



RWANDA NATURAL CAPITAL ACCOUNTS – ECOSYSTEMS



Version 1.0
November 2019



The Rwanda Natural Capital Accounts for Ecosystems have been compiled, designed and published by the National Institute of Statistics of Rwanda (NISR), the Ministry of Finance and Economic Planning (MINECOFIN) and the Ministry of Environment (MoE) with assistance from the World Bank and the WAVES Global Partnership. Additional information about the NCA Ecosystems 2019 may be obtained from:

NISR: KN, 2 Av, 36, P.O.Box 6139, Kigali Rwanda; Telephone: +250 252 571 035

Website: www.statistics.gov.rw

Email: info@statistics.gov.rw

Ministry of Finance and Economic Planning (MINECOFIN): P.O.Box 158, Kigali, Rwanda

Ministry of Environment: P.O. Box 3502, Kigali Rwanda; Telephone +250 788 305 291

Website: www.moe.gov.rw

Contents

Figures	5
Tables.....	5
Acknowledgements.....	6
Executive summary.....	7
Acronyms and Abbreviations	12
1. Introduction.....	13
1.1. Background.....	13
1.2. Objectives of the report.....	15
2. Water and soil policy issues in Rwanda.....	19
2.1. Water and soil policy issues.....	19
2.2. Implications for strategic economic sectors.....	20
2.3. Ongoing challenges.....	20
2.3.1. Seasonal water shortages	20
2.3.2. Flooding and road infrastructure damage	21
2.3.3. Productive soil loss	21
2.3.4. Sedimentation of waterways and threats to water quality and hydro-energy generation infrastructure.....	21
2.4. Emerging opportunities.....	21
2.4.1. Cooperative governance.....	21
2.4.2. Water storage without Nile Basin negotiations.....	22
3. Key findings.....	22
3.1. Soil erosion	23
3.1.1. Trends in national potential soil erosion.....	23
3.1.2. Soil loss (or sediment exports).....	25
3.2. Water yield and quickflow.....	27
3.2.1. Trends in national water yield and quickflow.....	27
3.2.2. Catchment water yields.....	31
3.2.3. Water yield per hectare	32
3.3. Baseflow	33

3.3.1. Trends in national baseflow	33
3.3.2. Baseflow per catchment	35
3.3.3. Baseflow per hectare	36
4. Policy implications and recommendations	38
4.1. Strategic implications of soil erosion and soil loss accounts	38
4.2. Strategic implications of the water yield, quickflow and baseflow accounts	38
4.3. Strategic recommendations for enhancing soil and water security	41
4.3.1. Promote sustainable land use management practices	41
4.3.2. Mobilize financing for the implementation of Rwanda’s Forest Investment Plan	41
4.3.3. Operationalize natural resource-based fee collection system for improved catchment management	41
4.3.4. Explore natural resource-based fee collection system for improved catchment resilience across landscapes, through innovative insurance schemes	42
4.3.5. Improve land use planning in targeted areas	42
4.3.6. Implement planned basin-wide flood and environment management programs	42
4.3.7. Promote catchment planning in targeted areas	42
4.3.8. Promote sustainable or green urbanisation	43
Annex 1: Methods	44
Annex 2: Data used in the accounts	46
Annex 3: Soil erosion	49
Annex 4: Soil loss (sediment export)	51
Annex 5: Annual water yield	53
Annex 6: Baseflow	55
Annex 7: Quickflow	57

Figures

Figure 1: Total wealth per capita in Rwanda US\$21,619 (2014) (with natural capital broken down to show contribution of different resources) (Source: Lange <i>et al</i> 2018).....	13
Figure 2: The land cover of Rwanda and boundaries of nine major catchments in Rwanda.....	16
Figure 3: The catchments of Rwanda	17
Figure 4: The district boundaries of Rwanda in relation to catchment boundaries.....	18
Figure 5: Potential soil erosion per catchment in 2015.....	24
Figure 6: Potential soil erosion per hectare per catchment in 1990, 2000, 2010 and 2015.....	25
Figure 7: Potential soil erosion in 2015 (per 30mx30m pixel)	26
Figure 8: Annual water yield in 2015	28
Figure 9: Relative contribution of catchments to national water yield in 2015	31
Figure 10: Relative water yields per hectare and their trends per catchment (in m ³ /ha/per year)	32
Figure 11: Seasonal mismatch between water demand and supply (as yield) in Rwanda	34
Figure 12: Baseflow per catchment (2015).....	36
Figure 13: Quantities and trends in baseflow per hectare for 1990, 2000, 2010 and 2015.....	37
Figure 14: Changes in water-related ecosystem services from 1990 to 2015 (billion m3). Baseflow and Quickflow generally sum to total water yield.....	39

Tables

Table 1: National potential soil erosion for 1990, 2000, 2010 and 2015 (positive changes show an increase in erosion and negative changes show a decline in erosion).....	23
Table 2: Sediment exported to water bodies in 1990, 2000, 2010, 2015 (positive changes show an increase in exports and negative changes show a decline in export)	25
Table 3: National annual water yield in years 1990, 2000, 2010 and 2015	27
Table 4: National annual quickflow in years 1990, 2000, 2010 and 2015.....	29
Table 5: District changes in Quickflow between 1990 and 2015	30
Table 6: National baseflow as a proxy for groundwater recharge	35
Table 7: Changes in the extent of land cover types 1990 to 2015	40

Acknowledgements

The Rwanda Natural Capital Accounts (NCA) for Ecosystems have been prepared through a collaborative effort of Ministry of Environment (MoE), its affiliated agencies of Rwanda Environment Management Authority (REMA) and Rwanda Water and Forest Authority (RWFA), National Institute of Statistics of Rwanda (NISR) and Ministry of Finance and Economic Planning (MINECOFIN). The Technical Working Group included Marie-Laetitia Busokeye (REMA), Dukuze Marie Dalie (REMA), Alexis Nizeyimana (REMA), Emmanuel Habimana (REMA), Valens Uwizeyimana (MoE), Theophile Dusengimana (MoE), Vital Munyandinda (RWFA), Philippe Kwitonda (RWFA), Felix Rurangwa (RWFA), Jean Claude Mutabazi (RWFA), Anastase Nyandwi (RWFA), Jean Claude Hafashimana (RWFA), Alphonsine Nambazimana (RWFA), Vellen Byandaga (RWFA), Dismas BAKUNDUKIZE (RWFA), Mr. Kayitare Patrick Ivan (NISR), Mr. Ephrem Rutagarama (NISR), Eng. Bisangwa Innocent (MINAGRI), Jean Niyigaba (NISR), Eng. Coletha Ruhamyia (REMA), Prime Ngabonziza (RWFA), Faustin Munyezikiwiye (REMA), Marc Manyifika (MoE) and Tetero Francois (RWFA).

Many institutions and individuals have contributed to the compilation of this volume and their support is gratefully acknowledged. The work was supported by the World Bank, University of Rwanda and Netherlands Statistics. The team included, Pablo Cesar Benitez, Timothy H. Brown, Myles Mander, Kenneth Bagstad, Evariste Rutebuka, Emmanuel Rukundo, Aimable Nyirinkindi, Peter Katanisa, Aussi Sayinzoga, Francois Naramabuye, Jean Pierre Bizimana, Sofia Elisabeth Ahlroth and Belinda Mutesi. The World Bank supported this effort with funding provided by the Wealth Accounting and Valuation of Ecosystem Services (WAVES) Global Partnership.

Executive summary

The Government of Rwanda’s strategic development plans emphasize the importance of environment protection, natural resource management and climate change preparedness. Natural Capital Accounts (NCA) are an important tool for tracking progress on socio-economic, environment and natural resource indicators. Natural Capital Accounting brings together information on how natural resources are contributing to the economy – information on resource stocks and flows, uses and users, scarcities and potentials – to improve development decisions. By design, NCA is linked to the System of National Accounts that helps to integrate natural resource use into economic development planning.

This process is guided by a Steering Committee led by the Ministry of Finance and Economic Planning (MINECOFIN), and its affiliated agency, National Institute of Statistics for Rwanda (NISR) together with the Ministry of Environment (MoE) and including members from the Ministry of Infrastructure, Ministry of Agriculture, Rwanda Development Board, and others. Since 2014, this Government-led initiative has been supported by the World Bank’s WAVES Initiative (<https://www.wavespartnership.org/>) following the UN Statistics Division’s (UNSD) System of Environmental Economic Accounting (<https://seea.un.org/>) of integrating NCA with the System of National Accounts.

Rwanda has developed Natural Capital Accounts for land, water, minerals and – with this document – ecosystems. The Land account document was published in March 2018; the water account document was validated in May 2019 (in process of being published); The Mineral Resources and Ecosystem Accounts are now being validated.

The objectives of the ecosystem accounts are to:

- Outline how ecosystems, as a form of capital in Rwanda, are changing over time,
- Identify how some of their associated ecosystem services are changing,
- Identify the implications of these changes for Rwandan society, and
- Make strategic recommendations for government to plan and manage future stocks, flows, risks and opportunities associated with ecosystems and natural capital.

The NCA approach helps to integrate natural resources into economic analysis and can provide a broader picture of development progress by providing consistent, reliable data to support economic assessments and sound policy formation. The ecosystem accounts build on the prior land and water accounts, using land cover analysis for the years 1990, 2000, 2010, and 2015 coupled with modelling of soil and water variables that describe landscape processes and ecosystem services.

Relevance of the ecosystem accounts

The ecosystem accounts shed light on some of the key natural resource management challenges facing the country over the 25-year period covered in this analysis. The ecosystem accounts introduce several new indicators that help to focus on landscape processes that influence soil erosion, soil loss, water flows (“baseflow”) and water run-off (“quickflow”). These indicators help to describe soil erosion and water flows in the landscape, which have impacts on economically important ecosystem services, including dry season water availability, flooding risk reduction, soil fertility and sedimentation avoidance. These ecosystem services, in turn, support hydropower, irrigation, drinking water and crop production.

Some 70 percent of the Rwandan population is rural, and 90 percent of cropland is located on steep slopes, generating a national dependence on vulnerable landscapes. Furthermore, a rapidly growing rural population relies on smaller and smaller land holdings on which to generate farm livelihoods, contributing to the need for more intensive production on vulnerable slopes. This can lead to unsustainable farming practices that contribute to soil degradation with the result that the soil nutrient balance in Rwanda is one of the most negative in Africa. The Government recognizes these threats and is implementing landscape management and restoration efforts, as well as an extensive terracing programme.

The combination of steep topography, inappropriate soil management practices with soil compaction and high intensity rainfall, leads to reduced water infiltration into the soil and accelerated rainwater run-off. The reduction in soil water infiltration reduces soil water available for crop production, dry-season stream flow and springs. The accelerated run-off is high erosive, washes away surface soil and elevates downstream flooding risks. It also washes the soil nutrients and clay out of the eroding soil and discharges them into rivers. The combined loss of agricultural soil, fertility and soil moisture contributes to declining crop productivity, which reduces food security. The discharge of clay and nutrients into rivers reduces water quality, biodiversity, dam storage capacity and hydropower capacity.

Rwanda has been endowed with abundant freshwater resources. However, the assurance of water resources supply is becoming more variable, with elevated flooding, more frequent drought periods and declining water quality. The widespread unsustainable cultivation practices in the steep topography of Rwanda reduce the ability of stream catchments to produce beneficial environmental services, including dry season flows, erosion control, slope stability and flood risk reduction.

A declining supply of water quantity and quality, when combined with a growing population and economy, will significantly elevate risks to households, enterprises and biodiversity. Rwanda's water security is highly sensitive to catchment degradation, as well as climate change variability, which may affect the frequency, seasonality, and intensity of rainfall events. Rwanda's challenge is to develop more resilient catchments that will be able to withstand both global shocks and greater local pressures.

Findings for soil

In 2015 approximately 158 million tonnes of soil were eroded (that is, soil that moved down slopes and/or onto wetlands), with an annual average of 62 tonnes per hectare or 13 tonnes per citizen per year. The trend since 1990 shows that soil erosion has increased by 54%. The levels in intensity of soil erosion across the Rwandan landscape are outlined in Figure 1. Annual soil loss (largely clay and nutrients that has been deposited into rivers) was 14 million tonnes with an average of 5.5 tonnes per hectare. Soil loss has increased 123% from 1990 in 2015.

The strategic implications of increasing soil erosion and soil loss are a threat to food security, due to declining soil fertility, increasing fertiliser costs (and imports) and result in food price increases. Declining soil quality and quantity contribute to increased food security risks, for both for farming households and urban consumers.

Increasing soil loss trends contribute to soil nutrient exports to downstream rivers and downstream countries, while also elevating the need for imported fertiliser to maintain soil fertility. Soil loss also elevates the risks to water security due to pollution of rivers and risks for energy security due to sedimentation of dams, filling dam storage space and reducing water storage volumes, and accelerating turbine erosion. The loss of storage capacity and elevated turbine erosion result in greater energy generation costs, while water volume available for generation decreases.

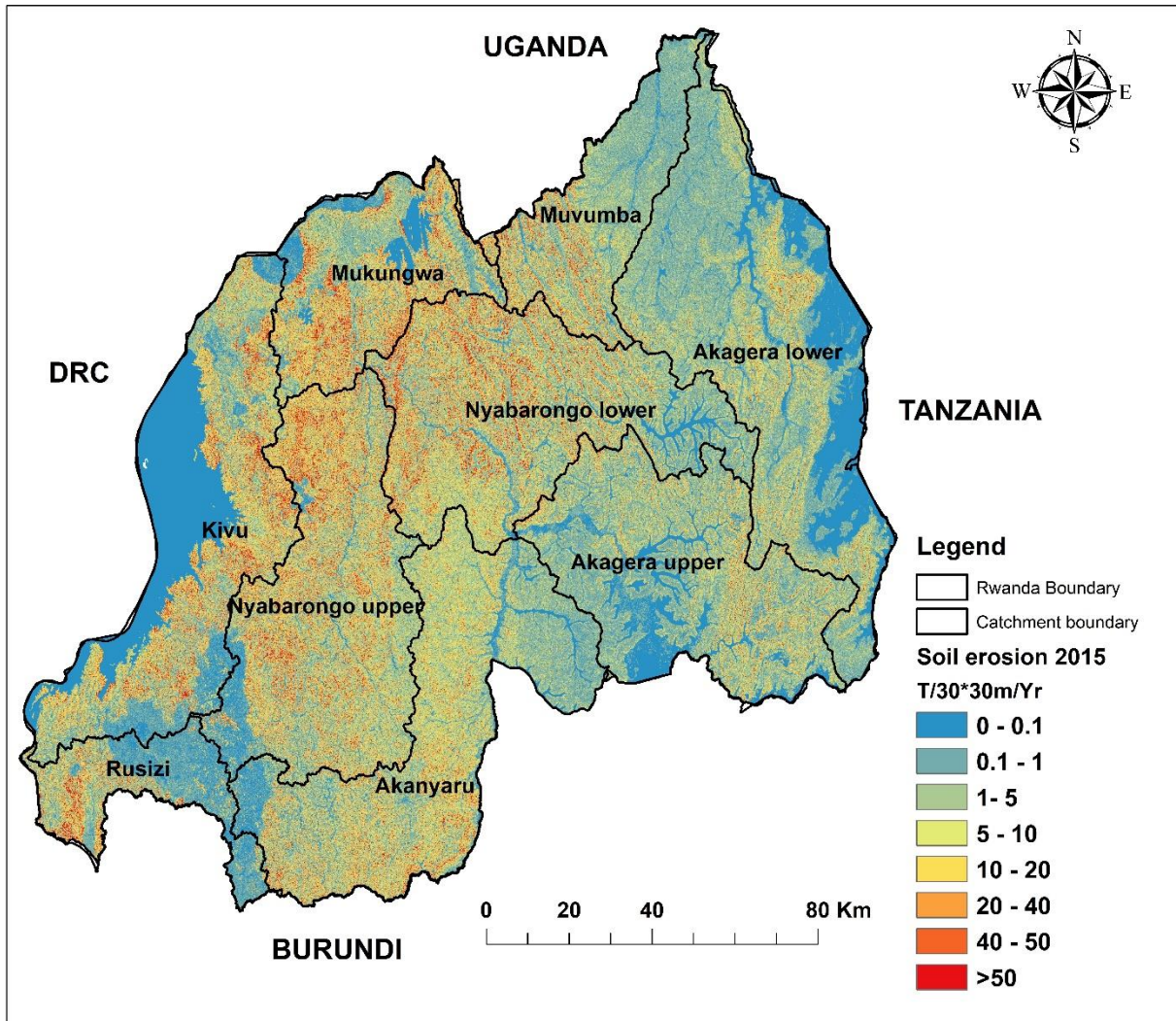


FIGURE 1: THE INTENSITY OF SOIL EROSION IN 2015 (PER 30MX30M PIXEL)

Findings for water

Over the 25 years of this analysis since 1990, the national water yield (water with potential for abstraction or in-stream use) has not changed very much, increasing only slightly by 4 percent. This modelling analysis examined two key aspects of water flows over time:

- *Quickflow* is water that runs off quickly during and just after storms. Quickflow (or also called run-off) is a measure of fast-flowing water that contributes to flooding, poor water quality, soil erosion, soil loss and biodiversity loss.
- *Baseflow* refers to water flows that comes from local recharge of soil moisture and aquifers, which is then slowly released as surface water. Baseflow is an important measure because it becomes available to supply water, especially in the dry season.

The trends in quickflow and baseflow are shown in Figure 2. These two measures are moving in opposite directions over time, while overall yield has risen slightly. Over the study period, quickflow has increased by 35 percent, while local recharge that supplies baseflow declined by 11 percent.

Rwanda has limited capacity to capture and store the water in large dams, thus there is little benefit from the increase in quickflow. The increase in quickflow indicates a trend of increasingly erratic and potentially destructive levels of run-off to surface water bodies, which is less suited to meeting a relatively constant consumer demand throughout the year. Related peak flows can generate high costs in terms of flooding.

Rwanda’s reliance on run-of-river water use implies the need for a constant, year-round flow to meet consumer, energy and irrigation demands. At the same time, the declining baseflow trend indicates there is a less steady flow available in rivers at the same time as water demand is rising from Rwanda’s developing agriculture, urban and consumer needs¹. A declining baseflow signals the growing risk of seasonal water deficits, trends which may grow in the future.

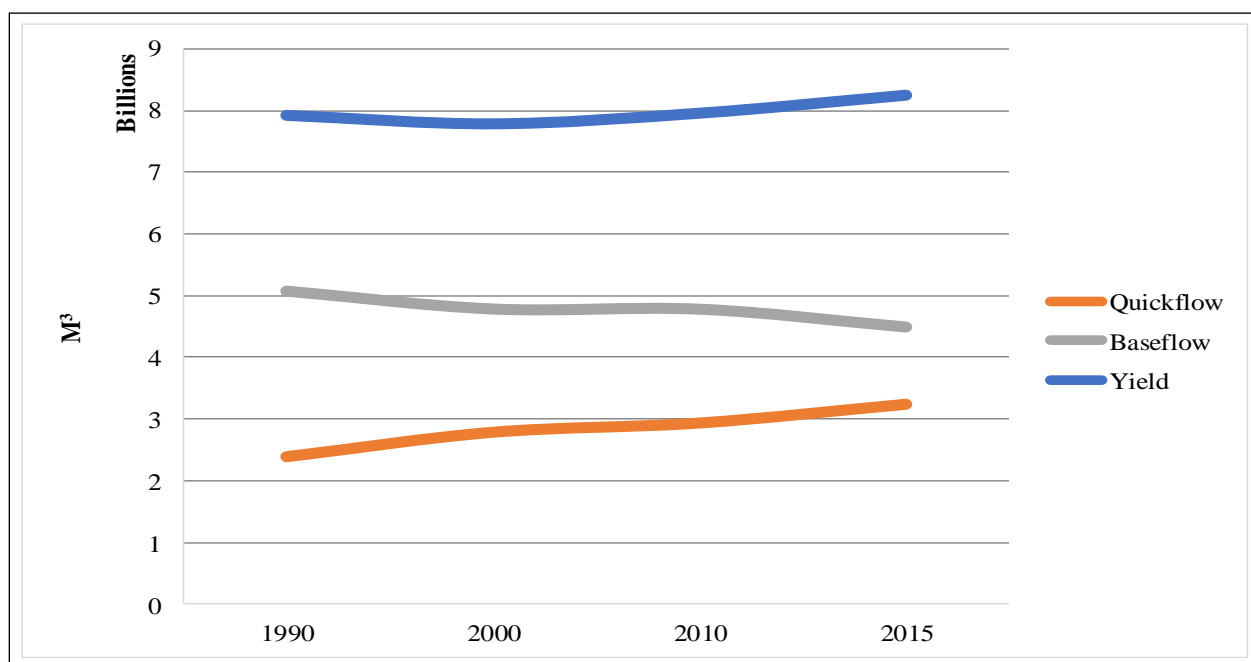


FIGURE 2: CHANGES IN WATER-RELATED ECOSYSTEM SERVICES FROM 1990 TO 2015 (BILLION M³). BASEFLOW AND QUICKFLOW GENERALLY SUM TO TOTAL WATER YIELD.

Increasing quickflow and declining baseflow suggest that water security may be declining in Rwanda. These ecosystem accounts provide additional evidence of Rwanda’s strategic landscape management issues and challenges:

- The declining trend in baseflow indicates that seasonal water deficits are likely to increase, impacting water security for household consumers, irrigation agriculture, hydropower generation and manufacturing.

¹ Government of Rwanda (NISR, Ministry of Environment). Natural Capital Accounts for Water, Version 1.0. October 2018. Kigali, Rwanda.

- The increasing trend in quickflow indicates increasing run-off and soil erosion, increasing incidence and magnitude of flooding, which can contribute to road transport infrastructure damage, health and safety risks in the rural and urban areas, and deterioration of hydropower generation infrastructure.

Recommendations

The ecosystem accounts are intended to inform the national development dialogue with new data and perspectives. These findings reinforce the need for national attention on measures to reduce soil loss and increase water baseflows – and provide key indicators that can be monitored to improve management going forward. The following strategic interventions emerged during the NCA development and consultation process. To reduce soil loss and increase baseflows, the Government can:

- Promote sustainable land use management practices such as conservation agriculture (such as mulching and no-till), perennial crops (such as coffee, tea and fruit) and terracing on slopes.
- Promote catchment management, with a focus on steep slopes and riverbank restoration, prioritising high yielding catchments for maintenance and restoration programmes, water-sensitive reforestation and riparian buffers.
- Develop basin-wide flood and environment management programs, including water and soil conservation measures, water-way rehabilitation and riverside landscape improvement.
- Promote sustainable or green urbanisation which includes effective water harvesting, urban food gardens (to promote water infiltration) and green open space (to promote infiltration and to dissipate local flooding).

These measures also need to be combined with efforts to increase resources and financing available for improved watershed and landscape management. To increase funds available for landscape improvement, forest management and tree planting, the Government could:

- Mobilize financing for the implementation of the Forest Investment Plan.
- Operationalize the FONERWA natural resource-based fee collection system for resourcing catchment management through national programs for payment for ecosystem services (PES).
- Employ a range of innovative insurance schemes to improve catchment resilience across landscapes.

Acronyms and Abbreviations

GDP:	Gross Domestic Product
GEF:	Global Environment Facility
GoR:	Government of Rwanda
ISIC:	International Standard Industrial Classification
IWRM:	Integrated Water Resources Management
MINAGRI:	Ministry of Agriculture and Animal Resources
MINECOFIN:	Ministry of Finance and Economic Planning
MININFRA:	Ministry of Infrastructure
MIS:	Monitoring and Evaluation System (Management Information System)
M ³ :	Cubic meter
MoE:	Ministry of Environment
NA:	National Accounts (following SNA)
NCA:	Natural Capital Accounting
NDC:	Rwanda's Nationally Determined Contributions to the Paris Agreement on Climate Change
NISR:	National Institute of Statistics of Rwanda
NLUDMP:	National Land Use Development Master Plan
NST1:	National Strategy for Transformation (NST1)-2017-2024
NWRMP:	National Water Resources Master Plan
RAB:	Rwanda Agriculture Board
RBM&E:	Results-Based Monitoring and Evaluation System
RDB:	Rwanda Development Board
REMA:	Rwanda Environment Management Authority
RNRA:	Rwanda Natural Resources Authority
RRA:	Rwanda Revenue Authority
RSB:	Rwanda Standards Board
RUDP2:	Rwanda's Urban Development Project 2
Rwf:	Rwandan Franc
RWFA	Rwanda Water and Forestry Authority
SC:	Steering Committee
SDGs:	Sustainable Development Goals
SEEA:	System of Environmental-Economic Accounting
SEEA-CF:	SEEA – Central Framework
SEEA-EEA:	SEEA - Experimental Ecosystem Accounts
SNA:	System of National Accounts
SNAPP	Science for Nature and People Partnership
SPCR:	Strategic Pilot Program for Climate Resilience
TWG:	Technical Working Group
UN:	United Nations
UR:	University of Rwanda
WAVES:	Wealth Accounting and Valuation of Ecosystem Services
WB:	World Bank
WBG:	World Bank Group
WCS:	Wildlife Conservation Society
7YGP:	Seven-Year Government Programme

1. Introduction

1.1. Background

A key role of government is to promote societal wellbeing, economic development and to reduce risks to society. In addressing these roles, government employs built capital (such as infrastructure), human capital (such as people and skills) and social capital (such as laws and trade). To develop, maintain and optimise the use of these capitals, government keeps a detailed account of these assets, their numbers, condition and their respective trends over time. Such accounts are used to inform planning of and budgeting for government interventions.

There is an additional form of capital, which is critical to measure and analyse - natural capital. Much of Rwanda relies directly or indirectly on natural capital to supply water security, food security, energy security and the reduction of disaster impacts. Based on global wealth accounts, Figure 1 outlines the total wealth per capita in Rwanda (US\$21,619), and highlights the values of produced, human and natural capital², with natural capital (US\$ 6,650) broken up into its components (timber, non-timber, protected areas, croplands, pasturelands and subsoil assets).

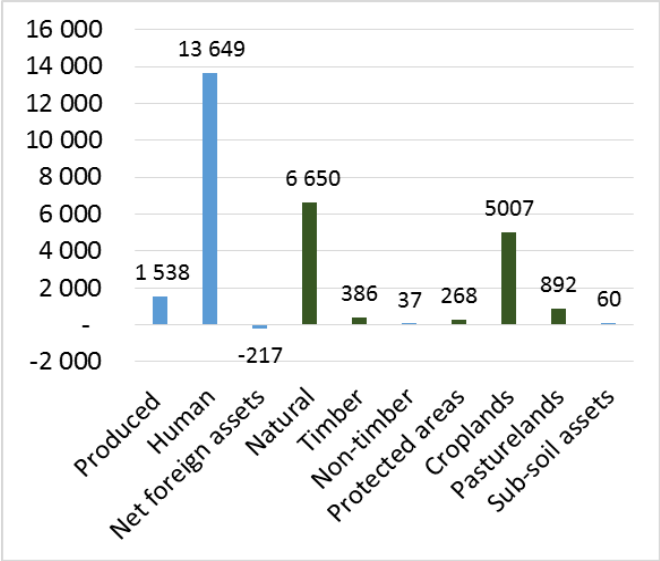


FIGURE 1: TOTAL WEALTH PER CAPITA IN RWANDA US\$21,619 (2014) (WITH NATURAL CAPITAL BROKEN DOWN TO SHOW CONTRIBUTION OF DIFFERENT RESOURCES) (SOURCE: LANGE ET AL 2018)

The discounted future returns from natural capital are four times greater than the return on produced assets, highlighting the importance of natural capital in the wealth of Rwanda. Consequently, natural capital is important to manage, in combination with built capital, human capital and social capital – to ensure that national water, food and energy security, and risk reduction processes are resilient and sustainable. To measure is to know, and therefore measuring natural capital is vital for effective decision making in national

² Lange, G-M., Wodon, Q., and Carey, K. (eds.) 2018. The Changing Wealth of Nations 2018: Building a Sustainable Future. Washington, DC: World Bank. doi:10.1596/978-1-4648-1046-6.

planning, and hence ecosystem accounts offer the Government of Rwanda a means to measure the changing state of natural capital and the nation's wealth.

Natural capital such as rivers, lakes, wetlands, forests, woodlands, shrublands, farmlands and plantations offer a wide range of services to Rwanda and its citizens. For example, rivers supply water for abstraction but also water for diluting pollution, and while farmlands supply food, farms can also supply soil erosion prevention and ground water recharge. Consequently, natural capital can be considered ecological assets which supply large volumes of ecosystem services to both rural and urban households. Measuring the size, condition and trends over time in natural capital is important in understanding current and future supplies of services such as water yields, erosion control, flood reduction and food yields.

Rwanda is engaged in developing Natural Capital Accounts, guided by a Steering Committee led by the Ministry of Finance and Economic Planning (MINECOFIN), National Institute of Statistics of Rwanda (NISR), the Ministry of Environment and its associated agencies of Rwanda Environment Management Authority (REMA), Rwanda Water and Forest Authority (RWFA) and Rwanda Land Management and Use Authority (RLMUA), and including members from the, Ministry of Infrastructure (MININFRA), Ministry of Agriculture and Animal Resources (MINAGRI), Rwanda Development Board (RDB), the Wildlife Conservation Society (WCS), and others. Natural Capital Accounting (NCA) brings together information on how natural resources are contributing to the economy – information on resource stocks and flows, uses and users, scarcities and potentials – to help improve development decisions. NCA is an extension of the System of National Accounts (SNA) that helps to describe the economy's use of natural assets, such as land, water, forests, and minerals. The approach helps to integrate natural resources into economic analysis and can provide a broader picture of development progress than standard measures, such as Gross Domestic Product (www.wavespartnership.org).

Natural Capital Accounting can add value in Rwanda's national development planning process by directing attention to economically vital natural resource sectors and by providing consistent, reliable data to support economic assessments and sound policy formation that takes cross-sectoral issues into account. NCA can help to identify trade-offs or potential constraints as Rwanda grows. NCA can also contribute to accountable governance by increasing the quality, credibility, and consistency of the statistics and analyses that support national development plans and targets. The methodology used is the internationally recognised United Nations System of Environmental-Economic Accounting (UN-SEEA).

Ecosystem accounts complement and build on SEEA Central Framework accounts such as land and water accounts. They provide a consistent framework for the integration of (i) information on ecosystem assets (i.e., ecosystem extent, ecosystem condition, ecosystem services and ecosystem capacity), and (ii) existing accounting information on economic and other human activity dependent on ecosystems, as well as the associated beneficiaries (households, businesses and governments). Fundamental for ecosystem accounting is the spatial approach taken, as well as – in line with the SEEA and the SNA - the distinction between flows of ecosystem services and stocks of ecosystem assets. In ecosystem accounting, ecosystem condition, capacity and services flows are analysed in a spatially explicit approach, i.e., using maps as well as tables. This is essential in order to allow integration of scarce data on multiple ecosystem services at aggregation levels relevant for accounting, such as the province, watershed, or country.

A first step in natural capital accounting is to identify what natural capital the nation has and where it is located, through the compilation of ecosystem extent accounts. Figure 2 illustrates the types of land cover in Rwanda, which is a good indicator of natural capital and its distribution in Rwanda. The land cover was

generated from the land accounts ³, and plays a key role in the ecosystem accounts, as the size or areas of the natural assets indicate the size or stock of natural assets and their associated flows of ecosystem services. The combination of the land accounts' data together with new data sets, such as soils and rainfall, provides new insights into Rwanda's ecosystems and associated societal wellbeing. Furthermore, the spatial location of the assets and their respective eco-hydrological processes shows the location of the stocks and flows of natural capital and ecosystem services in Rwanda. Importantly, the ability to repeat the ecosystem accounts every few years indicates trends and can facilitate effective planning for managing future risks and opportunities.

A key spatial element of the water-related ecosystem services are the catchments (see Figure 3) that produce services such as water yield, baseflow and quickflow. The combination of catchment area, land cover, slope, soil types, precipitation, temperature and evapotranspiration within a specific water catchment, produces the volumes and timing of water and sediment yield, baseflow and quickflow. We discuss many of the ecosystem accounts for hydrologic ecosystem services in terms of catchments.

While water yield is documented in the water accounts ⁴, the ecosystem accounts do so spatially while introducing new indicators such as baseflow, quickflow, and sediment yield (usually referred to as soil loss in this report). These indicators provide a more nuanced or finer description of water flows in the landscape which have impacts on ecosystem services or disservices associated with hydrological flows, such as seasonal flow regulation, dry season availability, flooding risk, sedimentation and pollution dilution.

1.2. Objectives of the report

The objectives of the ecosystem accounts are to:

- outline how ecosystems, as a form of capital in Rwanda, are changing over time,
- identify how some of their associated ecosystem services are changing,
- identify the implications, of the changes, for Rwandan society, and
- identify options for government to plan for managing future stocks, flows, risks and opportunities associated with ecosystems.

³ Government of Rwanda (NISR, Ministry of Environment and Ministry of Lands and Forestry), Natural Capital Accounts for Land, March 2018

⁴ Government of Rwanda (NISR, Ministry of Environment) 2019. Natural Capital Accounts for Water, Version 1.0.

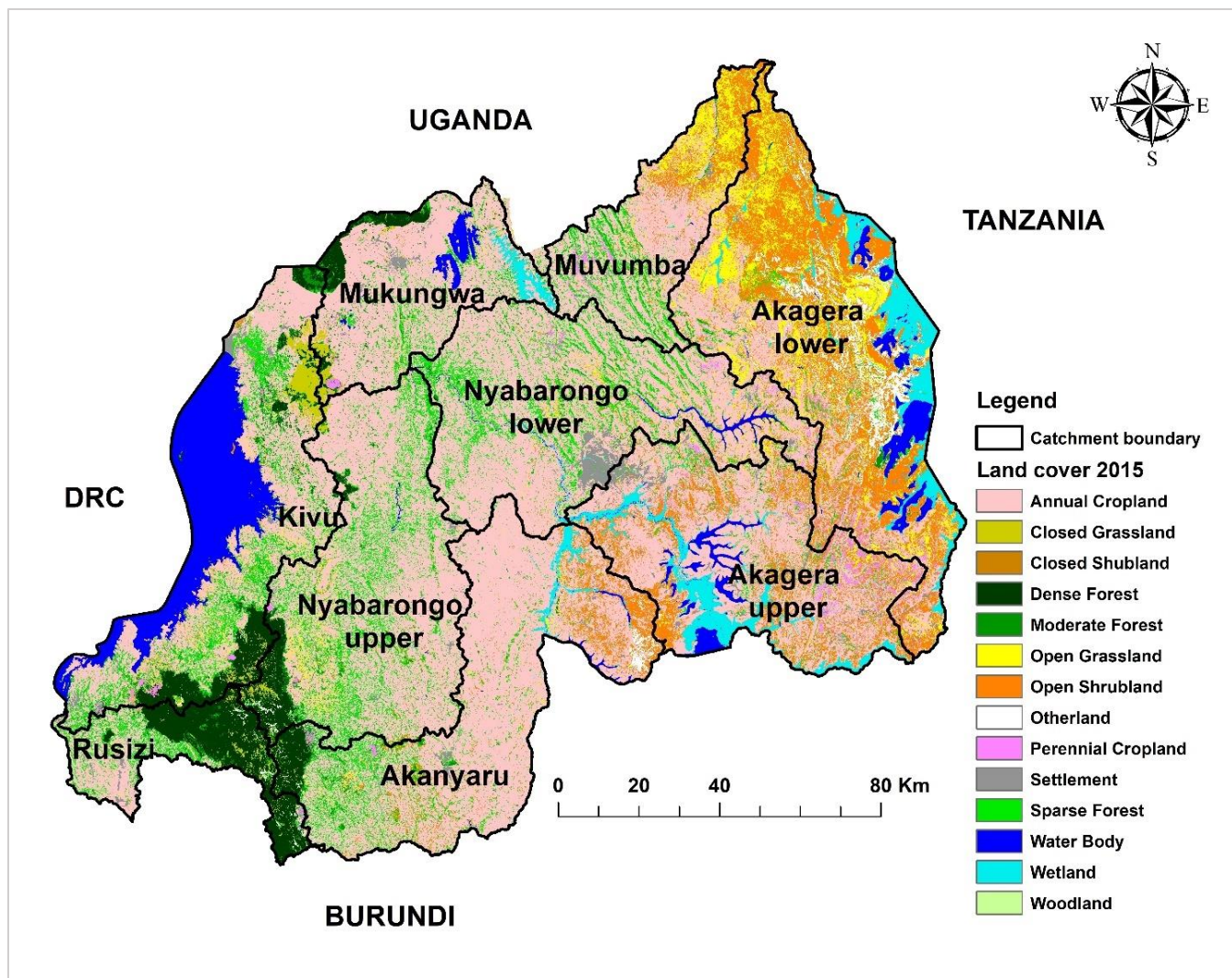


FIGURE 2: THE LAND COVER OF RWANDA AND BOUNDARIES OF NINE MAJOR CATCHMENTS IN RWANDA.

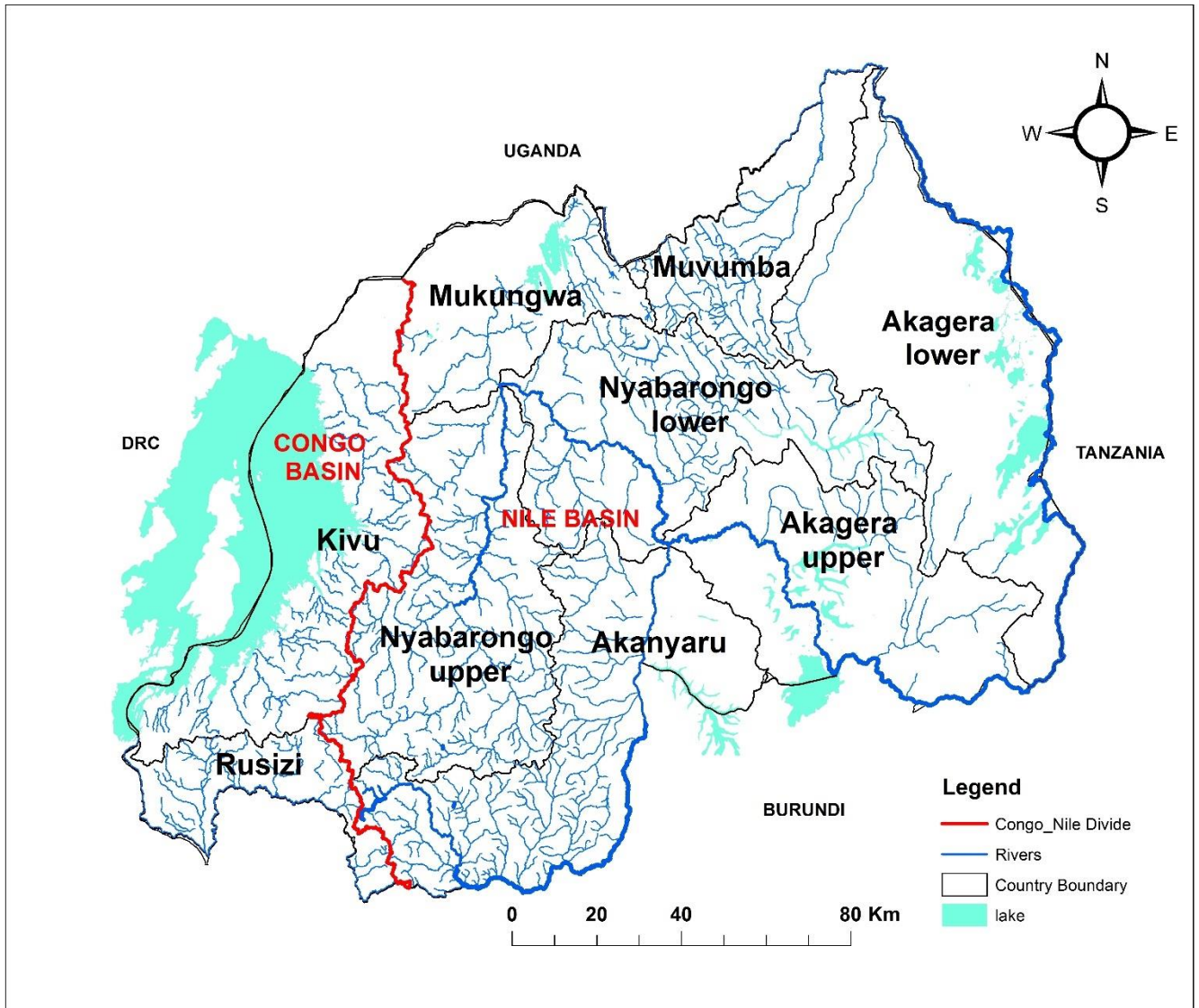


FIGURE 3: THE CATCHMENTS OF RWANDA

In addition to using catchments as key spatial illustration of the accounts, the services or disservices may also be shown at other levels such as districts, provinces, or other physical or political levels. We also report ecosystem accounts by districts and show these in relation to catchments (see Figure 4).

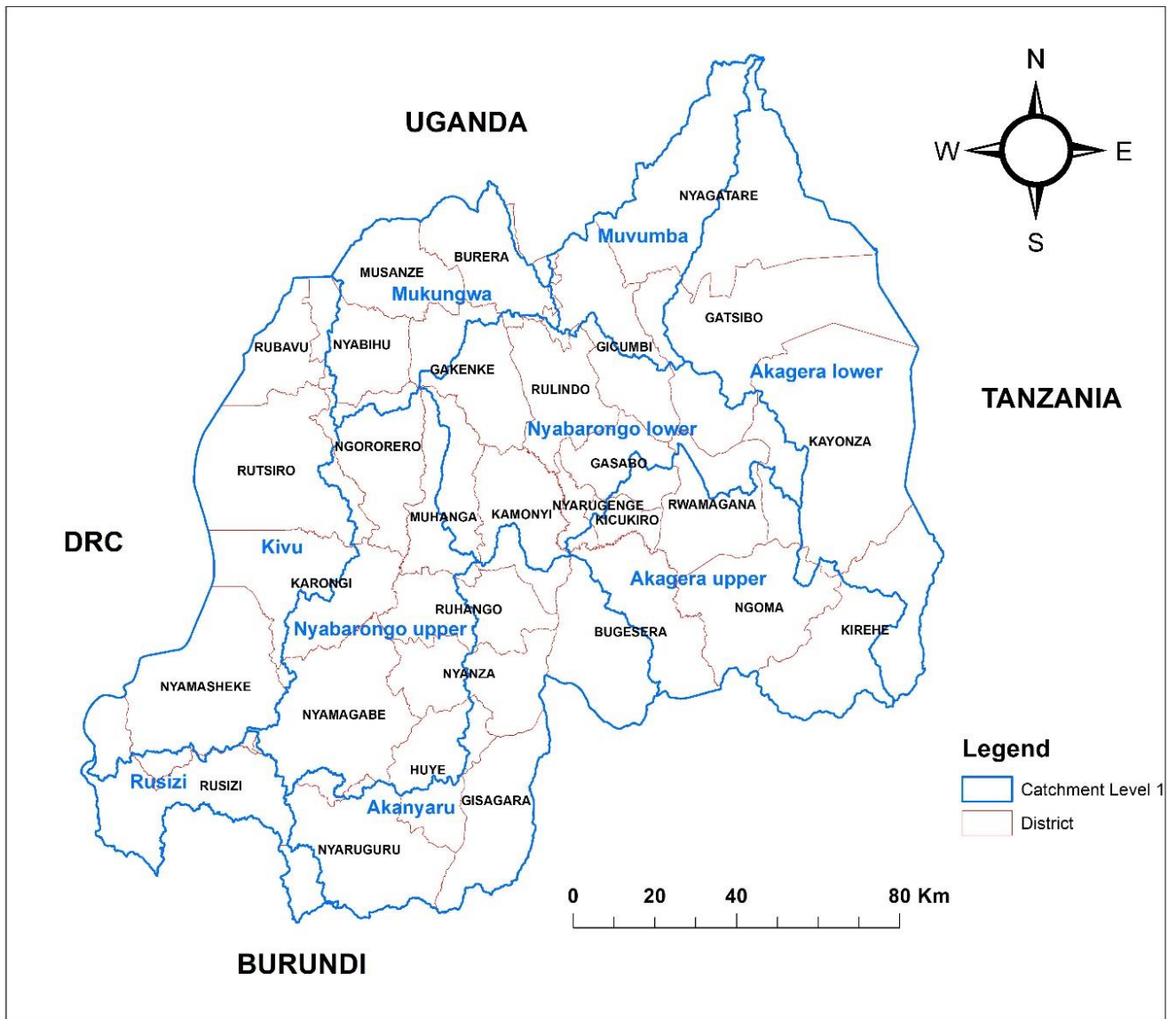


FIGURE 4: THE DISTRICT BOUNDARIES OF RWANDA IN RELATION TO CATCHMENT BOUNDARIES

2. Water and soil policy issues in Rwanda

2.1. Water and soil policy issues

Some 70% of the Rwandan population is rural and 90% of cropland located on steep slopes, generating a national dependence on vulnerable steep slopes. Furthermore, a rapidly growing rural population generates smaller and smaller land holdings on which to generate farm livelihoods, increasing extraction on smaller land holdings on vulnerable slopes. The elevated pressure on the natural resources leads to reduced vegetation cover on the landscape due land transformation, crop farming and resource harvesting. Without a thick vegetation cover; i) protecting the disturbed soil from high intensity falling rain, ii) the roots binding soil in place on slopes, and iii) slowing run-off across the surface, soil erosion proliferates. In addition, exposed soil surfaces on slopes reduce rainwater infiltration into the soil and promote further run-off. The soil erosion leads to the deposition of coarse sand on previously fertile lower slopes and wetlands. Soluble organic material and clay (containing nutrients) are washed out of the soil during erosion and are discharged or exported into streams and rivers. Soil erosion results in a loss of soil fertility from the cropland it originates from and secondly by the covering of low-lying fertile soil with infertile sand. Consequently, the soil nutrient balance in Rwanda is one of the most negative in Africa (World Bank; CIAT; 2015) (Rwanda SCD). <http://documents.worldbank.org/curated/en/219651563298568286/pdf/Rwanda-Systematic-Country-Diagnostic.pdf>

The soil organic matter, clay and nutrients that are washed out into rivers create negative impacts such as:

- high turbidity in rivers with elevated water purification costs and turbine erosion with elevated electricity generation costs,
- clay deposition leading to loss of dam storage space and elevated electricity generation costs,
- eutrophic (or excess nutrients) conditions leading to alien plant infestations and elevated water purification costs, and
- the loss of aquatic biodiversity due to sediments and eutrophication.

The reduction in soil water infiltration reduces soil water available for crop production. The accelerated run-off elevates downstream flooding risks. Given the widespread intensive cultivation with inadequate soil management, catchment benefits or services, such as erosion control, slope stability and flood reduction are at risk and/or declining.

Rwanda has been endowed with abundant freshwater resources. However, the assurance of water resources supply is declining showing a greater variability in supply, with elevated flooding, more frequent drought periods and declining water quality. Recent trends indicate:

- increasing soil erosion and sedimentation of rivers,
- increasing pollution from washed out soil nutrients, agricultural chemicals and fertilisers, industrial effluents and municipal waste,
- periodic declines in water levels and flow volumes, causing seasonal shortages,
- frequent periods of heavy flooding,
- declining ground water recharge, and
- declining biodiversity associated with terrestrial and aquatic ecosystem degradation.

These indicators all point to degrading or increasingly vulnerable catchments, with reduced assurance of supply and elevated risks to water access for household consumption, agricultural production, hydropower generation and manufacturing. A declining assurance of supply, when combined with a growing population and economy, will significantly elevate risks to households and economy. These changes could be attributed to changing land use practices and global warming phenomena.

Without access to healthy catchments and large-scale water impoundments, Rwanda's water security, is highly sensitive to climate variability and to catchment degradation. With limited opportunities to influence global climate change impacts, Rwanda's challenge is to develop resilient catchments, able to withstand both global shocks and greater local pressures.

2.2. Implications for strategic economic sectors

The reduction in soil assets and catchment services have national implications for food security, water security, hydro-power security and transport access.

The agriculture sector may be affected by a reduction in crop productivity as a result of declining soil water and soil fertility. Declining crop productivity could result in lower crop yields with a reduction in household and national food security, or it could result in elevated inputs costs, associated with increased fertiliser applications (which causes additional water quality impacts). Local consumption and export could be negatively impacted.

Degrading catchments and declining water supply and quality could impact numerous sectors dependent on access to a regular supply of water. For those industries dependent on water for production and who are unable to store adequate volumes of water in the dry season for their production process, seasonal shortages could constitute a serious barrier to production sustainability.

The problem of elevated run-off also manifests in soil erosion and sedimentation. Sedimentation is a threat to hydro-electric power generation in two ways. First, the sediment in the water causes turbine erosion, resulting in the turbines having to be replaced before their normal lifespan, which implies that a shorter period of time is available to raise the finance necessary for replacement, requiring a higher price to be charged to consumers per unit of energy produced. Second, sediment deposited in the feeder dam occupies volume previously occupied by water, and therefore is not available for power generation, effectively creating a smaller dam with less energy generation potential. This reduces the lifespan of the dam, and further elevates the costs per unit of energy, as the total volume of water moving through the turbines during their lifespan will be reduced.

2.3. Ongoing challenges

2.3.1. Seasonal water shortages

The media and Kigali residents report that they experience shortages of water during the dry season (July and August). This implies that water demand exceeds supply at certain times of the year, while the annual volume of water available in Rwanda is more than adequate to meet demand. There is a mismatch between annual supply and seasonal demand and takes its form in terms of high wet season flows and low dry season flows. A key constraint is the limited storage of wet season high flows associated with the costs of building large dams and the geopolitics of damming water in the Nile Basin.

There is a growing need to understand seasonal flows and to find ecological mechanisms to elevate dry season river flows that will match consumer demand. Such approaches are cheaper and less controversial to build and maintain than large infrastructure projects and generate co-benefits in terms of additional ecosystem services.

2.3.2. Flooding and road infrastructure damage

Wet-season high flows have also led to increasing risk and incidence of infrastructure flooding, road wash-aways and landslides – all of which generate high and recurring costs to the Rwandan economy. The increasing incidence of these events indicates a growing problem and a need to find solutions. The Government of Rwanda has recognised these problems and mobilised on a large scale to address these issues, including programs like landscape restoration, building multipurpose dams (domestic water supply, hydropower generation and irrigation), national rainwater harvesting strategy, a new green building code that enforces rainwater harvesting, building appropriate drainage systems in both rural and urban residential and commercial areas, agroforestry strategy to increase land cover in agricultural lands. In addition, a national program for payment for ecosystem services (PES) being implemented by the GoR aims to address the ecosystem disservices related to flood risks, landslides, flooding, sedimentation and pollution. Ecosystem accounts can support such mitigating actions, by institutionalising regular monitoring of the Rwandan landscape to support decision making, prioritisation in terms of location and timing, and the establishment of early-warning systems.

2.3.3. Productive soil loss

Given the large dependence of rural society on agriculture and its critical role in the Rwandan economy, productive agricultural soils are a critical asset to individual farmers and the nation. The ongoing high levels of soil erosion in the Rwandan landscape have been recognised as a national intervention priority by the Government of Rwanda. Like flooding, ecosystem accounts offer a means to strengthen government response to soil erosion issues, by measuring key indicators across the landscape and from different sectors, to ensure a comprehensive or systematic understanding of the state and trends in soil assets is always in place, for responding to emerging problems and for anticipating future mitigation.

2.3.4. Sedimentation of waterways and threats to water quality and hydro-energy generation infrastructure

The erosion of soils not only generates food security concerns, but also compromises water and energy security, by reducing water quality, elevating water purification costs, reducing water storage space in dams (affecting water, energy and food security) and by accelerating turbine erosion in hydro-electric generation facilities. Sedimentation threatens aquatic biodiversity by changing river habitats. Understanding and tracking the state of key drivers of soil erosion to support mitigation and prevention is therefore critical. As with the previous issues, the Government mitigation strategies and actions could benefit significantly by being informed proactively by ecosystem accounting.

2.4. Emerging opportunities

2.4.1. Cooperative governance

The problems observed above are largely associated complex systems, such as multi-jurisdiction hydrological catchments or ecological systems, wherein numerous government departments and economic sectors function. While many of the actors monitor indicators relevant to their own interest, there are seldom measures of the health of the system. Ecosystem accounts offer an opportunity to measure key

indicators of system health and sustainability, to consolidate indicators from different data sources, and to present a big-picture perspective. The ecosystem accounts also present a platform for a range of government departments to interact, synergise and enhance cooperative governance.

Similarly, having a system that tracks landscape conditions can add considerable value to the land accounts (which focus on quantity and not quality or condition), and thereby adding a quality component that would enhance land use optimisation and planning. Ecosystem accounts also add valuable detail to the water accounts, by generating spatial information using models of hydrologic processes.

2.4.2. Water storage without Nile Basin negotiations

A national challenge of the Rwandan Government is to store water in Rwanda without having to negotiate agreements with the entire Nile Basin community. Ecosystems, in association with conservation farming, offer such an opportunity to the nation. The elevated flooding, accelerated soil erosion and growing dry season water shortages, illustrate the consequences of a landscape declining in its natural water storage services. A reversal of the current trend of accelerated water run-off, that is, slowing the surface water flows and providing more opportunity for water infiltration into the landscape soils, could re-instate previous natural water storage levels, thereby promoting farm productivity, reduce the cost burden of flooding, and enhance river flows for consumers in the dry season. An ecosystem focus is required for such an approach, and ecosystem accounts are a good starting point or platform, for developing a collective response by the key government and community actors.

3. Key findings

The focus of this first ecosystem account has been on indicators of ecosystem services, and includes:

- water yields and quickflow,
- baseflow,
- soil erosion and soil loss (or soil exports) to surface water bodies.

Water yields and baseflows can be considered beneficial services, while quickflow, soil erosion and soil loss can be considered disservices given their costs to Rwandan society. This list of services can be enlarged in future accounts.

The results of the ecosystem service modelling are outlined in sections 3.1 to 3.3 below.

For each ecosystem service analysed, the results are presented as supply levels for the nation and then per catchment. Catchments are important to consider as they are the eco-hydrological system that produces the services. However, as each catchment is different in size, land cover, soil, and climatic characteristics, it is also important to consider the inherent supply capability of each catchment without the effects of the catchment's size in calculations. Consequently, each service in each catchment is also considered in terms of the supply levels (or flows) per hectare and this identifies areas that offer the greatest benefits to management or restoration investment.

3.1. Soil erosion

These ecosystem accounts outline the Rwandan trends in potential soil erosion and soil loss. In Rwanda, soil erosion is predominantly the relocation of soil to lower lying areas or slopes within catchments. Eroded soil becomes disaggregated into sand, which is deposited on lower slopes and wetlands, and into soluble organic material and clay (containing nutrients) which is washed out into rivers. Eroded sand covers fertile soils rendering them unsuitable for crop production.

On the other hand, soil loss, that is the discharge of soluble organic material and clay into rivers is carried downstream and out of the catchment and lost to productive use. Due to the loss of soil from the system, soil loss can also be described as sediment export.

3.1.1. Trends in national potential soil erosion

Table 1 outlines the potential soil erosion in tonnes per year. In 2015 some 158 million tonnes of soil were eroded, with an average annual soil erosion of 62 tonnes per hectare. The trend since 1990 shows that soil erosion has increased by 54%, with a reduction in the rate of erosion in the period between 2000 and 2010.

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model can be used to highlight a range of soil loss or erosion indicators summed across different spatial extents (i.e., catchments, districts, provinces, or the nation). In the text below, several different tables and maps are used to highlight several key indicators of soil erosion.

Implications:

Soil fertility - an asset for food production, is being lost through soil erosion. Farmers either lose income due to lower crop yields, or they need to offset the fertility loss with additional fertiliser purchases. A further consequence of soil loss is the pollution of downstream water bodies due to both sedimentation and the elevated application of agrochemicals, such as fertiliser and pesticides.

TABLE 1: NATIONAL POTENTIAL SOIL EROSION FOR 1990, 2000, 2010 AND 2015 (POSITIVE CHANGES SHOW AN INCREASE IN EROSION AND NEGATIVE CHANGES SHOW A DECLINE IN EROSION)

National potential soil erosion (Tonnes/Yr)		Change in soil erosion from past to current period
1990	102,450,911	
2000	157,652,121	54%
2010	135,960,937	-14%
2015	158,166,230	16%
Change, 1990-2015	55,715,319	54%

The Upper Nyabarongo catchment had the greatest soil erosion of some 32 million tonnes in 2015 (Figure 5). The combined soil erosion volume of the Upper and Lower Nyabarongo contributed to 37% of the total soil erosion in Rwanda. The Rusizi catchment had the lowest soil erosion.

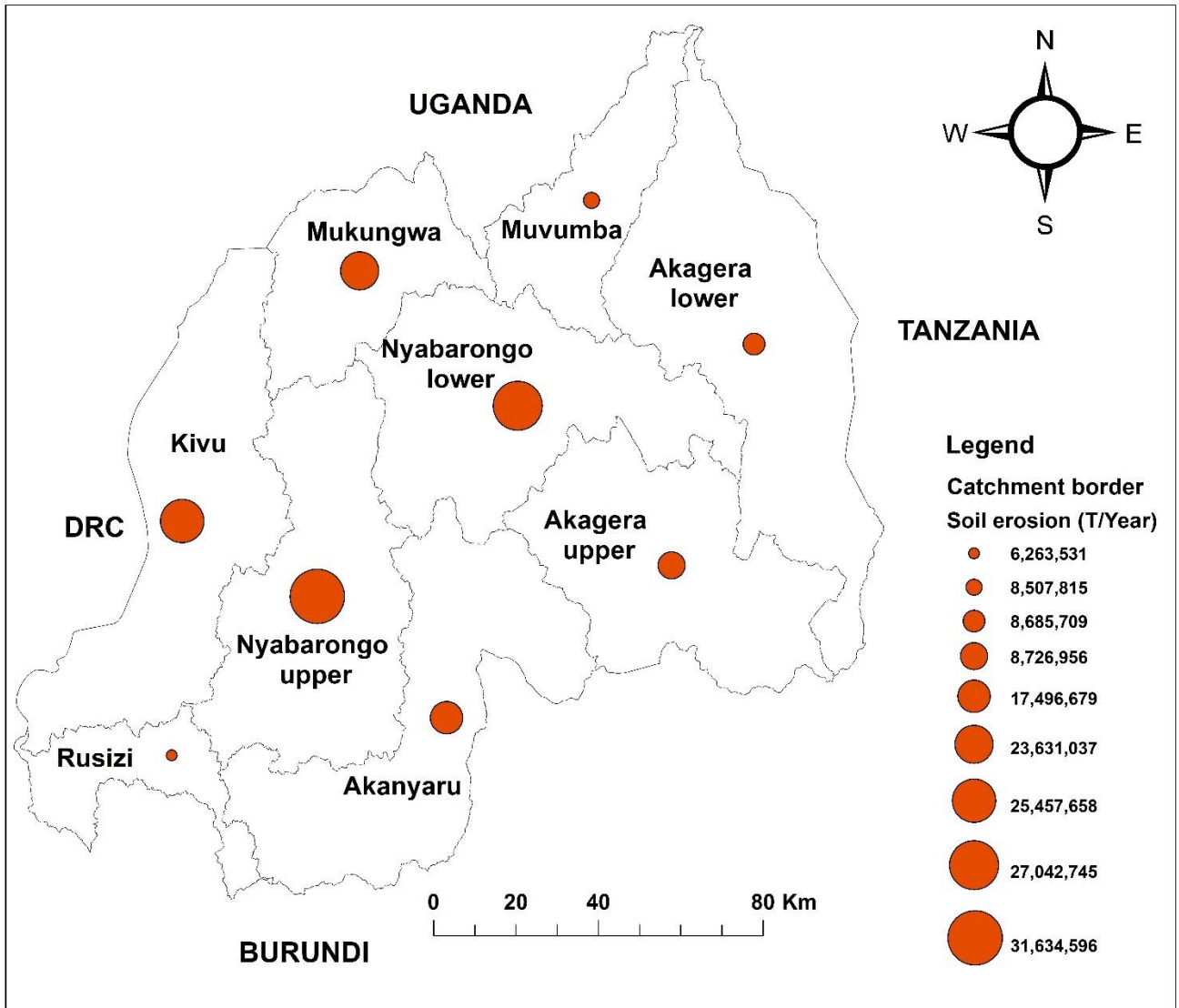


FIGURE 5: POTENTIAL SOIL EROSION PER CATCHMENT IN 2015

Potential soil erosion per hectare is depicted in Figure 6, and shows Mukungwa having the greatest soil erosion per hectare and also shows a 114% increase between 1990 in 2015. The Upper and Lower Nyabarongo and Kivu catchments show a similar increase in soil erosion.

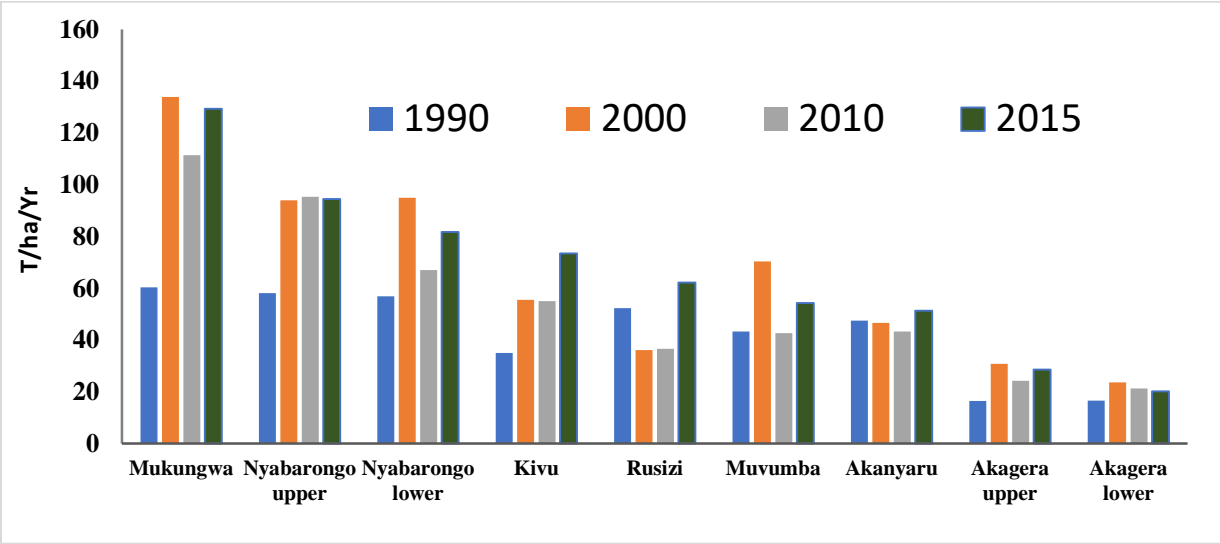


FIGURE 6: POTENTIAL SOIL EROSION PER HECTARE PER CATCHMENT IN 1990, 2000, 2010 AND 2015

3.1.2. Soil loss (or sediment exports)

Table 2 shows the quantities and trends in soil loss or sediment export to water bodies in Rwanda. In 2015 the total sediment exported was 14 million tonnes, having increased 123% from 6 million tonnes in 1990. The years between 2000 and 2010 showed a reversal in the general trend.

TABLE 2: SEDIMENT EXPORTED TO WATER BODIES IN 1990, 2000, 2010, 2015 (POSITIVE CHANGES SHOW AN INCREASE IN EXPORTS AND NEGATIVE CHANGES SHOW A DECLINE IN EXPORT)

National sediment exports to rivers (tonnes/yr)		Change in sediment export from previous year
1990	6,294,485	
2000	11,088,279	76.2%
2010	10,107,983	-8.8%
2015	14,039,860	38.9%
Change, 1990-2015	7,745,375	123.1%

In terms of the export of sediment to rivers per catchment, the trend is the same as for soil erosion.

The intensity of potential soil erosion varies considerably across the Rwandan landscape (Figure 7). Note the limited soil erosion occurring in Nyungwe National Park in the Rusizi catchment, despite it having similar rainfall intensity and slopes to the Upper and Lower Nyabarongo, and Mukungwa catchments. The avoided erosion and associated soil loss are largely a function of the intact forests within the national park.

Implications:

The soil erosion in a catchment results in both deposition on the land and the export of sediment to streams, lakes and wetlands. The sediment exported generates high costs to Rwandan society, in terms of poor water quality for consumers, sedimentation of critical infrastructure such as hydroelectric supply dams, and changing habitat for biodiversity. Sediment also elevates turbine erosion, increasing energy generation costs. These impacts reduce water and energy security.

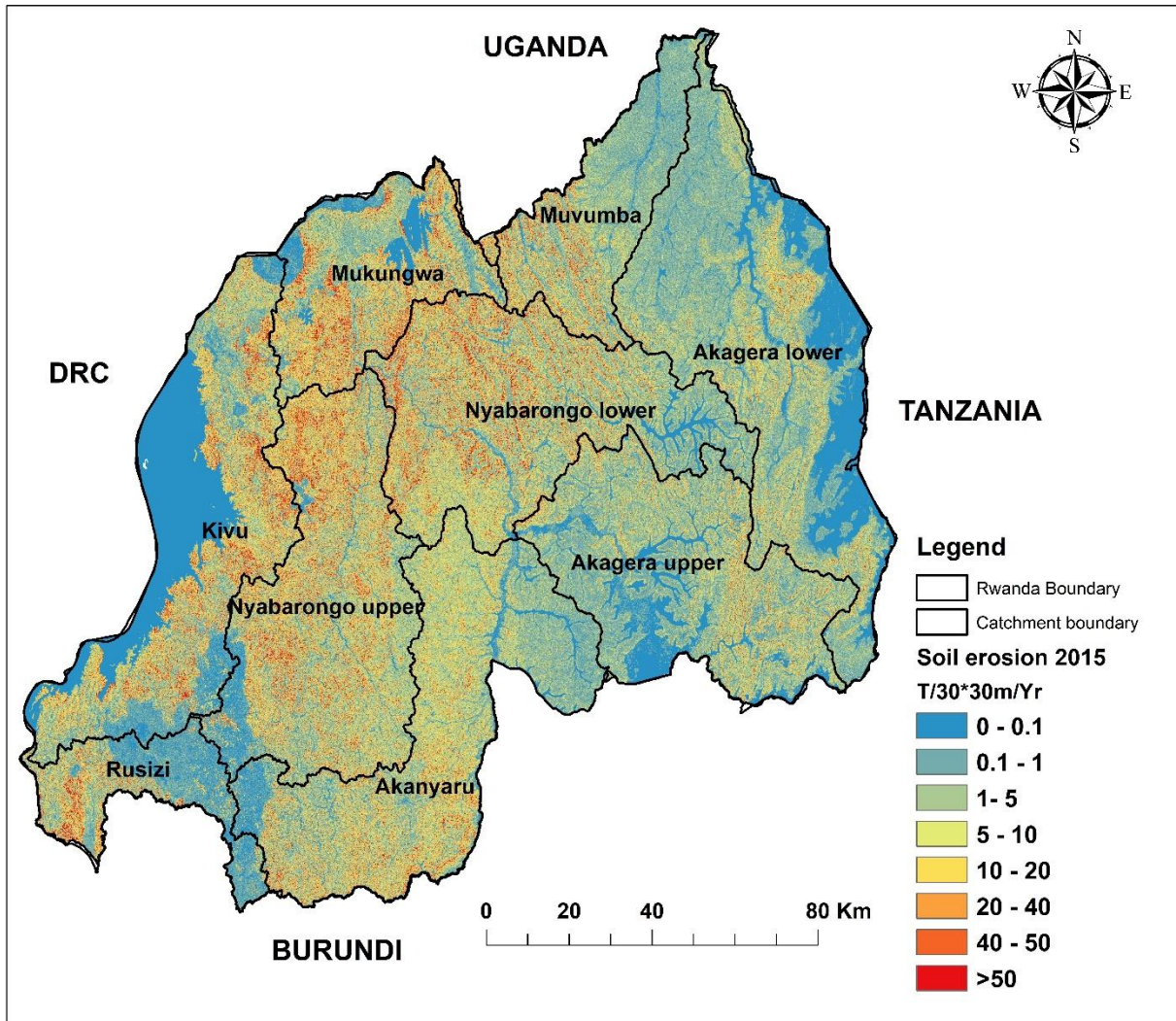


FIGURE 7: POTENTIAL SOIL EROSION IN 2015 (PER 30MX30M PIXEL)

3.2. Water yield and quickflow

Water yield is the amount or volume of water produced by the watershed in a year, which is the total annual precipitation which falls in the entire catchment less the evapotranspiration by plants and surface water bodies. The yield is in theory the total amount of water that can be utilised or abstracted from the rivers by society or used for instream purposes such as hydroelectric power generation, pollution dilution and fishing.

Another key hydrological measure is quickflow. This is the amount of water (in a year) that runs off the land in a catchment in minutes and hours after a rainfall event (in a year). Quickflow can contribute to soil erosion, flooding, diminished water quality, and reduced infiltration (and baseflow).

3.2.1. Trends in national water yield and quickflow

The national water yield in 2015 was 8.3 billion m³ (Table 3). This yield has increased by 4% from 1990 to 2015, with the greatest increase (3.6%) occurring in the most recent time period measured (2010 to 2015)⁵. In these estimates, rainfall has been kept constant for all iterations in order to remove annual variations of the weather and to identify human- induced change (primarily land use/land cover), which government policy and interventions can influence.

TABLE 3: NATIONAL ANNUAL WATER YIELD IN YEARS 1990, 2000, 210 AND 2015

National annual water yield (m ³ /yr)		Change in yield from previous period
1990	7,928,109,461	
2000	7,793,320,618	-1.70 %
2010	7,962,700,158	2.17 %
2015	8,249,488,807	3.60 %
Change 1990-2015	321,379,346	4.1%

The spatial differences in the intensity of the water yield are highlighted in Figure 8, with the Congo-Nile watershed divide showing the location of greatest yields.

A comparison between the InVEST modelled annual yield in 2015 (of some 8.3 billion m³) and the Water Accounts⁶ annual renewable water in 2015 (of some 10.4 billion m³) shows a 20% difference between the two approaches. Furthermore, the total renewable water in the Rwanda Water Master Plan in 2012 was estimated as 6.8 billion m³. These differences in estimates are due to precipitation estimates being kept constant in the InVEST model and varying from year to year in the other estimates.

⁵ The InVEST model uses a constant rainfall estimate for all years computed, and the changes in yield are therefore due to factors (such as reduced vegetation cover) other than rainfall. This may account the differences between the water master plan and ecosystem accounts' estimates.

⁶ Government of Rwanda (NISR, Ministry of Environment). Natural Capital Accounts for Water, Version 1.0. October 2018. Kigali, Rwanda.

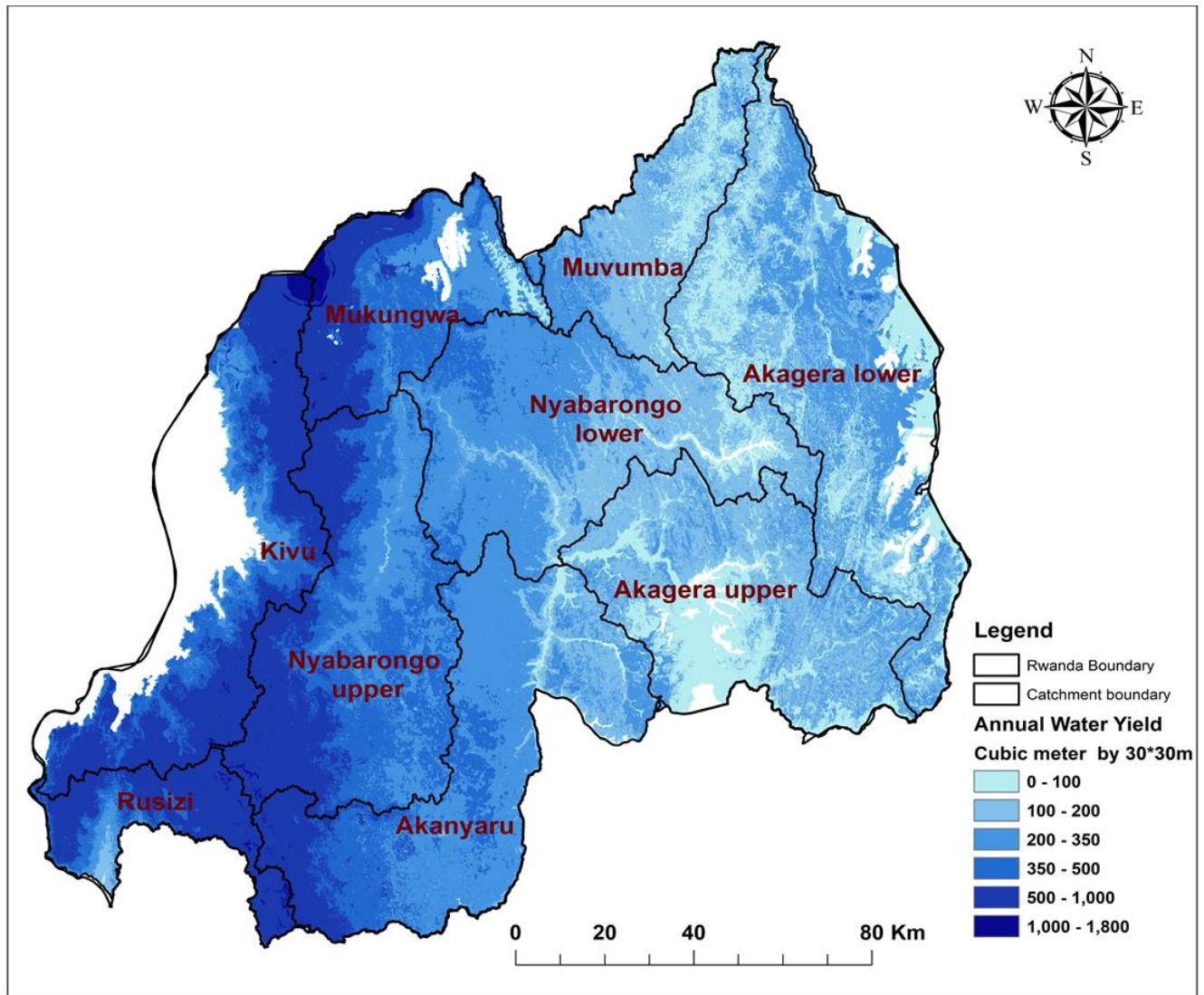


FIGURE 8: ANNUAL WATER YIELD IN 2015

An increase in national quickflow is associated with the increase in water yield (Table 4). Quickflow is an important measure to track, as it reflects the quantity of water running off the land surface immediately (typically within a few hours) following a rainfall event. Quickflow is a driver of flooding, land-slides, soil erosion, reduced water quality, and reduced infiltration and baseflow.

Quickflow has increased by 35% across Rwanda in the last 25 years, with the most recent time (2010 to 2015) period showing a 10% increase. Table 5 indicates a ranked list of changes in quickflow per district, with Rutsiro, Rubavu and Nyabihu showing serious problems with more than a 100% increase in quickflow, while Gisagara and Kayonza show a decrease in quickflow.

In 2015, 39% of the water yield was composed of quickflow, indicating that a large percentage of the water was relatively destructive and moved downstream rapidly, causing flooding, soil erosion, sedimentation of rivers and dams, increased water purification costs and infrastructure repair costs.

TABLE 4: NATIONAL ANNUAL QUICKFLOW IN YEARS 1990, 2000, 2010 AND 2015

National annual quickflow (m ³ /yr)		Change in quickflow from previous period
1990	2,391,447,164	
2000	2,781,146,534	16%
2010	2,928,383,754	5%
2015	3,227,117,062	10%
Change 1990-2015	835,669,898	35%

Implications:

The increase in water yield could in theory be considered an opportunity for Rwanda, as more water is available for abstraction and value addition in the economy. However, the realisation of this opportunity is dependent on Rwanda’s capability to capture and store the water yield, to ensure that the rate of water supply matches the rate of water consumption.

While yield shows an increasing trend, that is, more water available for abstraction, this increase comes with elevated quickflow and associated damage costs. Increasing quickflow results from less vegetation plant cover in the landscape (particularly trees and other native vegetation), less infiltration and less soil water storage. In simple terms, if water supply occurs too rapidly (i.e., with too much of it from quickflow rather than infiltration), it cannot be captured without expensive infrastructure, and causes costly damages that can also affect downstream countries.

From a policy perspective, a trend of increasing quickflow (independent of rainfall variation) signals a degrading catchment landscape with elevated risk and damage costs, and implies the need for catchment restoration interventions. This option is particularly relevant in the Nile Basin context, where damming rivers to capture quickflow is problematic due to serious geopolitical challenges.

The district quickflow trends in Table 5 provide an example of guiding prioritisation of locations for interventions.

TABLE 5: DISTRICT CHANGES IN QUICKFLOW BETWEEN 1990 AND 2015

Province (and NISR codes)	District (and NISR codes)	Change in quickflow
3. Western province	3.7 Rutsiro	169%
3. Western province	3.5 Rubavu	125%
3. Western province	3.3 Nyabihu	106%
4. Northern province	4.2 Gakenke	91%
3. Western province	3.1 Karongi	84%
3. Western province	3.2 Ngororero	84%
2. Southern province	2.4 Muhanga	75%
5. Eastern province	5.7 Rwamagana	74%
4. Northern province	4.4 Musanze	70%
2. Southern province	2.5 Nyamagabe	64%
3. Western province	3.4 Nyamasheke	58%
4. Northern province	4.1 Burera	53%
4. Northern province	4.5 Rulindo	52%
1. Kigali city	1.1 Gasabo	45%
5. Eastern province	5.5 Ngoma	41%
3. Western province	3.6 Rusizi	36%
2. Southern province	2.3 Kamonyi	36%
4. Northern province	4.3 Gicumbi	35%
2. Southern province	2.8 Ruhango	35%
2. Southern province	2.6 Nyanza	25%
1. Kigali city	1.2 Kicukiro	25%
2. Southern province	2.7 Nyaruguru	20%
5. Eastern province	5.4 Kirehe	19%
5. Eastern province	5.2 Gatsibo	17%
1. Kigali city	1.3 Nyarugenge	12%
2. Southern province	2.2 Huye	12%
5. Eastern province	5.6 Nyagatare	7%
5. Eastern province	5.1 Bugesera	3%
5. Eastern province	5.3 Kayonza	0%
2. Southern province	2.1 Gisagara	-5%

3.2.2. Catchment water yields

Importantly, the water yield is not uniform across Rwanda (Figure 9). The volumes listed in the graph are the estimated total yield for the catchment.

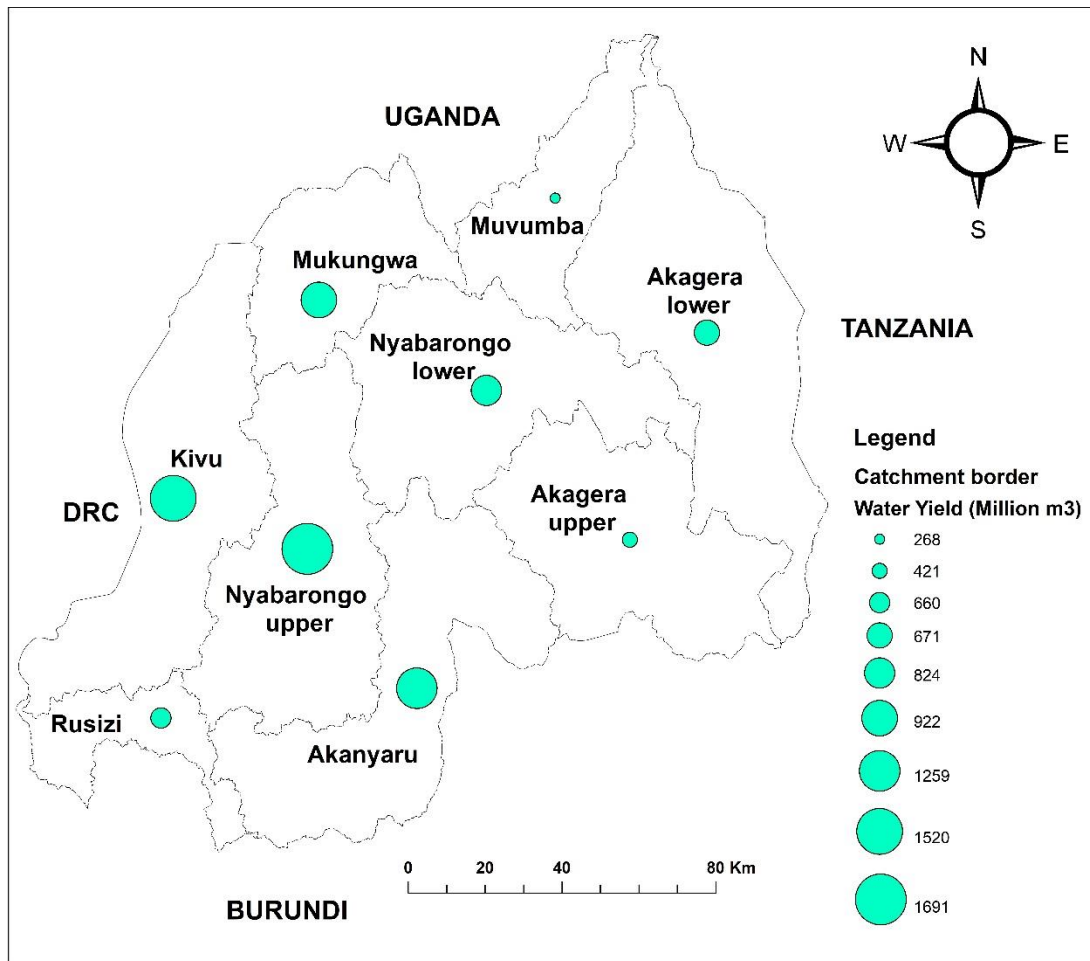


FIGURE 9: RELATIVE CONTRIBUTION OF CATCHMENTS TO NATIONAL WATER YIELD IN 2015

The water yield supplied per catchment is largely driven by Rwanda’s rainfall gradient, with the greatest precipitation and water yield occurring in the mountainous western parts of the country, and the smallest yield occurring in the east. The Upper Nyabarongo catchment showed the highest water yield, producing some 1.7 billion m³ in 2015, while Muvumba catchment yielded the least, with only 268 million m³.

Implications:

When considering water resources development such as dams and hydro-electric schemes, the highest yielding catchments indicate rivers with greatest potential.

3.2.3. Water yield per hectare

In terms of greatest yield per hectare, the Rusizi catchment yields the most with some 6,544 m³ per hectare per year (Figure 10). Rusizi also shows the maintenance of a relative constant yield over time, largely a function of the intact Nyungwe forests. The Upper Akagera catchment on the other hand yields the least water per hectare with only 1,377 m³ per hectare, approximately 5 times less than Rusizi. In addition, the Upper Akagera catchment showed the greatest percentage increase in yield, with a 7% increase between 1990 and 2015. The Muvumba catchment on the other hand showed a 5% decline in water yield.

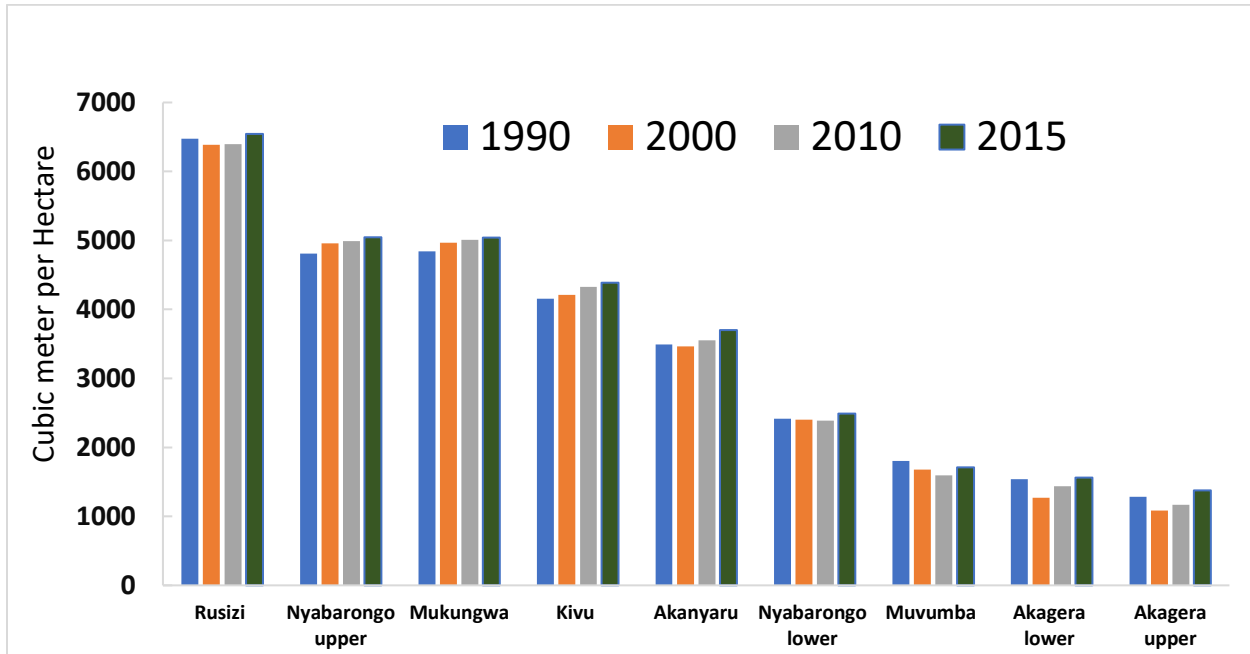


FIGURE 10: RELATIVE WATER YIELDS PER HECTARE AND THEIR TRENDS PER CATCHMENT (IN M³/HA/PER YEAR)

Implications:

The Rusizi catchment shows the greatest supply of water per hectare, and will provide the greatest water benefits if maintained, such as keeping the Nyungwe forests intact. It also indicates an area suited to crops with high water requirements, such as timber and fruit trees.

3.3. Baseflow

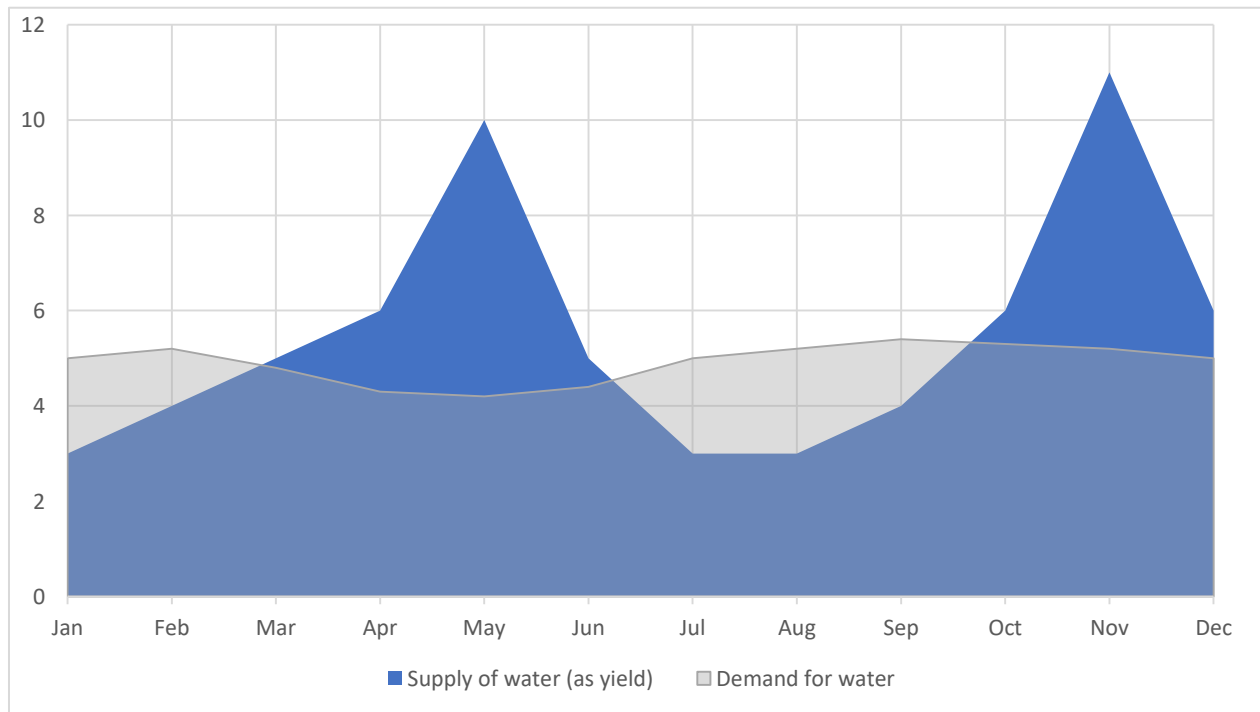
Baseflow water that supplies sustained low flow in rivers during the dry season and is generated by groundwater discharge and interflow. Water enters the soil during and after rainfall events (as infiltration or recharge) and then takes months or years to seep back out of the soil to become baseflow into surface water bodies. Interflow is water that enters the soil but moves sideways through the soil and exits in the soil in a few days after the rainfall event⁷. The InVEST seasonal water yield model quantifies local recharge, which ultimately becomes available as baseflow, as distinct from quickflow. In these ecosystem accounts, groundwater recharge is used as a proxy or indicator for baseflow, as the InVEST model does not estimate baseflow.

As much of Rwanda’s water abstraction is from ‘run-of-river’, that is, directly abstracted from rivers, baseflow tends to be a better indicator of useable or accessible water volumes. Baseflow is more like an ‘average’ flow in the river, without the peak flows such as floods which cannot easily be captured by abstraction.

3.3.1. Trends in national baseflow

As noted above, 39% of Rwanda’s water yield occurs as quickflow, immediately after rainfall events. In other words, some 39% of the yield is supplied as large volume pulses in a short period of time, with 61% supplied as local recharge. These intense flows usually exceed the Rwandan demand for water during the same time period, which implies that much of the yield is then exported to downstream countries. In Figure

11



⁷ In summary, after a rainfall event, quickflow does not enter the soil and runs off the land immediately in minutes and hours. Interflow enters the soil and seeps out days after the rainfall. Baseflow enters the deeper soils and seeps out months to years after the rainfall event.

, the yield supplied (dark blue area) is high in the rainy season and low in dry season, while demand for water (the grey area) is relatively constant across the year, with people using much the same quantities of water, and an increase in irrigation demand in the dry season. The graphic illustrates the seasonal mismatch that occurs, with the greatest volumes water (the two blue peaks) arriving at the time when it is least required, the wet season. The water above the demand line (the blue peaks) is in theory available as yield but not useable unless it can be captured and stored for later use in the dry season by a dam. Conversely, the demand for water (the grey area) is above the supply volume in the dry season and indicates a water shortage or deficit. Consequently, unless Rwanda has many huge dams which can capture and store these high-volume water pulses to use later in the dry season, the yield tends to exaggerate the amount of water available, hence an additional indicator is necessary to support decision making on seasonal water allocation.

Baseflow measures the amount of water available, when the quickflow component is excluded, indicating a more realistic volume of water available for abstraction in Rwanda, where abstraction is largely from rivers.

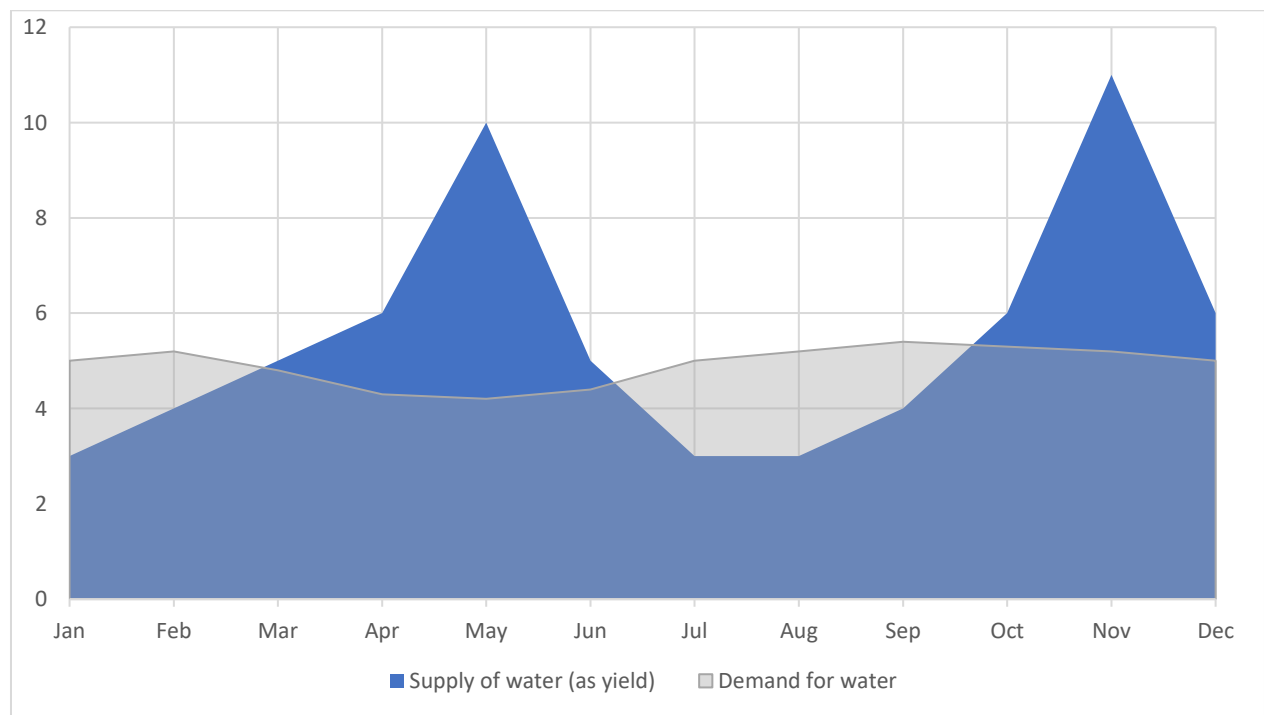


FIGURE 11: SEASONAL MISMATCH BETWEEN WATER DEMAND AND SUPPLY (AS YIELD) IN RWANDA

Conventionally baseflow is calculated using both groundwater recharge and interflow⁸. The InVEST model for groundwater recharge does not differentiate between interflow and groundwater recharge, and therefore sums both volumes – essentially releasing the same volume of water as a conventional baseflow calculation, but with a longer timescale. For the purposes of these accounts, the differences are not important, and groundwater recharge is a fair proxy for baseflow.

Table 6 outlines the quantities and trends in baseflow. In 2015, baseflow was 4.5 billion m³, which was some 54% of water yield. The trend between 1990 and 2015 shows a decline of 11%. All districts have

⁸ Smakhtin, V.U. 2001. Low flow hydrology: a review. Journal of Hydrology 240 (2001).

shown a decrease in baseflow, with the greatest percentage declines in Kicukiro (32%), Ngoma (29%) Nyarugenge (27%) and Gasabo (25%), and the greatest volume declines in Rutsiro, Nyabihu, Nyamagabe, Musanze and Nyamasheke – each of which have declined by more than 40 million m³ per year.

Implications:

Over half the water yield is available as baseflow, which serves as a proxy for the volume available for dry season use. The general trend of declining baseflow indicates a decline in water availability in the dry season, the period when water demand and water vulnerability is greatest.

TABLE 6: NATIONAL BASEFLOW AS A PROXY FOR GROUNDWATER RECHARGE

National baseflow (m ³ /yr)		Change in baseflow from previous period
1990	5,072,284,215	
2000	4,783,300,582	-5.7%
2010	4,780,294,682	-0.1%
2015	4,492,574,435	-6.0%
Change, 1990-2015	-579,709,780	-11.4%

3.3.2. Baseflow per catchment

Figure 12 indicates the baseflow volume per catchment in 2015. The Kivu and Upper Nyabarongo catchments contributing the most, with a baseflow of 1.2 billion m³ and 1.1 billion m³ respectively. The Upper Akagera catchment only produces 88 million m³, some 14 times less baseflow than Kivu catchment.

The baseflow changes per district are listed in Annexure 3.

Implications:

Kivu and Upper Nyabarongo are critical generators of water security of downstream river water users.

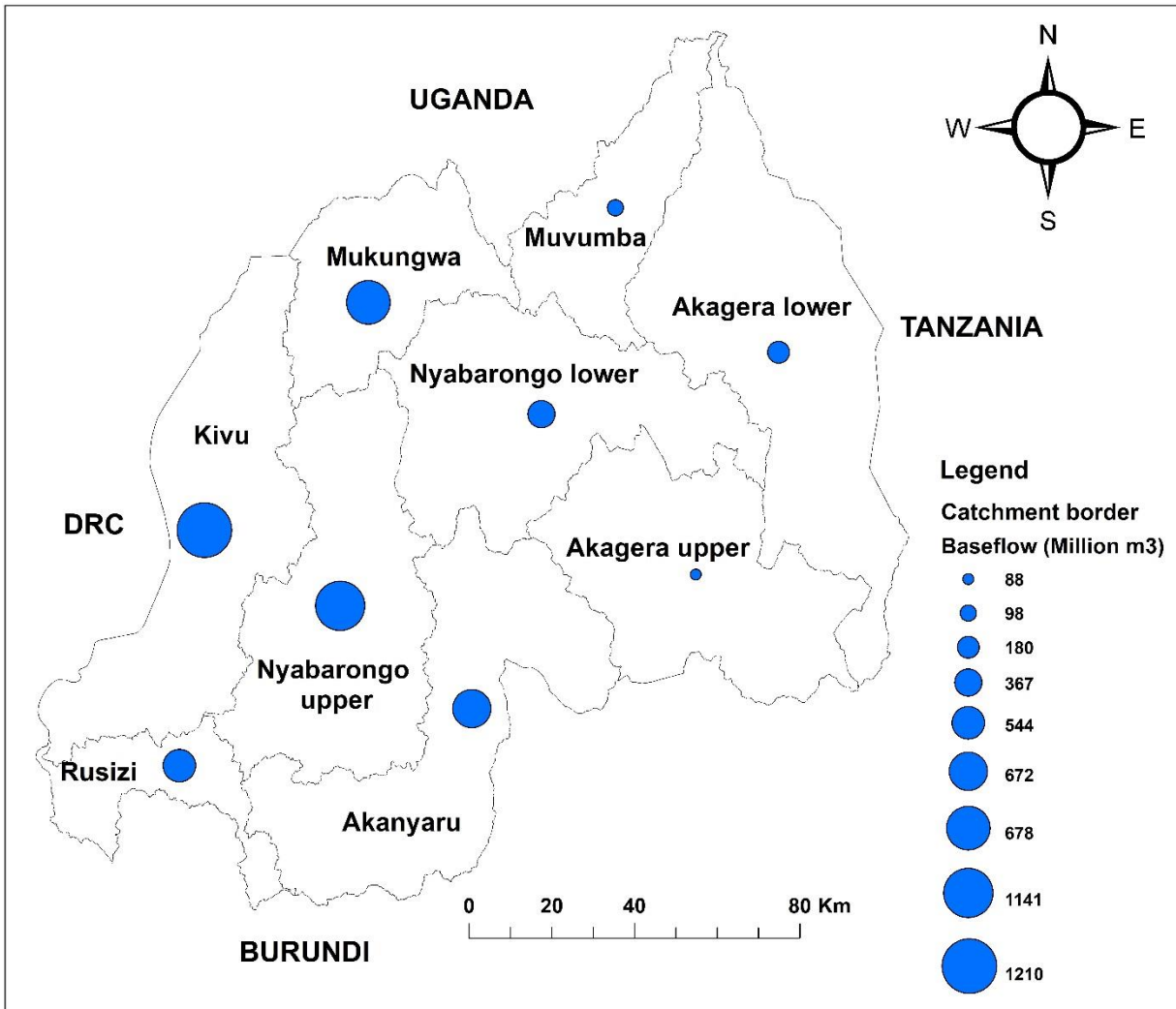


FIGURE 12: BASEFLOW PER CATCHMENT (2015)

3.3.3. Baseflow per hectare

In terms of the baseflow per hectare, the Rusizi and Kivu catchments make the greatest contribution, generating some of the most reliable dry season flows in Rwanda and neighbouring countries (DRC and Burundi) (Figure 13). However, all the catchments show a downward supply trend from 1990 to 2015, but with some catchments showing a slight improvement in the years 2000 and 2010.

The Upper Akagera catchment shows the greatest decline (24%) in baseflow per hectare, with Lower Nyabarongo (17%) and Mukungwa (16%) also showing significant declines. In the last 5 years, both the Rusizi and Kivu catchments showed the largest declines per hectare.

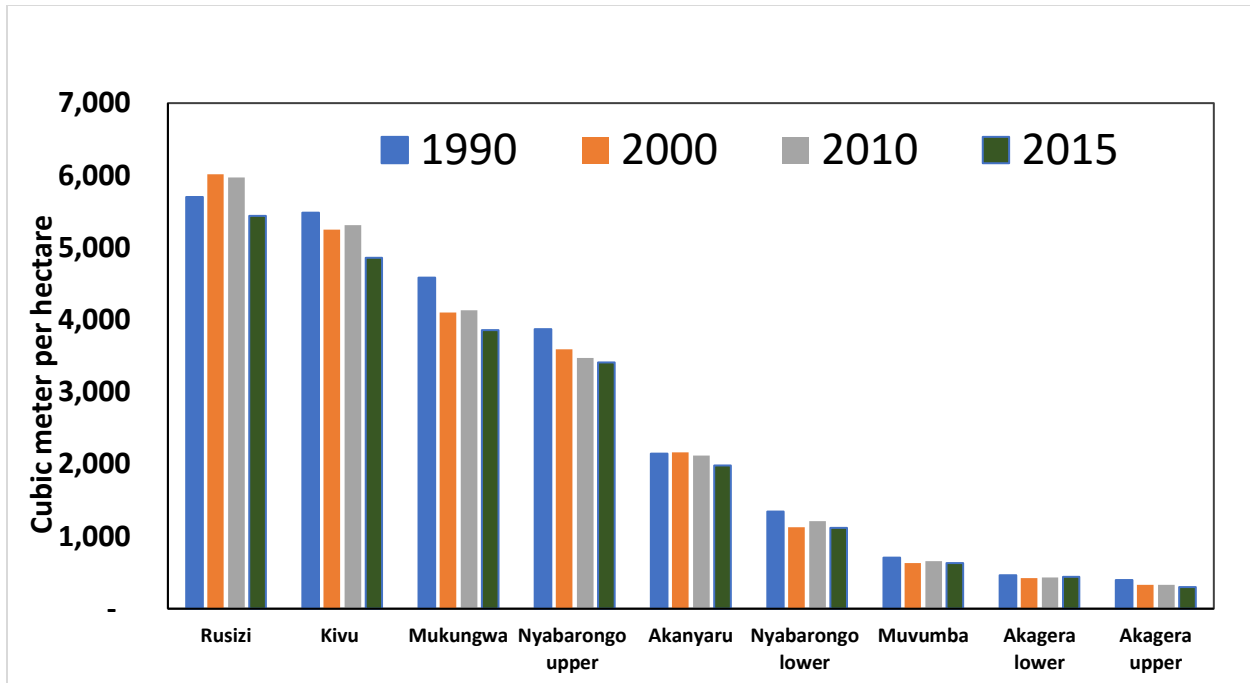


FIGURE 13: QUANTITIES AND TRENDS IN BASEFLOW PER HECTARE FOR 1990, 2000, 2010 AND 2015

Implications:

The catchments with the highest baseflow per hectare maintain high baseflows in rivers downstream and indicate parts of the landscape that offer the greatest water benefits on a per-hectare basis.

The declines in baseflow indicate degrading catchments. The degradation in high-baseflow catchments, such as Rusizi, Kivu, Mukungwa and Upper Nyabarongo indicate serious risks to downstream water security.

4. Policy implications and recommendations

4.1. Strategic implications of soil erosion and soil loss accounts

In 2015 approximately 158 million tonnes of soil were eroded, with an annual average of 62 tonnes per hectare. The trend since 1990 shows that soil erosion has increased by 54%. Soil loss (or sediment export to rivers) was 14 million tonnes in 2015, with an annual average loss of 5.5 tonnes per hectare. Soil loss has increased 123% from 1990 in 2015.

The strategic implications of increasing soil erosion are a threat to food security, due to declining soil fertility, increasing fertiliser costs (and imports) and concomitant food price increases. Soil loss elevates the risks for water security, energy security and biodiversity, due to sedimentation effects on rivers and dams, and pollution of surface water bodies.

The key drivers of soil erosion and soil loss are largely a reduction in vegetation cover and the resulting exposure of bare soils to rainfall and run-off. In addition to an increase in farming areas and on-farm practices (such as predominantly annual crops with poor ground cover), the decline of vegetation cover outside of cultivated areas due to land transformation and harvesting, particularly on river banks and in forests, is a serious concern.

Strategic issues highlighted by the ecosystem accounts:

- Declining trends in soil quality and quantity elevate food security risks, for both for farming households and urban consumers.
- Increasing soil loss trends accelerates soil nutrient exports to downstream rivers and downstream countries, while elevating the need for replacement fertiliser imports. The loss of soil nutrients results in river pollution, biodiversity loss and increasing food and water prices.
- National energy security is likely to be reduced as soil loss results in sedimentation replacing water storage space in dams and accelerating turbine erosion. The loss of storage capacity and elevated turbine erosion will result in greater energy generation costs, as the life span of infrastructure declines.

4.2. Strategic implications of the water yield, quickflow and baseflow accounts

In the last 25 years national water yield (water with potential for abstraction) has increased only slightly by 4%. However, quickflow (fast flowing and potentially destructive water) has increased by 35% with baseflow (which supplies dry-season water flows) declining by 11% (Figure 14).

This small increase in yield is of little benefit in Rwanda as there is limited capacity to capture and store this volume of water in large dams. The increase in quickflow indicates a trend of increasingly erratic and seasonally fluctuating river levels, unsuited to meeting a relatively constant consumer demand throughout the year and with increased risk and costs from flooding.

Rwanda's reliance of run-of-river water use implies the need for a large constant flow, all year round, to meet consumer and irrigation demands. However, the declining baseflow trend indicates there is less steady flow available now and, in the future, despite rising water demand from Rwanda's developing agriculture,

urban and consumer needs⁹, compounded by future effects of climate change. A declining baseflow signals the risk of worsening seasonal water deficits.

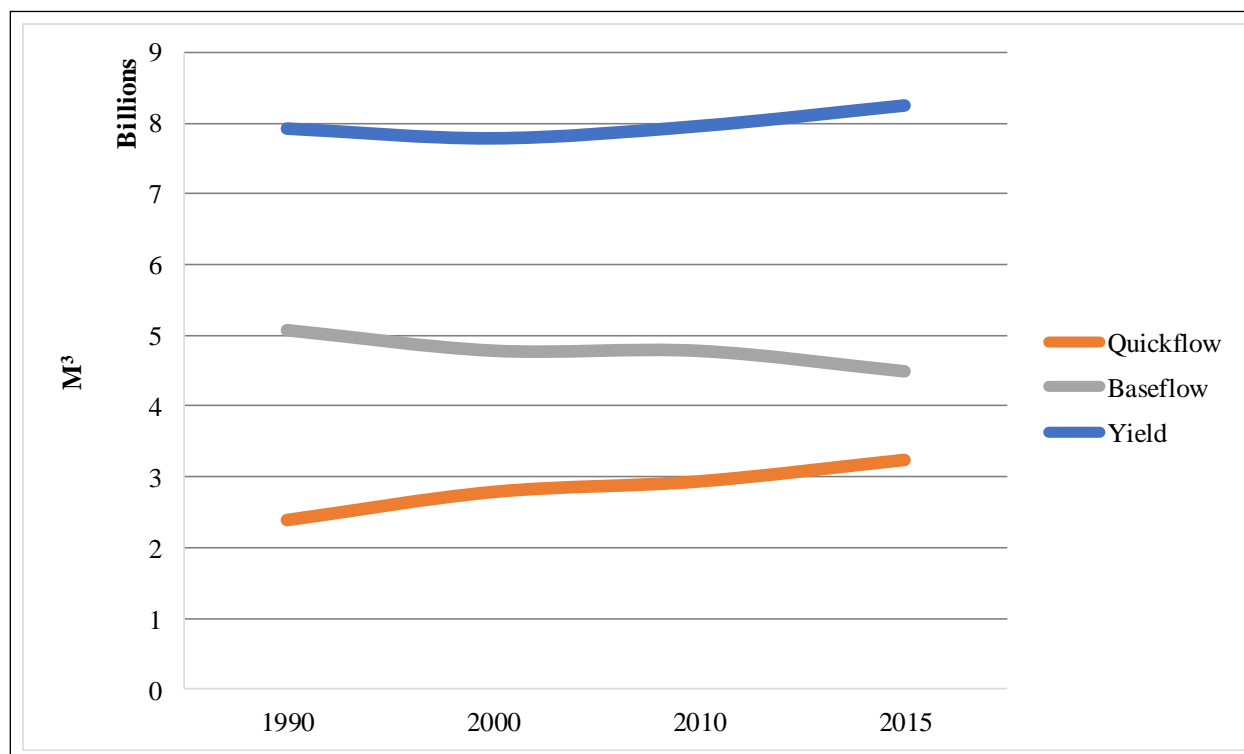


FIGURE 14: CHANGES IN WATER-RELATED ECOSYSTEM SERVICES FROM 1990 TO 2015 (BILLION M³). BASEFLOW AND QUICKFLOW GENERALLY SUM TO TOTAL WATER YIELD

The key drivers of increased quickflow and reduced baseflow, have been the transformation of natural vegetation, such as forests, to croplands and the growth of urban settlement with impervious or sealed surfaces (such as, pavements, rooftops and roads). Dense vegetation cover promotes water infiltration into the soil, thereby storing rainwater in the soil for months or years. In addition, coarser soils, such as riverbanks, also promote elevated infiltration. The percentage increase or decrease in land cover types (from the land accounts¹⁰) is outlined in

Key land cover types	Percentage of national cover in 1990	Percentage of national cover in 2015	Change in cover 1990 to 2015
Sparse Forest	37.1%	10.6%	-71.4%
Annual Cropland	24.2%	51.7%	113.6%
Water Body	6.1%	6.0%	-0.7%

⁹ Government of Rwanda (NISR, Ministry of Environment). Natural Capital Accounts for Water, Version 1.0. October 2018. Kigali, Rwanda.

¹⁰ Government of Rwanda (NISR, Ministry of Environment and Ministry of Lands and Forestry), Natural Capital Accounts for Land, March 2018

Wetland	4.3%	3.5%	-18.9%
Dense Forest	3.3%	4.6%	37.6%
Moderate Forest	2.5%	1.9%	-24.9%
Urban & settlement	0.5%	1.4%	212.3%
Perennial Cropland	0.4%	1.3%	218.3%

Table 7 and highlights the growth of annual croplands and urban areas. Because of greater quickflow, baseflow has declined, thereby elevating water insecurity in Rwanda, particularly during the dry season.

This implies that forest restoration, farming practices and managing sealed surface in urban area should be the focus of interventions to manage quickflow.

Key land cover types	Percentage of national cover in 1990	Percentage of national cover in 2015	Change in cover 1990 to 2015
Sparse Forest	37.1%	10.6%	-71.4%
Annual Cropland	24.2%	51.7%	113.6%
Water Body	6.1%	6.0%	-0.7%
Wetland	4.3%	3.5%	-18.9%
Dense Forest	3.3%	4.6%	37.6%
Moderate Forest	2.5%	1.9%	-24.9%
Urban & settlement	0.5%	1.4%	212.3%
Perennial Cropland	0.4%	1.3%	218.3%

TABLE 7: CHANGES IN THE EXTENT OF LAND COVER TYPES 1990 TO 2015

The findings from these ecosystem accounts resonate and reinforce the Government's assessment of the strategic landscape and watershed management issues that the country is facing:

- Seasonal water deficits are likely to increase given the declining trend in baseflow, impacting water security for household consumers, irrigation agriculture, hydroelectric power generation, and manufacturing.
- An increasing incidence and magnitude of flooding, road transport infrastructure damage, and health and safety risks are likely due to the increasing trend in quickflow.

4.3. Strategic recommendations for enhancing soil and water security

To reduce soil loss and to enhance water security, a number of strategic interventions have emerged from the consultative processes and technical discussions during the development of the accounts. These are presented for further discussion and prioritization through GoR planning and investment processes.

4.3.1. Promote sustainable land use management practices

- Scale up sustainable land management, building on the experience of ongoing programs¹¹.
- Mainstream conservation agriculture into agricultural sector investment plans. Conservation agriculture could be established that reduces tillage, elevates mulch, increases soil fertility, increases ground cover and reduces rainwater run-off. Promote investments for perennial crops.
- Develop stronger policies to discourage the use of charcoal (a major driver of forest and land degradation), promote efficient charcoal stoves (reduce waste) and advance alternative fuel uses (e.g., sustainably produced pellets, biogas, LPG, solar etc). This is in alignment with the NST1(2017-2024) target to halve the number of households depending on firewood/charcoal as a source of energy for cooking from 79.9% (2016/17) to 42% by 2024.

4.3.2. Mobilize financing for the implementation of Rwanda’s Forest Investment Plan

- Mobilise the necessary finance for:
 - Promoting agroforestry to stabilise farmland, increase soil structure and fertility and enhance farm production and income opportunities.
 - Rehabilitation of public forests and improving tree planting by individuals and groups to improve productivity and delivery of ecosystem services.
 - Increasing efficiency along the wood supply chain to provide rapid reduction of the wood supply gap.
 - Increasing efficiency of charcoal burning stoves (improved cook stoves) to reduce wastage.

4.3.3. Operationalize natural resource-based fee collection system for improved catchment management

- FONERWA could provide a mechanism to integrate the current 34 different types fees and penalties from various domestic sources and deploy these to improve landscape management and ecosystem resilience through programs like payment for ecosystem services (PES).
- Non-compliance fees should be enforced by the responsible sister agencies, such as REMA, RDB, RMB and RWFA, and directed towards catchment management.

¹¹ This includes lessons from investments under the Landscape Approach to Forest Restoration and Conservation Project.

4.3.4. Explore natural resource-based fee collection system for improved catchment resilience across landscapes, through innovative insurance schemes

- The Government of Rwanda, in collaboration with the World Bank, has recently developed the National Agricultural Insurance Scheme (NAIS), and are embarking on pilot projects. The program can potentially be expanded to:
 - Include coverage to support landscape restoration (i.e., investments that include forestry, agriculture, climate smart agriculture).
 - Upgrade the scheme in a way that the insurance premium can be adjusted (reduced) when landowners adopt sustainable management practices that reduce systemic risk.

4.3.5. Improve land use planning in targeted areas

- The strategic importance of specific catchments for baseflow maintenance needs to be identified in land use planning and land use management, in order to either set limits on land conversion, target reforestation/restoration, or to guide the agricultural practices on the land. For example, catchments that exhibit high baseflows but with a declining flow trend indicate priorities for restoration, conversion of annual crops to perennial crops and rainwater harvesting in both agricultural and settlements. This information could inform the National Land Use Development Master Plan (NLUDMP). This also implies that catchment planning and the Land Use Master Plan could be integrated.

4.3.6. Implement planned basin-wide flood and environment management programs

- The Government of Rwanda, with funding of the Strategic Pilot Program for Climate Resilience (SPCR), has recently prepared a project on “Flood risk management in the Volcanoes Region of North-Western Rwanda” which has been identified as a priority under the National Strategy for Transformation (NST1). It is one of the most climate sensitive regions in the country due to soil instability, soil erosion, building in flood-prone areas, high rainfall and the steep slopes, which are a source of high run-off and consequently a priority for financing and implementation. The proposed project could be potentially financed by the Green Climate Fund, the World Bank and/or other international financial institutions.

4.3.7. Promote catchment planning in targeted areas

- Catchments or districts showing increasing quickflow trends could be targeted for restoration and prioritised for conservation agriculture. These are areas that propagate destructive water flows and need urgent interventions, such as agricultural engineering of terraces and perennial crops, as well as riverbank vegetation buffers. These buffers should be composed of high value trees such as fruit trees, that will be protected by local residents and can continue to buffer the river (rather than low value trees that face harvesting pressure for charcoal energy). Trees planted along rivers need to be adapted to higher groundwater levels and flood disturbance. Targeting reforestation on sensitive slopes and soils, especially those prone to erosion, would also be valuable.
- Catchments or districts with high water yields and stable baseflows could be maintained and not be further transformed. It is economically strategic to maintain high-value areas before they are degraded. Policy could be developed and implemented to promote higher levels of land use regulation in these highly functional areas, to avoid deforestation and bush fires.

- Catchments with high yields flowing into the Congo basin could be a focus for reforestation as the water supply exceeds consumer demand in the catchment. These are areas where the opportunity costs of plantation water use are low.
- A national policy on water harvesting and soil water storage could help to promote water storage on farmland in the upper catchments of the Nile basin. This could be a large-scale intervention across the landscape and could be well-suited to the community works programmes.

4.3.8. Promote sustainable or green urbanisation

- Urban planning could promote settlement densification to prevent the conversion of farmland to houses as the population grows.
- Limit the expansion of impervious surfaces (roads, parking lots and buildings) that cover coarse soils that enable good infiltration (such as riverbanks and floodplains).
- The urban planning could also include effective water harvesting, urban food gardens (to promote water infiltration and reduce food production pressures on rural lands) and green open space (to promote infiltration and to dissipate local flooding).
- There are opportunities to affect some of these interventions through the planned Rwanda's Urban Development Project 2 (RUDP2) which will be financed by the World Bank and the Global Environmental Facility (GEF). This project will pilot nature-based solutions for sustainable urban development. This includes strategic planning and wetland restoration investments for integrating biodiversity and ecosystem values in urban development processes.

Annex 1: Methods

The process used to develop the ecosystem accounts was the acquisition of existing data from various recent studies in Rwanda¹², and then modelling this data using the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model, to produce several measures of ecosystem services^{13,14}. No primary data were collected for these accounts.

InVEST modelling was used as the model is freeware, which is easily accessible and uses available data, enabling the accounts to be repeatedly generated using available information (such as the land accounts) on a regular basis. While other tools, such as the ACRU¹⁵ model which are more accurate, are not freely available, require very large data sets and usually require a substantial consulting budget to run. The InVEST model on the other hand has been designed to operate in data-poor environments but is able to generate outputs of relatively high credibility on a repeatable basis. InVEST is considered one of the more credible freeware tools available^{16 & 17}.

The InVEST models used in preparing the accounts, are unique to each of the services analysed. Each of the respective models combined ecosystem stocks, such as vegetation or land cover, area of vegetation cover, vegetation/climatic characteristics (such as evapotranspiration), annual precipitation, soil type and topography (as either spatial data or aggregate point data in a GIS) which was then used to model the particular flows of services, such as water yield, baseflow, quickflow and soil erosion and soil loss. InVEST models use known production functions (based on published research), which is linked to the model as biophysical lookup tables that define how changes in an ecosystem's structure and function are likely to affect the generation of hydrological flows in the catchments. Ecosystem services are usually estimated as a supply per grid cell or hectare. InVEST models are spatially explicit, using maps as model inputs and in turn generating maps as outputs¹⁸. The model results can be presented in different scales, and in these accounts, information is presented at the pixel, catchment or district level, depending on

¹² For example, to estimate a cover management factor for erosion control in Rwanda, the following reference was used - Clay, D. C., & Lewis, L. A. (1990). Land use, soil loss, and sustainable agriculture in Rwanda. *Human Ecology*, 18(2), 147–161.

¹³ Rukundo, E., Liu, S., Rutebuka, E., Dong, Y., Asamoah, E.F., Xu, J. and Wu, X. 2018. Spatio-temporal dynamics of critical ecosystem services in response to agricultural expansion in Rwanda, East Africa. *Ecol Indic.* 89:696-705.

¹⁴ For more detail about biophysical table value, please refer to Bagstad, K. J., Ingram, J.C., Lange, G. M., Masozera, M., Rutebuka, E., Zachary, H., Ancona Z. H., Bana, M., Kagabo D., Musana, B., Nabahungu, N. L., Polasky, S., Rukundo, E., Rugege, D. and Uwera, C. 2019. Toward ecosystem accounts for Rwanda: Tracking 25 years of change in ecosystem service potential and flows (In Press).

¹⁵ ACRU – Agricultural Catchments Research Unit of the University of KwaZulu-Natal.

¹⁶ Bullock, J.M. and Ding, H. 2018. A guide to selecting ecosystem services models for decision making: Lessons from Sub-Saharan Africa. WRI, CEH & ESPA.

¹⁷ Neugarten, R. A., Langhammer, P. F., Osipova, E., Bagstad, K. J., Bhagabati, N., Butchart, S. H. & Ivanic, K. Z. 2018. Tools for measuring, modelling, and valuing ecosystem services: guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas. IUCN.

¹⁸ <https://naturalcapitalproject.stanford.edu/invest/#invest-models>

appropriateness. Modelling hydrological flows is global best practice as undertaking detailed measures on every hectare in all catchments is not practical nor affordable.

A key purpose of accounts, is to show trends or changes in service levels over time. In this set of accounts, the InVEST models have compared ecosystem service supply in four time periods - 1990, 2000, 2010 and 2015.

The InVEST model generates two outputs which explain soil movement based on the Universal Soil Loss Equation¹⁹ and Indices of Connectivity (IC)²⁰. The model first computes the amount of eroded sediment here recorded as soil erosion or displaced soil particles but not necessary reaching streams (using RUSLE), then the sediment delivery ratio (SDR), which is the proportion of soil eroded reaching streams and rivers.

Importantly, while the InVEST model relied extensively on the Rwanda land accounts data, the water services' estimates did not use the water accounts. The InVEST model generated independent water indicators but did use the same or similar inputs (such as annual precipitation). This implies that the InVEST estimates will differ from the water accounts to some degree.

¹⁹ Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D *et al.* 2018. InVEST 3.5.0.post358+he23ea3e79185 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

²⁰ Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. *Catena* 75, 268–277.

Annex 2: Data used in the accounts

Data sources

The data used in the modelling was accessed from a range of data sources and include:

Models	Dataset	Data source	Spatial resolution	Year	Data processing notes
All	Land cover	Regional Centre for Mapping Resources for Development (RCMRD) Scheme II land cover classification	30 m	1990, 2000, 2010, 2015	
Annual & seasonal water	Precipitation	WorldClim	30 arc second	1970-2000	
	Rain Events	Meteo Rwanda			
Annual & seasonal water	Reference evapotranspiration	Consultative Group on International Agricultural Research (CGIAR) Global Aridity and Potential Evapotranspiration database	30 arc second	1950-2000	
Annual water	Depth to root restricting layer	International Soil Reference and Information Centre (ISRIC) African SoilGrids 250 m	250 m	n/a	
Annual water	Plant available water fraction	ISRIC African SoilGrids 250 m	250 m	n/a	
Annual water (calibration)	2008-2012 precipitation data	East Anglia Climate Research Unit Climate Research Unit (CRU) TS v. 3.24.01	0.5 degree	2008-2012	Summed monthly totals to obtain annual value
Annual water (calibration)	Stream gage discharge data	Rwanda Water and Forestry Authority	Point data	1956-present, in selected locations	
Annual water	Depth to root restricting layer	ISRIC African: SoilGrids - Root zone depth	250 m	n/a	
Seasonal water	Ecoregions	World Wildlife Fund	Polygon data	n/a	
Annual water	Stream gage data for six watersheds in Rwanda	RWFA			
Seasonal water	Hydrologic soil group	ISRIC African SoilGrids 250 m	250 m	n/a	Based on soil texture
Seasonal water	Potential & actual evapotranspiration	Moderate Resolution Imaging Spectroradiometer (MODIS) MOD16 product	0.05 degree		Divided actual by potential ET to estimate K_c and compare

					with land cover
Seasonal water, Sediment delivery ratio (SDR)	Void-filled digital elevation model	Shuttle Radar Topography Mission	30 m	n/a	
SDR	Rainfall erosivity	Panagos et al. (2017)	30 arc arc-seconds		
SDR	Soil erodibility	Derived from ISRIC African SoilGrids 250 m	250 m	n/a	Calculated according to Williams 1995

Data quality

The accounts are based on a wide range of existing data already collected by various institutions and researchers. A brief note on strengths and weaknesses of the data are outlined below.

Strengths of data used

The data used are credible in so much that they have already been published in government reports and in scientific journals. For example, the landcover data used has already undergone a thorough verification process during the course of the land accounts development. The meteorological data used is based on a 30-year average to provide a credible average²¹. In addition, several international data sets such as Worldclim, World Soil Information and World Wildlife Fund ecoregion data have been used. Some of these data has been verified by field verification in Rwanda or in the region, such as Panagos²² and Ryumugabe et al²³. In addition, annual water yield was calibrated.

Weaknesses of data used

A weakness of accessing a wide range of data over a long period of time is that they vary in their consistency, including data collection, verification, interpolation methods, and other aspects. Data collections methods may vary in time, due to a number of reasons, including methodological improvements. The spatial resolution of some data sets was not high such as precipitation (1km) and soil grid dataset (250m) and some of the published data did not employ local field verification such as the soil erodibility factor.

In some cases, locally available data or estimates, necessary in model lookup tables, were not available. This required the use of estimates from regional studies, such as the curve number values for land cover

²¹ Arguez, A., & Vose, R. S. 2011. The definition of the standard WMO climate normal: The key to deriving alternative climate normals. *Bulletin of the American Meteorological Society*, 92(6), 699-704.

²² Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Lim, K. J. & Sadeghi, S. H. 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific reports*, 7(1), 4175.

²³ Ryumugabe, J. B., & Berding, F. R. 1992. Variabilité de l'indice d'agressivité des pluies au Rwanda. *Bulletin Réseau Erosion*, 12, 113-119.

and soils²⁴. Some data are relatively old or dated, such as a vegetation cover management factor estimated by Clay in the 1990's. In addition, soil conservation work such as progressive and radical terraces, have not be broadly mapped.

To address these weaknesses, new estimates were generated based on newly available data or through discussions with previous workers (such as Karamage Fidele and Rwanda Water for Growth project) in order to reach consensus on problematic factors. Some limitations still exist, such as an updated cover management factor and low spatial and temporal resolution of satellite images used to generated land use and land cover. There are now orthophotos of 0.25-meter resolution available from World View.

²⁴ Baker, T.J. and S.N. Miller. 2013. Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. *Journal of Hydrology* 486:100-111.

Annex 3: Soil erosion

Soil erosion per province (T)

Year	Kigali City	South	West	North	East
1990	2,467,731	32,970,767	28,331,209	22,174,545	16,506,659
2000	2,960,659	39,963,924	45,384,347	43,582,281	25,760,910
2010	2,532,819	38,004,728	44,636,726	29,607,123	21,179,541
2015	3,400,146	40,909,469	55,504,764	35,649,067	22,702,783
Per Ha/2015	47	69	94	109	24
Change, 1990-2015	932,415	7,938,702	27,173,555	13,474,522	6,196,125
% change	37.8%	24.1%	95.9%	60.8%	37.5%

Soil erosion per district (T/Ha/Yr)

District	Year				Change			
	1990	2000	2010	2015	1990 to 2000	2000 to 2010	2010 to 2015	1990 to 2015
Rutsiro	23	64	50	79	182%	-22%	59%	250%
Rubavu	27	55	94	93	104%	71%	-1%	244%
Ngoma	13	35	24	31	164%	-31%	29%	135%
Nyabihu	76	165	163	175	117%	-1%	7%	130%
Karongi	43	67	72	90	53%	9%	24%	106%
Gakenke	66	124	83	129	89%	-33%	55%	97%
Burera	60	139	101	112	134%	-28%	11%	88%
Ngororero	82	152	140	150	86%	-8%	7%	83%
Musanze	54	108	89	98	100%	-18%	11%	81%
Muhanga	63	101	74	105	60%	-26%	41%	66%
Kirehe	17	32	26	28	84%	-17%	6%	61%
Nyarugenge	30	42	42	48	38%	0%	15%	58%
Kicukiro	16	19	25	25	15%	35%	0%	56%
Nyamagabe	50	73	93	77	46%	28%	-17%	54%
Nyamasheke	44	48	51	65	9%	6%	28%	48%

Rwamagana	21	37	27	32	71%	-26%	16%	48%
Rulindo	76	156	114	109	105%	-27%	-5%	43%
Kamonyi	48	68	59	63	42%	-14%	7%	31%
Kayonza	17	28	23	22	66%	-18%	-4%	31%
Gasabo	42	49	36	54	17%	-26%	50%	31%
Ruhango	46	67	59	57	45%	-12%	-4%	23%
Gicumbi	79	136	73	96	73%	-46%	31%	22%
Nyagatare	16	22	17	20	32%	-19%	14%	21%
Gatsibo	25	33	28	30	32%	-15%	7%	21%
Rusizi	58	47	40	69	-20%	-14%	73%	20%
Nyanza	48	70	58	57	46%	-18%	-2%	18%
Bugesera	12	13	15	13	13%	10%	-9%	13%
Gisagara	57	60	48	63	6%	-19%	30%	12%
Nyaruguru	60	42	50	63	-30%	19%	26%	4%
Huye	72	65	56	61	-10%	-14%	10%	-15%

Soil erosion per catchment (T/Year)

Catchment	1990	2000	2010	Per ha	
				2015	2015
Nyabarongo upper	19,477,859	31,471,881	31,912,226	31,634,596	94
Nyabarongo lower	18,812,582	31,385,516	22,155,113	27,042,745	82
Kivu	12,132,640	19,248,260	19,089,828	25,457,658	73
Mukungwa	11,042,586	24,471,717	20,360,060	23,631,037	129
Akanyaru	16,168,219	15,872,977	14,766,542	17,496,679	51
Akagera upper	5,051,921	9,418,946	7,408,049	8,726,956	29
Akagera lower	7,112,464	10,151,734	9,158,900	8,685,709	20
Muvumba	6,779,803	11,019,345	6,680,973	8,507,815	54
Rusizi	5,273,982	3,643,399	3,692,109	6,263,531	62

Annex 4: Soil loss (sediment export)

Soil loss (Sediment export) per province (T)

Year	Kigali City	South	West	North	East
1990	139,988	1,892,623	1,861,381	1,476,586	923,907
2000	176,562	2,556,296	3,260,344	3,507,318	1,587,759
2010	158,599	2,972,259	3,778,812	1,937,058	1,261,256
2015	290,403	3,459,140	5,459,398	3,011,206	1,819,714
Per Ha_2015	4.0	5.8	9.3	9.2	1.9
Change,1990-2015	150,415	1,566,516	3,598,017	1,534,620	895,807
change	107.4%	82.8%	193.3%	103.9%	97.0%

Soil loss per district (T)

District					T/ha	T/ha	T/ha	T/ha
	1990(T)	2000(T)	2010(T)	2015(T)	1990	2000	2010	2015
Nyabihu	277,260	690,877	756,752	970,741	5	13	14	18
Ngororero	394,410	841,908	902,187	1,083,841	6	12	13	16
Muhanga	252,299	434,467	359,929	637,176	4	7	6	10
Rulindo	293,956	780,848	477,372	548,385	5	14	8	10
Rusizi	162,778	528,682	478,814	903,930	2	6	5	9
Karongi	284,507	455,495	612,080	866,926	3	5	6	9
Rubavu	56,072	119,331	281,809	306,598	1	3	7	8
Musanze	192,160	435,005	316,425	394,702	4	8	6	7
Nyamagabe	305,012	495,581	880,715	705,860	3	5	8	6
Nyamasheke	293,217	347,348	466,141	683,952	2	3	4	6
Rutsiro	393,137	276,703	281,030	643,410	3	2	2	6
Gisagara	217,514	247,710	235,419	354,504	3	4	3	5
Nyaruguru	326,815	227,202	342,935	513,687	3	2	3	5
Gasabo	102,705	127,905	96,698	209,812	2	3	2	5
Ruhango	171,276	289,460	295,830	288,455	3	5	5	5
Nyanza	178,353	305,234	298,386	303,409	3	5	4	5
Nyarugenge	22,690	32,308	35,440	50,607	2	2	3	4

Rwamagana	75,219	142,300	100,008	165,816	1	2	1	2
Ngoma	48,975	168,867	102,254	200,318	1	2	1	2
Kirehe	121,608	255,767	202,769	271,591	1	2	2	2
Kayonza	196,599	352,130	298,081	357,214	1	2	2	2
Kicukiro	14,593	16,349	26,460	29,984	1	1	2	2
Nyagatare	182,244	259,550	214,836	321,339	1	1	1	2
Bugesera	79,053	81,475	96,987	108,612	1	1	1	1

Soil loss (Sediment export) per catchment

Catchment					T/ha	T/ha	T/ha	T/ha
	1990 (T)	2000 (T)	2010 (T)	2015 (T)	1990	2000	2010	2015
Mukungwa	701,935	1,854,187	1,528,825	2,082,366	3.84	10.15	8.36	11.39
Nyabarongo U.	1,207,538	2,194,491	2,776,813	2,933,298	3.61	6.55	8.29	8.76
Nyabarongo L.	1,212,706	2,409,648	1,535,322	2,403,649	3.67	7.29	4.64	7.27
Kivu	724,579	1,247,083	1,472,422	2,350,099	2.09	3.60	4.25	6.78
Rusizi	350,873	219,907	264,224	619,391	3.49	2.18	2.62	6.15
Muvumba	430,996	885,545	411,547	767,857	2.75	5.65	2.63	4.90
Akanyaru	922,908	960,958	1,045,072	1,405,508	2.71	2.82	3.07	4.13
Akagera upper	265,784	559,708	416,503	683,416	0.87	1.83	1.36	2.24
Akagera lower	416,850	652,742	585,198	706,731	0.97	1.52	1.36	1.65

Annex 5: Annual water yield

Annual water yield per province (Cubic meter)

Year	Kigali City	South	West	North	East
1990	1.15E+08	2.49E+09	2.82E+09	1.10E+09	1.40E+09
2000	1.08E+08	2.54E+09	2.85E+09	1.12E+09	1.16E+09
2010	1.12E+08	2.57E+09	2.91E+09	1.11E+09	1.26E+09
2015	1.22E+08	2.61E+09	2.95E+09	1.14E+09	1.42E+09
Per ha_ 2015	1,674	4,383	5,021	3,467	1,505
Change,1990-2015	7.62E+06	1.24E+08	1.29E+08	3.89E+07	2.10E+07
change	6.6%	5.0%	4.6%	3.5%	1.5%

Annual Water yield per district in Cubic meter

District	1990	2000	2010	2015	Change	
					1990-2015	Change
Ngoma	84,742,567	80,125,504	85,514,533	101,551,163	16,808,596	19.8%
Gisagara	198,210,074	209,366,295	207,488,305	227,086,770	28,876,696	14.6%
Kicukiro	21,340,355	20,806,099	22,536,976	23,987,383	2,647,028	12.4%
Kayonza	273,650,552	236,457,712	270,517,753	306,683,451	33,032,898	12.1%
Rubavu	183,904,367	191,434,822	210,812,138	205,581,196	21,676,829	11.8%
Nyarugenge	20,837,195	20,415,325	21,529,975	22,732,079	1,894,884	9.1%
Rwamagana	97,397,041	85,806,602	89,841,009	105,727,940	8,330,899	8.6%
Rutsiro	365,877,416	382,904,257	387,501,890	394,830,100	28,952,683	7.9%
Gakenke	247,799,113	257,383,586	251,337,390	265,242,493	17,443,381	7.0%
Nyanza	221,806,119	231,890,684	226,489,183	235,459,163	13,653,044	6.2%
Ngororero	348,291,194	360,106,343	362,915,477	368,297,186	20,005,992	5.7%
Muhanga	210,501,372	215,412,677	210,663,746	222,287,326	11,785,954	5.6%
Huye	215,826,486	225,129,127	228,821,177	226,981,036	11,154,551	5.2%
Rulindo	156,185,802	166,027,756	164,033,017	163,632,956	7,447,155	4.8%
Nyamagabe	660,313,585	676,394,092	689,632,973	690,930,755	30,617,170	4.6%

Nyabihu	390,325,783	402,840,476	405,440,430	407,243,564	16,917,781	4.3%
Gasabo	72,440,501	66,508,787	68,098,715	75,516,642	3,076,141	4.2%
Nyamasheke	572,439,528	573,175,012	584,477,197	596,466,097	24,026,569	4.2%
Karongi	397,443,172	391,760,216	404,526,194	412,327,568	14,884,396	3.7%
Nyaruguru	595,686,675	600,861,282	620,461,002	617,892,520	22,205,845	3.7%
Burera	196,206,389	202,337,773	200,314,260	201,477,171	5,270,782	2.7%
Musanze	316,179,871	317,513,617	326,288,705	324,376,325	8,196,454	2.6%
Kamonyi	175,892,130	174,901,516	180,017,768	179,975,380	4,083,250	2.3%
Bugesera	198,721,858	152,005,239	158,090,768	201,042,660	2,320,802	1.2%
Ruhango	211,626,180	209,958,793	208,756,658	213,687,013	2,060,834	1.0%
Rusizi	565,568,047	551,610,215	549,586,594	568,507,856	2,939,809	0.5%
Gicumbi	180,526,263	180,830,843	169,416,829	181,045,060	518,798	0.3%
Kirehe	175,206,969	138,084,720	146,959,018	175,625,703	418,734	0.2%
Gatsibo	249,070,910	210,863,942	223,002,214	240,805,012	-8,265,897	-3.3%
Nyagatare	324,091,949	260,407,307	287,628,263	292,489,238	-31,602,710	-9.8%

Water yield per catchment in cubic meter

Catchment	1990	2000	2010	2015	Per ha	Per ha	Per ha	Per ha
					1990	2000	2010	2015
Rusizi	6.53E+08	6.44E+08	6.45E+08	6.60E+08	6,475	6,386	6,396	6,544
Nyabarongo U	1.61E+09	1.66E+09	1.67E+09	1.69E+09	4,809	4,958	4,988	5,048
Mukungwa	8.85E+08	9.08E+08	9.16E+08	9.22E+08	4,841	4,967	5,011	5,043
Kivu	1.44E+09	1.46E+09	1.50E+09	1.52E+09	4,154	4,212	4,327	4,385
Akanyaru	1.19E+09	1.18E+09	1.21E+09	1.26E+09	3,494	3,465	3,553	3,700
Nyabarongo L	7.99E+08	7.94E+08	7.90E+08	8.24E+08	2,417	2,401	2,389	2,492
Muvumba	2.83E+08	2.63E+08	2.50E+08	2.68E+08	1,805	1,677	1,594	1,709
Akagera lower	6.60E+08	5.46E+08	6.18E+08	6.71E+08	1,537	1,271	1,439	1,562
Akagera upper	3.93E+08	3.32E+08	3.57E+08	4.21E+08	1,286	1,086	1,168	1,377

Annex 6: Baseflow

Baseflow per province (Cubic meter)

Year	Kigali City	South	West	North	East
1990	30,934,728	1,602,994,722	2,294,526,524	778,577,513	365,250,728
2000	27,977,336	1,545,306,802	2,195,935,987	691,720,334	322,360,122
2010	27,762,501	1,513,900,331	2,198,618,416	716,597,711	323,415,722
2015	22,819,042	1,451,176,662	2,032,630,327	666,759,984	319,188,420
Per ha_2015	313	2,433	3,456	2,035	337
Change, 1990-2015	-8,115,686	-151,818,060	-261,896,197	-111,817,529	-46,062,308
Change	-26.2%	-9.5%	-11.4%	-14.4%	-12.6%

Baseflow per district (cubic meter)

District	1990	2000	2010	2015	Change 1990-2015	% change
Kicukiro	4,525,045	4,543,617	3,592,619	3,075,879	-1,449,166	-32%
Ngoma	29,352,637	22,200,400	23,203,935	20,883,479	-8,469,158	-29%
Rwamagana	23,972,885	18,663,299	20,086,340	17,408,075	-6,564,811	-27%
Nyarugenge	6,992,769	6,001,174	5,681,598	5,119,807	-1,872,962	-27%
Gasabo	19,416,913	17,432,545	18,488,283	14,623,355	-4,793,558	-25%
Kamonyi	68,881,180	55,242,791	57,264,601	53,562,757	-15,318,423	-22%
Muhanga	142,317,996	118,677,452	127,129,774	115,849,567	-26,468,429	-19%
Kirehe	53,333,579	46,175,342	45,597,970	43,534,217	-9,799,361	-18%
Rutsiro	320,938,674	283,393,911	294,257,675	266,572,010	-54,366,664	-17%
Nyanza	100,836,535	84,909,673	85,084,787	84,399,693	-16,436,842	-16%
Burera	153,563,571	132,688,899	137,429,851	128,819,394	-24,744,177	-16%
Gakenke	181,360,580	156,695,211	170,673,309	153,380,579	-27,980,001	-15%
Ruhango	102,821,080	88,395,625	85,837,368	87,070,921	-15,750,158	-15%
Musanze	269,359,350	253,859,714	249,289,090	229,356,019	-40,003,331	-15%
Ngororero	256,072,860	226,538,411	226,711,599	218,847,835	-37,225,025	-15%

Baseflow by catchment (cubic meter)

Catchment	1990	2000	2010	2015	Per ha 1990	Per ha 2000	Per ha 2010	Per ha 2015
Rusizi	5.71E+08	6.02E+08	5.98E+08	5.45E+08	5,703	6,015	5,972	5,441
Kivu	1.37E+09	1.31E+09	1.32E+09	1.21E+09	5,485	5,250	5,309	4,858
Mukungwa	8.05E+08	7.20E+08	7.26E+08	6.78E+08	4,582	4,099	4,133	3,858
Nyabarongo U	1.30E+09	1.20E+09	1.16E+09	1.14E+09	3,871	3,590	3,471	3,409
Akanyaru	7.27E+08	7.34E+08	7.18E+08	6.73E+08	2,146	2,165	2,118	1,984
Nyabarongo L	4.41E+08	3.70E+08	3.98E+08	3.67E+08	1,345	1,126	1,212	1,119
Muvumba	1.11E+08	9.89E+07	1.03E+08	9.88E+07	705	631	660	630
Akagera lower	1.91E+08	1.73E+08	1.77E+08	1.80E+08	465	423	431	440
Akagera upper	1.18E+08	9.77E+07	9.76E+07	8.89E+07	398	330	330	300

Annex 7: Quickflow

Quick flow per province (Cubic meter)

Year	Kigali City	South	West	North	East
1990	75,760,674	703,308,800	394,231,527	266,094,064	952,052,098
2000	73,223,181	794,289,265	545,231,639	405,505,060	962,897,390
2010	82,259,388	844,526,802	585,040,775	360,239,305	1,056,317,482
2015	98,993,946	899,527,045	725,501,428	424,575,822	1,078,518,821
Per ha 2015	1,356	1,508	1,233	1,296	1,140
Change, 1990-2015	23,233,272	196,218,244	331,269,901	158,481,758	126,466,723
% change	30.7%	27.9%	84.0%	59.6%	13.3%

Quickflow per district (Cubic meter)

District	1990	2000	2010	2015	Change 1990-2015	Change
Rutsiro	41,880,374	86,394,318	78,995,067	112,680,115	70,799,741	169.1%
Rubavu	26,722,442	38,737,881	56,291,781	60,205,674	33,483,232	125.3%
Nyabihu	46,632,858	85,077,723	86,951,922	96,131,332	49,498,474	106.1%
Gakenke	48,310,065	81,643,015	63,658,134	92,302,735	43,992,670	91.1%
Karongi	63,358,720	78,514,720	96,226,320	116,721,507	53,362,787	84.2%
Ngororero	60,541,497	99,995,620	99,949,999	111,104,333	50,562,836	83.5%
Muhanga	54,361,161	85,764,538	77,395,592	94,938,995	40,577,834	74.6%
Rwamagana	39,294,588	59,035,957	58,725,539	68,340,757	29,046,169	73.9%
Musanze	52,094,627	74,977,744	80,637,647	88,733,887	36,639,260	70.3%
Nyamagabe	85,637,397	107,619,510	142,579,547	140,145,889	54,508,493	63.7%
Nyamasheke	79,317,907	88,332,905	97,525,607	125,514,431	46,196,523	58.2%
Burera	70,925,510	103,641,125	96,835,991	108,514,987	37,589,476	53.0%
Rulindo	39,258,997	66,791,708	59,898,056	59,845,906	20,586,909	52.4%
Gasabo	33,154,932	34,577,616	35,009,049	48,135,812	14,980,881	45.2%
Ngoma	78,138,169	100,218,644	102,010,416	110,341,744	32,203,575	41.2%

Rusizi	75,777,729	68,178,471	69,100,079	103,144,037	27,366,308	36.1%
Kamonyi	75,464,945	98,868,565	97,342,503	102,688,094	27,223,149	36.1%
Gicumbi	55,504,865	78,451,467	59,209,478	75,178,308	19,673,443	35.4%
Ruhango	69,223,375	92,820,824	98,523,193	93,291,903	24,068,527	34.8%
Nyanza	92,568,813	117,663,712	118,529,313	115,957,388	23,388,575	25.3%
Kicukiro	23,377,804	19,090,586	25,324,838	29,233,676	5,855,872	25.0%
Nyaruguru	116,370,355	93,697,049	108,825,093	139,159,551	22,789,197	19.6%
Kirehe	131,238,568	137,042,996	145,760,505	156,532,510	25,293,943	19.3%
Gatsibo	153,078,307	145,709,875	170,877,554	178,860,681	25,782,375	16.8%
Nyarugenge	19,227,939	19,554,979	21,925,502	21,624,458	2,396,519	12.5%
Huye	82,263,466	82,520,088	85,183,121	92,432,126	10,168,659	12.4%
Nyagatare	139,378,026	129,899,523	148,320,841	148,553,554	9,175,528	6.6%
Bugesera	189,904,630	182,269,490	205,410,912	195,282,750	5,378,120	2.8%
Kayonza	221,019,811	208,720,905	225,211,717	220,606,825	-412,987	-0.2%
Gisagara	127,419,288	115,334,979	116,148,440	120,913,098	-6,506,190	-5.1%

Quickflow per catchment (Cubic meter/ha)

Name	1990	2000	2010	2015	Change 1990_2015
Kivu	914	1,221	1,315	1,684	84%
Mukungwa	1,141	1,805	1,788	2,035	78%
Nyabarongo upper	1,035	1,441	1,623	1,678	62%
Nyabarongo lower	871	1,264	1,126	1,319	51%
Rusizi	724	596	664	1,015	40%
Akagera upper	1,153	1,305	1,390	1,508	31%
Muvumba	673	737	712	783	16%
Akanyaru	1,532	1,494	1,582	1,690	10%
Akagera lower	1,282	1,151	1,316	1,308	2%