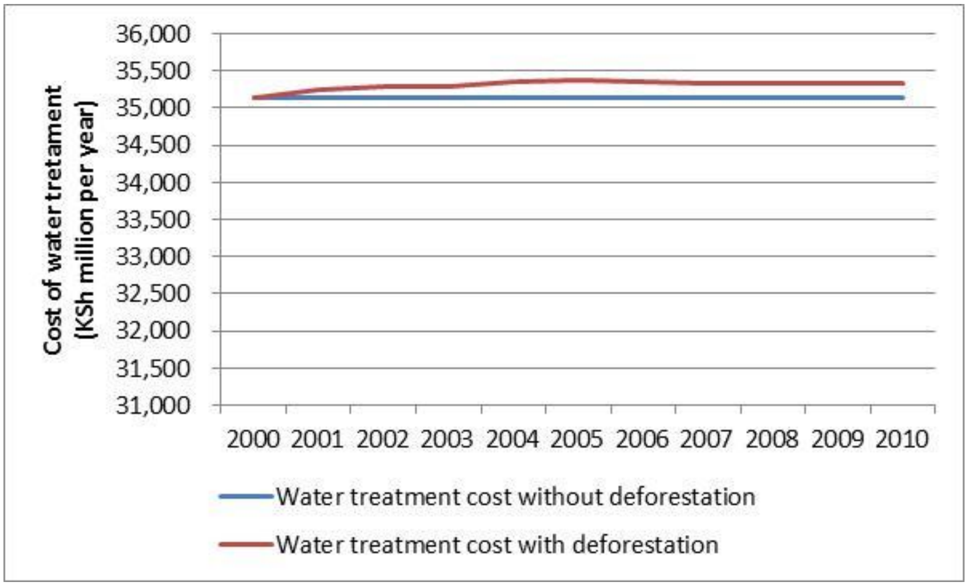

Figure 16. The cost of water treatment by government water schemes increase as a result of nutrient pollution due to deforestation. The resultant cost increase is KSh 192 million in 2010, which is a 0.55% cost increase compared to the pre-deforestation scenario.

6.6 The effect of deforestation on tourism

Tourism is a key source of foreign exchange earning in Kenya, with the hotels and accommodation sector contributing 1.7% (42,546 million KSH) to GDP in 2010 (KNBS, 2011). Kenya offers a number of parks and game reserves, 7 of which cover the montane forests of the country. These forest parks only account for a very small (5%) percentage of all tourist visitors in Kenya annually (Table 8). There is insufficient evidence to quantify the effect of deforestation on tourism. In addition, there is little economic evidence that removal of the forests from these national parks will result in less visitors to these areas.

Table 8: Description and visitor number for 2000-2010 to Kenya national parks and reserves which cover forested areas of the country.

				Visitos (thousands)										
Park/Reserve	Size* (km^2)	Altitude (m)	Habitat*/Topography	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Aberdare National Park	767	1829-4001	Part of the Aberdare Mountain Range. Deep ravines that cut through forested slopes	44.9	40.5	41.5	30.3	44.0	48.3	54.5	50.4	26.2	36.7	42.8
Mount Kenya	2800	up to 5199	Rugged glacier-clad summits, Afro-alpine moorlands and diverse forests	11.5	26.3	27.9	25.5	27.7	39.5	43.8	39.6	21.7	25.0	29.2
Mount Longonot	52	up to 2776	On the sides of the mountain are V-shaped valleys and ridges with little vegetation; however a thick forest occurs within the crater.			12.8	12.2	9.5	11.5	22.6	24.7	27.8	30.8	39.1
Others**				13.1	9.9	6.3	17.4	17.3	12.9	14.4	16.6	12.3	19.7	16.2
Mt Elgon	196													
Oldonyo Sabuk	20.7		The ecosystem constitutes a mountain which is entirely covered with dense montane forest except for a small area at the top											
Marsabit	1554		Densely forested mountain and three crater lakes that are the only permanent surface of water in the region											
Kakamega Forest National Reserve	44		Only remnant in Kenya of the unique Guineo-Congolian forest ecosystem											
TOTAL	**3879.7**			**69.5**	**76.7**	**88.5**	**85.4**	**98.5**	**112.2**	**135.3**	**131.3**	**88.0**	**112.2**	**127.3**
Pecent of total tourist visits.				**4%**	**5%**	**5%**	**5%**	**5%**	**5%**	**6%**	**5%**	**5%**	**5%**	**5%**

Deforestation has been associated with the potential to impact, directly or indirectly, on the tourism sector through (1) a reduction in visitor to the parks covered by indigenous montane forests; (2) reduced yield and flow of the Mara River impacting on the Mara–Serengeti ecosystem and effecting the annual wildebeest migrations; and (3) loss of forests species or genetic resources. Evidence shown by Table 8 suggests that visitors to Kenya's forest parks have actually been increasing in the past 10 years, despite the levels of deforestation in the country. Changes in visitor numbers can be more directly linked to the political stability of the country and the global economy. A sharp decline in visitors was evident during the political unrest and recession in 2008 (Figure 18).

The Wildebeest Migration in East Africa takes place between Kenya's Masai Mara and Tanzania's Serengeti National Park, with wildebeest and zebra following seasonal rainfall patterns (Figure 17). The natural resource which Kenya contribute to this migration are dry season-forage and water from the Masai Mara National Reserve (which includes the Mara River) and wet-season grazing rangelands near the town of Narok (World Resources Institute et al., 2007). Deforestation of the upper reaches of the Mara River has the potential to reduce the annual flow (low flow in particular) of the river and could impact on the migration patterns of wildlife and the tourism activities linked to the migration. However, evidence suggests that it is more likely that the increasing demand for water from domestic livestock (to some extent due to deforestation) in the Mara catchment will have a greater impact on the Mara River and that conversion of grazing rangelands to agriculture will have more significant effects on the wildlife migration. Livestock water demand is estimated to have increased from 159 m^3 per year in 1990 to 190 m^3 per year in 2000 (Mati et al., 2008). This water demand was expect to reach 228 m^3 per year in 2010 (JICA, 1992). It is likely that increasing livestock water demand from the Mara River and rangeland conversion will have a greater impact on the annual migration than deforestation of the upper reach of the Mara River.

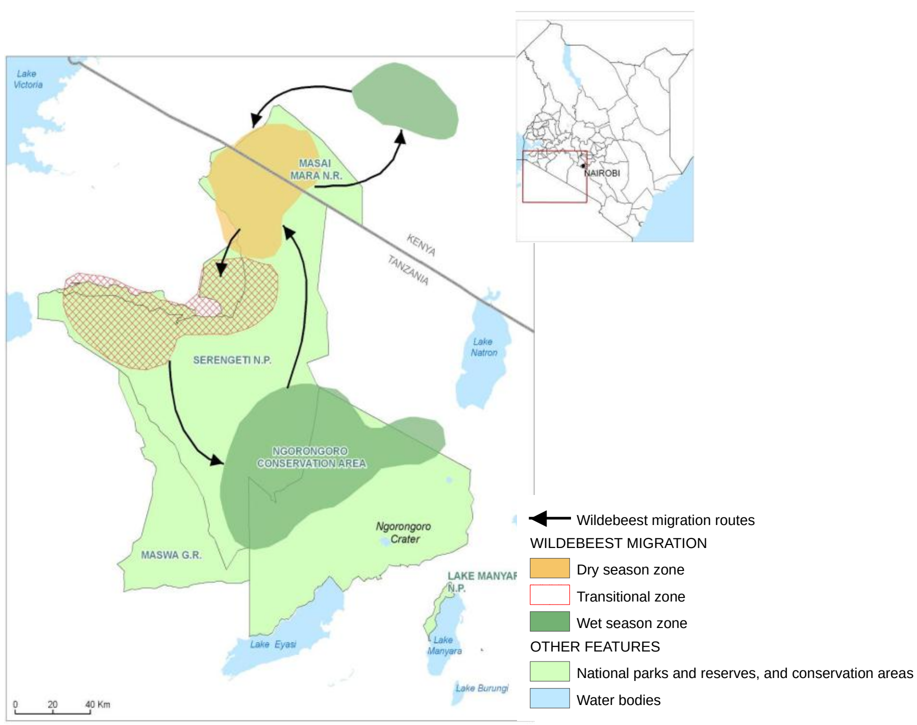

Figure 17: Wildebeest and zebra migrate between the Serengeti plains of Tanzania and the rangelands of Kenya's Narok District (source: World Resources Institute et al., 2007)

Kenya has two forest based red data species, *Atoconeura kenya* a species of dragonfly found in the montane forest streams and *Galagoides cocos* (http://www.iucnredlist.org/apps/redlist/search). Both species are however listed as species of Least Concern as they are fairly widespread and there is no indication that they are currently undergoing a significant wide range decline. Since tourists are unlikely to visit Kenya's montane forested parks to observe these particular species and the species are not likely to become extinct in the near future, it is highly unlikely that deforestation will result in loss of species and genetic and impact on the tourism sector of the country.

There is however, anecdotal evidence that deforestation has resulted in fewer visitors visiting the Thompson's Falls situated in Nyahururu Town in the central province and draws water from the River Ewaso Nyiro (http://voicesofafrica.africanews.com/site/list_message/23838)

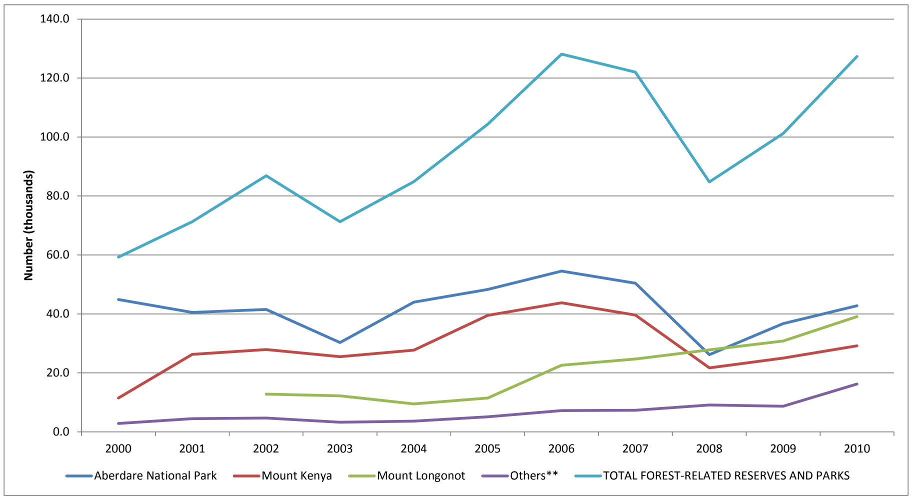

Figure 18: Visitor trends to forest-related national parks ad reserves in Kenya between 2000-2010.

6.7 The effect of deforestation on public administration - carbon sequestration

Carbon trading mechanisms provide an opportunity for the Government of Kenya to earn foreign revenue. Once appropriate carbon trading mechanisms are available, unmitigated deforestation is thus a forgone revenue opportunity for the Government of Kenya, money that could otherwise have been spent on public administration.

As deforestation accounts for about 18% of global greenhouse gas (GHG) emissions, reducing emissions from deforestation and forest degradation (REDD), has become a prominent potential mitigation strategy within the basket of major climate change mitigation strategies. REDD is an initiative by the United Nations (UN) which intends to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. The REDD concept is predicated on the assumption that forests will contribute to climate change mitigation only if their value increases to a level that makes protecting forests consistent with viable development strategies (Zarin et al., 2009).

"REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The UN estimates that financial flows for greenhouse gas emission reductions from REDD+ could reach up to US$30 billion a year. This flow of funds could reward a meaningful reduction of carbon emissions and could also support new, pro-poor development, help conserve biodiversity and secure vital ecosystem services[4].

Mitigation activities potentially included under REDD include reduced deforestation as well as reduced degradation (Zarin et al. 2009).

The above-ground carbon storage potential of montane forests varies between 100-310 tons per ha (Wilson and Spracklen, 2009, Zarin et al., 2009). At a carbon value of US$6/ton, and assuming an average carbon storage value of 205 tons per ha, this implies that the potential carbon value lost to deforestation in 2010 was KSh 210 million (Figure 19).

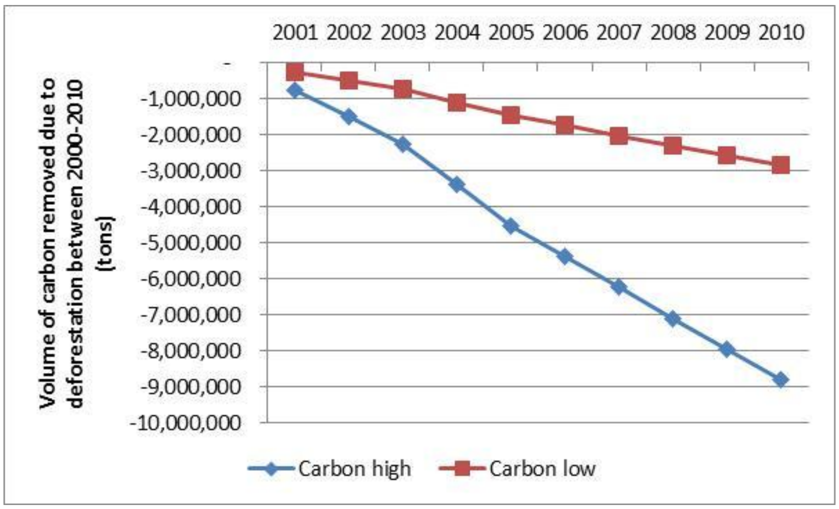

Figure 19. Reduction in above-ground carbon storage capacity in Kenya due to deforestation between 2000 and 2010.

6.8 The effect of deforestation on public administration - public health

In Kenya an estimated 170 million working days are lost annually as a result of malaria (Maneno et al., 1998). Malaria treatment is the most common treatment provided by the health system, with 17 million doses of malaria medicines issued in 2009 in the public health care system alone (National Coordinating Agency for Population and Development et al., 2011). Malaria accounted for 25% of total health expenditure, amounting to a total of KSh 30.7 billion in 2009/10 (Republic of Kenya, 2010) or 1.4% of the GDP. Based on census population statistics this amounts to 794.57 KSh per person in Kenya.

Despite the significant burden of malaria on health expenditure, the disease also has significant impact on household budgets specifically in poor households. At least 52% of malaria expenditure in Kenya is funded by the private sector, including household funds. Chuma et al. (2010) reported that households in one of the districts on the epidemic prone western highlands of Kenya, Gucha district, were spending KSh 60 per malaria episode at a shop to purchase malaria treatment products, while KSh 116 was spent at a facility (i.e. per action taken at public dispensaries) for treatment of malaria.

[4] (http://www.un-redd.org/AboutREDD/tabid/582/Default.aspx)

Malaria also results in a loss of productivity. Chuma et al. (2010) also found that the mean number of days affected by fever for ill individuals and caretakers in the households was 7.8 and 5.9 respectively and school days lost to fever were 4.2 days.

In the Rift Valley and Nyanza provinces 31% of the population is treated for malaria every year. At this incidence rate, people living in deforested areas (an estimated population of 150,000 or 5 people per ha), the health cost of malaria treatment due to deforestation was KSh 85 million in 2010. An additional productivity loss of KSh 151 occurred.

7 Indicative results

In the 10 year period, 2000-2010, deforestation in Kenya's Water Towers was approximately 28,427 ha. By 2010, such deforestation of montane forest yielded a timber and fuelwood volume of 210 m^3/ha with a cash value of approximately 270,000 KSh/ha. At an estimated deforestation rate of 2,762 ha in 2010, this is equivalent to a revenue of KSh 796 million 2010. This is a considerable economic incentive for illegal loggers.

However, the indirect costs of deforestation are borne by sectors and households elsewhere in the economy through the reduction in the value of regulating services. Regulating services ensure the delivery of final consumption services over a range of environmental conditions (Perrings, 2006). Thus, regulating services reduce risk to the economy. Regulating services can also be considered as providing an insurance value to the economy. This insurance value is important, not only to maintain economic resilience to seasonal environmental and economic changes, but also to long term economic hazards such as climate change.

Moreover, deforestation has a cumulative effect. Thus, whereas the cash value of timber and fuelwood has a once-off value, the consequences of deforestation in preceding years continues to be felt in the economy in every subsequent year.

The regulating services of Kenya's natural ecosystems are important production factors to the *Agriculture, forest and fishing* sectors, the *Electricity and water* sectors, and the *Public administration and defense* sector. These sectors, together, contributed between 33-39 % to GDP between 2000-2010. In addition, these sectors have a very significant multiplier effect on the rest of the economy's GDP.

By 2010, the cumulative negative effect of deforestation on the economy through reduction in regulating services was approximately KSh 2,231 million/yr (Table 9).

The largest component of this was attributable to a reduction in dry season river flows, which reduced the assurance of water supply to irrigation agriculture. This reduced irrigation area by 5,287ha and reduced agriculture output by KSh 1,499 million. Reduced river flows also reduced hydropower generation by KSh 8 million. Although this is relatively not a very large value, the multiplier effect of hydropower on the rest of the economy is considerable.

Reduction in water quality due to siltation and elevated nutrient levels running off degraded land into fresh water systems reduced inland fish catch by KSh 86 million and increased the cost of water treatment for potable use by KSh 192 million.

Deforestation increases malarial disease prevalence. Incidence of malaria under an exposed population of approximately 150,000 people is estimated to be KSh 237 million by 2010. This is in the form of additional health costs to the Government of Kenya, and through losses in labour productivity.

Forest loss is also detrimental to the global carbon cycle. Reducing emissions from deforestation and forest degradation (REDD), an initiative by the United Nations (UN), is a prominent potential mitigation strategy within the basket of major climate change mitigation strategies. REDD intends to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. REDD+ goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The above-ground carbon storage value forgone through deforestation was estimated at KSh 210 million in 2010.

Thus, in 2010, the total net cumulative effect of deforestation on the economy of Kenya was a loss of KSh 1,435 million. This loss in output has a considerable multiplier effect on the rest of the Kenyan economy.

Thus whereas the immediate cash benefit of deforestation through timber and fuelwood sales is KSh 272,000/ha, the total effect of regulating services lost is estimated to be a loss KSh 763,283/ha. Thus cost to the economy in 2010 outweighed the cash benefits by at least 2.8 times. This ratio will increase into the future as the cumulative effect of deforestation endures (Table 10).

Of interest in the analysis below, is that a carbon value of US$ 6/ton provides insufficient economic incentive (KSh 71,768/ha) to compensate for deforestation (KSh 272,000/ha). However, this analysis shows that the total ecosystem service value of the montane forests far exceeds the carbon value. Carbon, as a proxy for regulating ecosystem services, has a regulating service multiplier effect of 10.6.

The key policy implication for the Government of Kenya lies in (1) sustainable use of the forest resources (mainly timber en wood) through selective thinning regimes, instead of clear-felling of large area; (2) the protection of the forests against uncontrolled settlement; (3) adequate allocation and policing of water withdrawals; (4) improved management of degraded land. This can be achieved through:

- proper road and path planning, design, and maintenance;
- establishment on crop systems that protect the soil and create microclimatic condition resembling forest conditions as close as possible (shamba-system for example);
- terracing on steep upstream cropped areas to reduce surface runoff and increase infiltration;
- mulching bare areas to protect the soil, avoid weed growth to reduce soil water loss through evaporation from the soil and through transpiration by weeds;
- tied ridges are very effective in controlling surface runoff and improving soil moisture conditions;
- payments for ecosystem services schemes related to the REDD+ initiative.

The cost of these mitigation measures is expected to be far less than the value of regulating services lost.

Table 9. At an average annual deforestation rate of 2,762 ha/yr, the deforestation in Kenya Water Towers in 2010 generated and estimated KSh 796 million in timber and fuelwood revenue. However, the negative effects of deforestation on the economy through reduction in regulating services, was far higher than this, at KSh2,231 million.

	Cash revenue generated by deforestation through the harvesting of timber and fuelwood (KSh million)	Negative effects of deforestation on the economy through changes in regulating services (KSh million)
Total effect (million KSh) (2010)	**796**	**-2,231**
Growing of crops and horticulture		**-1,499**
Forestry and logging	**796**	
Fishing		**-86**
Electricity supply		**-8**
Water supply		**-192**
Public administration and defence		**-447**
Deforestation effects on conservation.		*0*
Deforestation effects on carbon sequestration.		*-210*
Deforestation effects on health (malaria).		*-237*

Table 10. The effects of deforestation on the economy in KSh/ha.

	Cash revenue generated by deforestation through the harvesting of timber and fuelwood	Negative effects of deforestation on the economy through changes in regulating services
Total effect (Ksh/ha) (2010)	**272,393**	**-763,283**
Growing of crops and horticulture		-512,741
Forestry and logging	272,393	
Fishing		-29,392
Electricity supply		-2,648
Water supply		-65,703
Hotels and restaurants		
Public administration and defence		-152,800
Deforestation effects on carbon sequestration.		*-71,768*
Deforestation effects on health (malaria).		*-81,034*

8 References

Afrane, Y.A., Little, T.J., Lawson, B.W., Githeko, A.K. and Yan, G., 2008. Deforestation and vectorial capacity of *Anopheles gambiaev* Giles mosquitoes in malaria transmission, Kenya. *Emerging Infectious Diseases*, 14 (10): 1533-1538.

Afrane, Y.A., Zhou, G., Lawson, B.W., Githeko, A.K. and Yan, G., 2006. Effects Of microclimatic changes caused by deforestation on the survivorship and reproductive fitness of *Anopheles Gambiae* in western Kenya highlands. *Am. J. Trop. Med. Hyg.,* 74(5): 772–778.

DRSRS 2004. Akotsi, E. and Gachanja, M. Changes in forest cover in Kenya's five "water towers" 2000 – 2003. Report prepared by: KFWG and DRSRS.

DRSRS 2006. Akotsi, E. and Gachanja, M. Changes in forest cover in Kenya's five Water Towers 2003-2005. Report prepared by: KFWG and DRSRS.

Brakel, W.H., 1984. Seasonal dynamics of suspended-sediment plumes from the Tana and Sabaki Rivers, Kenya: Analysis of landsat imagery. *Remote Sensing of Environment* 16:165-173.

Briguglio, L., Cordina, G., Bugeja, S. and Farrugia, N. 2005. Conceptualizing and measuring economic resilience

Bruijnzeel, L.A., 1988. (De)forestation and dry season flow in the tropics: a closer look. *Journal of Tropical Forest Science* 1 (3): 229–243.

Bruijnzeel, L.A., 2001. Hydrology of tropical montane cloud forests: A reassessment. *Land Use and Water Resources Research* 1 (2001) 1.1-1.18

Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? *Agric. Ecosyst. Environ.* 104:185–228.

Central Bureau of Statistics (CBS), 2003. *Economic Survey 2003*. Government Printers, Nairobi Kenya.

Central Bureau of Statistics (CBS), 2005. *Statistical Abstracts 2005*. Government Printers, Nairobi Kenya.

Chen, H., Githeko, A.K., Zhou, G., Githure, J.I. and Yan, G., 2006. New records of *Anopheles arabiensis* breeding on the Mount Kenya highlands indicate indigenous malaria transmission. *Malaria Journal,* 5 (17).

Chuma, J., Okungu, V. andMolyneux, C., 2010. The economic costs of malaria in four Kenyan districts: do household costs differ by disease endemicity? *Malaria Journal*, 9:149.

Decurtins, S., Leibundgut, C. and Wetzel, J., 1988. *River water potential and rural water supply in in eastern Laikipia (Kenya) for small scale farming*. Laikipia Report 12: Resources of River Water in Eastern Laikipia.

GOK, 2005

Hamilton, L.S. and Bruijnzeel, L.A., 1997. pp. 337-370 In: *Mountains of the World: A Global Priority*, B. Messerli and J.D. Ives (Editors). Parthenon Publishing Group, New York, USA and Carnforth, UK.

Hewlett, J. D. and Bosch, J.M., 1984. The dependence of storm flows on rainfall intensity and vegetal cover in South Africa. *J Hydrol*, 75: 365-381.

Hewlett, J.D. and Helvey, J.D., 1970. Effects of forest clearfelling on the storm hydrograph. *Water Resources res*, 6 (3):768-782.

Japan International Cooperation Agency (JICA), 1992. *Study of the National Water Master Plan*. Ministry of Water Resources and Management, Nairobi, Kenya.

Kabat, P., Claussen, M., Dirmeyer, P.A., Gash, J.H.C., Bravo de Guenni, L., Meybeck, M., Pielke Sr., R.A., Vörösmarty, C.J., Hutjes, R.W.A and Lutkemeier S. (eds.) 2004. Vegetation, Water, Humans and the Climate. Springer, Heidelberg.

KenGen, 2005. [Get full reference]

Kenya Forest Master Plan, 1994a. *Kenya Forestry Master Plan*. KFMP, Forestry Deparmtnet, Nairobi.
Kenyan National Bureau of Statistic (KNBS) 2010. Statistical Abstracts 2010. Government Printers, Nairobi Kenya.
Kenyan National Bureau of Statistic (KNBS), 2008. Economic Survey 2008. Government Printers, Nairobi Kenya.
Kenyan National Bureau of Statistics (KNBS), 2011. Economic Survey 2011. Government Printers, Nairobi Kenya.
Kirby, C., Newson, M.D. ad Gilman, K., 1991. *Plynlimon research: the first two decades, report no. 109*. Institude of Hydrology, Wallingford, UK.
Lal R., 1995. The role of residue management in sustainable agricultural systems. *J Sustain Agric*, 5: 51–78.
Lal, R., 1981a. Soil erosion problems on an alfisol in western Nigeria. VI. Effects of erosion on experimental plots. *Geoderma* 25: 215-230.
Lal, R., 1981b. Analyses of different processes governing soil erosion by water in the tropics. In: *Erosion and Sediment Transport Measurement* (Proc. Florence Symp., June 1981), 351-364. IAHS Publ. no. 133.
Lal, R., 1981c. Deforestation of tropical rainforest and hydrological problems. In: *Tropical Agricultural Hydrology* (ed. by R.Lai & E.W.Russell), 131-140. Wiley & Sons, Chichester, UK.
Lal, R., 1985. Soil erosion and sediment transport research in tropical Africa. *Hydrological Sciences Journal*, 30 (2):239-256.
Lange, G-M (2011). Wealth Accounting and Valuation of Ecosystem Services. Environment Department, The World Bank. 29 March, 2011. Washington, DC
http://siteresources.worldbank.org/INTRANETENVIRONMENT/Resources/WAVESpartnermtgMarch29-312011.pdf
Malakooti, M. A., Biomndo, K. and Shanks, G. D., 1998. Reemergence of epidemic malaria in the highlands of western Kenya. *Emerging Infectious Diseases*, 4 (4): 671-676.
Maneno, J., Oloo, A. and Kireria, A.M. 1998. *Malaria control in Kenya: Priorities and strategies*. Interdisciplinary Rapid Assessment Mission, World Bank, WHO, UNICEF.
Mati, B.M., Mutie, S., Gadain, H., Home, P. and Mtalo, F., 2008. Impacts of land-use/cover changes on the hydrology of the transboundary Mara River, Kenya/Tanzania. *Lakes & Reservoirs: Research and Management*, 13: 169–177.
MEA 2005. Millennium Ecosystem Assessment. [Online] Available: http://www.maweb.org
Minakawa, N., Omukunda, E., Zhou, G., Githeko, A. and Yan, G., 2006. Malaria vector productivity in relation to the highland environment in Kenya. *Am. J. Trop. Med. Hyg.,* 75(3): 448–453.
Molyneux, D.H., 1997. Patterns of change in vector-borne diseases. *Annals of Tropical Medicine & Parasitology*, 91 (7): 827-839.
Nabutola, W., 2010. The Mau Forest in the Rift Valley: Kenya's Largest Water Tower: a Perfect Model for the Challenges and Opportunities of a Sustainable Development Project? FIG Congress 2010: Facing the Challenges – Building the Capacity Sydney, Australia, 11-16 April 2010.
National Coordinating Agency for Population and Development, Ministry of Medical Services, Ministry of Public Health and Sanitation, Kenya National Bureau of Statistics, ICF Macro, 2011. Kenya Service Provision Assessment Survey 2010. National Coordinating Agency for Population and Development, Ministry of Medical Services, Ministry of Public Health and Sanitation, Kenya National Bureau of Statistics, and ICF Macro, Nairobi, Kenya.
Nkako, F.M., Lambrechts, C., Gachanja, M. and Woodley, B., 2005. *Maasai Mau Forest Status Report 2005*. Report by Ewaso Nyiro South Development Authority, UNEP, the Kenya Forests Working Group, and Kenya Wildlife Service, Nairobi.

Ongwenyi, G.S, S.M. Kithiia, and F.O. Denga, 1993. An overview of the soil erosion and sedimentation problems in Kenya. *Sediment Problems: Strategies for Monitoring, Prediction and Control* (Proceedings of the Yokohama Symposium, July 1993). IAHS Publ. no. 217, 1993.

Perrings C., 2006. Ecological Economics after the Millennium Assessment. International Journal of Ecological Economics & Statistics (IJEES). *Int. J. Ecol. Econ. Stat.*, 6 (F06): 8-22.

Republic of Kenya, 2007. *Kenya Vision 2030. A Globally Competitive and Prosperous Kenya*. Government printers, Nairobi.

Republic of Kenya, 2009. *Irrigation and Drainage Master Plan*. Minstry of Water and Irrigation, Nairobi.

Republic of Kenya, 2010a. *Agricultural Sector Development Strategy 2010–2020*. Government printers, Nairobi.

Republic of Kenya, 2010b. *Kenya national health accounts 2009/10*. Government printers, Nairobi.

resilience [Online]. Available:https://secure.um.edu.mt/__data/assets/pdf_file/0013/44122/resilience_index.pdf (14 December 2011)

Sahin, V., and Hall, M. J., 1996. The effects of afforestation and deforestation on water yields. *Journal of Hydrology* 178:293–309.

Simonit S., Cattaneo, F. and Perrings, C., 2005. Modelling the hydrological externalities of agriculture in wetlands: the case of rice in Esteros del Iberà, Argentina. *Ecological Modeling,* 186(1): 123-141.

Simonit, S. and Perrings, C., 2005. Indirect economic indicators in bioeconomic fishery models: agricultural price indicators and fish stocks in Lake Victoria. ICES *Journal of Marine Science, 62*(3): 483-492.

Simonit, S. and Perrings, C., 2011. Sustainability and the value of the 'regulating' services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70: 1189–1199.

Taylor, C.H. and Pearce, A.J., 1982. Storm run-off processes and sub-catchments characteristics in a New Zealand hill country catchment, Earth Surf Process Land Forms, 7, pp439-447.

Thairu, N.K., 2010. Agricultural Production and Irrigation Management: The Case of Irrigated Rice Production in Kenya. Masters Thesis, Institute of Social Studies, The Hague, Netherlands.

UNEP, 2006. Kenya National Water Development Report. Prepared for the 2nd UN World Water Development Report. 'Water: A shared responsibility'. World Water Assessment Programme.

UNEP. 2009a. Classification Of Kenya's Forest Regulating Services. Unpublished Report. UNEP, Narobi, Kenya.

UNEP, 2009b. Kenya. Altlas of our changing environment. UNEP, Nairobi, Kenya.

Wilson, R. and Spracklen, D., 2009. Forest loss and restoration – a case study of tropical montane forest, World Land Trust, University of Leeds.

Dominick Spracklen, University of Leeds

World Bank, 2006. Mogaka, H., Gichere, S., Davis, R. and Hirji, R., 2006. *Climate Variability and Water Resources Degradation in Kenya. Improving Water Resources Development and Management.* World Bank Working Paper no. 69. The World Bank, Washington D.C.

World Bank, 2010. The State of Kenya's Economy. The World Bank, Washing D.C.

World Bank (2011). Wealth Accounting and the Valuation of Ecosystem Services (WAVES): A Global Partnership. Paper prepared by the World Bank for the Sixth Meeting of the UN Committee of Experts on Environmental-Economic Accounting, New York, 15-17 June 2011. ESA/STAT/AC.23. UNCEEA/6/7

World Resources Institute, Department of Resource Surveys and Remote Sensing, Ministry of Environment and Natural Resources, Kenya, Central Bureau of Statistics, Ministry of Planning and National Development, Kenya and International Livestock Research Institute, 2007.

Nature's Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being. World Resources Institute, Washington, DC and Nairobi.

Yasuoka, J. and Levins, R., 2007. Impact of deforestation and agricultural development on *Anopheline* ecology and malaria epidemiology. *Am. J. Trop. Med. Hyg.*, 76(3): 450–460

Zhou, G., Minakawa, N., Githeko, A., and Yan, G., 2004. Association between climate variability and malaria epidemics in the East African highlands. *Proc Natl Acad Sci*, 101: 2375–2380.

Zhou, G., Munga, S., Minakawa, N., Githeko, A.K. and Yan, G., 2007. Spatial Relationship between Adult Malaria Vector Abundance and Environmental Factors in Western Kenya Highlands. *Am. J. Trop. Med. Hyg.,* 77(1): 29–35.

References in Appendices

Afrane, Y.A., Little, T.J., Lawson, B.W., Githeko, A.K. and Yan, G., 2008. Deforestation and vectorial capacity of *Anopheles gambiaev* Giles mosquitoes in malaria transmission, Kenya. *Emerging Infectious Diseases*, 14 (10): 1533-1538.

Afrane, Y.A., Zhou, G., Lawson, B.W., Githeko, A.K. and Yan, G., 2006. Effects Of microclimatic changes caused by deforestation on the survivorship and reproductive fitness of *Anopheles Gambiae* in western Kenya highlands. *Am. J. Trop. Med. Hyg.,* 74(5): 772–778.

Akotsi, E. and M. Gachanja, 2004. Changes in forest cover in Kenya's five "water towers" 2000 – 2003. Report prepared by: KFWG and DRSRS.

Bosch, J. M. and Hewlett, J. D., 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3–23.

Brakel, W.H., 1984. Seasonal dynamics of suspended-sediment plumes from the Tana and Sabaki Rivers, Kenya: Analysis of landsat imagery. *Remote Sensing of Environment* 16:165-173.

Brown, A. E., Zhang, L., McMahon, T.A., Western, A. and Vertessy, T.A., 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology*, 310: 28–61.

Brown, M.B., de la Roca, I., Vallejo, A., Ford, G., Casey, J., Aguilar, B. and Haacker, R., 1996. *A Valuation analysis of the Role of Cloud Forests in Watershed Protection.* Sierra de las Minas Biosphere Reserve, Guatemala and Cusuco N.P., Honduras. RARE Center for Tropical Conservation, Philadelphia, U.S.A.

Bruijnzeel, , L.A., 1990. Hydrology of most tropical forests and effects of conversion: A state of knowledge review, UNESCO Humid Tropic Programme. Amsterdam.

Bruijnzeel, L.A., 1988. (De)forestation and dry season flow in the tropics: a closer look. *Journal of Tropical Forest Science* 1 (3): 229–243.

Bruijnzeel, L.A., 2001. Hydrology of tropical montane cloud forests: A reassessment. *Land Use and Water Resources Research* 1 (2001) 1.1-1.18

Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? *Agric. Ecosyst. Environ.* 104:185–228.

Calder, I.R., 1999. *The Blue Revolution Land Use and Integrated Water Resources Management*. Earthscan Publications Ltd. 188pp.

Central Bureau of Statistics (CBS) [Kenya], Ministry of Health (MOH) [Kenya], and ORC Macro. 2004. *Kenya Demographic and Health Survey 2003.* Calverton, Maryland: CBS, MOH, and ORC Macro.

Chen, H., Githeko, A.K., Zhou, G., Githure, J.I. and Yan, G., 2006. New records of *Anopheles arabiensis* breeding on the Mount Kenya highlands indicate indigenous malaria transmission. *Malaria Journal,* 5 (17).

Decurtins, S., Leibundgut, C. and Wetzel, J., 1988*. River water potential and rural water supply in in eastern Laikipia (Kenya) for small scale farming*. Laikipia Report 12: Resources of River Water in Eastern Laikipia.

Division of Malaria Control [Ministry of Public Health and Sanitation], Kenya National Bureau of Statistics, and ICF Macro. 2011. 2010 Kenya Malaria Indicator Survey. Nairobi, Kenya: DOMC, KNBS and ICF Macro.

Gash, J.H.C. and Nobre, C.A., 1997. Climatic effects of Amazonian deforestation: some results from ABRACOS*. Bull. American Meteorol. Soc*., 78 (5): 823-830.

Githeko, A.K. and Ndegwa, W., 2001. Predicting malaria epidemics in the Kenyan highlands using climate data: a tool for decision makers. *Global change & human health*, 2 (1): 54-63.

Hamilton, L.S. and Bruijnzeel, L.A., 1997. pp. 337-370 In: *Mountains of the World: A Global Priority*, B. Messerli and J.D. Ives (Editors). Parthenon Publishing Group, New York, USA and Carnforth, UK.

Hay, S.I., Simba, M., Busolo, M., Noor, M.M., Guyatt, H.L., Ochola, S.A. and Snow, R.W. 2002. Defining and Detecting Malaria Epidemics in the Highlands of Western Kenya. *Emerging Infectious Diseases*, 8(6): 555-562.

Hewlett, J. D. and Bosch, J.M., 1984. The dependence of storm flows on rainfall intensity and vegetal cover in South Africa. *J Hydrol*, 75: 365-381.

Hitimana, J; J.L. Kiyiapi and J.T Njunge, 2004. Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. Forest Ecology and Management 194 (2004) 269–291.

HMIS 2008. Annual Health Sector Statistical Report 2008. [Online]. Available: http://ebookbrowse.com/hmis-kenya-annual-report-2008-as-at-09-07-09-draft-1-doc-d19036111

Kabat, P., Claussen, M., Dirmeyer, P.A., Gash, J.H.C., Bravo de Guenni, L., Meybeck, M., Pielke Sr., R.A., Vörösmarty, C.J., Hutjes, R.W.A and Lutkemeier S. (eds.) 2004. Vegetation, Water, Humans and the Climate. Springer, Heidelberg.

Kabat, P., Claussen, M., Dirmeyer, P.A., Gash, J.H.C., Bravo de Guenni, L., Meybeck, M., Pielke Sr., R.A., Vörösmarty, C.J., Hutjes, R.W.A and Lutkemeier S. (eds.) 2004. Vegetation, Water, Humans and the Climate. Springer, Heidelberg.

Kang and Lal (1981) as quoted in in Hamilton and King (1983). Tropical Forested Watersheds – Hydrologic and Soils Response to Major Uses or Conversions. A Westview Replica Edition.

Lal R., 1995. The role of residue management in sustainable agricultural systems. *J Sustain Agric*, 5: 51–78.

Lal, R., 1981a. Soil erosion problems on an alfisol in western Nigeria. VI. Effects of erosion on experimental plots. *Geoderma* 25: 215-230.

Lal, R., 1981b. Analyses of different processes governing soil erosion by water in the tropics. In: *Erosion and Sediment Transport Measurement* (Proc. Florence Symp., June 1981), 351-364. IAHS Publ. no. 133.

Lal, R., 1981c. Deforestation of tropical rainforest and hydrological problems. In: *Tropical Agricultural Hydrology* (ed. by R.Lai & E.W.Russell), 131-140. Wiley & Sons, Chichester, UK.

Lal, R., 1985. Soil erosion and sediment transport research in tropical Africa. *Hydrological Sciences Journal*, 30 (2):239-256.

Leopoldo, P.R , Franken, W. K., and Villa Nova, N.A., 1995. Real evapotranspiration and transpiration through a tropical rain forest in central Amazonia as estimated by the water balance method. *Forest Ecology and Management*, 73(1-3): 185-195

Lindsay, S.W. and Martens, W.J.M., 1998, Malaria in the African highlands: past, present and future. *Bulletin of the World Health Organization*, 76 (1): 33-45

Malakooti, M. A., Biomndo, K. and Shanks, G. D., 1998. Reemergence of epidemic malaria in the highlands of western Kenya. *Emerging Infectious Diseases*, 4 (4): 671-676.
Molyneux, D.H., 1997. Patterns of change in vector-borne diseases. *Annals of Tropical Medicine & Parasitology*, 91 (7): 827-839.
Mugidde 2001 [Amelia]
Munga, S., Minakawa, N., Zhou, G., Mushinzimana, Z., Barrack, O-O.J., Githeko, A.K. and Yan, G., 2006; Association Between Land Cover And Habitat Productivity Of Malaria Vectors In Western Kenyan Highlands. *Am. J. Trop. Med. Hyg.,* 74(1): 69–75.
Munga, S., Yakob, L., Mushinzimana, E., Zhou, G., Ouna, T., Minakawa, N., Githeko, A. and Yan, G., 2009. Land Use and Land Cover Changes and Spatiotemporal Dynamics of Anopheline Larval Habitats during a Four-Year Period in a Highland Community of Africa. *Am. J. Trop. Med. Hyg.*, 81(6): 1079–1084.
Nabutola, W., 2010. The Mau Forest in the Rift Valley: Kenya's Largest Water Tower: a Perfect Model for the Challenges and Opportunities of a Sustainable Development Project? FIG Congress 2010: Facing the Challenges – Building the Capacity Sydney, Australia, 11-16 April 2010.
National Coordinating Agency for Population and Development, Ministry of Medical Services, Ministry of Public Health and Sanitation, Kenya National Bureau of Statistics, ICF Macro, 2011. Kenya Service Provision Assessment Survey 2010. National Coordinating Agency for Population and Development, Ministry of Medical Services, Ministry of Public Health and Sanitation, Kenya National Bureau of Statistics, and ICF Macro, Nairobi, Kenya.
Nkako, F.M., Lambrechts, C., Gachanja, M. and Woodley, B., 2005. *Maasai Mau Forest Status Report 2005*. Report by Ewaso Nyiro South Development Authority, UNEP, the Kenya Forests Working Group, and Kenya Wildlife Service, Nairobi.
Ongwenyi, G.S, S.M. Kithiia, and F.O. Denga, 1993. An overview of the soil erosion and sedimentation problems in Kenya. *Sediment Problems: Strategies for Monitoring, Prediction and Control* (Proceedings of the Yokohama Symposium, July 1993). IAHS Publ. no. 217, 1993.
Oparanya, W.A., 2011. Kenya Economic Survey 2011. Highlights. KNBS Powerpoint Presentation.
Pereira, H.C, 1989. Policy and practice in the management of tropical watersheds. Westview Press, Colorado, USA.
Republic of Kenya, 2005. The Forests Act, 2005. Government printers, Nairobi.
Republic of Kenya, 2007. Forest Policy (No. 1 of 2007). Government printers, Nairobi.
Republic of Kenya, 2007. *Kenya Vision 2030. A Globally Competitive and Prosperous Kenya*.
Government printers, Nairobi.
Republic of Kenya, 2009. *Irrigation and Drainage Master Plan*. Ministry of Water and Irrigation, Nairobi.
Republic of Kenya, 2010a. *Agricultural Sector Development Strategy 2010–2020*. Government printers, Nairobi.
Republic of Kenya, 2010b. *Kenya national health accounts 2009/10*. Government printers, Nairobi.
resilience [Online].
Available:https://secure.um.edu.mt/__data/assets/pdf_file/0013/44122/resilience_index.pdf (14 December 2011)
Shanks, G.D., Biomndot, K., Hay, S.I. and Snow, R., 2000. Changing patterns of clinical malaria since 1965 among a tea estate populationlocated in the Kenyan highlands. Transactions of the Royal Society of Tropical Medicine and Hygiene, 94: 253-255.
Thairu, N.K., 2010. Agricultural Production and Irrigation Management: The Case of Irrigated Rice Production in Kenya. Masters Thesis, Institute of Social Studies, The Hague, Netherlands.

Tuno, N., Okeka, W., Minakawa, N., Takagi, M. And Yan, G., 2005. Survivorship of *Anopheles gambiae* sensu stricto (Diptera: Culicidae) Larvae in Western Kenya Highland Forest. *Journal Of Medical Entomology* 42 (3): 270-277.

UNEP, 2006a. Kenya National Water Development Report. Prepared for the 2nd UN World Water Development Report. 'Water: A shared responsibility'. World Water Assessment Programme.

Vanleeue et al (2003). [Get reference]

Woodruff, J.F. and Hewelett , J.D.,1970. Predicting and Mapping the Average Hydrologic Response for the Eastern United States. *Water Resources Research*, 6(5): 1312-1326.

World Bank, 2006. Mogaka, H., Gichere, S., Davis, R. and Hirji, R., 2006. *Climate Variability and Water Resources Degradation in Kenya. Improving Water Resources Development and Management.* World Bank Working Paper no. 69. The World Bank, Washington D.C.

Yasuoka, J. and Levins, R., 2007. Impact of deforestation and agricultural development on *Anopheline* ecology and malaria epidemiology. *Am. J. Trop. Med. Hyg.*, 76(3): 450–460

Zeng, 2005. [Get reference]

Zhou, G., Minakawa, N., Githeko, A., and Yan, G., 2004. Association between climate variability and malaria epidemics in the East African highlands. *Proc Natl Acad Sci*, 101: 2375–2380.

Zhou, G., Munga, S., Minakawa, N., Githeko, A.K. and Yan, G., 2007. Spatial Relationship between Adult Malaria Vector Abundance and Environmental Factors in Western Kenya Highlands. *Am. J. Trop. Med. Hyg.,* 77(1): 29–35.

9 Appendix 1. Study objectives and case study methodology

This Report is the first in a series of Deliverables forming part of a UNEP study to evaluate the importance of regulating services to the economy of Kenya.

The study builds upon the 2009 UNEP report on the forest related regulating ecosystem services of Kenya, through valuation of the priority regulating services. The specific objectives of this study are:

1. To update data of natural resources data such as forest data, hydrological data and relevant scientific data on the production of ecosystem services. The second activity links regulating services to the economy and demonstrates that these services provide direct and indirect benefits sectors such as the commercial and subsistence agriculture sectors, water sector, the energy sector etc.;
2. To construct hybrid physical and monetary Input-Output models that will feed into the activity of building resource accounts for Kenya;
3. To conduct a regulating service valuation exercise. This activity will result in the quantification of intermediate input (also termed production factors) of ecosystems into the economy;
4. To construct monetary resource accounts as part of countries' satellite accounts. The monetary accounts will provide detailed information about inter-sectoral transactions, the product flows to final demand, both domestic and foreign, and non-industrial transactions (added value).
5. To strengthen national institutional capacities to construct and manage Input-Output tables , and carry out data collection and ecosystem services valuation) – the project is to be implemented through both formulating training modules on input-output as well as ecosystem services valuation supplemented with hands on exercises and training on planning, modelling and economic projections using the input-output models.
6. To write a paper to make a case for forestry in Kenya's linkages and contribution to the UN-REDD Programme Global Framework Document 2011-2015 and its work area 6 "Green economy transformation processes catalyzed as a result of REDD+ strategies and investment", output 6.1 "National level case studies" by piloting one case study and by providing a framework to assist carrying out other case studies.

10 Appendix 2: The montane indigenous forests of Kenya and their regulating services

This study is limited to investigating the effects of the montane indigenous forests of Kenya on the regulating ecosystem services of Kenya (see Table 11). "Montane forests" are the indigenous forests occurring in the montane belt between 1,500 m to 3,500 m (m a.s.l.) in the five "Water Towers". Typically these are closed broadleaved forests with the following dominant species: Camphor (*Ocotea spp*); Wet montane (*Aningers spp*, *Albizia spp*, *Olea spp*); Pillarwood (*Cassipourea spp*); *Croton spp; Diospyros spp*; riparian species, and others. But it may include open broadleaf forests: Wet upland (Hagenia spp); and Coniferous forests: *Podocarpus spp*; Cedar (*Juniperus spp*), and bamboo forests.

Table 11. Kenya's forests are classed into four types by the Forests Act (2005) and into six types by the Forest Policy (No. 1 of 2007). A report by the Kenya Forest Service and Kenya National Bureau of Statistics (GOK 2009) gives a detailed account of the bio-geographical nature of the forests. The Kenya Forest Act (2005) identifies four types of forestry and these are defined below.

Forest type	Description of forest type
Farm forestry	Farm forestry is the practice of managing trees on farms whether singly, in rows, lines, boundaries, or in woodlots or private forests.
Plantation forests	Plantation forests are established through afforestation or reforestation for commercial purposes.
Woodlands	Woodlands are open stands of trees less than ten metres tall which has come about by natural regeneration.
Indigenous forests	These are forests which have come about by natural regeneration of trees primarily native to Kenya, and include bamboo forests.

The distribution of indigenous forests is patchy and they are dispersed mainly over the montane areas, in particular the five "Water Towers" of Kenya. The five Water Towers are Mt. Kenya, the Aberdares, the Mau Complex, Mt. Elgon, and Cherangani, and they provide most of the water for the major rivers in the country (Mogaka, et al., 2006).

Various estimates of the extent of indigenous forest cover exist. The Kenya Forestry Master Plan, published in 1994, used Indigenous forest cover data sourced from KIFCON (Kenya Indigenous Forest Conservation Programme), who had conducted a 1990 survey of approximately 900,000ha of land using aerial photography and satellite images. The KFMP reports conflicting numbers for the extent of indigenous forest cover in Kenya. In its section 3.13, the KFMP reports an Indigenous forest cover of 1,240,000 ha, however, in Table 3.15 of the report, a forest cover of 1,090,619 ha is reported. It is possible that the discrepancy between the two data points is the inclusion of mangrove swamps in the KIFCON data. Additional information is available from the landcover mapping conducted by the DRSRS and the Food and Agriculture Organisation (FAO) as part of the FAO's Africover project. The work was done using satellite images from the year 2000. DRSRS and Africover report the existence of 1,185,189 ha of closed canopy indigenous forest. According to Mogaka, et al. (2006) the areas under indigenous forests on these mountains are: Mt Kenya: 200,871 ha; Aberdares: 148,916 ha; Mau complex: 415,977 ha; Mt Elgon: 73,706 ha; Cherangani: 120,842 ha, which totals to 960,312ha. This data was reported obtained from UNEP, but excluded the Aberdares National Park, which covers an area of 102,161 ha (UNEP, 2006).

From an interpretation of the information above, as summarised in Table 12, and the definition for "montane forest", the montane forests covered 1,062,473 ha in 2010.

Table 12. Summary of indigenous montane forest cover estimates as reported in literature. The revised year 2000 forest cover is 1,062,473 ha.

Source	Area	Year	Comments
Kenya Forestry Master Plan (KFMP)	1,240,000 ha	1990	This estimate is widely quoted in many subsequent documents. The estimate likely include mangrove swamps.
DRSRS and Africover	1,185,189 ha	2000	This estimate may include closed canopy forests outside of the five Water Towers
KIFCON data as quoted in the KFMP	1,090,619 ha	1990	
World Bank (2006)	960,312 ha	2000	This estimate excludes the forest area of the Aberdares National Park
Estimate used in this study	1,062,473 ha	2000	This estimate is based on data sourced from UNEP (2001) (as quoted in Mogaka, et al. (2006)) and DRSRS (2006).

There is no simple stratification of the forests either. Their distribution and stratification vary between aspect, elevation and complex catchment topography. Several reports deal with the composition and stratification of the forests. In summary these forests occur mainly between elevations of 1,500 m to about 3,500 m. See for example Decurtins (1985); Hitimana et al. (2004); Akotsi and Gachanja (2004). Forests are generally denser on the south eastern slopes of the mountain ranges from where the dominating rain systems come.

Despite their economic and environmental importance, forests in Kenya continue to be under threat of conversion to other land-use types which all have severely detrimental effects on the quality of water and several consequences in the downstream chain of applications. The main hazards are: Charcoal production; logging of indigenous trees; marijuana cultivation; cultivated fields in the indigenous forest; shamba-system practices; livestock grazing; quarries; landslides; human settlements. Various reports point to the extent and devastating effects of such practices on erosion sedimentation, water quality, etc. (UNEP, 2006; Ongwenyi, et al., 1993; Brakel, 1984; World Bank, 2006). Forest fires alone for example cost the government an estimated KSh 25.8 million and 28.6 million in suppression and damage losses respectively during 1999.

Forest clearing is reaching dramatic proportions in some areas. Mogaka, et al. (2006) shows that forests in the Lake Nakuru catchment has almost completely been converted to agricultural land. Clearings in the eastern Mau Forest Complex amounted to 35,301.01 ha in one year. The Molo forest was similarly cleared of 901.62 ha. Nabutola (2010) also mentions that during the past 15 years, more than 100,000 ha - one quarter of the protected forest reserve in the Mau Forest - have been settled and cleared. Nkako et al. (2005) in a status report on the Masaai Mau Forest report forest cover losses inside and outside the forest boundaries of 39,969 ha representing about 39% of the total forest cover. A survey of degraded land into the indigenous forest of Mt Kenya by Vanleeue, et al (2003) showed that encroachment of the forest was quite extensive in 2000 amounting to 11,021 ha, but that it decreased substantially, by 2002. Akotsi and Gachanja (2004) give an overall account of changes in forest cover over a period.

It remains difficult however to estimate the rate of overall reduction in Kenya's montane forests as a result of clearings and conversions. However, deforestation proceeded at a rate of approximately 2,923 ha/yr between 2000 and 2005 (Table 13).

Table 13. Deforestation between 1990 and 2005 based on data sourced from DRSRS (2006) and DRSRS (2004). Deforestation rates for the periods 1990-1999, 2000-2003 and 2004-2005 were 2,681 ha/yr, 2,427 ha/yr and 3,666 ha/yr respectively. The estimated deforestation for the period 2006-2010 is based on the average rate of deforestation for the period 2000-2005.

	1990	2000	2003	2005	2010
Mau Complex		415,977	408,893	399,413	
Mt Kenya	232,047	200,871	206,885	209,032	
Mt Elgon	102,696	73,706	73,521	73,521	
Cherangano Hills	97,397	120,842	120,995	120,995	
Aberdares	253,375	251,077	244,896	244,896	
Total	1,089,290	1,062,473	1,055,190	1,047,857	1,062,473
Deforestation rate (ha/yr)		-2,682	-2,428	-3,666	-2,923

Deforestation resulting from illegal logging provides roundwood that are sold for timber production and which are used for charcoal production, and thus provides an economic incentive for illegal loggers. Deforestation also results from forest fires, landslides and illegal settlements. Post deforestation land is often used for marijuana cultivation, other forms of subsistence farming, and livestock grazing. In most cases, these land uses perpetuate the degraded state of land, and devastating effects of such practices on regulating services. (DRSRS, 2006; Ongwenyi, et al., 1993; Brakel, 1984; World Bank, 2006).

Thus, in order to evaluate and quantify the regulating services of forests we have to consider the cumulative consequences of land degradation following deforestation. Thus, although deforestation in 2010 amounted to an estimated 2,923 ha, the Kenyan economy would have experienced a cumulative negative effect of deforestation for the period 2000-2010.

11 Appendix 3: Local climate regulation

At macro-scale, the rainfall in Kenya is driven by global processes such as the seasonal northward and southward movements of the low pressure belt around the equator known as the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is influenced by macro factors such as the sea surface temperatures of the Atlantic and Indian oceans. Forest's influence on the macro-climate depends largely on the extent of the forests relative to the extent of governing weather systems. Since montane forests constitute less than 3% of Kenya's area, it is unlikely that partial deforestation will have an effect on the macroclimate over the whole of Kenya.

At a meso-scale, the annual rainfall and its distribution during the year are influenced by land characteristics, such as topography and land cover. This is evidenced by large differences in annual rainfall in Kenya between two areas that are only 50 kilometres apart (Kabat et al., 2004). Forests thus have an influence on the meso-climate through their moisture interaction with the atmospheric boundary layer. Their physical structure also effects the movement of air masses and interception of moisture in the atmosphere. A key reason for example for potential increased local rainfall is that tall forests may intercept fog or moisture from clouds as a result of their higher leaf area, larger canopies, and higher aerodynamic roughness than shorter crops. Bruijnzeel (2001) presents a comprehensive and detailed review of cloud interception by tropical rain forests. Hamilton and Bruijnzeel (1997) and Bruijnzeel (2001) suggest that cloud deposition can be as high as 5% to 20% of annual rainfall. Forests also provide a slight orographic lift and concomitant cooling of air masses resulting in precipitation.

At micro-scale, climate is regulated primarily by ground cover (type of vegetation). Forests protect the soil (and thus also surface hydrological processes) in many ways and create an ecosystem conducive to such protective functions. Such ecosystems are dependent on the temperature and moisture conditions resulting from forest cover protection.

Water yield from high elevated, high rainfall areas is high. At an average annual rainfall of 2,300 mm and a potential rainfall-runoff ration of 65%, it means that total water yield from the Water Towers could be more than 15,800 million m^3 /yr, which is more than 75% of the renewable surface water resources of Kenya.

The ultimate hydrological consideration of the forests in Kenya is their contribution to the water resources of the land system. It is the water resources of the land that are usable and which have economic implications. The water balance of the land system for the purpose of this exercise can be expressed (in very simple terms) as:

$$Q = P + CD - ET + \Delta S \qquad \text{Equation 1}$$

Where Q is the water yield from a hydrological land unit (catchment); P = precipitation (Rainfall plus snow, etc.); CD is cloud deposition (fog interception); ET is evapotranspiration (which includes water loss to the atmosphere through transpiration, evaporation of canopy interception, and evaporation from the soil surface); ΔS is change in soil water storage (including groundwater). These components are usually expressed in mm and is converted to m^3 for comparison with water use generally in Kenya. The text below considers the impact of changes in the forest canopy on each of these processes.

Conflicting views on the effects of forests on rainfall still persist amongst researchers in this field since the early 1900. Much of the disagreement is related to the very varied conditions under which experiments were conducted and because of the inability to accurately measure or model the processes involved. Many scholars have attempted reviews which resulted in conflicting conclusions.

Forests in Kenya comprise only around 3% of the total area. Considering the extent of the forests and the fact that the macro climate in Kenya is influenced by large weather systems such as the seasonal northward and southward movements of the low pressure belt around the equator known as the Inter-Tropical Convergence Zone (ITCZ), it is unlikely that these forests will have a significant influences on the macro climate over Kenya. The ITCZ is influenced by macro factors such as the sea surface temperatures of the Atlantic and Indian oceans for example.

The water evaporated from the forests is also only relatively little seeing that the montane forest belt is only between 1,500 m to 3,500 m and ET under the cloudy moist conditions in this belt can maximally be 800 to 900 mm per year. It is therefore also unlikely that relatively smaller changes in the montane forest cover in Kenya will have any influence on the macro climate of the country such as overall annual and seasonal rainfall and temperature.

Although there are reported observational and modelling evidence (see Gash and Nobre, 1997 as quoted in Kabat, 1999) that the land surface directly affects the atmospheric boundary layer at scales of less than 50 km, there is no conclusive methodology yet to accurately quantify the effects at the scale of the Kenya forest conversions.

There is the potential however for forests to influence the microclimate; changes in albedo and surface temperatures will influence the evapotranspiration (ET) processes. The changes in temperature and larger exposure of crops and soils after conversion will certainly have a large impact on the plant and soil biological and ecological processes.

Forests could potentially cause more rain to fall on an area locally, compared to other land cover types. Vegetation evaporates (meaning water loss to the atmosphere through soil evaporation, interception, and transpiration) water into the atmosphere which could be assumed to affect the surface boundary layer to such an extent that most of the evaporated water will return as additional rain locally. The assumption then being that because forests evaporate more water than other land-use types, that areas of converted forest will put less water into the atmosphere with consequent less potential to increase rain. However, the potential for increased rain as a result of higher evaporation from Kenya's forests is small. Cloud formation over the Water Towers is probably mainly caused by topographical features. Forests are not likely to evaporate more than about 300 mm compared to replacement vegetation under the same conditions. An additional 300 mm of water into an air mass of several km^3 is unlikely to have an influence on the overall annual rainfall. The most likely way of returning some of the evaporated water to the land is through interception of the cloud moisture (non-rain) by the forests.

Forests may intercept fog or moisture from clouds as a result of their higher leaf area, larger canopies, and higher aerodynamic roughness than shorter crops. It is also claimed that forests could provide a slight orographic lift and concomitant cooling of air masses resulting in precipitation. Bruijnzeel (2001) presents a comprehensive and detailed review of cloud interception by tropical rain forests. Although cloud interception is recognised as an important process in montane forests that may cause water deposition on the soil surface, there is no clear scientific evidence as to the magnitude of cloud deposition in these forests. The lack of evidence is partly because it is very difficult to determine experimentally, but also because there are competing processes related to the slight orographic effect of tall trees and advection. Such processes are difficult to define. The same factors (high leaf area, larger canopies, and aerodynamic roughness) favouring cloud deposition from advection, may also favour higher evapotranspiration (ET) as a result of the transport of heat to the forest surface from the atmosphere through advection (Calder, 1999). The evapotranspiration process is a very complex interaction of vegetation characteristics, available energy, vapour pressure difference between water surface and atmosphere, and the efficiency of the vapour transport system. For the purpose of this discussion it can be assumed that ET = f(leaf area, aerodynamic properties of the vegetation, the drying power of the air, the energy available for evaporation, the availability of water for evaporation, the ease at which the water can be transferred from the surface to the atmosphere).

There are conflicting theories and results on the role of forests to augment rainfall in the literature. Calder (1999) discusses the potential of forests to increase rainfall locally and globally. He argues that advection (winds) which are needed for cloud interception of significance allow for competing processes (ET) which will counter fog or cloud deposition. He points to the improbability of forests to influence rainfall significantly, except in cases at the scale of for example the total removal of the Amazonian rainforests. Pereira (1989) is blunt in his opinion that the possibility of forests to increase rainfall as a myth. Brown et al. (1996) suggests that ridgetop forests may intercept large amounts of cloud water but their spatial extent is usually limited.

However, on the basis of the suggestion by Hamilton and Bruijnzeel (1997) that cloud deposition can be as high as 5% to 20% of annual rainfall; and a further account by Bruijnzeel (2001) of cloud interception, the potential of cloud deposition in Kenya's mountain forests should not be discarded. The first question to consider is what proportion of Kenya's forests is exposed to persistent cloud contact of significance. This is also not simple, but according to Bruijnzeel persistent cloud bands occur in the forests between 2,100 to 3,600 meters in the Aberdares and Mau Ranges of Kenya for about three or four months of the year. This is typically the montane forest belt and for purposes of this exercise all montane forests of indigenous forests is exposed to these cloudy conditions to the extent that they can contribute to cloud water deposition.

The next question to address is the quantity of water that can potentially be intercepted by the forests. Bruijnzeel (2001), reviewed experimental results of cloud water deposition from Australia, Hawai and several Central American countries. But the high variability and uncertainty around the quantities do not justify any very accurate conclusions regarding cloud interception of Kenya's forests. Based on the various discussion on existing experimental evidence (although scant and inconclusive) of the potential of cloud interception (Hamilton, 1997; Bruijnzeel, 2001; World Bank, 2006) a potential interception of 5 to 20% is assumed.

However, additional water from cloud deposition by forests could be completely or partially discounted by lower water use (ET) of the replacement vegetation. It is likely that a clearing of the montane forests, considering their ET, will result in maximally about 300 to 400 mm more water yield from the area (see discussion further down), disregarding for the moment the probable highly degraded nature, poor quality, and change in timing of flow of this additional water to the land system.

12 Appendix 4: Water yield regulation

Water yield from high elevated, high rainfall areas is high. At an average annual rainfall of 2,300 mm and a rainfall-runoff ration of 65%, it means that total water yield from the Water Towers could be as more than 15 800 million m^3 /yr, which is more than 75% of the renewable surface water resources of Kenya.

Any conversion of high forest to a shorter vegetation type will result in more water available to the land system; mainly as a result of lower ET. Bosch and Hewlett (1980) having summarised 93 catchment experiments worldwide for example showed that water-use of woody vegetation generally exceeds that of herbaceous or shorter vegetation types. These findings are supported by many other more recent studies. See for example Sahin and Hall, 1996; Farley et al., 2005. There are claims that most experimental results relate to plantations of exotic trees and that indigenous rainforests use less water than plantations of exotic trees. This may be true, but their water use is still higher than lower forms of vegetation in a specific area. Bruijnzeel (2001) quotes ET (water use) figures for tropical rain forests in Central American countries ranging from 890 to 1260 mm. Mark Gush (personal communication) in his PhD (still in process) used sophisticated scintillometry equipment to measure water use of an indigenous sub-tropical forest near George in South Africa. Total annual water use of this forest was in the order of 960 mm. These forests types are similar in structure to the montane forest of Kenya, but they grow under different climatic conditions. Available energy (higher temperatures) and evaporative demand (dryness of the air) is much higher in George and will thus favour higher ET than the forests located in the higher elevated mountains of

Kenya with their cloudy conditions. On the basis of results mentioned above and others (Leopoldo et al., 1995), ET from Kenya forests averages 800 mm per year.

Shorter vegetation is likely to use about 400 to 500 mm per year (Bosch and Hewlett, 1982; Brown et al., 2005). Thus, conversion of montane forest will result in a reduction in ET of between 300 mm and 400 mm per year depending on the change in cover. ET differences will be smaller when the replacement land-use is for example fields irrigated throughout the year. In such situations ET may be relatively high as a result of higher temperatures (than in forests) and irrigation water available for evaporation from the canopy and soil surface. ET differences will be relatively high when converted areas are for example covered by seasonal rain-fed agricultural crops with bare soil for long periods of the year. Conversion of indigenous forest to exotic pine plantations are not likely to result in reduced ET and conversion to Shamba-systems may result in small reductions of about 100 mm to 200 mm.

In spite of the above theoretical results, the reality is that converted land-use ranges from irrigated crops to areas partially bare for periods of the year; and thus a hypothetical reduction in ET of between 300 mm to 400 mm.

Furthermore, and more importantly, the Water Towers regulate the seasonal flow of water in rivers, and deforestation can severely reduce dry season river flows. Rainfall in Kenya occurs mainly during two rain seasons. The long rains are typically from March to May while short rains are typically from October to November. Rainfall distribution and the associated need for water management to meet water needs towards the end of the dry seasons or during droughts is therefore of crucial importance to the Kenyan economy. Although human interventions, such as large dams, contribute to increasing water yield during dry seasons, the Water Towers also contribute to such management.

Forests create soil protective and infiltrative conditions conducive to the water holding capacity and slow release of water from a catchment, which will result in a more even distribution of flow throughout the year. Generally the higher the overall water yield from a catchment the higher the flow in all seasons and the more sustainable the flow during prolonged periods of drought. Forest conversions is likely to reduce ET and make more water available to the land system. Considering the role of forest's contribution to seasonal flow it thus means that forested catchment's protective qualities also come at the cost of the quantity of water it uses and thus the quantity of water available for infiltration and distribution to the river systems.

A review by Brown et al. (2005) of available experimental evidence of the effects of vegetation conversions on seasonal flows showed conflicting results. Their conclusions tell how difficult it is to extrapolate the available evidence to situations such as those in Kenya where no experimental data exists. They concluded: "*Generalisations about seasonal water yield are difficult to make based on the reported literature due to different definitions of seasons and the graphical and descriptive nature of the results. Based on climate groups, different seasonal responses are observed. Tropical or summer dominant rainfall catchments show larger absolute changes in the wet season, while proportional changes are either similar during all seasons or greater during the winter months. Winter dominant rainfall catchments show largest absolute responses in the winter season, while larger proportional reductions are observed during the summer months*".

Bruijnzeel (1988) in a discussion on the effects of vegetation changes on dry season flow in the tropics concluded that if infiltration opportunities after forest removal decrease to the extent that the amount of water leaving an area as quick flow exceeds the gain in baseflow associated with decreased evapotranspiration, then diminished dry season flows will result; and if surface infiltration characteristics are maintained the effect of reduced evapotranspiration after clearing will show up as an increase in baseflow.

In forest conversions one thus has to consider the influence of a replacement cover on the total water yield, as well as on the resultant destruction of the soil protective conditions. There is experimental evidence to suggest that it is not only forests that contribute to favourable soil protective conditions, but that any "natural" undisturbed or well managed vegetation may have the same consequence. Hewlett and Bosch (1982) showed for example that stormflow response from well maintained grassland and forests in South Africa are similar and relatively small. In other words, a well maintained grass cover may have the same water regulating quality but lower ET and thus yield more water in the wet and dry season compared to a forested catchment under similar climatic conditions.

The reality unfortunately is that "uncontrolled" forest conversions such as in Kenya invariably result in poorly managed replacement land-use with detrimental effects on infiltration and overland flow processes, which are likely to lead to a situation described by Bruijnzeel (1988) where the reduction in infiltration exceeds increased base flow resulting from reduced ET.

The hydrological response factor of a catchment is a simple measure of the amount of quickflow (also termed stormflow) generated by a rainfall event in a catchment and thus also of the infiltration capacity of the catchment. The response factor is expressed simply as the quickflow from a specific catchment area over a specific period as a fraction of the rainfall over the same area for the same period. Woodruff and Hewlett (1970) reported on response factors for 90 selected test basins from New York to Alabama. Response factors were all very low (meaning infiltration was good) and they failed to detect the influence of vegetation on these. Bosch (1980) reported on response factors for 10 small catchments in the Drakensberg (South Africa) ranging from forested to well managed grassland. Response factors were small (0,001 to 0,04) with no significant differences between forested and grassland catchments. Bosch showed also from other catchment data that response factors are influenced primarily by the amount of rock outcrops in a catchment.

However, a fire in an exotic pine plantations in one of the Drakensberg catchments had such a dramatic effect on surface runoff and erosion with the firsts rains after the fire that the measuring weir and other measuring equipment were totally flooded by mud and prevented any further data gathering (Bosch: Personal com). The damage was of such proportion that it was not possible to estimate the amount of sediment, but it was estimated at about $50m^3$/ha during the first significant rainstorm! It was unfortunately also not possible to measure the effects on later streamflow, but it was clear, just through casual observation that wet season flows increased with high incidents of flash floods of very dirty water and base flows receded in the years to follow. This was clearly a situation where a specific land-use activity completely changed the water regulation properties of a catchment, regardless of the lower ET from the catchment after the fire! This particular catchment had a very low response factor before the fire.

This mass erosion was triggered by soil water repellency, which occurs under certain vegetative, climatic and fire intensity condition, but the point is that this is one example of the potential consequences of losing indigenous forest cover and possible ensuing incidents of fire.

There is evidence that dry season flows have decreased significantly in a number of Kenyan rivers after clearance and settlement of large parts of their catchments. Such reductions are all related to the land-use subsequent to clearing of indigenous forest. For example, where areas have been cleared for settlements and associated planting of annual crops, water is abstracted from rivers to support the settlements. Such abstractions are more likely to influence seasonal flows. Mogaka, et al. (2006) notes that "*if extensive abstraction is allowed to occur, then flows can decrease by (in the case of the Ewaso Nyiro North catchment) a factor of 10 in dry months*". They also mention that there was a 300-% increase in water use in Laikipia District which was mainly due to increased human settlement and an expansion of irrigated agriculture. Poor land management causing compaction and degradation will result in lower infiltration and higher levels of overland flow. Conversion of forest to annual cropping or grazing is almost inevitably followed by increases in amounts of surface runoff as a result of either over grazing or other means of compaction (Bruijnzeel, 1990). So secondary aspects related to forest conversion are mainly the cause of disrupted seasonal flow.

There is thus no doubt, considering evidence of the conditions in alternative land-uses in Kenya's forest conversions, such as human settlement, clearfelling combined with fires, intensive crop cultivation, etc., that these activities will result in changes in seasonal flow. However, such areas are patchy and it is not possible to estimate their impact on a larger catchment scale. The problem is how to quantify such influences without any experimental data or even circumstantial evidence.

Total annual renewable surface water in Kenya rivers is about 19,700 million m^3/yr (World Bank, 2006). A hypothetical seasonal distribution of this flow based on the streamflow distribution in the Tana and Sabaki river as reported by Brakel (1984) and figures from Decurtins, et al., 1988 in the Ewaso Ng' iro River Basin provides the basis for analysing this flow. The assumption is then that the distribution of flow as a result of Kenya's so called "long rains" (March to May) and the "short rains" (November), is as follows: flow in January to February is roughly 598 million m^3/yr (4% of total yield); 7 475 million m^3/yr (50%) in March to May; 1 794 million m^3/yr (12%) in June to October; and 5 083 million m^3/yr (34%) in November and December. This is not an attempt to get accurate flow distribution for water from the whole montane area. Detailed flow distribution and flow duration analyses are beyond the scope of this project.

On the assumption that 28,427 ha of forest, deforested between 2000 and 2010, will be exposed to compaction and reduced infiltration, water to the land surface will increase by 81 million m^3/yr as a result of less ET. This "additional" water will basically all runoff as overland flow from the resultant compacted areas after conversion. It will therefore contribute to an increase in wet season flow.

Settlements in converted areas will result in significant water extractions specifically during the dry season when water is needed for subsistence crop cultivation. Based on the reported observations of localised streamflow reductions we assume that the long dry period flow from June to October can be reduced by 120% and the short dry season by about 70%. This means that wet season flows can increase significantly with consequent additional risk of flooding and higher sediment transport, which we deal with in the next session. It also means that dry season flow will diminish radically and even dry up for a few months in the long dry season.

An important further consequence of increased wet season flow is the fact that less water thus infiltrates and so reduces the water holding capacity of the catchment, either as ground water or soil water. This will on the long run further reduce base flow from the catchments. Abstractions through bore holes and open pits to maintain alternative crops exacerbate the water holding capacity problem.

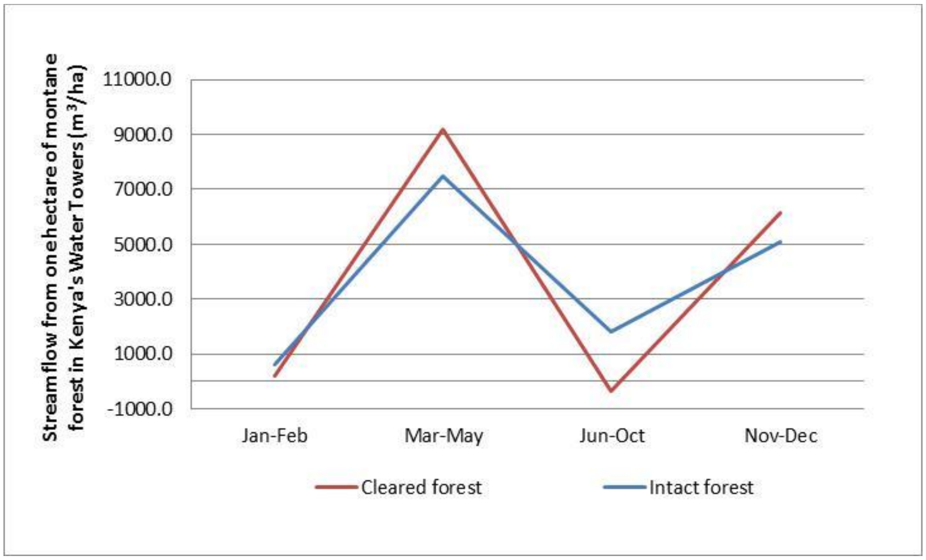

Figure 20. Changes in long term seasonal flow distribution off one hectare of intact and cleared montane forest areas in Kenya's Water Towers (adapted from Brakel (1988) and Decurtins (1984)). During the long rains season (March-May), increased runoff off deforested areas result in elevated sediment loads and reduced water quality in fresh water systems. During the low flow seasons, especially the 5-month period from June-October, reduced water availability become a limiting factor to economic activities.

Kenya's montane forest may have minimal direct regulation effects on major ground water aquifers, but there are several factors which may result in a gradual depletion of ground water resources. The fact that alternative land-use may reduce infiltration and increase peakflows will mean that more and more water will leave catchments as flash floods and less will infiltrate the soil to be released slowly to rivers and to replenish ground water. The possibility is also that lower dry season flows and perhaps even dried up rivers will result in more ground water extractions by means of boreholes to maintain water supplies for agricultural crops in converted forest areas.

13 Appendix 5: Erosion and sedimentation

Erosion and sedimentation reduce soil fertility, cause siltation of channels, reservoirs and dams and increase turbidity of water supplies. The World Bank (2006) point out that apart from the loss of storage volume in larger reservoirs, sedimentation has also affected numerous small dams and pans in the arid and semi arid lands of Kenya. In the 25 most drought-affected districts, there are 1,531 water dams and pans with a capacity of 27.9 million m^3 and 4,329 boreholes yielding 166,486 m^3 daily (UNEP/GOK 2000).

It is difficult to provide an accurate overall figure of erosion "protection" provided by montane forests, because erosion is very site specific and the consequence of interaction between many physical terrain factors such as slope, rain intensity, soils, vegetation cover, but also of land-management practices such as road making, burning and cultivation. Most experimental results from plot studies are also not applicable for up-scaling. Hamilton and Bruijnzeel (1997) quotes a figure of 1t/ha/yr for indigenous forest in the Etheopian Highlands. Ongwenyi, et al. (1993) reviewed data on sediment loss in Kenya and showed the high variation between regions. They summarised sediment yield over the period 1948 to 1965, calculated from suspended sediment samples and discharge records. Sediment yields ranged from as low as 8.2t/km2/yr in the Sagana basin above Kiganio, consisting mostly of forests on steep slopes, to as high as 3 100t/km2/yr in the Kambure, Nzoia basin between Kindaruma and Uaso Nyiro, under agriculture and grazing. They underscore the fact that sediment yields from undisturbed forests are "extremely low" and note that: "*The highest rates of soil loss are encountered in an area of very steep slopes on the eastern sides of Mt Kenya where cultivation is practised in the steep valley slopes in the upper parts and cultivation and grazing are occurring in the gentler but drier hillslopes in the lower marginal parts*".

Brakel (1984) gives an account of the distribution of sediment pulses in rivers throughout the year. They coincide with the wet season flows.

Considering the complexity of interaction of specific local condition and a host of external factors, it is impossible to get a remotely accurate figure of erosion and sediment yield increase as a result of forest clearing. Mogaka, et al. (2006) notes: "*The majority of eroded material is usually deposited en route, with only a small fraction reaching downstream storages. Consequently, the abundant literature on erosion and sediment loss from plot-scale studies cannot be used to estimate a measure of sedimentation unless coupled with studies in the water storage itself*". Considering in detail the influence of all the negative impacts on all the secondary activities in forest clearing is beyond the scope of this project and will not contribute to this exercise.

Taking results from various small scale studies we assume that poor management collectively will result in higher peak flows (see previous section) and on average cause additional sediment (and thus nutrient losses) of about 20 to 45t/ha/yr. Mogaga, et al. (2006) quote a figure of 1,500 tons of sediment per km^2 per year originating in the Masinga Dam (on the Tana River) catchment area.

Changes in seasonal flow as described earlier may however have further implications regarding the distribution of sediment. Higher wet season flows will result in sediment being transported further down the river systems and thus reaching more storages further down. The lower dry season flows resulting from increased water extractions will again encourage deposition of sediment in flatter areas even at higher elevations.

14 Appendix 6: The effect of deforestation on water quality

Deforestation in the upper reaches of catchments adversely affects the water quality of rivers and receiving water bodies. Soil physical properties, soil chemical properties, hydrology and water quality data indicate the drastic adverse effects from deforestation and intensive land use.

The consequences of deforestation include increased soil loss, increased runoff amounts and durations, increased occurrences of flashfloods, decreased soil fertility and increased nutrient losses which are all linked to the degradation of soil physical and chemical properties. Soil structure is an especially important physical property for it sustains bioactivity, regulates and partitions water and solute quantities and cycles and stores nutrient. High quality soils have well developed structure, low bulk densities (indicating pore spaces between micro-aggregates for water and air), high infiltration rates, high water holding capacities, and high soil organic carbon (SOC) content. Suspended loads in surface runoff, total water yield and dry season flow closely relate to the physical quality of the soil.

Soil chemical quality relates to the dissolved load in surface flow and seepage water as well as illuviation (vertical erosion). It might be concluded that the primary impact of deforestation is the degradation of soil structure with all other impacts secondary as a result of the degradation of soil structure.

Deforestation degrades soil structure in two ways: (1) the SOC content decreases resulting in the breakup of micro-aggregates (SOC typically found to decrease by 0,05 %/year) and (2) macro-aggregates breakup as a result of poor land use practices after land conversion. The impact of poor land use practices on soil structure is the increase in the proportion of micro-aggregates as compared to macro-aggregates. The results are compacted soils with increased bulk densities, decreased infiltration rates (increased penetration resistance) and decreased water-holding capacities. The water holding capacity typically decreases with between 25% and 63% with deforestation.

SOC is essential for good soil structure, low soil bulk densities and the production of humic and fulvic acids. Humic and fulvic acids are charged particles and colloidal in nature. These acids are essential for micro-aggregate formation (they function as a glue between soil particles) and high cation exchange capacities (CEC). The soils CEC represents the degree to which basic plant nutrients (Ca, Mg, K, Na) are retained in the soil rendering them unavailable for loss through leaching and maintaining a preferable basic soil pH. CEC also allows the adsorption of pollutants (agrochemicals) rendering them inaccessible to aquatic biota and humans. As SOC decreases, micro-aggregates may disperse (which could lead to crusting on the soil surface further decreasing the infiltration rate) and the soil CEC will decrease by approximately 0,48 cmol/kg/year. As CEC decreases, plant nutrients are no longer retained and they may leach from the soil resulting in salinization of receiving waters. Due to the decrease in plant nutrients, soil fertility decreases resulting in crop failures. The loss of plant nutrients may necessitate the application of fertilisers for improved crop production that may further impact on water quality. Soil pH will also decreases by 0,23 units/year due to the loss of basic cations further impacting crop production. Decreased soil CEC will also result in decreased retention of agrochemicals (herbicides and pesticides) rendering them available for human ingestion and possible toxic effects on aquatic-biota.

As a consequence of deforestation and soil physical property degradation suspended loads in runoff and seepage water increases, but loads however do decrease with time after deforestation (Figure 21). Figure 21 was constructed by using data from Lal (1995) for the annual suspended load in runoff years after deforestation. The typical %age decrease in suspended load in runoff after years of deforestation is 72,2%, 52,7%, 41,2%, etc.

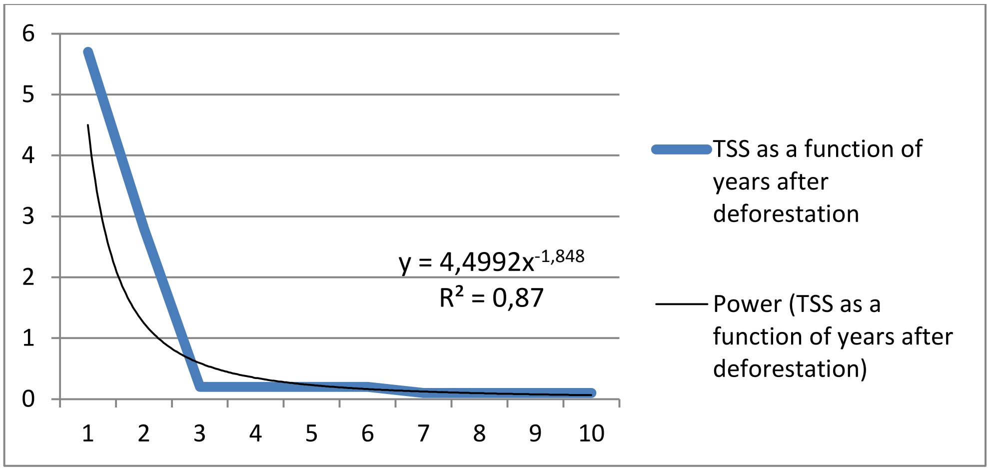

Figure 21. Change in sediment as a result of deforestation between 2000 and 2010.

Under natural conditions, freshwater ecosystems have the ability to self-regulate water quality. Deforestation induced erosion and sedimentation results in water quality degradation in the downstream catchment area, to levels that exceed the ability of the natural systems to purify and treat water. This is the result of both increased sediments loads and nutrients loads. Elevated sediment loads and nutrient levels reduce water storage capacity, and thus reduces water yield, reduces fish production and increases the cost of water treatment.

Sedimentation affects fisheries in a number of ways. It results in elevated levels of suspended solids in water and this causes increased water turbidity. Increased turbidity results in decreased light penetrability in the water, which in turn inhibits phytoplankton growth. Phytoplankton is an important element in the food chain for fisheries. Increased turbidity results in increased water temperatures due to the heat adsorbing characteristics of sediment particles, and this adversely affects aquatic biota by decreasing the amount of dissolved oxygen available and also by increasing the rate of biochemical reactions, which require more oxygen by fish. Fish therefore become oxygen derived. Turbid water also results in the abrasion of gill membranes and interferes with the feeding of visual feeders. Deposited sediments can also be harmful to fish habitats. Some of the impacts of increased sediment deposits on lake floors include the destruction of habitat of bottom-dwelling organisms such as crayfish and insects on which fish rely for food, the elimination of sheltered areas between boulders and gravel particles which young fish need for survival and the clogging of spaces between gravel particles that prevent the free flowing of oxygenated water and the removal of waste products from developing egg deposits in the gravel. The prevention of the exchange between oxygenated water and waste containing water often suffocates eggs resulting in their death and may even make gravel beds unsuitable for the future incubation of eggs (http://www.dfo-mpo.gc.ca/regions/central/pub/fact-fait-mb/mb6-eng.htm). The re-suspension of sediments from lake bottoms due to temporal stratified layer mixing or by flash flood incidences may re-introduce contaminants into the water system. These contaminants include adsorbed pollutants and nutrients that attached to deposited sediments.

Deforestation directly results in the increase of nutrients into receiving water bodies due to the degradation of soil properties. The main implications are the release of adsorbed basic cations, nitrates and phosphates due to decreased SOC and the transport of the soil particles and adsorbed nutrients due to the destruction of soil structure.

The introduction of plant nutrients, including nitrate nitrogen (NO_3-N), ortho-phosphates (PO_4-P), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and iron (Fe), into the water system taKSh place through various mechanisms. As discussed in Section 6 the decline in the soil CEC will result in the leaching of basic cations. Leaching is the transport of water vertically through the water column. The basic cations no longer retained by the soil due to the decreased CEC will dissolve in the water and will be removed from the soil column. Leached water may enter groundwater ultimately flowing into low lying water bodies or resurface at a lower point forming part of surface runoff. Ions may also become dissolved in surface water and may be removed from the system as part of surface runoff. The concentrations of nitrates in surface runoff and leached water is generally greater than the concentrations of phosphates due to the greater mobility of nitrates (higher solubilities) and the greater adsorption capacities of phosphates onto soil particles. The mechanisms for nitrate and phosphate loss from soils would therefore include leaching as dissolved solids, part of surface runoff as dissolved solids and transport by suspended particles as adsorbed nutrients.

The trophic state of a water body is defined as the total biomass weight in the water at a given time and gives a rough estimate of the biological condition (water quality) of the water body. The primary determinates of a water body's trophic state are the quantities of nitrogen and phosphorous for increases in these nutrients will result in increased plant growth (primary production) and the subsequent increase in the trophic level. For the purposes of this report only phosphorous will be considered as the limiting plant nutrient for it seems to be the key element influencing phytoplankton growth in inshore waters (Mugidde, 2001). Table 14 summarises the differences between water trophic states in terms of chlorophyll-a (representing the plant growth and and total biomass weight) and phosphorous concentrations (representing the plant growth limiting nutrient).

Table 14. Relationship between chlorophyl-a, phosphorous and primary production of trophic states.

Chlorophyll-a	Phosphorous	Trophic Class	Primary productivity
0—2.6	0—12	Oligotrophic	Low primary production Low nutrient content
2.6—20	12—24	Mesotrophic	Intermediate level of productivity Moderate nutrient content
20—56	24—96	Eutrophic	High primary production Excessive nutrient contents subject to algal blooms and decreased water quality
56—155+	96—384+	Hypereutrophic	Very nutrient laKSh Severe nuisance algal blooms

Increased nutrient loading in water systems increases the risk of eutrophication. Eutrophication is a result of algal blooms (biomass increase) from the plant growth limiting nutrients (NO_3-N and especially PO_4-P) now present in excess within the water system. Eutrophication results in decreased dissolved oxygen concentrations, due to the greater oxygen demand of the primary producers (algae), which result in fish kills. The formation of the algal mats on the water surface results in decreased light penetrability. Increased primary production will also result in increased hyacinth growth. Increased hyacinth growth will further decrease the water quality by the increase in organic material content of by plant material degradation and the resulting toxic conditions. Hyacinths also influence the accessibility of water as resource and negatively impacts on the fishing communities due to increased hiding places for fish and decreased sites of extraction. Cyanobacteria also flourish in the presence of increased accessible nutrients. Cyanobacteria produce toxic substances resulting in secondary water quality degradation.

The adverse effects of deforestation on water quality degradation were modeled by considering various previous studies on sediment and nutrient loading. The sediment load and nutrient additions into Lake Victoria as a result of deforestation was calculated by considering (i) the study on sediment load following deforestation by Lal (1995), (ii) the direct relationship for nutrient loading with associated sediment transport from “Regional Trans-boundary Diagnostic Analysis of the Lake Victoria Basin” (2007) and (iii) from the nutrient additions as dissolved solids investigated by Lal (1989).

Lal (1995) performed a study on the effects of deforestation on soil and nutrient loss from the watershed years after deforestation. From the data a %age decline in sediment delivery could be calculated for years after deforestation. This study is based on the continuous deforestation over a period of 10 years (2000-2011) resulting in sediment loss of 45 ton/ha/yr with a total land clearance of 28,427 ha.

Phosphorous loading was modeled from the estimation of soil erosion and associated sediment delivery assuming no soil management to reduce soil erosion on deforested land. According to a study performed by Zeng (2005) on the Loess Plateu in China, a direct relationship between sediment loss and nutrient load exists (Equation 3). The relationship was determined as

$$nutrient\ loss\ (kg.km^{-2}) = (\alpha) erosion\ intensity\ (ton.km^{-2}) \qquad \text{Equation 3}$$

with α the proportionality constant equal to 0,0053 for phosphorous loss and 0,1195 for nitrogen loss. However, during 2007 the East Africa Company, Lake Victoria Basin released the document “Regional Trans-boundary Diagnostic Analysis of the Lake Victoria Basin” presenting proportionality constants of 0,0076 for phosphorous and 0,032 for nitrogen in relation to sediment loss. These calculations are based on the proportionality constants obtained from the East Africa Company. Figure 22 illustrates the sediment as total suspended solids (TSS) and nutrient increases over the ten-year period of interest.

Phosphorous and nitrogen can also enter the water body in its dissolved state as part on runoff and leachate. The proportionality constants used to determine the quantity of nutrients in runoff are 0,008 kg P/ha and 0,5 kg N/ha as adopted from Kang and Lal (1981). The results for nutrient loading as part of sediment delivery and runoff are presented in Figure 22.

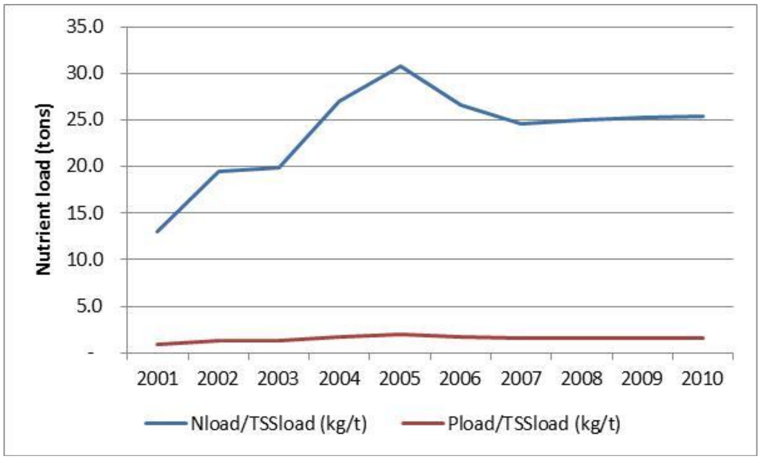

Figure 22. Nutrient load resulting from deforestation in Kenya.

14.1 The effect of deforestation on water services

Poor water quality resulting from increased nutrient content increases the cost of water treatment for urban and domestic use. These costs are borne by water treatment works operated by the Government of Kenya. Reduced water quality increases the costs of removing sediment and nutrient loads from treated water.

Nutrients in the form of nitrogen and phosphorous are removed from waters by employing treatment processes such as primary sedimentation, bio-filters and biological nutrient removal (BNR) processes which remove suspended solids, nitrogen (as NO_3-N) and phosphorous (as PO_4-P).

The cost of nutrient removal is estimated through a marginal abatement cost curve (MCA). An (MCA) consists of two parts, the cost of wastewater treatment with pollution loadings within the normal range of wastewaters (C_{ww}); and the cost of with pollutant load exceeding the normal pollution load ($C_{N,}$) (Equation 1).

Pollution load needs to be reduced for the total volume of water used by urban, rural and industrial water users. The resultant cost increase is KSh192 million in 2010, which is a 0.55% cost increase compared to the pre-deforestation scenario (Figure 16).

Equation 2. Equations that comprise the marginal cost of abatement curve for removing elevated nutrient loads in water treatment plants.

$$C_{ww} = Water\ demand\ (m^3.year^{-1})xTreatment\ cost\ (KSH.m^3)$$

$$C_{NP} = Water\ demand\ (m^3.year^{-1})xTreatment\ cost\ (KSh.m^3)x\left[\left(f_N\frac{N_{in}}{N_{out}}\right)+\left(f_P\frac{P_{in}}{P_{out}}\right)\right]$$

$$C_{NP} = C_{ww} + C_{NP}$$

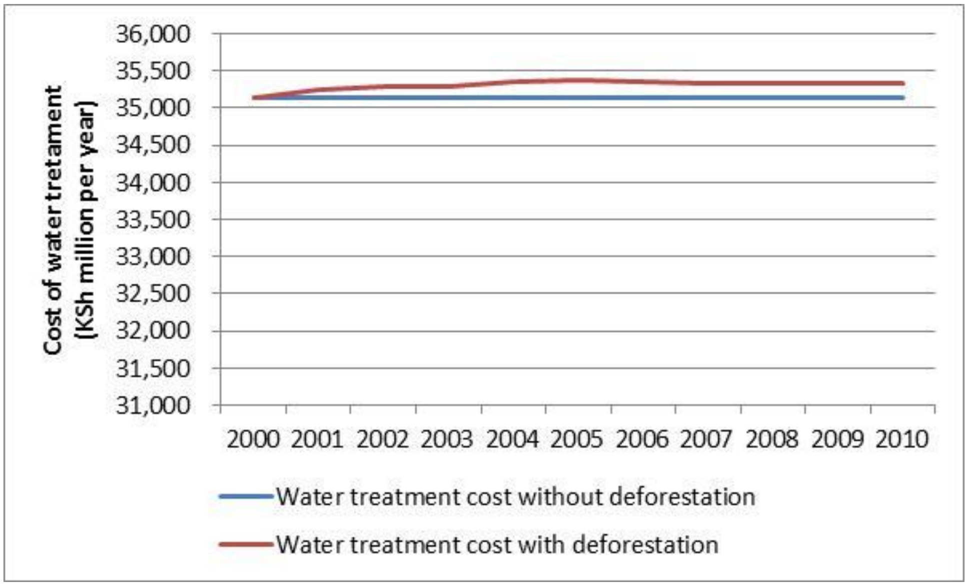

Figure 23. The cost of water treatment by government water schemes increase as a result of nutrient pollution due to deforestation. The resultant cost increase is KSh 192 million in 2010, which is a 0.55% cost increase compared to the pre-deforestation scenario.

15 Appendix 7: Disease Regulation

Deforestation has been linked to a change in a number of vectorborne diseases, largely due to changes in the vector-insect groups which transfer these diseases (Molyneux, 1997). Through the process of clearing forests and subsequent agricultural development, deforestation alters every element of local ecosystems including the microclimate, soil, and aquatic conditions, and most significantly, the ecology of local flora and fauna, including human disease vectors (Yasuoka and Levins, 2007). The prevalence and distribution of the vectors carrying the disease malaria (vector: mosiqutoe), leishmaniasis (vector: sand fly), onchocerciasis (river blindness) ((vector: black fly), schistosomiasis (bilhazia) (vector: fluKSh) and loaiasis (vector: deer fly) have all been shown to be impacted by deforestation. The malaria carrying mosquito however, is the vector-insect which is most sensitive to change in forest cover, with their density and distribution significantly influenced by small changes in environmental conditions (Yasuoka and Levins, 2007).

Since the late 1980s, a series of malaria outbreaks has occurred in the western Kenya highlands where malaria incidence were low (Zhou et al., 2007), due to low ambient temperature.
These highland areas, with an altitude greater than 1,500 m, were generally considered to have marginal climate conditions for malaria transmission (Afrane et al., 2006). Several hypotheses have been proposed to explain the increase in malaria in these highland areas, including

1) increased travel from the malaria-endemic Lake Victoria basin to the highlands (Shanks et al. 2002);
2) degradation of the health care infrastructure (Lindsay and Martens, 1998; Malakooti et al., 1998);
3) 3) antimalarial drug resistance (Shanks et al., 2000);
4) increased micro-climate variability (Zhou et al., 2004; Afrane et al., 2006; Minakawa et al., 2006; Zhou et al., 2007; Afrane et al., 2008); and

5) landuse changes (Lindsay and Martens, 1998, Minakawa et al., 2005; Tuno et al., 2005; Afrane et al., 2006; Munga et al., 2006; Munga et al., 2009).

In the last 10 years malaria has also been reported from residents on the west side of Mount Kenya, an area historically malaria free (Chen et al., 2006). Chen et al. (2006) attributes this recent increase to topography and changing microclimate, but also to a 25% increase in population over the past 20 years. With the increasing population on the highlands, enhanced human activities including deforestation, farming and livestock rearing could create more vector habitats.

The factors necessary for malaria transmission are threefold; (1) the presence of the Plasmodium parasite in the female mosquito, (2) the presence of the Anopheles mosquito vector, and finally (3) the presence of a human host (Malakooti et al., 1998). Both temperature and rainfall have been shown to affect the presence of all three of these transmission factors. A mosquito ecology study in the highlands of Western Kenya reported that mosquitoes in houses in the deforested area showed a 64.8–79.5% higher fecundity than those in houses located in the forested area (Zhou et al., 2007). According to the report female mosquitoes in the deforested area showed a 38.5–40.6% increase in net reproductive rate and an 11.6–42.9% increase in intrinsic growth rate than those in the forested area. In addition, larvae-to-adult survivorship was only 2% for habitats in forested areas, whereas the larval survivorship exceeded 49% in habitats located in the farmland and larvae from forested habitats took a much longer time to develop into adults than those from farmland habitats (three weeks versus two weeks) (Zhou et al., 2007). All these changes could be attributed to increases in the water temperature of larval habitats, ambient temperature and a combination of topography and rainfall patterns. Small changes in climate may therefore provide suitable conditions for transmission of malaria in populations which general do not have functional immunity to the disease (Hay et al., 2002).

Although climate factors can increase malaria transmission, the outcome of the clinical disease depends on the level of immunity of the infected person, how early the disease is treated, and the effectiveness of the antimalarial drugs (Githeko and Ndegwa, 2001).

The transmission of malaria has been described in mathematical terms as the vectorial capacity, the number of new mosquito infections daily that arise from one infected individual in a non-immune population if all the biting mosquitoes become infected (Githeko and Ndegwa, 2001).

$C = Ma^2p^n/-\log_e p$

C = vectorial capacity
Ma = composite index of the daily mosquito man-biting rate
a = daily mosquito man biting habit, how often the mosquito feeds on man in a day (24 hours):

a= HBI/b (HBI = human blood index; b= interval between blood means in days)

p = probability of the vector surviving through 1 day (24 hours):

$p=P^{1/b}$ (**Eq 6**) (P equals the proportion of females that have laid eggs or the parity rate and a function of the daily survival probability of p. Changes in the probability of survival, p, has a large effect on C as p is raised to the power n in the numerator and as a log in the denominator in Eq. 4.

n = parasites extrinsic incubation period – the duration it taKSh the parasite to develop, mature and become infectious in the mosquito:

n= T/t-t_{min} (Eq 7) (where T is the constant (thermal sum), 111 , for *P. falciparum,* t is the actual mean temperature and t_{min} 16.5-18^{o}C (temperature in degrees centigrade) during the incubation period, n. Because n has an exponential effect on C, small changes in temperature will have a great effect on malaria transmission)

According to the Macdonald's formula for vectorial capacity, all of the above transmission parameters are affected by temperature. Afrane et al. (2008) demonstrated these effects on the transmissions parameters of forested and deforested areas (Table 15). Deforestation, through changes in micro-climate has been shown to:

1. **increase the female mosquito density (m)** relative to humans from 3.05 mosquitoes/person/day in the highland forested area to approximately 4.64 in the highland deforested area and ≈8 in the lowland site .
2. **increase the number of daily mosquito man biting habit (a)** (i.e. how often the mosquito feeds on man in a day (24 hours)) from 0.198 in forested sites to 0.233 and 0.465 in the deforested areas of the highlands and lowlands. This is attributed to a higher ambient temperature which facilitates blood meal digestion in the mosquito and thus increasing the blood feeding frequency (Afrane et al., 2006).
3. **reduce the sporogony (n)** of mosquitoes from 13.9 days to 12.8 days in deforested highland areas. Sporogony is the development of malaria parasites in mosquitoes (sporogony), usually the time it taKSh from ingestions of the malaria parasite gametocytes by the anopheline mosquitoes to the point where the sporozoites in the salivary glands in the mosquito are ready for transmission to the next human host (Afrane et al., 2008). This incubation period is usually inversely correlated to temperature, with a small increase in temperature resulting in a shorter development process.

Table 15: Estimated vectorial capacity of *Anopheles gambiae* mosquitoes in forested and deforested areas, western Kenyan highland and lowland* (Source: Afrane et al., 2008

Site	Land use type	*m*	*a*	*N*	*P*	Vectorial capacity
Highland	Forested	3.05	0.198	13.9	0.927	0.54
Highland	Deforested	4.64	0.233	12.8	0.917	0.96
Lowland	Deforested	7.85	0.465	11.7	0.923	8.3

**m*, relative density of vectors in relation to humans; *a*, average no. children bitten by 1 mosquito in 1 day; *n*, duration of sporogony in days; *P*, proportion of vectors surviving per day.

These, together with other parameters that are also influenced by deforestation, such as enhanced survivorship translates into an increase in vectorial capacity of *An. Gambiae* mosquitoes by 77.7% (Afrane et al., 2008). There is thus significant clinical and ecological evidence to support this statement of the negative effect of deforestation on malaria infections in Kenya (Lindsay and Martens, 1998, Malakooti et al., 1998; Zhou et al., 2004; Afrane et al., 2006; Minakawa et al., 2006; Zhou et al., 2007; Afrane et al., 2008; Minakawa et al., 2005; Tuno et al., 2005; Afrane et al., 2006; Munga et al., 2006; Munga et al., 2009).

In Kenya clinically diagnosed malaria is responsible for 30 % of outpatient consultations, 15 % of hospital admissions, and approximately 3.5 % of inpatient deaths in endemic areas. About 8.9 million malaria cases were reported in 2006 (HMIS 2008; Republic of Kenya, 2011). The country is divided into four malaria eco-zones (Figure 23) seasonal malaria 3) highlands prone to malaria epidemics, and

4) malaria free (Central Bureau of Statistics, Ministry of Health and ORC Macro, 2004). On the basis of malaria risk data and the eco-epidemiology of malaria , Kenya district have been stratified in Figure 23 into four malaria zones (Division of Malaria Control, Kenya National Bureau of Statistics and ICF Macro., 2011):

1. Endemic lake and coastal regions (risk class equal to or above 20 %) (Nyanza, coast, and western provinces);
2. Epidemic-prone highland districts (risk class 5 to less than 20 %) (mainly in Rift Valley Province and some parts of Nyanza Province);
3. Seasonal transmission risk districts (risk class less than 5 %) (central, eastern, and north eastern Provinces);
4. Low-risk districts (risk class less than 0.1 %) (Nairobi and some parts of central Province).

Of particular interest to deforestation and the disease regulations services of forest is the highland epidemic prone areas. Malaria in this area is seasonal, with considerable year-to-year variation. Climate conditions need to be favourable for malaria transmission, with a minimum temperature of around 18°C required (Malakooti et al., 1998), usually occurring during the long rains of April-June every year. The whole of this population is vulnerable as it is believed that the population have little functional immunity to malaria (Hay et al., 2002), resulting in case fatality rates of up to ten times greater than those experienced in regions where malaria occurs regularly (Division of Malaria Control, Kenya National Bureau of Statistics and ICF Macro., 2011).

Figure 24: Map of the four malaria zones of Kenya (source: Division of Malaria Control, Kenya National Bureau of Statistics and ICF Macro., 2011)

16 Appendix 8: The effects of deforestation on irrigation

The agriculture and forestry sector of Kenya is by far the largest economic sector and contributed between 25% and 30% to GDP in the period 2000-2010 (Figure 24) (Republic of Kenya, 2010).

GDP growth in the agriculture sector is highly sensitive to favourable weather conditions, agriculture input costs (e.g. seeds and fertilizers), and agricultural commodity prices (Oparanya, 2011). Table 16 provides econometric evidence of these relationships. The FAO food price index, cost of agricultural inputs and rainfall in the year preceding, explains 98% of the variation in agricultural input.

As a result, the Government of Kenya has introduced numerous policy interventions to reduce agricultural input costs. This includes for instance the Economic Recovery Strategy in 2003 and the Strategy for Revitalizing Agriculture (SAR) in 2004. Severe droughts in 1999-2000; 2005-2006, 2009 and again in 2011 reduced agricultural output and demonstrate the vulnerability of agriculture to rainfall.

Table 16. GDP growth in the agriculture sector in Kenya is highly sensitive to favourable weather conditions, agriculture input costs, and agricultural commodity prices. This table provides econometric evidence of these relationships. The FAO food price index, cost of agricultural inputs and rainfall in the year preceding, explains 98% of the variation in agricultural input.

Dependent Variable: LN(AGRICULTURAL OUTPUT (t))			
	Coefficient	t-Statistic	Prob.
LN(FOAFOOD Index) (t-1)	1.44	5.75125	0.0289
LN(INPUT Cost) KSh million (t-1)	1.53	3.495771	0.073
RAINFALL (mm/yr (t-1))	0.00030	1.92049	0.1948
C	-20.41	-3.198153	0.0854
Adjusted R-squared	0.980		

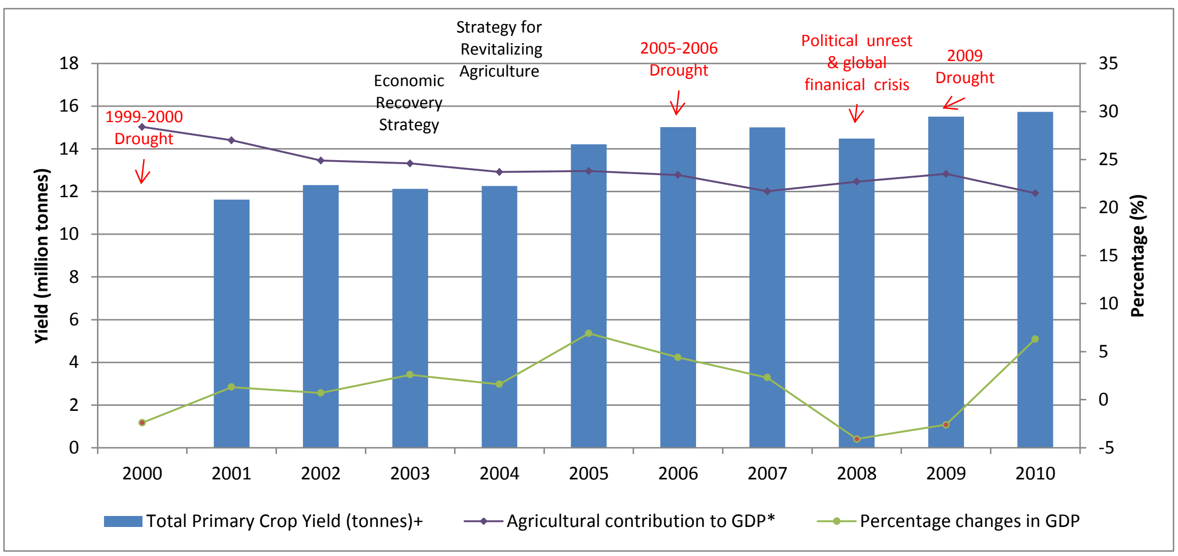

Figure 25: Agricultural statistics and shocks between 2001 and 2010

Although agricultural output in Kenya is dominated by rainfed agriculture, the irrigation sector still plays an important role, and has the potential to grow significantly in future. Of the total land area under agriculture, irrigation accounts for only 1.7% although can provide up to 18% of the value of all agricultural produce (Republic of Kenya, 2010).

Irrigation is principally practiced along the lower reaches of Tana River and in Elgeyo-Marakwet, West Pokot and Baringo district. Irrigation agriculture in Kenya consists of three types of irrigation based on the size, management and ownership of the farming unit: smallholder irrigation schemes; private irrigation schemes; and public irrigations schemes (Table 17). These irrigation schemes vary in size from 5 to 400 ha, although the bulk ranges in size between 50-100 ha (Republic of Kenya, 2009). Large commercial farms account for 40 % of irrigated land, smallholder farmers 42 %, and Government-managed schemes 11 % (Republic of Kenya, 2010) (Table 17). During the years between 2003 to 2007, the irrigated area experienced an increase, chiefly in the smallholder and private sector scheme. Table 18 shows that public irrigation schemes recorded positive growth in 2010, with the area under cultivation almost doubling from 10,072 ha in 2009, to 17,611 ha in 2010.

Irrigation crops include rice (22% of the irrigated area); food crops (25% of the irrigated area) and horticulture crops (53% of the irrigated area) (Republic of Kenya, 2009). Horticulture crops are more common in Mt Kenya region in central and eastern provinces and in the coast province. The horticulture export industry in Kenya has shown declining performance since 2008 due to the global economic recession effect on the international markets for these products. This reduction in export volumes was mainly driven by the significant drop in export volumes of cut flowers, largely due to market limitations and interruptions in air traffic over Europe in 2010 due to poor weather.

Various publications (World Bank 2006, UNEP 2006) report irrigation water requirements for 2010, but these are all based on estimates done in 1990, at the time of development of the Kenya Water Master Plan. Data from various sources suggests that the 2010 irrigation area comprises 121,411 ha with a total water requirement of 1,434 million m^3 (Table 18). The output of irrigation was approximately KSh 28,672 million, which was 9.3% of total agricultural output.

Table 17. Types of Irrigation Schemes in Kenya (Source: Republic of Kenya, 2009; Thairu, 2010)

Type of irrigation scheme	Features
Smallholder (community based) irrigation scheme	They are owned and managed; The general management of these schemes is done by the Ministry of water and Irrigation.
Private Schemes	These scheme are located mostly in close proximity to the Thika River, Lake Naivasha, Athi basin and Nanyuki. Generally individual medium to large-scale farms growing export-oriented crops such as coffee, pineapples and flowers. Input cost are generally high and this type of farming requires intensive management. These private irrigation schemess account for 70% of the drip and sprinkler irrigation systems in the country
Public or 'national' Schemes.	Developed, and are managed by the Government, mostly via the National Irrigation Board (NIB). Two categories of public scheme exist, namely (1) centrally controlled, tenant-based schemes manage by the government, with plots allocated to the tenants and inputs provided to them; and (2) regional authority owned and managed schemes. There are seven public irrigation schemes in Kenya namely: • Mwea (in Central province growing rice), • Ahero and West kano (in Nyanza province growing rice), • Bunyala (in Western province growing rice), • Bura (in Coast province growing cotton), • Hola (in Coast province growing cotton) and • Perkerra (in Rift valley province growing horticulture that is chillies/onions and maize)

Table 18. The estimated irrigation water use in Kenya in 2010 was 1,434 million m^3. This was estimated based on irrigation areas for smallholder, national and private schemes and estimating average water use per ha for crops as set out below.

Irrigation water use	Irrigated area (2010)	Ave water use	Total Water Use		
	ha	m^3/ha	million m^3	**Commodities grown***	**Irrigation type***
Smallholder schemes	54,800	10,000	548	Rice, Maize, Horticulture	88% surface; 9% sprinkler; 3% drip
National schemes	17,611	22,500	396	Cotton, Rice, Horticulture, Seed Maize	surface irrigation
Private schemes	49,000	10,000	490	Coffee, pineapples, cut flowers	drip irrigation and sprinkler
Total	**121,411**	**11,813**	**1,434**		

Sources:
Republic of Kenya 2009. Irrigation and drainage master plan
Thairu (2010) Agricultural Production and Irrigation Management: The Case of Irrigated Rice Production in Kenya
Republic of Kenya (2007) Vision 2030
KNBS Various Economic Surveys (2003; 2008; 2011)
Ministry of Water and Irrigation - Department of Irrigation and Drainage – 2010

Deforestation at a rate of 2,762ha per year between 2000 and 2010 would reduce available (mostly low flow) water by 62 million m^3 per year by 2010. Irrigation usually has the lowest assurance of supply of all water users and it can thus be assumed that this reduced water yield will directly reduce irrigation agriculture. Thus due to deforestation between 2000 and 2010, Kenya had forgone the opportunity to cultivate 5,287 ha of irrigation agriculture.

An irrigation production function can be estimated from data obtained from the KNBS. Irrigation output is affected principally by the area under irrigation and the cost of agricultural inputs. By applying an agricultural production function for 2010 (Table 19), it can be concluded that irrigation output in 2010 had reduced by KSh1,499 million as a result of decreased water availability due to deforestation (Figure 25).

Agricultural output in Kenya is largely dependent upon rainfed agriculture, and the irrigation sector is relatively poorly developed. As a result, a number of policies (i.e. Vision 2030; Medium Term Plant 2008-2012, Irrigation and Drainage Master Plan) have identified future irrigation expansion as important to unlocking the agricultural potential of the country (Republic of Kenya, 2009). The consequences of reduced water availability and poor water quality can therefore be significantly more detrimental to agricultural output in future.

Table 19. Irrigation output production function developed using KNBS data

Dependent Variable: LN(Irrigation output)			
	Coefficient	t-Statistic	Prob.
LN(Input cost index)	-0.41307	-3.214577	0.0236
LN(Irrigated area)	1.195254	115.7301	0
Adjusted R-squared	0.812566		

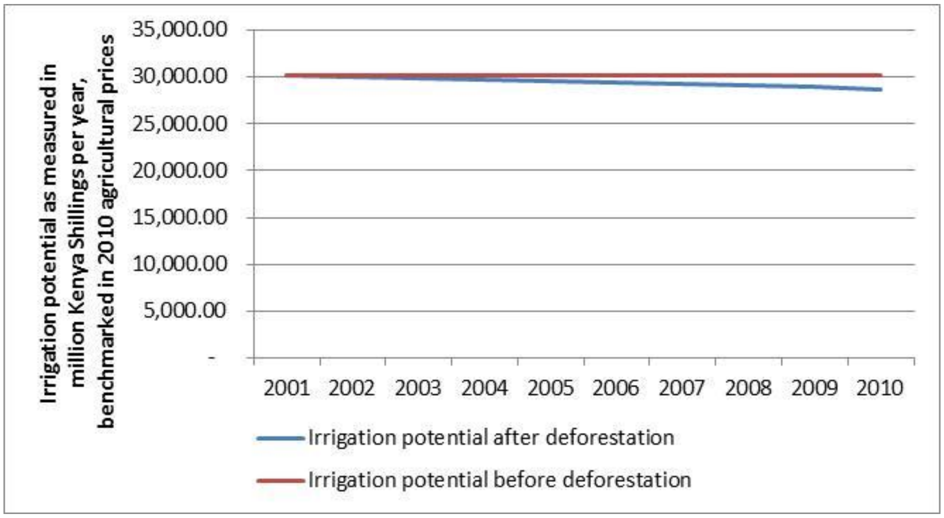

Figure 26. Irrigation potential in Kenya reduces as a result of deforestation. This is because of lower assurance of water supply to irrigation, due to low season reduced runoff from the Water Towers. The irrigation sector output lost in 2010 is estimated at KSh 1,499 million.