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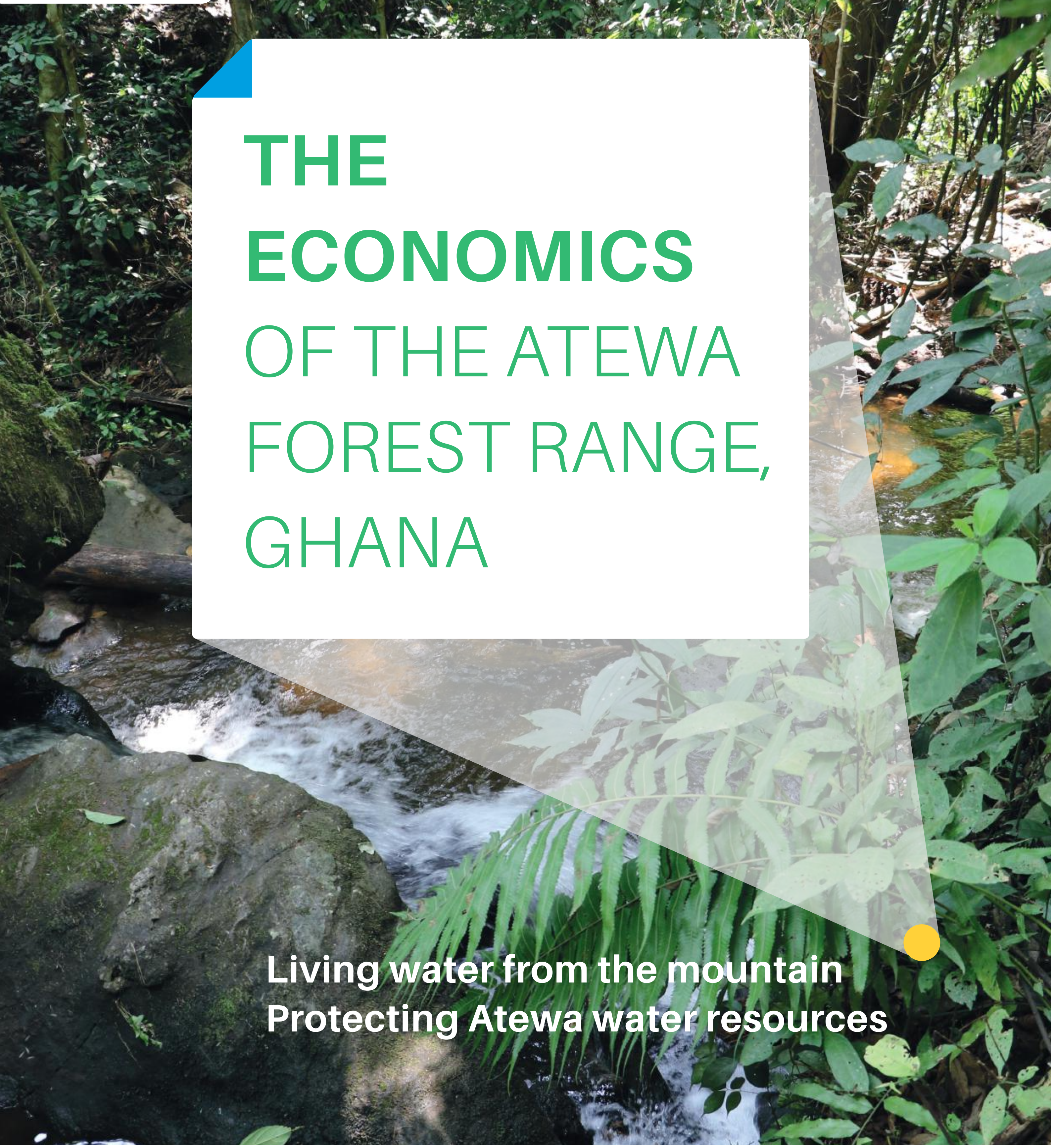

THE ECONOMICS OF THE ATEWA FOREST RANGE, GHANA

Living water from the mountain
Protecting Atewa water resources

IUCN National Committee of The Netherlands
Save Atewa Forest – For Biodiversity, Livelihood And Climate
IVM Institute for Environmental Studies
VU Vrije Universiteit Amsterdam
Ghana A Rocha – Caring for God's Creation
Wolfs Company – Nature by Numbers
Forestry Commission
Kingdom of the Netherlands

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DISCLAIMER

This report was commissioned by IUCN NL and A Rocha Ghana as part of the 'Living Water from the mountain - Protecting Atewa water resources' project. The study received support of the Forestry Commission, the Water Resource Commission and the NGO Coalition Against Mining Atewa (CONAMA) and financial assistance of the Dutch Ministry of Foreign Affairs as part of the Ghana – Netherlands WASH program. The findings, interpretations and conclusions expressed here are those of the authors and do not necessarily reflect the views of the Dutch Ministry of Foreign Affairs, IUCN NL, A Rocha Ghana, the Forestry Commission, the Water Resource Commission or the NGO Coalition Against Mining Atewa (CONAMA). Any errors are purely the responsibility of the authors.

Not all economic values presented in this study are captured by market mechanisms or translated to financial streams; the values of ecosystem services calculated in this study should therefore not be interpreted as financial values. Economic values represent wellbeing of stakeholders and do not represent the financial return of an investment case. The study should not be used as the basis for investments or related actions and activities without obtaining specific professional advice.

This report is prepared by
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Photo Jan Willem den Besten

FOREWORD

The Government of Ghana recognizes healthy ecosystems and the priceless services they provide as pivotal to the countries socio-economic development. As such, Government policies to ensure sound management of the environment and natural resources while pursuing economic growth has been reflected in the country's revised Medium-Term National Development Policy Framework, the Ghana Shared Growth and Development Agenda II (GSGDA II) and the forthcoming 40-year long-term national development plan by the National Development Planning Commission. Additionally, in order to take the next steps to move the country towards a low-carbon green economy, Ghana's Ministry of Environment, Science, Technology and Innovation, together with the United Nations Environment Programme (UNEP), has undertaken a Green Economy Scoping study. Specifically for the forestry sector, the current and revised 2012 forest and wildlife policy also sets out the strategic direction for forest ecosystem management and the promotion of training, research, and technology development that supports sustainable forest management whilst promoting information uptake both by forestry institutions and the general public.

A major drawback is often the absence or limited integration of ecosystem and biodiversity issues into development planning. Inadequate research, public education and awareness on the linkages and dependences between forests, biodiversity, ecosystem services and societal well-being has also been a challenge.

The Economics and Ecosystems and Biodiversity (TEEB) for Atewa Forest Range is therefore expected to inform and support policy reform towards sustainable growth and low emissions development, while contributing to the long-term security of Ghana's important watersheds biodiversity and stimulating green developments at the broader landscape level. This pioneering initiative carried out with the participation and contributions from key national and international forest and water-resources sector institutions, researchers and academia and other major stakeholders, presents the economic basis for actions needed to enhance the conservation and sustainable use of forest ecosystem and its contributions to meeting human needs. It outlines the value of ecosystem services with a special focus on water from the Atewa Range Forest Reserve (for Accra and other urban centers, as well as local communities and business downstream) and the cost benefit analysis of land-use change scenarios in the forest area.

The alternative sets of scenarios presented sets out the full range of long-term implications from the business as usual scenario to increased protection, intensification of industrial extraction of mineral resources which adds to national policy initiatives to mainstreaming natural capital into forest, natural resource management and governance decisions. Ultimately, it contributes to promoting understanding and provides access to useable empirical data and information essential to support government's policy on how land-use planning and investment decisions may positively or negatively affect the long-term conservation of the Atewa forest range.

By connecting the value of ecosystem services to development goals, we will be one step closer to ensuring that nature and its contributions to human well-being will be carefully considered alongside other economic factors in key development and investment decisions. There is also the need to focus on extending the existing ecosystem service modeling tools including TEEB and their replication and scale up across other important ecosystems, water towers and watersheds in Ghana. All stakeholders together with government urgently need to forge strong partnerships to implement, monitor and see this through.

Clearly, we simply cannot continue doing business as usual and to this I reiterate the commitment of the Government of Ghana to designate Atewa Range Forest Reserve as a National Park.

Nii Osah Mills
Minister
Ministry of Land and Natural Resources

CONTENTS

EXECUTIVE SUMMARY

The Atewa Range is a strip of unique upland forest surrounded by a mixture of farms, small scale gold mines and villages. It lies about 90km north of Accra in Ghana. The forest functions as the source of three important rivers – the Densu, Birim and Ayensu rivers. The Atewa Range supports several communities who live on the forest fringes, as well as being home to a large diversity of plants and animals. A section of the forest is protected as the Atewa Range Forest Reserve and is recognized as a Global Significant Biodiversity Area (Figure a). Despite this status, the forest both inside and outside the Forest Reserve[1] is steadily degrading due to timber and non-timber harvesting and the encroachment of farms and gold mines. This is affecting water flows and water quality and those dependent on water downstream in the three river basins, including businesses, the households of over 1 million people in Accra, as well as local communities and farmers that live around the Forest Reserve.

To understand how changes in the Atewa Range may affect the future of key forest functions for both upstream and downstream groups, in particular risks to the quantity and quality of water supply in the river basins, IUCN Netherlands, A Rocha Ghana and the Forestry Commission of Ghana with the support of the Dutch Embassy in Ghana initiated this ecosystem valuation study.

The study aims to demonstrate the costs and benefits in economic terms of current developments in the Atewa Range compared to potential alternatives, and support the Government of Ghana in deciding what the most optimal and sustainable management regime is for the Atewa Range.

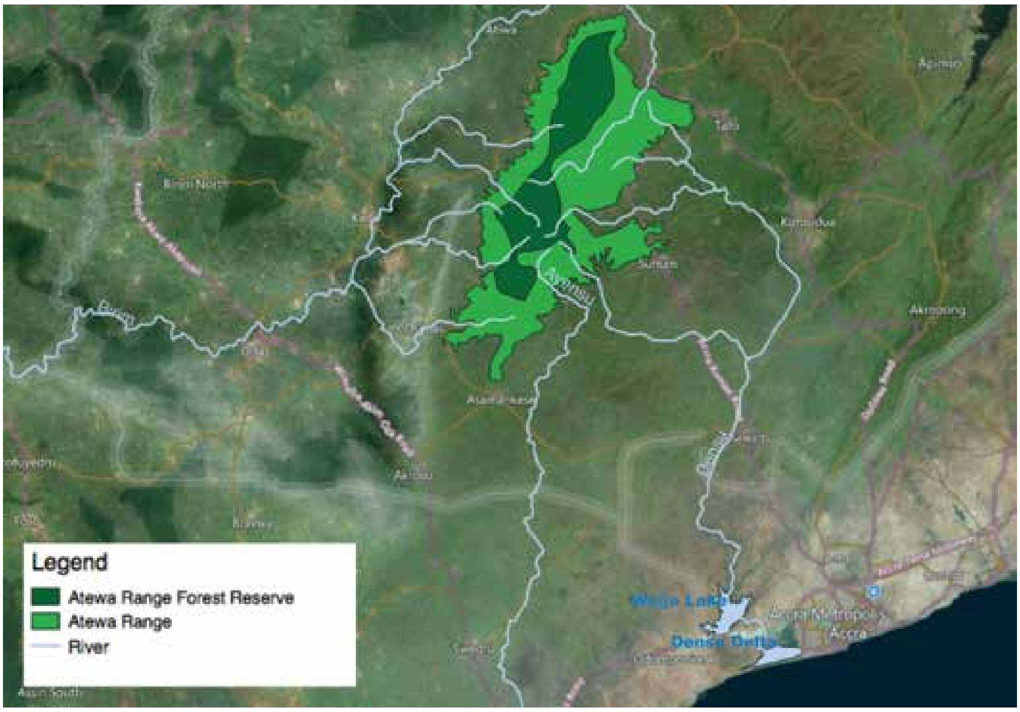

Figure a. Atewa Range Forest Reserve (dark green), the Atewa range (dark + light green) – the primary study area - and the three river basins which it supports (Densu, Birim and Ayensu)

Assessing the value of the Atewa Range

Many of the benefits provided by the Atewa Range[2], such as its role in maintaining water to downstream users, as well as the environmental costs of alternative land use such as gold mining, are not measured or fully taken into account when deciding how to manage the forest. Decisions taken around the management and use of the Atewa Range, both formal and informal, may therefore be unsustainable and sub-optimal. This study aims to make these costs and benefits visible and estimate the value in economic terms of future land management options for Atewa. The study follows the framework set out in the internationally recognized UN Economics of Ecosystems and Biodiversity (TEEB) initiative. TEEB presents an approach that can help decision makers recognize, demonstrate and, where appropriate, capture the values of ecosystems and biodiversity such as those provided by the forest in the Atewa Range (TEEB, 2010).

The study draws on established methods and best practices to classify and quantify the values of all the major products and services provided by the forest (ecosystem services) and land around the forest (e.g. crops and mines), building on ecological, hydrological and land use assessments. These values are then incorporated into an 'extended' cost benefit analysis, i.e. one that includes ecosystem services, of current developments and future scenarios.
The study uses primarily market based methods to estimate the values of different ecosystem services, supplemented by household surveys, avoided cost methods and transfer of values from similar studies[3]. The study does not explain how these values can be captured by market mechanisms or specify detailed policy changes to maintainthese values. In other words, the values presented in the study do not represent an investment case as such, but rather a way to improve our understanding and evaluation of different landscape management options, including the implications – cost and benefits – for different stakeholders.

Four possible scenarios for the Atewa Range

The study uses current and historical data and projects changes to the Atewa Range (Forest Reserve plus a buffer zone around it) under four scenarios over thirty years, and estimates how these changes could affect the forest values in economic terms. **The study assesses the four scenarios, their extended costs and benefits, the time frames of these costs and benefits, and how they affect different groups in different ways.**

NOTES

1 Forest Reserve is used as a shorthand for the Atewa Range Forest Reserve.

2 In this study, the Atewa Range is defined as everything above 220m sea level. The Atewa Range encompasses the Forest Reserve plus a Buffer zone.

3 Given the limitations of information and data availability, certain ecosystem services have not been included in the analysis. The roles of the Atewa Range in regulating the local micro-climate as well as the costs of potential flooding have not been included in the current analysis given a lack of data.

The study highlights four potential simplified scenarios for the future of Atewa:

- Scenario 1: Leave the Forest Reserve as it currently is, with resultant harvesting and mining, and let the forest steadily degrade with resultant downstream costs (Business as Usual);
- Scenario 2: Increase protection status of just the Forest Reserve area to a National Park; allow current land use practices including mining in the buffer zone;
- Scenario 3: Establish a National Park and create a buffer zone around it - invest in green businesses, phase out destructive land use practices, and restore the buffer zone;
- Scenario 4: Extract all the timber and mineral resources, including the bauxite that is located in the Forest Reserve, forego the forest and the forest benefits.

The current status of the Atewa Range - ecosystems, hydrology and values

The Atewa Range consists of closed and open canopy upland evergreen forest, grasslands and herbaceous areas, cocoa and other crop plantations, small scale gold mining and some built up areas.

The Atewa Range Forest Reserve is one of only two reserves with upland evergreen forest in Ghana. This unique forest type is home to around 656 species of vascular plants, around 63 species of mammals and 227 species of birds. Recent data shows that the closed canopy forest has decreased by around 10% in the Forest Reserve and by at least 35% in the buffer zone around the reserve in the last twenty years (CERSGIS, 1990, 2000, 2010). These changes have primarily been caused by farm expansion, mainly for tree crops, and by timber extraction. Gold mining around the reserve took off in 2009 and now occupies around 2.8% of the buffer zone (RMSC, 2016).

Of the three rivers flowing from the Atewa Range, the Densu river basin is the most densely populated. As such, this basin is the focus of the hydrological assessment and it is used to assess changes in water values. The Weija Dam blocks the flow of the Densu River and was built in 1978 for irrigation purposes and to provide potable water to the city of Accra. As a result of upstream soil erosion the reservoir is silting up at around 2% per year and the average depth of the reservoir has been reduced from 5m to 3m since it was constructed.

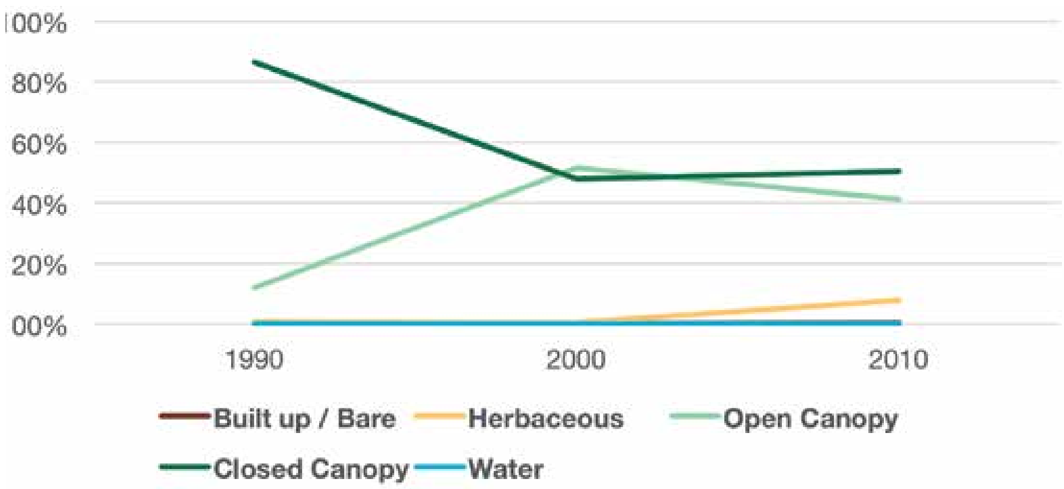

Figure b. Land cover change in the Atewa Range buffer zone (1990-2010). Open and closed canopy include cocoa and other tree crops in current data sets

From the analyzed ecosystem services provided by the Atewa Range, timber products currently offer the largest economic benefits, estimated at US$40.6 million per year. This value reflects legally permitted and illegal or unregulated extraction of timber species from the forest, either for use and consumption by local communities or sale in local markets. An estimated 75% of timber harvesting is currently illegal or unregulated.

Several animal and plant species from the Atewa Range are extracted, consumed and sold as non-timber products by local communities. The economic value of these goods is estimated at around US$12.4 million per year. The land of the Atewa Range is also very suitable for cocoa farming, which currently provides additional benefits to local communities of over US$9.3 million per year.

Downstream from the Atewa Range, the valuation of water for consumption shows that the industrial sector and domestic households in the Densu, Ayensu and Birim basins obtain estimated combined benefits of approximately US$25 million per year. In Greater Accra alone, over 1 million people depend on water from Atewa. Furthermore, water for agriculture provides benefits that account for approximately US$3.1 million per year in irrigated lands and floodplains.

The future of the Atewa Range - results of the cost and benefit analysis

In Chapter 6 the study presents an extended cost-benefit analysis demonstrating the net present value of the set of products and services provided by the Atewa Range and its various uses under the four scenarios. This approach allows a comparison of all the values, including ecosystem services (the 'extended' part of the analysis), generated by different land use options and how decisions today affect the values spread over a 30-year period (the net present value part of the analysis).

The study concludes that creating an Atewa National Park with a supporting buffer zone (Scenario 3) results in the highest net present value - US$1,157 million, 30-year period, 5% discount rate (Figure c). Secondly in both economic and conservation terms, only the conditions provided by the National Park with a supporting buffer zone (Scenario 3) will catalyze a long term increasing trend in value. In fact, additional conservation and green investment actions in Scenario 3 will yield long-term economic benefits for both the forest fringe communities as well as downstream users in the Densu, Ayensu and Birim river basins.

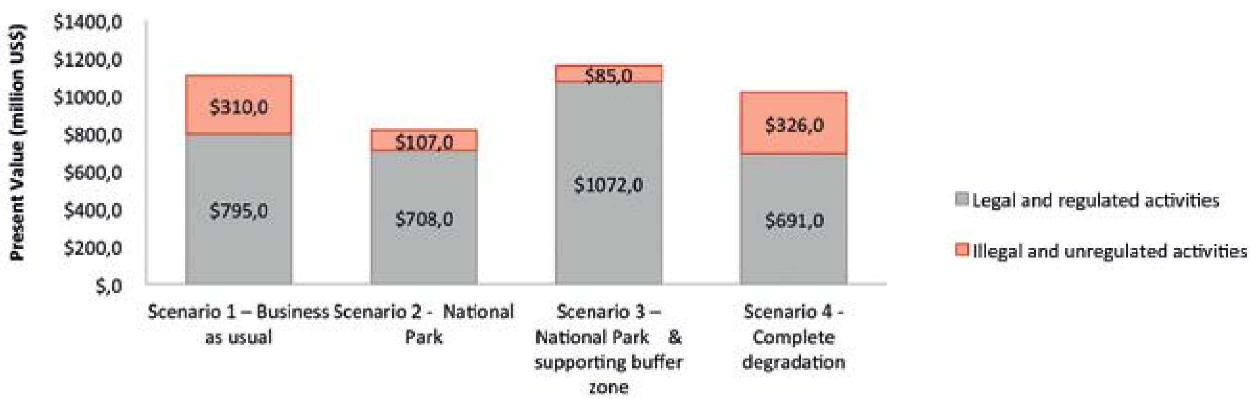

Figure c. Net present value of different scenarios, including legally permitted and illegal and unregulated activities (millions US$, 30-year period and discount rate of 5%)

Results of the hydrological analysis of the Densu basin indicate that losing the vegetation cover in the Atewa Range might slightly increase the annual water availability in the Densu River. However, deforestation would also lead to a higher variability in the water discharge thereby increasing the probability of drought and flood events. Furthermore, households and industries downstream will be negatively affected by degradation of the Atewa Range through an increase in pollution and sediment in the water bodies in scenarios with intensive and extractive activities (i.e. mining and logging in Scenarios 1, 2 and 4).

Although the implementation of the National Park might restrict part of the extractive activities that support the livelihoods of fringe communities, it strengthens the protection of culturally significant areas. Furthermore, Scenario 3 entails that additional management efforts in the buffer zone should ensure that part of the traditional activities of local communities develop in a sustainable manner and still provide economic benefits locally. In addition to the current supply of the ecosystem services described above, the potential for tourism to the Atewa Range in Scenario 3 is estimated at approximately US$5.8 million per year based on a comparison with other natural areas and national parks in Ghana.

Additional economic benefits from tourism and the multiple and sustainable forest use in Scenario 3 lead to the highest net present value and an increasing trend in the total annual value of the ecosystem services of the forest and the buffer zone. In contrast, the cost-benefit analysis suggests that the total value of ecosystem services steadily depreciates in the other three scenarios. Scenarios 1 (business as usual), 2 (National Park without buffer) and 4 (complete degradation) all face decreasing benefits in the long run due to the maintained extractive and farming activities in the area around the forest.

In Scenario 2 that foresees the creation of a National Park, forest degrading practices in the buffer zone will persist, thereby negatively affecting the water supply. Similarly, forest degrading practices in the buffer zone and also in the Forest Reserve will hamper the implementation of sustainable management solutions in Scenario 1. Although bauxite mining in Scenario 4 yields high profits to a limited number of mining companies, the costs of the loss of associated ecosystem services for other stakeholders are significant. Ultimately, degradation of the Atewa Range leads to a decline in annual values and more unequal distribution of the benefits (Figure d).

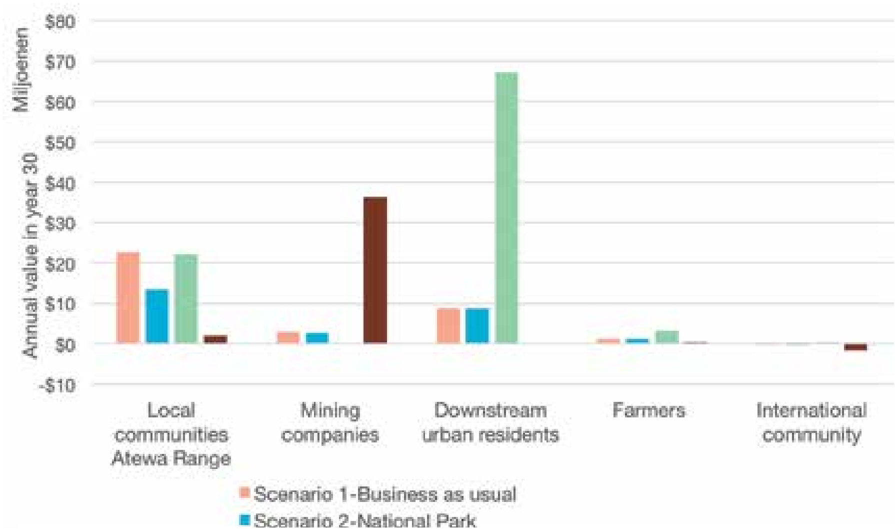

Figure d. Net present value for different stakeholder groups in each of the four scenarios

Recommendations

This report represents a comprehensive knowledge basis for sustainable management in the Atewa Range, as the study results provide insight into the change in costs and benefits, including ecosystem costs and benefits, for various stakeholders in different scenarios. **Increasing the status of the Atewa Range Forest Reserve to a National Park is a key intervention to achieve a more optimal and sustainable flow of ecosystem services to both upstream and downstream beneficiaries.** In addition to this, sustainable land-use within the buffer zone is fundamental to ensure long term benefits. This implies that close cooperation between the central government, political districts and community leaders is imperative to define the new management objectives of a National Park. A Community Resource Management Area (CREMA) or other similar framework would offer the adequate setting for communities, farmers and other stakeholders to co-benefit from changes in management.

The implementation of new sustainable management schemes in the Atewa Range require a shift in local livelihoods that must be researched in order to find alternatives that are tailored to the needs of the local communities. Findings of this study show tourism can be a potential alternative. Furthermore, sufficient incentives to adapt the existing practices should be put in place and an increased awareness of the benefits of protecting the Atewa Range must be promoted.

Payments for ecosystem services (PES) is a potential mechanism to compensate local communities for possible restrictions they might face due to additional protection measures to the forest. In such schemes, downstream beneficiaries of ecosystem services could contribute to a fund to catalyse the transition of fringe communities towards alternative and supplementary livelihoods that stop unsustainable and unregulated activities in the forest. Findings of this study indicate existing potential for payments for water services by downstream beneficiaries of the Densu river and the development of voluntary carbon credits.

The implementation of a National Park and sustainable management systems in the buffer zone will require further actions to strengthen monitoring and enforcement of regulation in the Atewa Range. Strategies to ensure the effectiveness of this process should consider awareness raising campaigns, training and capacity building for patrolling, increased presence on the ground, improved enforcement logistics alongside creating alternative livelihoods.

The successful adoption of all the possible alternatives to protect the values of the Atewa Range will only be possible with the collaboration between diverse actors, which might include: the Environmental Protection Agency, the Forestry Commission, FORIG, the Ministry of Local Government and Rural Development, the Ministry of Lands and Natural Resources, the Minerals Commission, the Ministry of Food and Agriculture, the District Assemblies, the Traditional Authority, the fringe communities, and the downstream farmers and industries. A National Park that benefits both up- and downstream stakeholders and contributes to socioeconomic development in Ghana will ultimately have a greater chance of success.

LIST OF ACRONYMS AND ABBREVIATIONS

CBA	Cost benefit analysis
CBD	Convention on Biological Diversity
CREMA	Community Resource Management Area
FC	Forestry Commission of Ghana
FSD	Forest Services Division
MA	Millennium Ecosystem Assessment
NP	National Park
NPV	Net Present Value
NTFP	Non-timber Forest Products
RMSC	Resource Management Support Centre from the Forestry Commission of Ghana
RUSLE	Revised Universal Soil Loss Equation
TEEB	The Economics of Ecosystems and Biodiversity
WRC	Water Resources Commission of Ghana
WTP	Willingness to Pay

1 INTRODUCTION

1.1 GENERAL BACKGROUND

About 90 km north of Ghana's capital, Accra, the Atewa Range Forest Reserve (or Forest Reserve) covers an area of 253 km^2 that comprises important fragments of upland evergreen forests. Due to its particular location in the head of three river-basins, the Atewa Forest ecosystem provides a wide range benefits to people. According to the literature, these benefits are referred to as ecosystem services (MA, 2005; TEEB, 2010). In the case of the Atewa Range, these ecosystem services are supplied mainly to beneficiaries in the surroundings of the Forest Reserve and in downstream areas, but also reach stakeholders at the national and international scales.

- Locally, the communities around the Forest Reserve depend on the upland forests in the range to obtain food, raw materials and firewood. In addition, local communities attach spiritual and cultural values to the Atewa Forest, as this represents a source of stories, myths and local traditions.
- Regionally and nationally, the Atewa Forest is the source of three rivers, namely: Ayensu (103 km), Densu (116 km) and Birim (175 km). These rivers provide many of the inhabitants of the Eastern, Greater Accra and Central regions of Ghana with drinking water (i.e. over 1 million people in Accra alone). At the same time the rivers support numerous industrial and agricultural activities along the river banks (GNWP, 2014).
- Internationally, the Atewa Forest is recognized for its high biodiversity and unique species it harbours (McCullough *et al.*, 2007).

Upland evergreen forests are rare in Ghana and are represented in only two of the forest reserves in the country. The Atewa Range Forest Reserve is one of these reserves (together with the Tano Offin Reserve) and is the largest in area. Unfortunately, forest degradation within the Forest Reserve and the deforestation in the surrounding areas have accelerated over the past few decades. This is due to a number of pressures, which include: an increase in farming activities (including illegal encroachment), illegal logging, illegal and unregulated artisanal and small-scale gold mining, illegal and unregulated hunting for bush meat, and over-exploitation of certain non-timber forest products. A latent but serious threat to the ecosystem is the potential for large-scale bauxite mining and quarrying within the boundaries of the Forest Reserve.

Within the Forestry Commission, which manages the Forest Reserve, there is the intention to update the status of the reserve to a National Park. An upgrade to National Park would imply a higher priority to conservation of the forest, an increase in conservation efforts and a shift of management from the Forestry Services Division to the Wildlife Division. However, it would not necessarily lead to improved management within the surrounding area of the reserve, where unsustainable agriculture is being practiced and gold mining activities take place. The Minerals Commission, which is part of the Ministry of Land and Natural Resources, is in charge of providing concessions to eligible mining companies. Therefore, the management of the biggest threat to the watersheds of the Atewa Range outside the Forest Reserve (gold mining) lies within this jurisdiction. The Water Resources Commission is responsible for regulating and managing Ghanaian watersheds, including the river basins situated downstream the Atewa Range.

It is against this background, that the Government of Ghana, through the Forestry Commission and the Water Resources Commission, and with the support of IUCN National Committee of the Netherlands (IUCN NL), A Rocha Ghana and The Netherlands Ministry of Foreign Affairs, currently works on the analysis of the societal costs and benefits of future land use scenarios in the Atewa Range (see Box 1).

1.2 RESEARCH OBJECTIVE

The main objective of this research is to provide insight into the economic value of the Atewa Range ecosystem and its river basins for local communities and downstream beneficiaries. This information will support the Government of Ghana in its efforts towards the sustainable land use and forest management in this area, so as to safeguard the ecosystem services supply to both local and downstream stakeholders.

In order to achieve the main objective, the analysis presented in this study builds upon the following sub-objectives:

- Collect information to determine a baseline of the **state of ecosystems** in the study area, which is defined as the Atewa Range and its river basins. The study focuses on the Densu River basin, because of its importance as a water source for an important part of the Greater Accra Region of Ghana.
- Undertake an assessment of the **hydrological status** of the Densu River Basin under different land use management regimes.
- Determine the **economic value** of the ecosystem services provided by the Atewa Range (including the Forest Reserve and its surrounding areas), to local and downstream stakeholders.
- Establish an **extended costs-benefit framework** to create more transparent choices and trade-offs for sustainable management of the Atewa Range, including the Forest Reserve and the surrounding area, and all relevant stakeholders for land use management decisions.

By valuing changes in key ecosystem services, this research will provide evidence for relevant stakeholders to support equitable management of the Atewa Range and its forest ecosystems. Furthermore, the findings of this study are expected to create awareness on the importance and value of the Atewa Range to the different beneficiaries from the Ghanaian society and the international community, thereby catalysing investment in the protection and restoration of the ecosystems in this area.

Box 1 Definition of relevant zones within the upstream area

- Forest Reserve: this refers to the official area of the Atewa Range Forest Reserve (25,400 ha).
- Buffer zone: this is the area that surrounds the Forest Reserve and is located at an altitude of at least 220 meters above sea level (50,600 ha).
- Atewa Range: corresponds to the Forest Reserve and the buffer zone together (76,000 ha)
- Atewa Forest: refers to the forest ecosystems situated within the Atewa Range.

1.3 RESEARCH SCOPE

1.3.1 Geographical scope

This research is limited to the Atewa Range and the three downstream river-basins that benefit from the ecosystem services provided by the range. From these areas, the Densu Basin is considered the most critical one as it covers an important part of the Greater Accra Region, the most densely populated area in Ghana, and the economic and political heart of the country. When relevant, the Ayensu and Birim basins are also incorporated into the analysis, but this is explicitly described in the corresponding sections of the report.

Figure 1 provides an overview of the areas considered in the study, as described below:

Upstream area: It corresponds to the Atewa Range, which is made up of the Atewa Range Forest Reserve and a buffer zone around the reserve (Box 1). The project team defined the buffer zone (in consultation with stakeholders in Ghana and the Netherlands in April 2016) as the area that surrounds the Forest Reserve and is located at an altitude of at least 220 meters above sea level. The upstream area embraces the headwaters of the Densu, Ayensu and Birim rivers.

Midstream area: Limited to the Densu Basin, this area represents the economically important agricultural landscape around Nsawam that ranges between Suhum and Koforidua in the North and the Weija Lake in the south. For this research, the Weija Lake represents the border between the midstream and downstream areas.

Downstream area: Also limited to the Densu Basin, it includes the urban area of Accra, which depends on the Densu River and the Weija Lake to obtain water for more than 1 million people. In addition to Accra, it also includes the Densu Delta, a wetland that is internationally recognized as a Ramsar site (Ramsar, 2016).

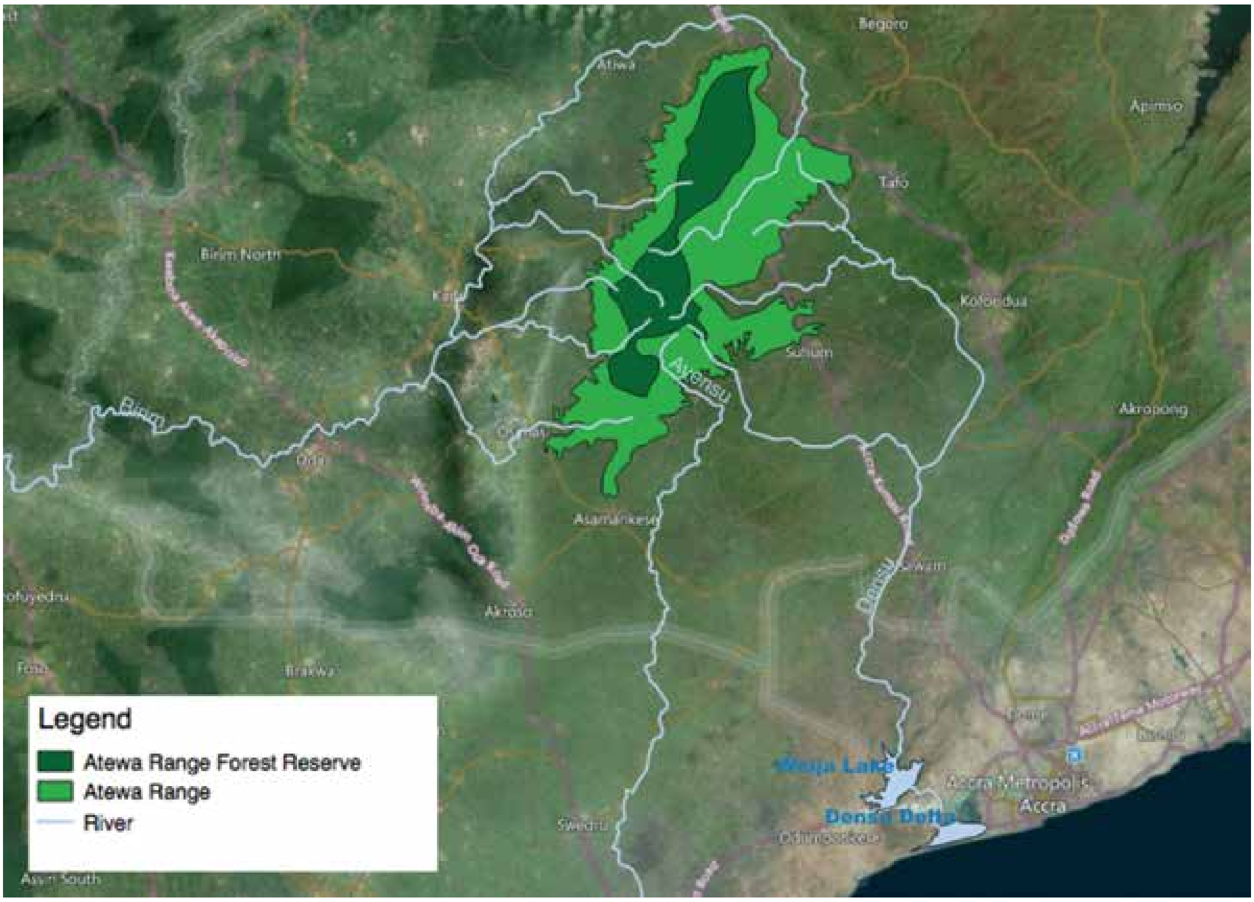

Figure 1 Location of the Forest Reserve , buffer zone and the Ayensu, Birim and Densu rivers

1.3.2 Scope of the analysis

As shown in Figure 2, the boundaries of this study, or scope of the analysis, encompass pressures on ecosystems, their biophysical effects, the corresponding changes in human wellbeing and the governance setting in which all these aspects are dealt with.

The main pressures (Figure 2) on the ecosystems of the Atewa Range are analysed in four scenarios, which were developed in close consultation with a wide range of stakeholders. Since most of the actual and potential changes in the area correspond to land management decisions, the scenarios are collectively referred to as land use scenarios.

The biophysical effects of actual and possible pressures (Figure 2) are analysed as changes in the ecosystem state, including land-cover changes in the Atewa Range and water regime variations in the Densu Basin. Land-cover changes are analysed according to the conditions defined in each scenario, while the fluctuations in the water regime are obtained as an output of a hydrological model specifically designed for the Densu Basin.

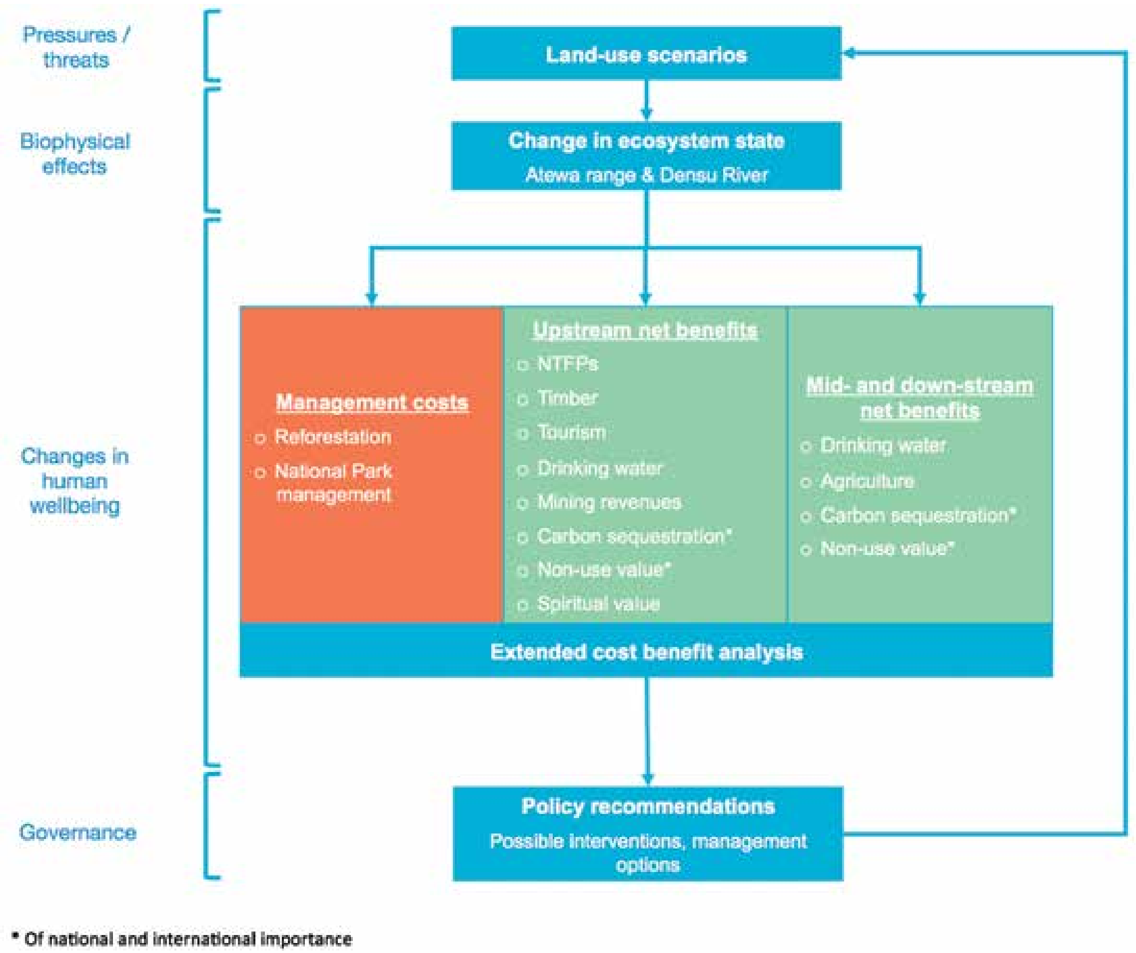

Figure 2 Scope of the analysis (adapted version of the framework proposed by Daily *et al.*, 2009)

The analysis of changes in human wellbeing follows the TEEB[4] approach and includes, in the first place, the current benefits provided by the ecosystems of the Atewa Range to the upstream, midstream and downstream areas. Furthermore, the analysis covers expected changes in benefits and new financial costs that might arise in the context of the different land use scenarios, which are compared with each other on the basis of different value measures (Figure 2). The results of this analysis thus provide insight into the trade-offs and implications of the different scenarios for the stakeholders in the Atewa Range, (Forest Reserve and buffer zone) and the Densu River Basin. The different phases of the analysis ultimately lead to policy recommendations regarding land use options and possible interventions and policy instruments to facilitate a sustainable future of the Atewa Range.

The integrated approach of this study is characterized by multitude aspects. First, the range of affected ecosystem services throughout the range and river basin is expected to involve a wide range of economic sectors, which are all taken into account in the analysis. Second, since the relevant ecosystem services do not change in total isolation of each other, a comprehensive approach is adopted to account for mutual dependencies. Third, there is spatial variation in the distribution of ecosystem services, with the main distinction between effects in the upstream, midstream and downstream areas. Fourth, changes in ecosystem services are not constant over time, and hence, the analysis distinguishes between short-term and long-term effects, as well as seasonal fluctuations.

In the context of the policy recommendations, there are four main authorities within the national Government that are particularly relevant for this study: the Forestry and the Minerals commissions from the Ministry of Lands and Natural Resources, the Water Resources Commission from the Ministry of Water Resources, Works and Housing, and the Ministry of Food and Agriculture. Therefore, the recommendations are mainly, although not exclusively, directed towards these parties.

Detailed information about the methods to analyse each of the aspects included in the scope of the analysis is provided in the corresponding chapters of the report.

1.4 PROJECT ORGANIZATION

1.4.1 Research team

This study adopted a multi- and transdisciplinary approach, by establishing a research team of ecologists, hydrologists and economists from Ghana and the Netherlands. Research organizations involved during the project included the Forestry Commission, the Water Resources Commission, the VU University Amsterdam and Wolfs Company. This process was facilitated by IUCN NL and A Rocha Ghana. Additionally, Ghanaian students were selected to take part in the research in order to build local capacities to conduct studies on ecosystem services.

1.4.2 Stakeholder support

Stakeholder workshops and field visits were organised at various stages of the research process, including scoping, data sharing, reviewing, outreach and dissemination. The intention was to maximise engagement and incorporate local knowledge and visions of policy makers, practitioners and local communities into the study. Throughout the activities included in the consultation process (Figure 3), a wide range of stakeholders supported the project and provided researchers with relevant input.

NOTE

4 The framework adapted in this study is coherent with The Economics of Ecosystems and Biodiversity (TEEB) approach (MA, 2005; TEEB, 2010). Further information on this approach is provided in Chapter 5.

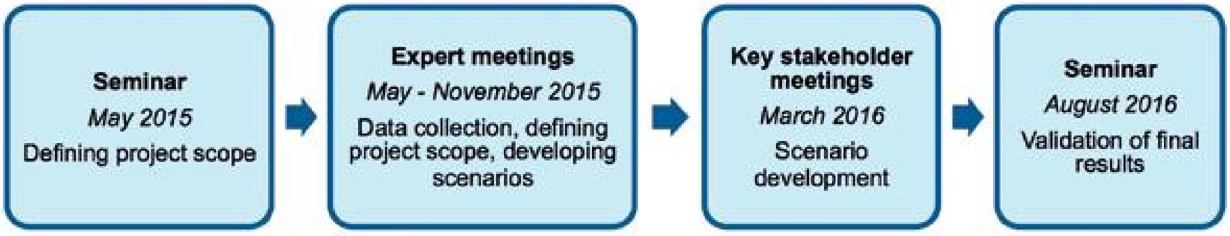

Figure 3 Overview of the stakeholder consultation process

First, stakeholders participated in the inception workshop in May 2015, which has proven to be an important contribution in terms of scoping of the research project. During the workshop, researchers and stakeholders developed a long-list of relevant ecosystem services, threats, and possible policy interventions for the sustainable development of the area (see Annex A for an overview). In the next stage, international and Ghanaian members of the research team held expert meetings with stakeholders on an individual basis to collect available data, develop scenarios and verify preliminary results. Furthermore, in March 2016, additional meetings with key stakeholders were organized to develop the scenarios for the final analysis. To validate the final results, a seminar was held in August 2016.

Representatives from the following organizations participated in the research design and also provided valuable access to important data (Annex A provides an overview of all stakeholders consulted):

- Forestry Commission
- RMSC
- Wildlife Division
- Forestry Department
- Minerals Commission
- Ministry of Agriculture
- Ministry of Health
- CERSGIS
- Ghana Water Company Limited
- Water Resources Commission
- ISODEC
- Various district assemblies
- Ghana Tourism Authority
- Environmental Protection Agency
- Water Resources Institute
- Kwame Nkrumah University of Science and Technology (KNUST)
- Ghana Statistical Service

1.5 REPORT OUTLINE

The subsequent chapters of the report elaborate further on the various sub-components of the research as presented in Figure 4 and the previously described research scope.

Chapter 2 synthetizes the available ecological and environmental information about the Atewa Range and the main pressures on the ecosystems of this area. In Chapter 3, the land use scenarios are described. These scenarios guide the subsequent analysis are described. The status of the Forest Reserve and surrounding area are assessed and other relevant ecosystems along the course of the Densu River, such as the Densu Delta and Weija Lake, are discussed.

Building upon the ecological and environmental information and the land use scenarios previously defined, Chapter 4 presents an in-depth hydrological assessment of the Densu River Basin. In order to analyse the downstream effects of land use changes in the Atewa Range, a hydrological model of the Densu River Basin is developed.

To be able to assess the changes in human wellbeing in each land use scenario, Chapter 5 addresses the economic valuation of the current supply of ecosystem services in the up-, mid- and downstream areas. Starting from the current value of these services, Chapter 6 presents a cost-benefit analysis that focuses on future changes in value associated to each land use scenario. This chapter thus explores how local and regional human wellbeing is affected by changes in the ecosystems of the Atewa Range. Additionally, the chapter identifies how different stakeholder groups benefit or lose in the different scenarios.

Finally, policy recommendations are formulated in Chapter 7 to explains how the results of the study can be applied to pursue equitable management of the Atewa Range Forest Reserve and the Densu river. Chapter 7 specifically reflects on how policy interventions can influence land use trends in the Atewa Range.

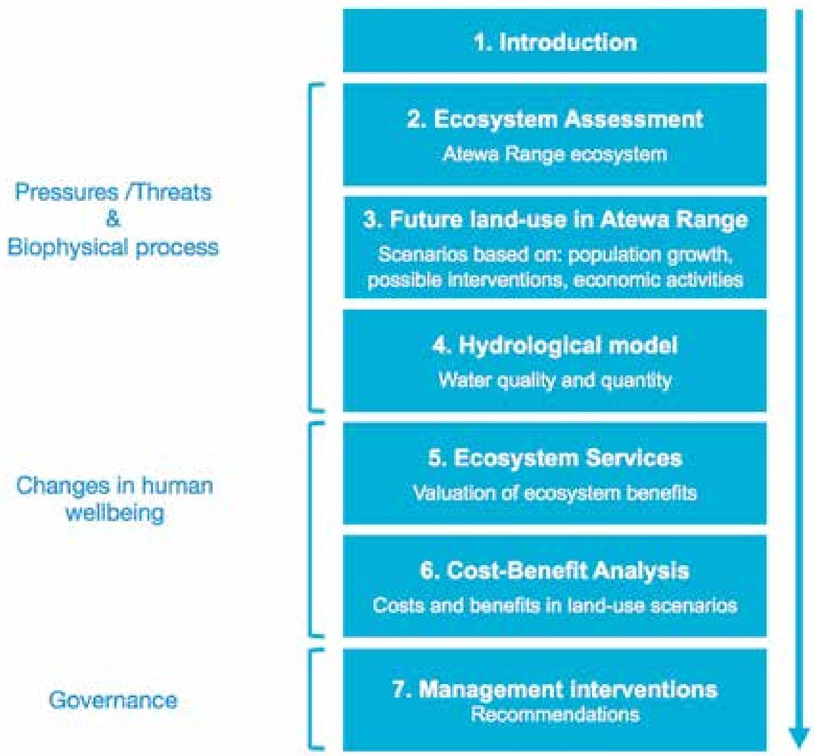

Figure 4 Structure of the report

2 **ASSESSMENT** OF THE ATEWA RANGE ECOSYSTEM

The aim of this chapter is to synthetize existing ecological and environmental information about the Atewa Range to support the analysis presented in subsequent sections of the report. This chapter consequently provides a synthesis of the current knowledge about the state of the ecosystems of the Atewa Range and the main pressures on this area. Given the scattered nature of the available data, this ecosystem assessment is mainly qualitative. The assessment is only supported with quantitative information when robust and sufficiently complete data were available.

Secondary information on the ecology of the Atewa Range was collated from existing reports, scientific publications and policy documents. Furthermore, Consultations were held with focal persons at various institutions to complement the existing data. It is important to notice that available data is insufficient to describe relevant areas of the Atewa Range, and therefore the majority of the information gathered refers only to the Forest Reserve.
This chapter starts with a description of the state of the ecosystems that is followed by a description of pressures and how these influence the state of the relevant ecosystems.

2.1 STATE OF THE ATEWA RANGE

The Atewa Range varies between 200m and 840m above sea level. The range has many steep slopes dissected by numerous streams (McCullough *et al.*, 2007). The steep slopes of the range, as well as the rugged and deep gorges have evolved over a long period of time into a unique forest. The Atewa Range provides habitat for numerous endemic and rare species, in part due to the unique floristic composition of its cloud forest, which is supported by the misty conditions on top of the plateaus (McCullough *et al.*, 2007).

The Atewa Range Forest Reserve (or Forest Reserve), which is located in the Atewa Range, is one of only two forest reserves in Ghana with Upland Evergreen Forest (Hall and Swaine 1981, Abu-Juam *et al.* 2003), the other being the Tano Offin Forest Reserve, which is generally considered as highly degraded.

The Atewa Range Forest Reserve has been officially classified under various different protection schemes over the past 90 years. This change had not much to do with variations in biodiversity or ecological values of the Atewa Range, but rather with changes in policy programs and designations from the Government of Ghana. The Forest Reserve area was declared a National Forest Reserve in 1925, then it was classified as a Special Biological Protection Area in 1994, as a Hill Sanctuary in 1995 and, finally in 1999, as one of Ghana's 30 Globally Significant Biodiversity Areas (GSBAs). In addition to its official conservation status, part of the Atewa Range was listed as an Important Bird Area (IBA) by BirdLife International in 2001 (Ntiamoa-Baidu *et al.*, 2001).

The protection of a part of the Atewa Range was principally based on its high diversity of plant and animal species (Abu-Juam *et al.*, 2003). One of the most remarkable characteristics of the area are several endemic butterfly species (Larsen 2006). Furthermore, the seasonal marshy grasslands, swamps and thickets on the tops of the range's plateaus are nationally unique (Hall and Swaine, 1981).

2.1.1 Plant richness and composition

The Atewa Range Forest Reserve Management Plan was developed in 2003 (Abu-Juam *et al.*, 2003). In the reserve, 656 species of vascular plants have so far been recorded in Atewa. These include 323 tree species, 83 shrub species, 155 liane and climber species, 68 herbaceous species, 22 epiphytes and 5 grass species.

According to the star rating system (Hawthorne and Abu-Juam, 1995), a national equivalent of the IUCN red list system for the forest species in Ghana, the Forest Reserve is home to several important species for conservation. The total list of plant species within the Forest Reserve includes 5 Black Star species, which are species of global significance with the highest conservation priority in Ghana (Abu-Juam *et al.*, 2003). From these species, three have been assessed and classified on the IUCN red list[5], namely: *Sapium aubrevillei* (vulnerable), *Neolemonniera clitandrifolia* (endangered) and *Lecaniodiscus punctatus* (endangered). In addition to these, 33 plant species from the Forest Reserve are classified within the Gold Star category, which means that these are fairly rare at an international and or local level (Abu-Juam *et al.*, 2003). From this group, 23 species have not yet been assessed for the IUCN red list, 8 species are included in the list as vulnerable (i.e. *Alafia whytei, Calycosiphonia macrochlamys, Cussonia bancoensis, Drypetes afzelii, Piptostigma fugax, Placodiscus boya, Robynsia glabrata and Xylopia elliotii*) and two as endangered (i.e. *Okoubaka aubrevillei* and *Placodiscus attenuates*).

Available records indicate that various other extensive surveys have been conducted in the reserve. However, detailed data on species composition and abundance of plant species is lacking. Abundance and richness are only available from Permanent Sample Plots (PSP) data collected between 1992 and 1998. Lack of consistency in spatial and temporal data derived from PSPs makes comparison and trend analysis difficult. A summary of inventories conducted in the Forest Reserve is provided in Annex B.

2.1.2 Fauna

The Atewa Range Forest Reserve has a high faunal diversity in terrestrial and aquatic habitats. The most important data source for fauna species in the Atewa Range, and more specifically the Forest Reserve, is the Rapid Assessment Program (RAP) by McCullough *et al.* (2007). The animal species recorded and considered to reside in the Forest Reserve according to the RAP and other sources are summarized in the subsequent sections, which follow the groups presented in Table 1.

NOTE

5 Classification available at: http://www.iucnredlist.org (Retrieved on 1 July 2016)

GROUP	NUMBER OF SPECIES	SOURCE
Insects		
Odonata	approximately 120*	McCullough *et al.* (2007)
Lepidoptera	approximately 700*	McCullough *et al.* (2007); Larsen (2007)
Orthoptera	> 61**	McCullough *et al.* (2007)
Others	No information	-
Fish	> 19 freshwater species **	McCullough *et al.* (2007)
Amphibian	approximately 40-50 species *	As above
Birds	227 species	Dowsett-Lemaire and Dowsett (2011)
Mammals		
Chiroptera (bats)	> 12**	McCullough *et al.* (2007
Rodentia (rodents)	> 16**	Decher (2004); Decher *et al.* (2005a, 2005b); Norris (2006) and Monadjem and Fahr (2007), cited in McCullough *et al.* (2007)
Soricomorpha (shrews)	> 7**	As above
Large mammals (e.g. duikers, squirrels, pangolins, porcupines, etc.)	> 22**	McCullough *et al.* (2007)
	> 6*	
Primates		McCullough *et al.* (2007)

Table 1 Overview of the faunal diversity in the Atewa Range

* It corresponds to an estimate of the total number of species that potentially exist in the Atewa Range.

** It shows the number of species recorded in surveys, and therefore, it only indicates the minimum number of species expected in the Atewa Range from the corresponding group.

Insects

A total of 72 species of Odonata (dragonflies & damselflies) were found in the RAP, while the authors had previously obtained records of six additional species in the area. Of the 120 odonate species that potentially occur in the Atewa Range, eight species were recorded in Ghana for the first time (McCullough *et al.*, 2007).

At least 700 different species of Lepidoptera (butterflies and moths) are estimated to occur in the Atewa Range (Larsen, 2006; McCullough *et al.* 2007). This is the highest number of butterfly species for any location in the tropical forest of West Africa (Larsen, 2006). Of these, the RAP confirmed 143 species belonging to 55 genera in five families, and Larsen (2006) recorded 575 species. The RAP expedition recorded 14 species that occur only in the West African sub-region and two endemic species to Ghana.

The RAP also recorded a total of 61 orthoptera species (katydids or bush crickets); this is the highest number of katydids known from a single location anywhere in Africa. Of these, at least 8 were new to science, and 36 were not known in Ghana before the assessment.

Fishes

The freshwater ecosystem studied during the RAP survey included the streams of Atewa, which protect the headwaters of the Ayensu, Birim and Densu river basins. A total of 15 streams within the Atewa Range were surveyed. Nineteen species of freshwater fish were recorded. All these species were previously recorded in other river basins in West Africa.

Amphibians

A total of 32 species of amphibians were recorded during the RAP. In total, it is estimated that Atewa Range may be home to 40-50 species of amphibians. Among other exceptional features, the amphibian community of the Atewa Range is largely dominated by forest species and comprises a high percentage of species that is endemic to the Upper Guinea forests. Furthermore, the RAP found out that about one third of the identified species of Amphibian in the Atewa Range is endangered according to the IUCN red list available at the time of such assessment (2007). Although more recent versions of the red list have been made available in subsequent years, the lack of a complete and specific dataset for Amphibian in the Atewa Range at the time of this analysis does not allow an update the estimate of the present number of threatened species.

According to the RAP, the Atewa Range is believed to be one of the only habitats for *Conraua derooi,* a Critically Endangered (and possibly extinct) species.

Birds

During the RAP, 155 bird species were recorded. However, the avifauna of the Atewa Range has been estimated at 227 species, of which 150 only occur within the Guineo-Congolian biome (Dowsett-Lemaire and Dowsett, 2011). Of these, 10 are of conservation concern, amongst which four are classified as Vulnerable and six as Near Threatened on the IUCN Red List. In addition to these, recent personal records (J. Lindsell, in litt.) from the Atewa Range suggest the presence of another globally Vulnerable bird species in the area, the West Wattled Cuckoo-Shrike.

Mammals

The results from the RAP provide insight into small mammals, large mammals and primates in the Atewa Range.

From the small mammals, the sampling efforts of this survey focused on bats (Chiroptera), among which identified 12 bat species, two of these being recorded for the first time in Ghana. All the bat species recorded in the survey are currently classified in the least concern category of the IUCN red list.

Due to the sampling efforts, rodents (Rodentia) and shrews (Soricomorpha) were underrepresented in the RAP, which recorded only three and one species from these families respectively. Previous surveys cited in the RAP, however, had recorded up to seven shrew species and 16 rodent species (Decher 2004; Decher *et al.* 2005a, 2005b; Norris 2006; Monadjem and Fahr 2007; cited in McCullough *et al.*, 2007).

From the large mammals, the RAP recorded 22 species, among which the long-tailed pangolin (*Uromanis tetradactyla*) is currently classified as vulnerable, two duiker species (*Cephalophus silvicultor and Cephalophus dorsalis*) as near threatened, and the Pel's flying squirrel (*Anomalurus pelii*) as data deficient according to the IUCN red list.

Regarding primates, the RAP survey identified six primate species belonging to four families were identified in the Atewa Range; two families of nocturnal prosimians and four diurnal monkeys belonging to two families were found. Two of these six species are of conservation concern according to the IUCN red list: The Geoffroy's pied colobus (*Colobus vellerosus*), which is currently classified as Vulnerable) and the olive colobus (*Procolobus verus*), currently identified as a near-threatened species.

2.2 TRENDS IN LAND COVER

At the time of writing, the main data on which the ecosystem trends can be based for the Atewa Range are the land cover maps for the years 1990, 2000 and 2010 (Figure 5) made available through the Centre for Remote Sensing and Geographic Information Services (CERSGIS). Based on these data, Table 2 summarizes the main land cover categories found in the Forest Reserve and the Densu River Basin.

In the remainder of this section, we analyse land cover and land cover change in the Atewa Range in more detail. As presented in Box 2, the available land-cover classifications from years 1990, 2000 and 2010 identify five different categories in the Atewa Range.

ATEWA RANGE	1990	2000	2010
Built up / bare landscape	0.5%	0.1%	0.3%
Herbaceous landscape	0.5%	0.3%	5.9%
Open canopy forest	10.9%	39.0%	34.3%
Closed canopy forest	87.9%	60.6%	59.5%
Surface water	0.0%	0.0%	0.0%
Densu River Basin	1990	2000	2010
Built up / bare landscape	4.3%	6.4%	12.4%
Herbaceous landscape	2.1%	9.6%	24.8%
Open canopy forest	28.7%	68.9%	42.4%
Closed canopy forest	63.9%	14.0%	19.2%
Surface water	1.0%	1.2%	1.2%

Table 2 Summary of land-cover data in study area (CERSGIS, 1990, 2000, 2010)

Box 2 Description of the land cover categories identified in the Atewa Range

Based on available data for the Atewa Range (CERSGIS, 1990, 2000, 2010), this study considers the following land-cover categories:

Built-up and bare land: this includes degraded and urban landscape.

Herbaceous: this includes grass- and shrub lands and also represents landscape that is potentially suitable for agricultural activities

Closed canopy forest: forest area with forests with a canopy exceeding 60%.

Open canopy forest: forest area with canopy cover between 10-60%.

Surface water: this represents fresh surface water bodies in the study area.

It is important to notice that the Ghana forest definition, as presented in the box above, is consistent with FAO (2000), which establishes a minimum of 0.5 hectares, 5 meters of tree height and 10% canopy cover to classify an area as a forest. The current forest definition of Ghana, however, may lead to the erroneous classification of tree crops with more than 10% canopy cover as forest areas (Indufor Oy, 2013). It is therefore likely that part of the forest lands identified in the available land-cover data for the Atewa Range and the Densu River Basin in fact correspond to tree crops, such as oil palm, rubber and shade cocoa. This issue is further dealt with in Chapter 5, in which the potential area of tree crops classified as forests is determined on the basis of available crop data for the year 2000.

In terms of land use, the dataset from the year 2000 (obtained through CERSGIS) included more specific categories. Among others, it distinguished cocoa plantations and sub-canopy crop areas, which were useful to estimate the percentage of areas classified as forests that might actually correspond to tree crops. By intersecting the land-cover with the land use information from the year 2000, we estimated that approximately 44% of the open-canopy and 48% of the closed-canopy forest overlapped with the cocoa plantations and sub-canopy crop categories of land use in the buffer zone and the Densu Basin[6]. wDue to lack of land use data to estimate these percentages for the years 1990 and 2010, this aspect is not discussed in detail in the trend analysis presented in subsequent paragraphs.

2.2.1 Trends in the Atewa Range

Figure 5 indicates that the closed canopy forest cover in the Atewa Range decreased from almost 88% (668 km^2) of the total range area in 1990 to a little less than 60% (452 km^2) in 2010. This change, however, is differently distributed over the range.

The decrease in closed-canopy forest within the Forest Reserve boundaries has been clearly lower than in the entire Atewa Range: In 1990, the closed-canopy forest formed about 91% (212 km^2) of the total reserve area; whereas in 2010, it decreased to around 81% (190 km^2) of the Forest Reserve. This means that the closed-canopy forest in the reserve shrank by around 20 km^2 in 20 years.

NOTE

6 In Chapter 5, the percentage of these tree crops is calculated exclusively in the buffer zone, given the importance of making such distinction in this specific area for the estimation of the current supply of ecosystem services, such as, timber and non-timber products.

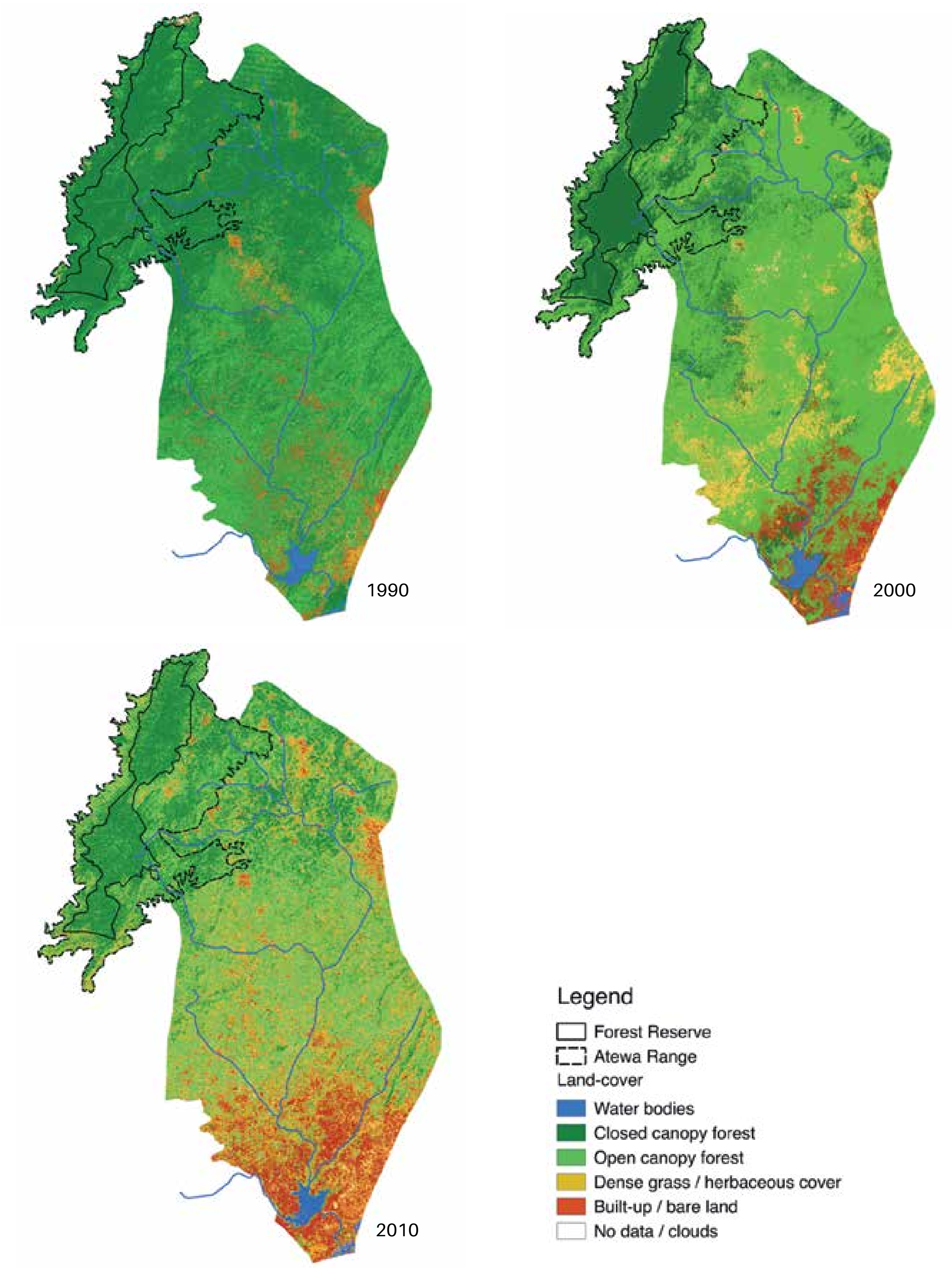

Figure 5 Change in land-cover in the Densu River Basin and Atewa Range between 1990 and 2010

In terms of land use, the dataset from the year 2000 (obtained through CERSGIS) included more specific categories than other available layers of information. Among others, it distinguished cocoa plantations and sub-canopy crop areas, which were useful to estimate the percentage of areas classified as forests that might actually correspond to tree crops. By intersecting the land-cover with the land use information from the year 2000, we estimated that approximately 44% of the open-canopy and 48% of the closed-canopy forest overlapped with the cocoa plantations and sub-canopy crop categories of land use in the buffer zone and the Densu Basin[7]. Due to lack of land use data to estimate these percentages for the years 1990 and 2010, this aspect is not discussed in detail in the trend analysis presented in subsequent paragraphs.

The trend presented in Figure 6 shows that most of the decrease in closed-canopy forest in the Forest Reserve occurred after 2000 and was accompanied by an increase in open-canopy forest. This might be explained by new pressures leading to the degradation of forest (from closed- to open-canopy), but it is also possible that differences in the classification process and data inputs between the years used for the comparison are present.

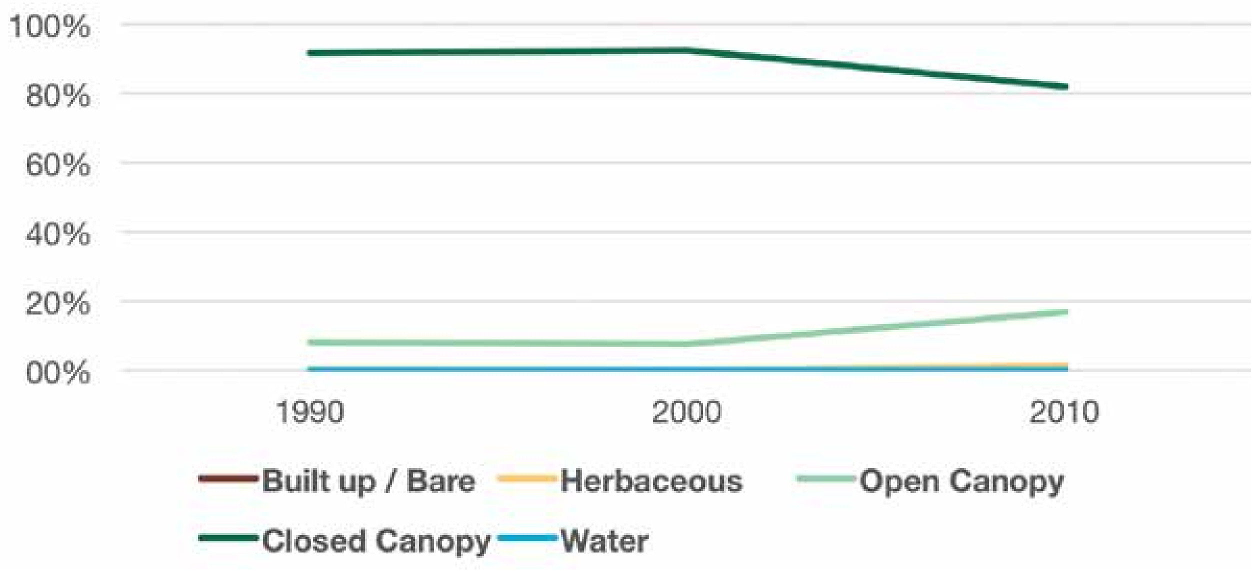

Figure 6 Land-cover trends inside the Forest Reserve

NOTE

7 SRTM DEM database accessible via website: http://www2.jpl.nasa.gov/srtm/

Figure 7 presents land-cover trends in the buffer zone, the area within the Atewa Range area that surrounds the Forest Reserve. As this area is not officially protected, it is expected that it might suffer from more severe degradation. Indeed, the available land-cover data suggest that the decline in closed canopy forest cover was much steeper than in the Forest Reserve: from little over 85% in 1990, closed-canopy forest decreased to nearly 50% of the total area of the buffer zone in 2010.

Since part of the area classified as forest in the buffer zone might actually correspond to tree crops, such as cocoa, the land-cover trend observed in Figure 7 does not allow for detailed conclusions with regard to the degradation or replacement of the forest. The increase in the area of open-canopy forest, however, suggests that closed-canopy forest in the buffer zone has been subject to interventions that have affected tree density and biomass. These interventions can include the replacement of these areas by tree crops, which were classified as open-canopy forest in the land-cover layers, or selective timber extraction leading to a decrease in the forest canopy cover.

The comparison of the trends presented in Figure 6 and Figure 7 indicates that deforestation and forest degradation (from closed- to open-canopy forest) in the past two decades have been much higher in the area that surrounds the reserve than within the boundaries of the Forest Reserve.

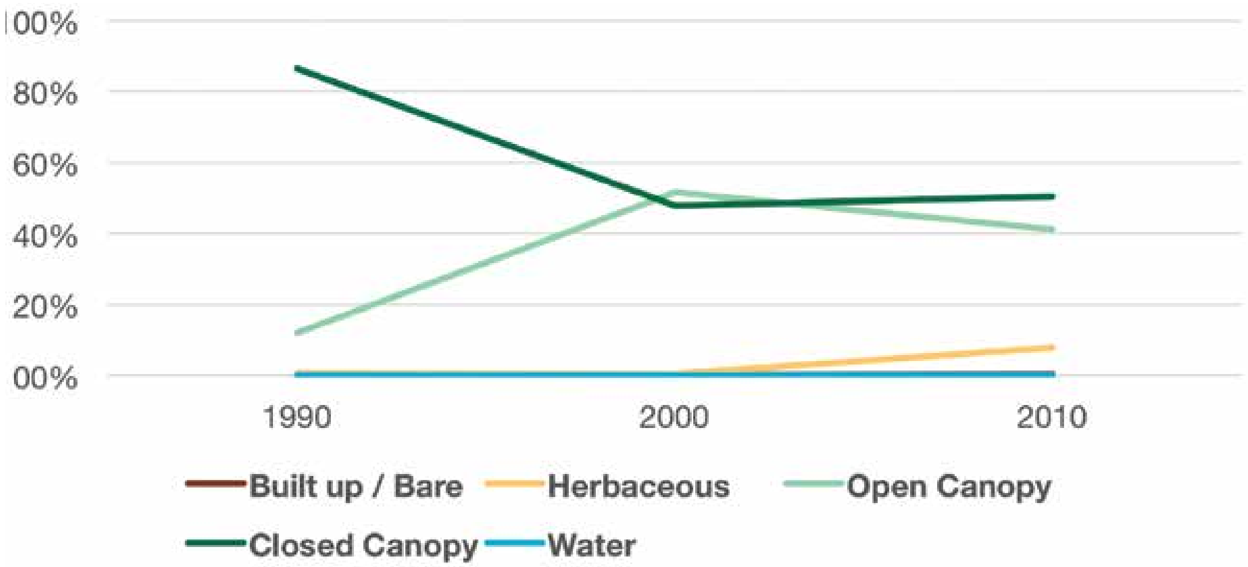

Figure 7 Land-cover trend in the buffer zone (outside the Forest Reserve)

2.2.2 Trends in the Densu Basin

The Densu River belongs to the coastal river system of Ghana and is one of the two main sources of water supply for the Accra urban area. The river takes its source from the Atewa Range and flows from its upstream section eastwards to the Akwadum-Koforidua area, from where it gradually changes its course and flows in southern direction past the town of Nsawam into the Weija Reservoir, which was created for water provision and irrigation.

When the Weija reservoir is full, excess flow discharges into the Densu Delta (Sakumo), a lagoon and salt pans complex, which constitutes one of Ghana's internationally recognized protected areas (i.e. Ramsar sites). The Densu Delta is an important area for over 57 water bird species, including several migratory bird species, and also serves as a sediment trapping platform and a shoreline stabilizer for local communities. Beyond the delta, the Densu River ultimately discharges into the Bay of Guinea (Atlantic Ocean) some 10 km west of Accra. In Chapter 4 (hydrological assessment) this research will more elaborately address the river system and water regimes within the Densu Basin.

Within the 2,600 km^2 of the Densu River Basin, including part of the Atewa Range, the comparison of available land-cover data indicates a change in forest canopy cover in the past 20 years (Figure 8). Whereas 65% of the basin used to be covered by closed-canopy forest in 1990, only 20% of forest with this type of canopy cover remained in 2010. Between 1990 and 2000 the decrease in closed canopy forest coincided with an increase in open-canopy forest cover. As also described for the buffer zone in the Atewa Range, part of the area classified as forest in the available land-cover maps in fact corresponds to cocoa or other tree crop plantations. Since the available spatial information about cocoa plantations is incomplete, it is impossible to arrive at robust conclusions regarding the processes that led to the differences in canopy cover during the period of analysis. These differences might be caused by the replacement of the closed-canopy forest by tree crops with a lower tree density and/or by timber logging, among other possible pressures that could not be determined within the scope of this study.

Between 2000 and 2010, the closed-canopy forest area remained relatively unchanged, but the built up, bare and herbaceous landscapes increased at the expense of the open-canopy forest. It is likely that this development is caused by the increase in population, urbanization (reflected in the built up cover) and increase in agricultural activities (reflected in the herbaceous cover) within the Densu Basin in this period.

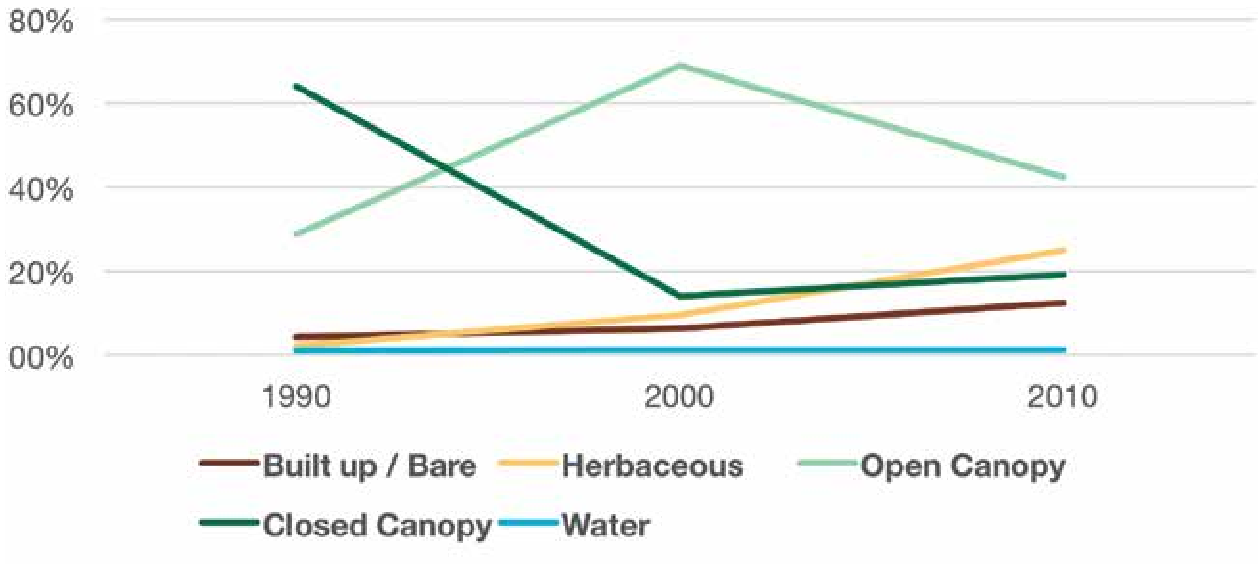

Figure 8 Land-cover in the Densu Basin downstream the Atewa Range

2.3 PRESSURES ON THE ATEWA RANGE

During the workshop held in May 2015 to introduce this study, participants identified several drivers of change and pressures that might affect the Atewa Range (Table 3). Although there are many environmental threats within the Densu Basin, it is beyond the scope of this analysis to assess drivers and pressures outside the Atewa Range. However, downstream effects of these pressures on the Densu Basin are taken into account. For the Atewa Range, drivers of change and pressures (e.g. on water quantity and quality) are incorporated as much as possible into the scenarios defined in Chapter 3 of this study.

One of the important drivers for several environmental issues is population growth. For the East Akim Region, population growth of 1.4% per year is expected (Water Resource Commission, 2007), while in certain municipalities within this region, census data from 2010 indicate population growth rates of around 3.1% (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014). Climate change is another driver that is often considered in environmental studies. In this study, however, the focus lies on the anthropogenic aspect of land cover change. Climate change is taken into account in the hydrological part to illustrate the uncertainty and width of potential change.

There are various local pressures. There is the threat of land conversion within the forest reserve and surrounding areas. The main economic activities in the communities in the Atewa Range are farming and artisanal and small-scale gold mining, also referred to as *galamsey.* Due to drivers such as population growth and the international demand for mineral resources, it is likely that these activities will increase and require more land to be accommodated.

Land-cover data in the Atewa Range indicates that this has indeed been the case between 1990 and 2010, as changes in forest area and canopy-cover have been registered. The fact that the area of herbaceous lands increased in this period suggests a growth of farming activities; while the increase in open-canopy forest may suggest more timber logging or forest replacement by tree crops.

As mining activities affect the vegetation cover severely, the land-cover classification includes the areas where these activities occur in the category "built up and bare" landscape. Although land-cover data for the area does not show a significant increase in built up and bare areas up till 2010, it is important to notice that according to most of the stakeholders mining near the reserve really took off around 2009. Unfortunately, land-cover data for subsequent years were not available to the research team at the time of the analysis.

Next to direct conversion of the landscape, the harvesting of timber and non-timber forest products represent an additional pressure on the quality of the forest ecosystems in the Atewa Range (Forest Reserve and buffer zone). These activities are very important for the livelihoods of local communities, and hence, these are assumed to increase with the population growth in the area.

DRIVERS OF CHANGE	LOCAL PRESSURES ON THE ATEWA FOREST AND RIVER BASINS
Availability of mineral resources and	Land-conversion
international demand for these	Farm expansion
Climate change	(Illegal and unregulated) gold mining
Economic growth	Potential bauxite mining
Population growth	Timber
Unemployment & poverty	(Illegal and unregulated) chainsaw logging
	Fuel-wood collection
	Overharvesting of Non-Timber Forest Products (NTFP)
	Bush meat hunting (including poaching)
	Other NTFPs

Table 3 Drivers and pressures identified during the inception workshop of this study on the 28th of May 2015

2.3.1 Timber and non-timber forest products (NTFP) harvesting (legally permitted and unregulated)

Timber and fuel wood

Between 1966 and 1998, about six commercial timber contractors were granted concessions to operate inside the Forest Reserve, but commercial timber extraction has not been a major activity because of the difficult terrain of the area. Illegal timber harvesting by chainsaw operators, however, is considered a major threat to the Forest Reserve. It can be expected that part of the conversion from closed to open canopy forest between 1990 and 2010 in the Forest Reserve area has been due to illegal chainsaw operations. Unfortunately, due to the illegal nature of this activity, there is very little data available on the exact scale of illegal timber harvesting. According to Ansah (2014), who conducted a household survey in ten communities around Atewa, about 10% of the local population harvests timber and roughly 90% of the population in communities around Atewa collects fuel wood from the Forest Reserve.

NON-TIMBER FOREST PRODUCTS (NTFPS)	
Bush meat	Rattans
Snails	Cane
Honey	Twine
Mushrooms	Chewing stick
Fruits	Chewing sponge
Spices	Wrapping leaves
Herbs	Spices

Table 4 List of relevant NTFPs in the Forest Reserve (Ansah, 2014)

NTFP harvesting

Illegal hunting activities were recorded during the Rapid Assessment (McCullough *et al.* 2007). Comprehensive data on the hunting for bush meat is, as for timber harvesting, lacking. However, few recent studies provide an indication on the importance of bush meat trade and consumption within the Atewa Range (Ansah, 2014; Ayivor and Gordon, 2012). For Ayivor and Gordon (2012) data on quantity of NTFPs harvested is lacking, but Ansah provides an insight in the magnitude of this pressure. The results of the study by Ansah (2014) suggest that hunting might represent a serious pressure on the Forest Reserve, as he estimated that approximately 370 tonnes of bush meat are annually harvested in this area. Table 4 provides an overview of the relevant NTFPs harvested from the Forest Reserve, while further information on timber and non-timber products is provided in Chapter 5.

2.3.2 Land-conversion

Farming

The expansion of farms in the Atewa Range has been identified as a significant factor for land-cover change in the area and a significant threat to the biodiversity of the Forest Reserve (McCullough *et al.*, 2007). Since the area experiences relatively high rainfall, removal of forest cover could readily lead to serious erosion and loss of topsoil. This could easily disrupt the forest structure, loss of biodiversity and other forest ecosystem functions such as watershed protection. The agricultural expansion in the area, together with timber logging, is thus likely to explain part of the change from forest to herbaceous lands observed in the Atewa Range between 1990 and 2010.

Potential for bauxite mining

The discovery of large quantities of bauxite in the Atewa Range in 1914 was the propelling reason for the British to plan to build a dam in the Volta River to provide enough electrical power to process the bauxite into aluminium. Within its mountain ridges, the Atewa Range hosts the second largest bauxite deposit in Ghana (Minerals Commission, 2015). As reflected in Table 5, the feasibility of developing an integrated bauxite/alumina operation in the area has been extensively explored (Patterson, 1967; Kesse, 1984; Mitchell, 1972; International Bauxite Association, 1977; EPIQ, 1997). The range of hills on which the bauxite occurs consists of flat or nearly flat-topped hills stretching 14.5 km from Apinamang in the west to Kibi in the east. The bauxite is lateritic in origin and is derived from the steeply dipping Birimian metavolcanic and metasedimentary rocks. The bauxite deposits are covered by the tropical forest in the forest reserve and 1.5-3.0m of thick overburden soil (Minerals Commission, 2015). This implies that the forest needs to be logged completely if open pit mines are developed.

SOURCE	MILLION TONNES (METRIC)	LOWER BOUND	HIGHER BOUND
Patterson (1967)	60	n/a	n/a
Michell (1972)	120	120	120
International Bauxite Association (1977)	241	182	300
Kesse (1984)	166	152	180
EPIQ (1997)	125	115	135
Average	**142.4**		

Table 5 Estimate of bauxite reserve in the Atewa Range

It was the intent of the mining company ALCOA to mine for bauxite in the Atewa. In June 2006, the company engaged Conservation International (CI) to conduct a biodiversity survey to obtain environmental information on areas of the reserve earmarked for potential bauxite mining. ALCOA did not pursue further their mining interests of Atewa. In March 2011, Vimetco Ghana Ltd. (a 100% owned subsidiary of Vimetco. N.V. an international industrial group that focuses on the aluminium industry) obtained several prospecting licenses in Ghana. However, actual Bauxite mining has not yet taken place in the Atewa Range.

The various studies carried out in Atewa since the 1960s indicate a significant bauxite reserve: over 140 million metric tonnes with an average grade of 45% Al2O3 (Vimetco, Annual Report 2011). Prospecting indicates that it is financially viable to mine the bauxite deposit and to process it into sandy type alumina in a potential plant in Kibi (Minerals Commission, 2015). Although this financial analysis considers required investments in infrastructure, it did not take into account possible negative environmental externalities that are affected by the open pit mines and related infrastructure and lead to a decrease in ecosystem service values, such as an increase in soil erosion, sediment load, and land degradation.

Gold mining

Gold exploration in the Atewa Range took off during the last decade of the nineteenth century (Chevyrock Engineering, 2010). Gold deposits originate from the underlying geological formation from the Birmian Supergroup (Figure 9). Investigations of gold resources around the Atewa range using airborne geophysics interpretations (magnetic and radiometric) show the most favourable zones for gold mineralization and deposits (Figure 9). From this, it can be seen that gold in the Atewa range is widespread, flanking most areas of the range and surrounding drainage systems.

Until recently, little was known about the scale of mining activities around Atewa. To fill this gap The Resource Management Support Centre (RMSC, 2016) from the Forestry Commission of Ghana conducted research to identify legally permitted, unregulated and illegal mining activities around the Atewa Range Forest Reserve area (Figure 11). Based on this information it is estimated that 2.8% of the buffer zone is currently mined by all legally permitted, unregulated and illegal gold mining operations. This relates to 14 km^2 of mined landscape in the buffer zone. Except a few locations where there are some gold panning activities in river streams (galamsey points in Figure 11) there are no significant gold mining sites in the Forest Reserve area.

Large-scale gold mining

The flanks of the Atewa range are now mostly covered with large-scale mining concession leases (Figure 10). Active concessions, i.e. concessions that produce > 50,000 metric tonnes of unprocessed material per year (Aryee *et al.*, 2002), are mostly in the hands of international mining companies like Xtra Gold Mining Co. Ltd. (Canadian owned, but the Government of Ghana has an interest of 10% in the company) and Med Mining Company (from Turkey). The processing method of the large-scale gold recovery is through separating the gold from the gravels efficiently in a wash plant using vibrating grizzlies, high pressure water beams, and rotating scrubbers (Goldenrae, 2006; MMC, 2005).

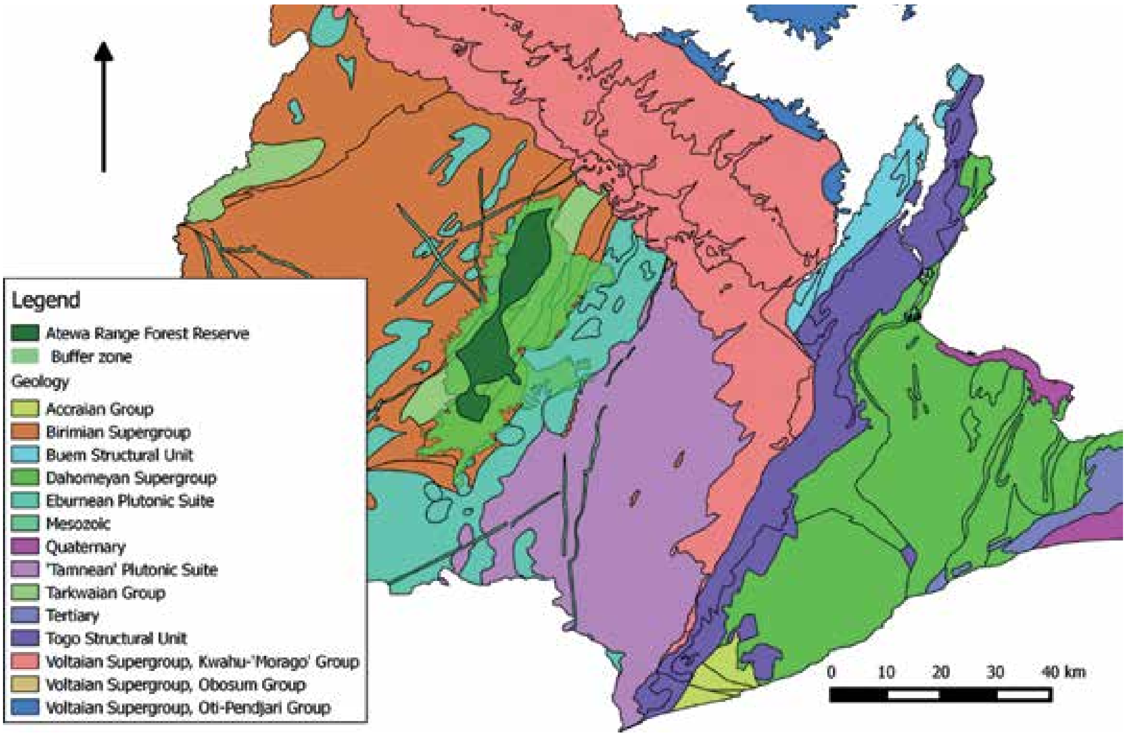

Figure 9 Geological map of the area around the Atewa range

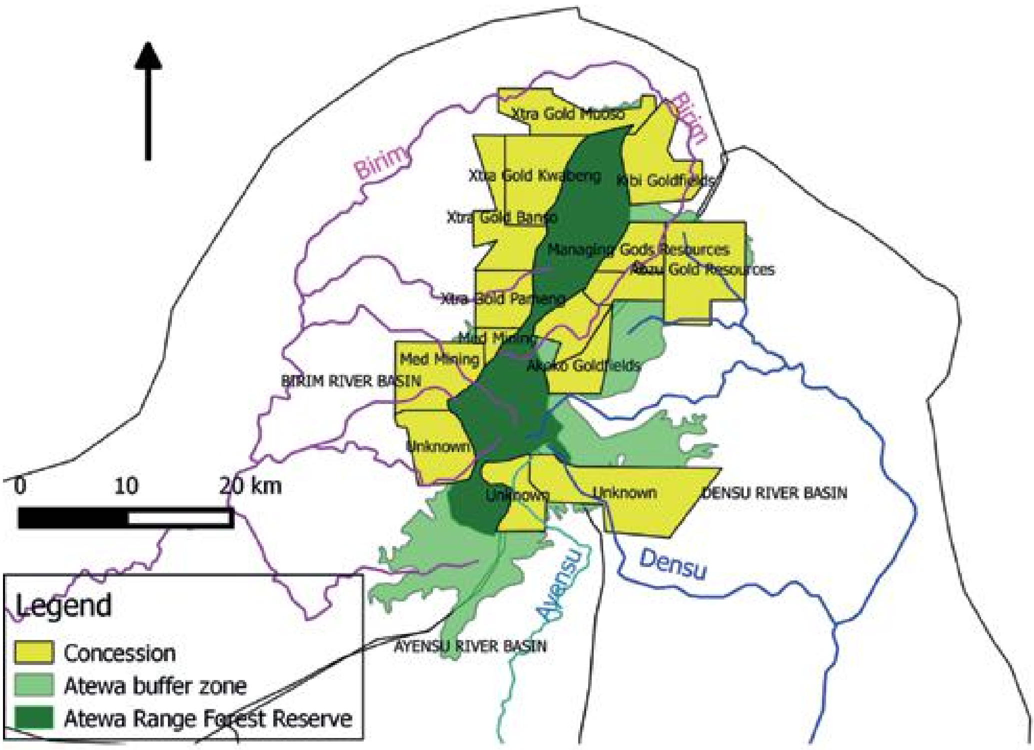

Figure 10 Concession map of the area within the three river basins of the Atewa forest reserve (adapted from Xtra Gold, 2012; Protea Geoservices, 2012)

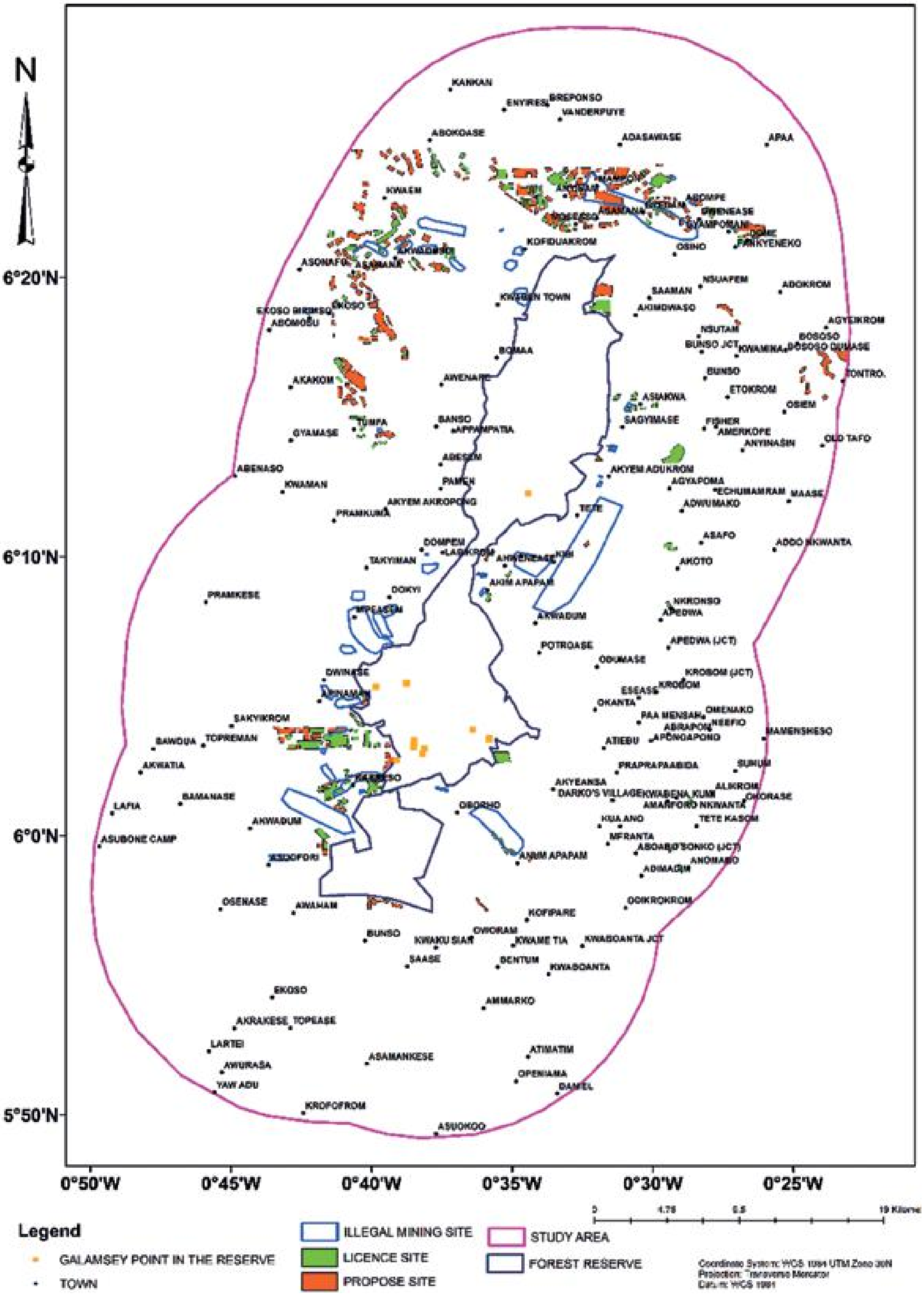

Figure 11 Current and proposed gold mining sites in the Atewa Range (Forestry Commission, 2016). Please note that the study area from the original source (pink polygon) differs from the one defined for this study

Small-scale gold mining

In recent years, small-scale gold mining activities (< 50,000 tonnes of unprocessed material per year [Aryee *et al.*, 2002]), or galamsey, have been on the rise in Ghana (Figure 12). These operations can be legally permitted, unregulated or illegal. The trend of an increase in galamsey is also observed around the Atewa Range (Boateng *et al.*, 2014). Currently, galamsey concentrates in or around concessions in the upper reaches of the Birim River, mainly in the stretch just downstream from Kibi to Bunso (Osafo, 2011). It is expected that most small-scale gold mining operations are either illegal or that part of the concessions of larger companies are sublet to smaller mining operators. Unfortunately, there is very little information on total amount of extracted gold at a small scale, since production volumes of illegal miners, unregulated operations and sublet concessions have not been recorded (Minerals Commission, 2015).

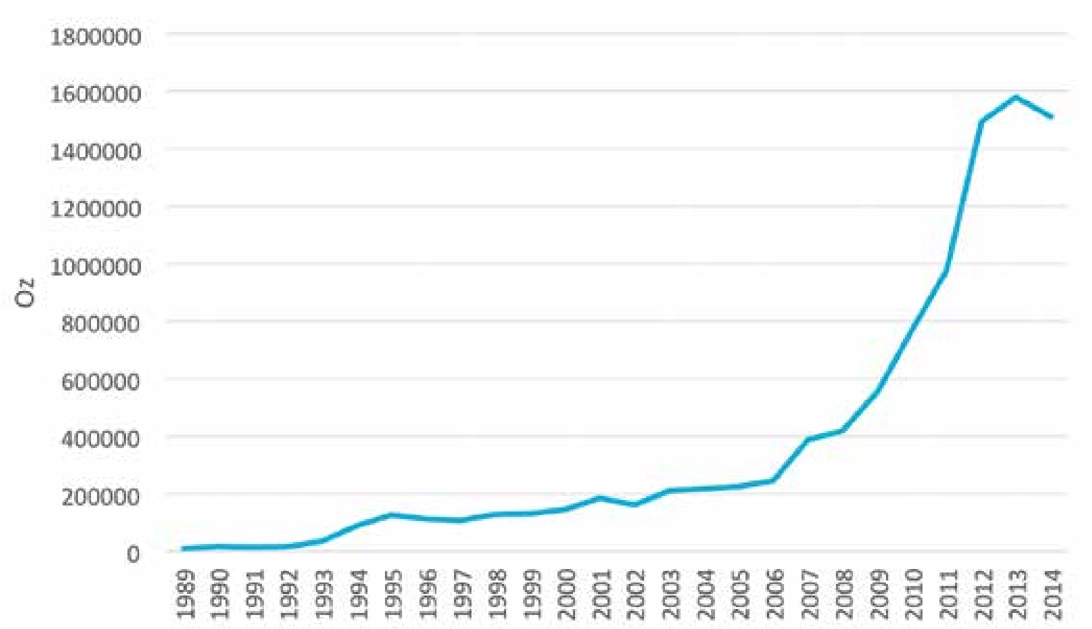

Figure 12 Development of small-scale gold mining in Ghana (Minerals Commission, 2015)

3 LAND USE SCENARIOS

To estimate how the value of key ecosystem services may change in the future as a consequence of different management regimes, a set of future perspectives (scenarios) has to be established with different utilizations of the land. The future is inherently unknown, and there are no publically-available land use models for the Atewa range area. Also, extrapolating past trends is not believed to reflect plausible future conditions in the area. Therefore, this study uses hypothetical scenarios of future end situations. As such, these scenarios are not fixed for a specific moment in time, but reflect a certain condition irrespective of time. It is important to notice that the scenarios do not reflect predictions of what will happen in the future (as this is inherently unknown), but serve a "what if" role; i.e. if land use ends up like this due to policies and management, "this or that" may happen in terms of (value of) ecosystem services.

Such a set of scenarios has to cover a relevant range of possibilities to include all the different ways in which the future could develop. Moreover, for the purpose of this study it is important to quantify the future state of key indicators, such as the different land-cover and land use areas. To arrive at these indicators, bilateral expert consultations have been carried out (March 2016) with several experts and key stakeholders (Forestry Commission, Mineral Commission, Water Resources Commission) as well as with knowledgeable partners in the study team.

In this chapter, the scenarios are introduced, including the narrative behind the different futures, and the quantification of varying land cover conditions. These biophysical parameters are used in the subsequent hydrological assessment, the valuation of the ecosystem services, and the cost-benefit analysis. Climate change has not been explicitly incorporated in the scenarios: while temperature is expected to increase due to climate change in Ghana, the net effects of climate change with respect to rainfall and discharge are highly uncertain (NCCC, 2010; Lauri *et al.* 2012; Maina *et al.* 2013). In chapter 6, the implications of the land use scenarios for the cost-benefit analysis are discussed in more detail.

3.1 GEOGRAPHIC AREA

The prime focus of the study is on the Forest Reserve in the Atewa Range (Figure 13, green area). However, because the study area forms the headwaters of this river, which provides water resources to millions of people, including a large part of the city of Accra, also the downstream users of the Densu Basin (Figure 13, blue area) are investigated. The mountain range in which the Forest Reserve is located is larger than just the reserve itself. Next to the Densu water resources and the Forest Reserve area, this land surrounding the Forest Reserve, the so-called 'buffer zone' area, is also explicitly considered in the scenario analysis (Figure 1, light brown area). In consultation with stakeholders, we selected an area above ~220 meters above sea level, designated as buffer zone. This corresponds roughly to the entire Atewa Range.

This study focusses on the ecosystem services of the Atewa Range. However, as the Atewa Range is part of the headwaters of the Densu river, providing fresh water for the Accra region, the Densu watershed is also taken into consideration. Due to budgetary and time constraints we focus on the Densu Basin alone, the Ayensu and Birim rivers are not directly addressed. For the Forest Reserve and the buffer zone, specific land cover and land use will be defined in different scenarios. For these scenarios, the effect on ecosystem services in the upstream (Forest Reserve and the buffer zone), the midstream (agricultural area around Nsawam) and downstream (Weija Lake, Accra, Densu delta) areas will be assessed (see Chapters 5 and 6).

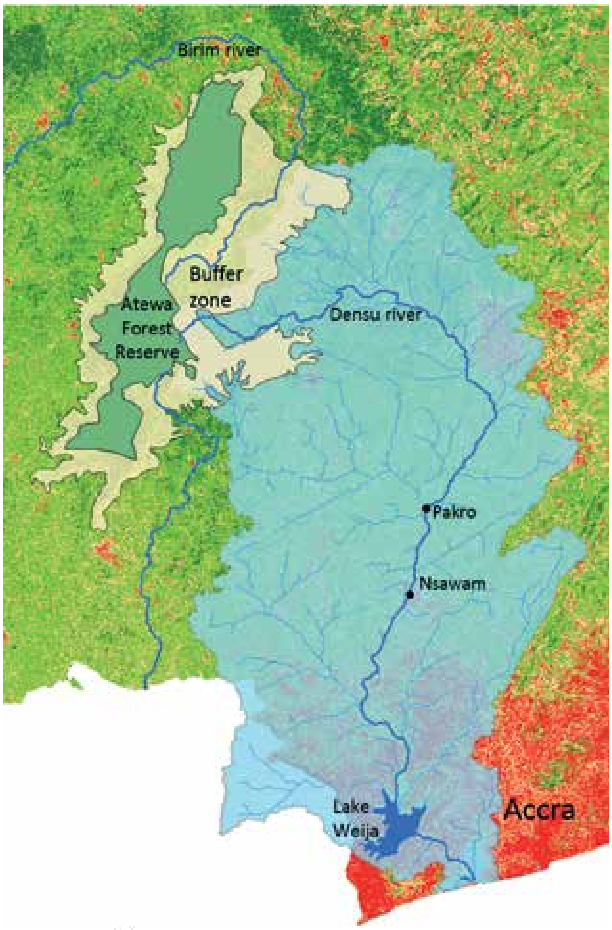

Figure 13 Overview map of the different geographic areas considered in this study

3.2 SET OF SCENARIOS

The scenarios that are developed for this study span up a range of possible futures for land cover in the Atewa Range. There is no explicit year associated with the scenarios, but in general a time horizon of several decades (~20 years) can be considered. In order to keep results digestible, we limited the amount of scenarios to four, relating to different uses of the Forest Reserve and the buffer zone surrounding the reserve.

- **Scenario 1: Business as usual:** This scenario represents continued land use developments along current trends (i.e. similar to a 'business as usual' scenario; BAU).

- **Scenario 2: National Park:** In this scenario, it is assumed that the Forest Reserve will be protected and restored, whilst in the surrounding buffer zone the same development continues to take place as in Scenario 1. This is comparable to a situation in which the Forest Reserve becomes a National Park and will benefit from a strengthened conservation regime.

- **Scenario 3: National Park and supporting buffer zone:** This scenario extends the Scenario 2 as it includes restoration and more compatible sustainable land use in the surrounding buffer zone as well (for as much as this is realistic, given that many communities reside in the buffer zone). Most notably, it is assumed that all gold mining activities in the area disappear, while sustainable agroforestry increases and tourism is developed.

- **Scenario 4: Complete degradation due to logging and mining:** This scenario is quite extreme, in that it assumes that the entire Forest Reserve and buffer zone area will be open for bauxite mining, gold mining, timber and other activities. Scenario 4 is used to span up the full range of what could happen.

Table 6 provides an overview of the characteristics of the four scenarios. Scenario 3 represents the most 'green' scenario, Scenario 4 the most destructive scenario, and the Scenarios 1 and 2 are in-between scenarios. To quantify the change in the scenarios, use is made of information on historic developments in terms of population growth, mining development rates and land use change. This is especially important for the 'further degradation' parts in the scenarios 1 and 2. There is not a specific time horizon for the scenarios (as they are 'what if' scenarios), but to quantify changes for the 'further degradation' changes as observed over about **20 years** will be used.

SCENARIO / AREA	FOREST RESERVE	ATEWA RANGE
Baseline	Current situation	Current situation
1. Business As Usual (BAU; continued developments in the Atewa Range)	Further degradation	Further degradation
2. National Park (restoration only in current reserve)	Complete restoration	Further degradation
3. National Park and supporting buffer zone	Complete restoration	Partial restoration (outside urban areas)
4. Complete degradation (extreme case)	Complete logging for bauxite mining	Complete logging due to mining/logging

Table 6 Overview of scenarios used in this study

3.2.1 Land cover information

An important starting condition for the scenarios is the land cover in the Forest Reserve and the buffer zone. In terms of land cover, three images based on remote sensing data have been made available through CERSGIS (Figure 5). These are images for the years 1990, 2000 and 2010, showing open canopy forest, closed canopy forest, herbaceous cover and build up areas. Figure 5 shows that over this period of time, significant changes in land cover occurred. These changes have been quantified in Table 7 and Table 8. Overall, we observe a change from closed canopy forest to open canopy forest in the Forest Reserve over time. In the buffer zone, on the other hand, this classical conversion is supplemented with a change from open canopy forest to herbaceous land cover. It should be noted that land cover does not completely equal land use. For instance, agricultural practices are mostly related to both herbaceous land cover, as well as open canopy forest (such as cacao, plantain and oil palm).

	1990	2000	2010
Closed Canopy Forest	92%	92%	82%
Open Canopy Forest	7%	8%	17%
Built up/ Bare land	0.1%	0.0%	0.0%
Grass/Herbaceous	0%	0%	1%
Total area (km^2)	**253.8 km^2**		

Table 7 Land cover in the ***Forest Reserve*** for 1990, 2000 and 2010

	1990	2000	2010
Closed Canopy Forest	86%	45%	48%
Open Canopy Forest	13%	55%	43%
Built up/ Bare land	0.7%	0.1%	0.5%
Grass/Herbaceous	1%	1%	8%
Total area (km^2)	**505.2 km^2**		

Table 8 Land cover in the ***buffer zone*** for 1990, 2000 and 2010

3.2.2 Baseline

As described above, the latest land cover information available dates back to 2010, which coincides with the start of many of the mining developments leading to recent changes in land-cover in the Atewa Range. This means that many of the current mining sites are not part of the latest land-cover maps. Recently, an inventory of mining sites has been completed by the RMSC (2016), revealing the areas of existing mining concessions, illegal or unregulated mining, and areas where prospecting is taking place. Using this new source of information, the 2010 land cover is updated. The RMSC study reports about 2,030 hectares of licensed mining sites (concessions) in their study area, which corresponds to 0.77% of their total study area (a 15km radius around the Forest Reserve). In addition, there are around 5,350 hectares of illegal or unregulated mining sites, corresponding to ~2% of the total area (2.65 times the size of the licensed area). In total, this results in approximately 2.8% of the area consisting of mining sites. We assume for the Buffer Zone that these mining sites are in cells that are classified in 2010 as grass/herbaceous cover, adjusting the land cover distribution accordingly. In the Forest Reserve itself, there are not many sites, just some small Galamsey points. Also with respect to agriculture, it was determined during consultation meetings with the Forestry Commission, that the amount of agricultural activities in the reserve itself is not significant at the moment. Therefore, the land cover distribution in the Forest Reserve itself was not changed.

FOREST RESERVE	2010	BASELINE
Closed Canopy Forest	82%	82%
Open Canopy Forest	17%	17%
Built up	0%	0%
Grass/Herbaceous	1%	1%
Mining		0%

BUFFER ZONE	2010	BASELINE
Closed Canopy Forest	48%	48%
Open Canopy Forest	43%	43%
Built up	1%	1%
Grass/Herbaceous	8%	5.4%
Mining	-	2.8%

Table 9 Land cover distribution in the Forest Reserve (upper part) and the buffer zone (lower part) for the baseline situation

3.2.3 Scenario 1: Business as usual (BAU)

Scenario 1 is a future perspective based on continued developments in the reserve and surrounding buffer zone. This means that population continues to increase and mining sites continue to be developed throughout the area. The scenarios, including this one, do not correspond to a specific year. However, in order to quantify development, changes corresponding to 20 years are assumed.

In terms of population, growth rates as stated for the East Akim region in the Densu Integrated Water Resource Management Plan (IWRM) plan are followed (WRC, 2007). This corresponds to 1.4% population growth per year, which over the span of two decades would result in a total increase of about 32% of the population. In terms of land-cover, however, the amount of build-up area is quite small (<1%). The increase of the build-up area in the study area is marginal and not traceable in the tables due to rounding. However, continued population pressure on the land is of course strongly related to other pressures, such as mining and pollution.

The increase in mining is mainly occurring in the buffer zone, as it has occurred in the past seven years. With gold reserves depleting in the buffer Zone (at least the ones that are most easily accessible), it is expected that activities will also start to take place in the Forest Reserve. In order to quantify these changes, the inventory of current mining sites (RMSC, 2016), and studies on potential gold zones (Akulga, 2013; Xtra Gold, 2012) have been used. Based on the inventory an annual development rate has been determined for official concessions (~300 ha/yr), assuming that the current mining sites have developed over the course of roughly seven years. In addition, the area associated with illegal and unregulated mining sites has also been determined, which corresponds to over 3.5 times the area of legal operations. Assuming two decades of such developments, the combined area of mining sites has been calculated. This corresponds to about 8% of the total area. This is well in line with the estimates of the studies on potential gold zones, covering around 12% of the buffer zone, in both the Densu and Birim basin. This amount has therefore been used for the baseline scenario 1 (Table 10). Also in the Forest Reserve these studies show a potential for gold mining of roughly 10%. However, because the forest has a protected status (of a forest reserve) in which mining is still prohibited, we assume a much lower percentage of mining landscape in the Forest Reserve area in the baseline scenario of only 1% (Table 10).

In terms of land cover and deforestation, the magnitude of land cover change over 1990-2010 has been used to assess the magnitude of forest change in the Forest Reserve and the buffer zone. Overall, Scenario 1 shows a change from Closed Canopy Forest into Open Canopy Forest; and Open Canopy Forest into Mining and Grassland (Table 10).

FOREST RESERVE	2010	BASELINE	1. BAU
Closed Canopy Forest	82%	82%	73%
Open Canopy Forest	17%	17%	24%
Built up	0%	0%	0%
Grass/Herbaceous	1%	1%	2%
Mining		0%	1%
BUFFER ZONE	**2010**	**BASELINE**	**1. BAU**
Closed Canopy Forest	48%	48%	27%
Open Canopy Forest	43%	43%	51%
Built up	1%	1%	1%
Grass/Herbaceous	8%	5.4%	9%
Mining	-	2.8%	12%

Table 10 Land cover distribution in the Forest Reserve (upper part) and the buffer zone (lower part) for the Business As Usual (BAU) scenario

3.2.4 Scenario 2: National Park

This scenario assumes that the Forest Reserve is given a higher protection status, resulting in increased efforts to not only preserve, but also restore (partially) degraded areas. Scenario 2 represents a situation in which the Forest Reserve becomes a National Park. The conversion to a national park is generally considered by stakeholders to have a positive impact on land cover changes in the reserve area. As a result, a substantial increase in closed-canopy Forest, and a decrease in open-canopy and grass/herbaceous area are assumed in the Forest Reserve. The land cover distribution in the reserve area is roughly similar to the one in 1990. In Scenario 2, however, no specific efforts are undertaken to stop ongoing development or restore degraded areas in the buffer zone: the land cover distribution in the buffer zone is the same as in the previous scenario (Scenario 1: BAU).

3.2.4 Scenario 2: National Park

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FOREST RESERVE	2010	BASELINE	1. BAU	2. NATIONAL PARK
Closed Canopy Forest	82%	82%	73%	95%
Open Canopy Forest	17%	17%	24%	5%
Built up	0%	0%	0%	0%
Grass/Herbaceous	1%	1%	2%	0%
Mining		0%	1%	0%
BUFFER ZONE	**2010**	**BASELINE**	**1. BAU**	**2. NATIONAL PARK**
Closed Canopy Forest	48%	48%	27%	27%
Open Canopy Forest	43%	43%	51%	51%
Built up	1%	1%	1%	1%
Grass/Herbaceous	8%	5.4%	9%	9%
Mining	-	2.8%	12%	12%

Table 11 Land cover distribution in the Forest Reserve (upper part) and the buffer zone (lower part) for the National Park scenario

3.2.5 Scenario 3: National Park and supporting buffer zone

Similar to the change in scenario 2, the Forest Reserve becomes a National Park. Additionally, efforts are undertaken in the buffer zone to promote compatible land use and support restoration of degraded areas. We assume that this is done though reforestation and the development of sustainable agroforestry practices, such as cocoa production and inter-canopy agriculture. It should be noted that the buffer zone does not fall under the jurisdiction of the Forestry Commission, which means that it is less straightforward to enable such management. For Scenario 3 to be implementable cooperation has to be sought with other government departments (e.g. the Water Resources Commission, Minerals Commission, Ministry of Agriculture), local communities, chiefs and kings to devise adequate measures that are mutually beneficial.

FOREST RESERVE	2010	BASELINE	1. BAU	2. NATIONAL PARK	3. NAT. PARK AND BUFFER
Closed Canopy Forest	82%	82%	73%	95%	95%
Open Canopy Forest	17%	17%	24%	5%	5%
Built up	0%	0%	0%	0%	0%
Grass/Herbaceous	1%	1%	2%	0%	0%
Mining		0%	1%	0%	0%
BUFFER ZONE	**2010**	**BASELINE**	**1. BAU**	**2. NATIONAL PARK**	**3. NAT. PARK AND BUFFER**
Closed Canopy Forest	48%	48%	27%	27%	88%
Open Canopy Forest	43%	43%	51%	51%	10%
Built up	1%	1%	1%	1%	1%
Grass/Herbaceous	8%	5.4%	9%	9%	1%
Mining	-	2.8%	12%	12%	0%

Table 12 Land cover distribution in the Forest Reserve (upper part) and the buffer zone (lower part) for the National Park and supporting buffer zone scenario

In terms of land cover distribution, the same land cover in the Forest Reserve is assumed as in Scenario 2. However, the land cover distribution the buffer zone is adjusted considerably. Also in Scenario 3, the land cover distribution from 1990 is taken as a starting point to determine what a restored buffer zone can look like. This results in a considerable increase in Closed Canopy Forest and the absence of mining sites. Because people are not expected to move out of the area and population is expected to grow in the future, the amount of built-up area stays the same as the BAU scenario (Scenario 1).

3.2.6 Scenario 4: Complete Degradation

The last scenario represents a worst-case scenario from an environmental perspective: complete deforestation/degradation in favour of logging and mining, being bauxite in the Forest Reserve, and gold in the Forest Reserve and buffer zone. Although in reality, it should not be considered as a particularly high probability, theoretically Scenario 4 could occur if the exploitation of resources, such as wood and metals, grows rampant beyond control of Ghanaian authorities. By taking this extreme perspective, Scenario 4 explores the far end of the spectrum of possibilities in terms of how the system functions; this is the most extreme case of possible environmental degradation in the Atewa Range. Being such an extreme scenario, it is difficult to determine a plausible land-cover distribution. Therefore, we use a configuration of 50% mining sites, and 50% grassland, in both the Forest Reserve as well as the buffer zone. In addition, build-up areas are still present.

FOREST RESERVE	2010	BASELINE	1. BAU	2. NATIONAL PARK	3. NAT. PARK AND BUFFER	4. TOTAL DEGRADATION
Closed Canopy Forest	82%	82%	73%	95%	95%	0%
Open Canopy Forest	17%	17%	24%	5%	5%	0%
Built up	0%	0%	0%	0%	0%	0%
Grass/Herbaceous	1%	1%	2%	0%	0%	50%
Mining		0%	1%	0%	0%	50%

BUFFER ZONE	2010	BASELINE	1. BAU	2. NATIONAL PARK	3. NAT. PARK AND BUFFER	4. TOTAL DEGRADATION
Closed Canopy Forest	48%	48%	27%	27%	88%	0%
Open Canopy Forest	43%	43%	51%	51%	10%	0%
Built up	1%	1%	1%	1%	1%	1%
Grass/Herbaceous	8%	5.4%	9%	9%	1%	50%
Mining	-	2.8%	12%	12%	0%	49%

Table 13 Land cover distribution in the Forest Reserve (upper part) and the buffer zone (lower part) for the complete degradation scenario

4 HYDROLOGICAL ASSESSMENT OF THE DENSU RIVER

4.1 BACKGROUND

4.1.1 River basins

The Atewa Range is the source of the headwaters of the Ayensu (1,238 km^2), Birim (3,922 km^2) and the Densu (1,873 km^2) river basins. The Ayensu River (103 km) and Densu River (116 km) flow south into the Atlantic, and the Birim River (175 km) makes a long detour north and southwest around the Atewa Range before joining the Pra river, which flows through agricultural and forest areas in the Akan lowlands into the Gulf of Guinea.

Of the three river basins that the Atewa Forest feeds, the Densu River Basin is the most densely populated one. This basin also has the highest dependency on, and share of, extracted water resources (WRC, 2007). Consequently, the value of the ecosystem services provided by the Atewa Forest to the Densu watershed has been assumed to be the most significant. This hydrological sub-study has taken the Densu River Basin as an example of how the value of the Atewa Forest can change under different land cover scenarios. The study focusses on land use options in the upper catchment areas, since affecting the source of the river will affect all downstream beneficiaries, notably that of Greater Accra.

4.1.2 Land use developments in the Densu River Basin

The Densu River Basin (lat. 5°30’N 6°17’N; lon. 0°10’W - 0°37’W) was originally covered by moist semi-deciduous forest with thick undergrowth featuring rich flora and fauna (WRC, 2007). Human land use activities through time, however, have greatly modified the landscape at an accelerating rate (see Chapter 3). The Densu River flows from the upstream stretches of the Forest Reserve towards the forest fringes in an easterly direction. A reduction in forest cover characterizes the increase in croplands until the river meets the urbanized area of Koforidua. Further downstream, the river gradually changes its course through more agricultural lands and flows in a southerly direction into the industrial and urban areas around the Weija Reservoir – which provides about half of the water supply for the Accra metropolitan area (GWCL, 2015). When the water level at the Weija dam reaches the maximum water level, excess flow discharges into the populated Densu delta, a Ramsar wetland, before discharging into the Bay of Guinea (Atlantic Ocean) some 10 km west of Accra. A description of the land use in the study area can be found in Chapter 2.

The goal of this hydrological section is to illustrate how different land uses of the Atewa Forest may affect downstream water resources, both in water quantity and in water quality. To achieve this, different scenarios have been simulated in terms of how land uses of the buffer zone and the Forest Reserve may change, and what kind of impacts this can have on water quantity, water quality, erosion and sedimentation. The results serve as input for the assessment how the delivery of ecosystem services from the Atewa Range will change under various land use management scenarios.

4.1.3 Reading guide

In this hydrological chapter, first the methodology concerning the hydrological model will be explained. After that, three sections will go into the results. The first two relate to water quantities and sedimentation, which have been used to quantitatively explore the scenarios. The third one relates to water quality. As this is not explicitly modelled and measurements in the Densu are scarce, literature and recent studies in the Birim River have been analysed in order to qualitatively address how water quality may look like in the different scenarios.

4.2 METHODOLOGY

In order to study the effect of future land cover change, a hydrological model was set up for the Densu River Basin. Hydrological indicators related to discharge and sediment load estimated from this model are linked to ecosystem services in the up-, mid- and downstream areas in order to assess the effects of such land uses on the delivery of those services.

For the purpose of this study, the STREAM model was used and further developed. STREAM is a transparent rainfall-runoff model that has been applied in numerous river basins all over the world to develop estimates for future water resources (e.g. Aerts *et al.*, 2007; Kummu *et al.*, 2010; Maina *et al.*, 2013; Lasage *et al.*, 2015; Beukering *et al.*, 2015). This water balance model was coupled with the RUSLE sediment model to estimate soil loss and sediment load.

An extensive amount of data was collected in order to gather as much hydrological information as possible related to water quantity, quality and potential drivers thereof; for instance, time series were collected of discharge, water quality indicators, deforestation, agriculture and mineral resources extractions. This information provided input for the modelling framework. The framework was supplemented by globally available spatial datasets.

4.2.1 Modelling water resources

For this study, the STREAM model - Spatial Tools for River Basins and Environment and Analysis of Management Options – has been used (Aerts *et al.* 1999). STREAM is a conceptual GIS-based rainfall-runoff model that calculates the water balance in each grid cell of the catchment and then routes overland flow and groundwater flow (Figure 14).

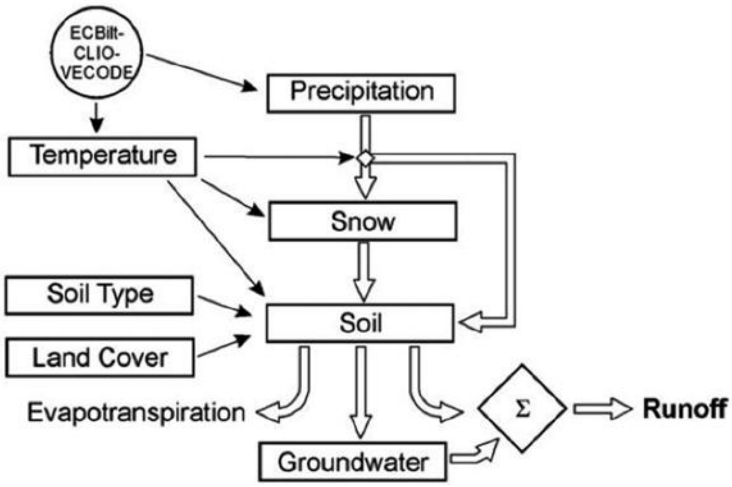

Figure 14 The operational concept of the STREAM tool (Aerts *et al.*, 1999)

The water balance was estimated for every individual grid cell using the Thornthwaite-Mather method (Thornthwaite and Mather, 1957) (Figure 15). The equation approaches the hydrological cycle as multiple compartments in order to simulate runoff (Q0), ground-water storage (S), and soil moisture reservoir (AWC) for the movement of water throughout the basin. Hence, a distinction can be made between fast and slow hydrological processes. Fast processes include runoff and water flow through the soil reservoir, both acting as linear components. Potential evapotranspiration is steered by surface temperature (T). Actual evapotranspiration is dependent on land use and soil water holding capacity.

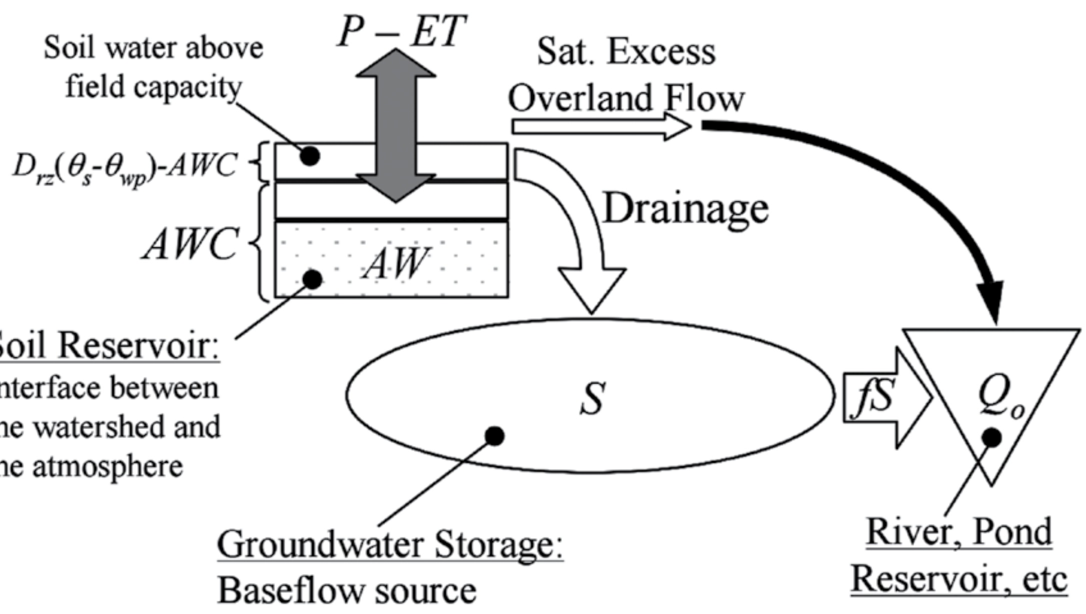

Figure 15 Illustration of the soil-water and watershed budget calculation method (Thornthwaite and Mather, 1957)

STREAM was set up with daily time-steps, calculating the water balance and routing the runoff downstream every day. To avoid STREAM flushing river flows from source to sink in one run, the model was lagged according to the travel time that water discharges to the basin outlet. For the Densu River, the number of routing days is on average seven days (UNDP-WHO, 1968), thus water flows with a speed of about 23 km/day, or roughly 0.2 - 0.3 m/s; only stopped by the Weija dam, which creates the Weija Reservoir.

Computations made by STREAM were solved using MATLAB. MATLAB is a multi-paradigm numerical computing and graphics software. The Topo-toolbox was added to the MATLAB interface to enable functions for topographic analysis (Schwanghart & Kuhn, 2010; Schwanghart & Scherler, 2014). The numerical results (quantified river discharge in this study) can then be shown in a number of optional ways to be chosen by the user, such as graphs, in table form, or as GIS raster layers.

4.2.2 Input data

STREAM requires spatial maps as input data. The input maps included:

- Daily maps of **precipitation and temperature**. These were sourced from the 1950-1999 global observations of Adam and Lettenmaier (2003), and downscaled using the bias correction/spatial downscaling method as described by Maurer *et al.* (2009) to a 0.5-degree grid.
- **Elevation** information was used to calculate the flow director map. For this, the SRTM dataset with a resolution of 3 arc seconds (about 90 m) was used[8]. This was also the resolution at which the model runs.

NOTE

8 SRTM DEM database accessible via website: http://www2.jpl.nasa.gov/srtm/

- The **water holding capacity** was processed from soil characteristics. For this, the global FAO-UNESCO Soil Map of the World (ISRIC-WISE, 2006) was reclassified by the ISRIC-WISE database (Batjes, 2006), including the water moisture capacity of the soil (TAWC). The water holding capacity map was resampled to a resolution of 1 arc minute (roughly 1850 by 1850 m) at which the computations were performed.
- Potential evapotranspiration was derived from land cover. For **land cover**, three maps have been provided by CERGIS, covering 1990, 2000 and 2010. The 2010 map served as the basis for land cover. From the land cover categories, crop factors were derived based on Doorenbos and Pruitt (1977). The recalculations can be obtained from the STREAM manual (Aerts and Bouwer, 2003). For the different scenarios, as well as the baseline situation, the 2010 map was adjusted to reflect update or new land cover.

4.2.3 Model calibration

The hydrological model needs to be calibrated in order to accurately simulate river discharge of the Densu River. With the calibrated model, change induces by the land cover changes can then be assessed (see scenarios). To execute calibration, discharge time series of the Densu River is required. Recorded flow data and information on runoff have been obtained from the Hydrological Services Department in Ghana, which operates a number of river gauging stations in the country. The STREAM model was set up for the entire Densu River Basin. In this basin, the Pakro gauging station, which is located midstream (Figure 13), is the most downstream station with the most adequate flow data; hence, this station has been used for model calibration of the Densu River.

During the calibration process, parameters values were adjusted manually one after the other, in order to determine the effect of the parameter on the improvement of correlation. The parameter adjustments were done based on the modeller's knowledge and understanding of the field properties and processes in the research area. Firstly, the annual water balance was corrected by the crop factor to obtain the same area under the simulated hydrograph and the measured hydrograph. Secondly, calibration was carried out to increase

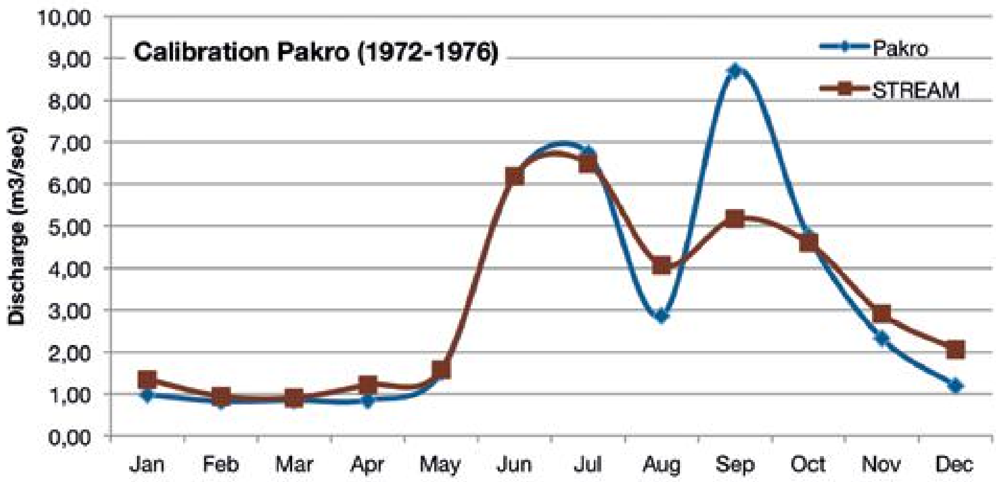

Figure 16 Model calibration for the average monthly discharge at Pakro (1972-1976)

correlation of the base flow, discharge peaks and timing. This was done by adjusting a factor for the slope, and a factor determining the contribution of ground water to the base flow.

The resulting hydrograph of the calibrated gauge station in Pakro is shown in Figure 16. As can be seen, the general flow of the Densu River is well simulated, barring the second peak, which is lower in the STREAM model as compared to the observations in Pakro. This is a precipitation signal present in the dataset used for precipitation and climate. In the calibration, therefore the objective was to get the low discharge correct early in the year, and the height of the first peak.

4.3 RUSLE SEDIMENT MODEL

Land use management can influence the magnitude of soil loss in an area. To analyse soil erosion processes in the Densu Basin for different land use pathways, the Revised Universal Soil Loss Equation (RUSLE) has been coupled to STREAM. RUSLE is a widely used erosion model that computes the average annual erosion by using a functional relationship of several factors, expressed in an equation as:

A = R * K * LS * C * P

Where:

- **A** is the estimated average soil loss (t ha-1yr-1).
- **R** is the rainfall-runoff erosivity factor (MJ mm ha-1 h-1 yr-1). It represents a measure of the total annual erosive rainfall for a specific location, as well as the distribution of erosive rainfall throughout the year. It is affected by storm energy and intensity, the amount of rainfall, snowfall and runoff that occurs during different seasons of the year.
- **K** is the soil erodibility factor (t ha h ha-1 MJ-1 mm-1). K represents a quantitative measure of a soil's inherent susceptibility or resistance to erosion and the soil's influence on runoff amount and rate. It is affected by soil texture and structure, organic matter content, permeability, and season of the year.
- **LS** is the slope length factor and slope steepness factor (dimensionless), which represents a measure of the effects of slope angle and length on erosion.
- **C** is the cover-management factor (dimensionless). C represents a measure of the relative effectiveness of soil and crop management systems in preventing or reducing soil loss.
- **P** is the support practice factor (dimensionless). P represents a measure of the effects of practices designed to modify flow pattern, grade, or direction of surface runoff, and thus reduces erosion rates.

The soil erosion parameters were sourced from the same input that has been used for STREAM: The R factor map was developed from the precipitation data, the K factor map was obtained from the soil map and for the LS factor map, the digital model (DEM) was used. Only the C factor has was sourced differently; the map was generated based on land use maps from the Centre for Remote Sensing and Geographical Information Systems (CERGIS) for 2010, the baseline and the scenarios to compare sediment loads under changing land use regimes. The P factor map was assumed to be 1 for the Densu River Basin because there have been barely any soil conservation practices put in place. By integrating the six factor maps in GIS through raster-based GIS-computing, the spatial distribution of soil loss in the Densu River Basin was obtained from the RUSLE model.

4.4 WEIJA RESERVOIR AND NSAWAM

The Weija Dam, commissioned in 1978, blocks the Densu River, and has the main function to safeguard water supply to the city of Accra, though it was originally commissioned to also provide water for irrigation. GWCL operates water abstraction activities in the Weija Reservoir for all water utilizing sectors by dividing the water volume of the lake into maximum permissible abstractions per sector. As such, a maximum of 60% abstraction has been set for irrigation purposes, 30% for potable water, and 10% for environmental purposes (GWCL, 2015). The total capacity of the reservoir is about 133 million m3 (WRC, 2007).

Given the size of the reservoir and the non-use of the portion that was once envisaged for irrigation, the amount of fresh water is not likely to be a limiting factor in the near future. Moreover, in terms of providing fresh drinking water, the infrastructure related to cleaning water and getting it into the homes may be more limiting. Water quality issues are related to eutrophication and sedimentation. Eutrophication is related to the surrounding residential developments, and as such not so much influenced by the Atewa region. Sedimentation in the reservoir is difficult to address as there are no objective data on it. Anecdotal evidence suggests that the reservoir is silting up (a couple of meters by now, since its construction in 1978), which is closely linked to upstream land use. This will be explored in the section on sedimentation later in this chapter. Another location where water is extracted from the Densu River is at Nsawam. There is no reservoir here, but water is directly extracted from the river behind a weir. Here, siltation has been reported to be an issue and in January 2016 the river dried up at Nsawam, illustrating the vulnerability of the area for climatic variations and siltation due to upstream erosion (WRC, pers. comm.). In the hydrological modelling, results will therefore be analysed for several locations. These include Weija and Nsawam, but also more upstream locations at Pakro (before and after the confluence) as this is closer to the study area and will show a stronger signal of the magnitude of the changes.

4.5 WATER QUANTITY

The flow regime of the Densu River exhibits a marked variability in annual flows. The erratic flow pattern has been put as an example in Figure 17. Annual surface water runoff in the Densu River Basin totals several hundred million m3 (Alfa, 2009). Surface water availability varies from year to year, as well as seasonally. To demonstrate the seasonal variability, Figure 17 shows the water flow recordings of Pakro in 2005.

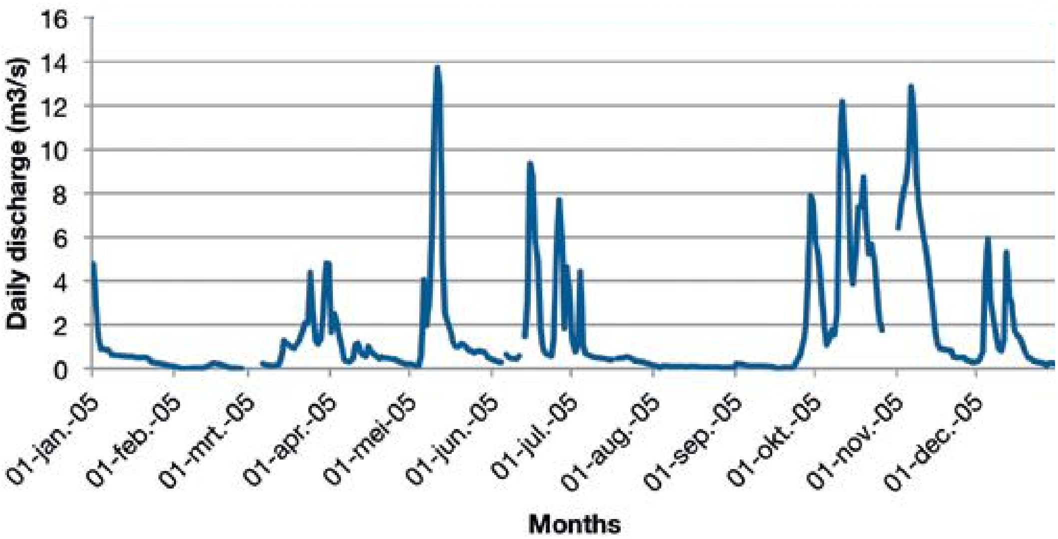

Figure 17 Densu River daily flows at the Pakro gauging station in 2005

4.6 WATER ABSTRACTION

The Densu River serves as the main source of water supply for a number of fast growing communities within and outside the basin. Table 14 summarizes the current water abstractions in the Densu River Basin for various sectors. The table shows that current water abstraction upstream of the Weija Lake is relatively small; just 13% of the total abstraction rate. The main reason for this low abstraction rate is that both spatial and temporal rainfall distributions are good in upstream parts of the basin so that agriculture is largely rain-fed. In addition, local industries and businesses are too small to abstract water in any appreciable quantities. Most of the communities upstream of the Weija Lake are rural with small domestic water use; the sum of rural water supply represents only 2% of the total abstraction in the basin. On the other hand, water abstraction from the Weija Lake is mainly to supply the potable water needs of urban and peri-urban Accra, which is considerably higher – about 87% of total abstraction. In absolute terms about 73 million m3 is abstracted yearly. With an inflow of several hundred million m3/yr and a capacity of almost twice this volume (133 million m3), there would be no capacity problem if the total capacity can be utilized.

Water in the Weija Reservoir is also utilized for irrigating 220 ha of adjacent farmland (WRC, 2007). The average water demand for irrigated land in the Densu River Basin is about 15.000 m3/ha/yr, which is equivalent to approximately 1.5 l/s/ha in an average year assuming a four-month irrigation season (WARM, 1998). The total land under irrigation in the Densu River Basin is presently around 250-270 ha. However, the potential irrigable land in the basin is about 1.500 ha (WRC, 2007).

USER CATEGORY		RATE OF ABSTRACTION (M3/DAY)	RATE OF ABSTRACTION (106M3/YEAR)	SHARE OF TOTAL	WATER SOURCE
Potable (domestic, industrial, institutional):	Urban water supply (from Weija) Rural water supply	210,820 (200,000) 3,840	76.96 (73.00) 1.40	92% (87%) 2%	Mainly surface water Mainly groundwater
Agriculture	Irrigation Livestock	11,000 600	4.00 0.22	5%	Mainly surface water Mainly surface water
Other	Industry (not served by piped water supply schemes)	2,740	1.00	<1% 1%	Mainly groundwater
Total for Densu Basin		**229,000**	**83.58**	**100%**	

Table 14 Current water resources abstractions in the Densu Basin (WRC, 2007)

It should be noted that the water resource abstractions are not covering the total water demand in the Densu River Basin. Water Resources Commission (2007) analysed the gap in service coverage and made assumptions on the current and future water demand in the Densu River Basin. The figures show that water demand is projected to increase by a third in 2020 compared to 2015. In absolute numbers, urban water demand will increase the most compared to other users, which is mainly the result of rapid urbanization towards Accra.

The key-reasons for not being able to cater for the unmet water demand are attributed to communities that have not yet been provided with piped water and from the urban population living within existing supply areas, but not reached by the water supply scheme. For this, the underlying reasons include mainly technical-economic and financial barriers in expanding the water systems' treatment capacity as well as the distribution network of the scheme. Furthermore, the Densu River has been experiencing lower base flows that result in a reduced capacity for water abstraction, or even a total cease in water production during the dry season (WRI, 2015).

4.6.1 Scenarios

It is well known that changes in land cover also affect the hydrological response of an area. As such, any future changes in the Atewa Range will affect the hydrology of the Densu, Birim and Ayensu rivers. In general, deforestation results in increased river discharge. This is the result of lower evapotranspiration rates of the deforested land (as it has less/no vegetation, where trees and their undergrowth transpire a lot). A second effect is related to the speed of the hydrological response. Due to the loss of forest floor cover, the soil is generally much less rich in humus, decreasing infiltration rates. Consequently, there is usually a faster response with more overland flow during rainfall events. This makes the discharge regime usually more erratic with respect to the forested condition. The loss of soil also means that less water is retained in the soil, decreasing its (green[9]) water availability for crops.

The effect of the scenarios on (blue) water has been assessed using the hydrological model STREAM. This is done for three places along the river: Pakro, Nsawam and Weija (going downstream). Hydrographs of the scenarios at these three locations are given in Figure 18, and percentages change for Pakro and Weija are given in Table 15 and Table 16. The figure and tables illustrate how overall a reduction in forest cover (Scenario 1 – business as usual; Scenario 2 – National Park; and Scenario 4 – complete degradation) would result in increased discharges due to decreased evapotranspiration. The opposite (increased evapotranspiration due to forest cover increase) can be seen in the results for Scenario 3 (National Park and supporting buffer zone), showing a decrease in average annual discharge. The similarity between Scenario 1 (business as usual) and 2 (National Park) also illustrates that developments in the reserve itself do not have a large effect on the Densu River. This is mainly related to the fact that only a very small area (~2-2.5 km2) of the reserve falls in the catchment of the Densu River (most of the reserve is in the Ayensu and Birim River basins). However, there is a substantial part of the buffer zone in the Densu catchment area, illustrating how land cover changes may impact the Densu River (and by association also the Birim and Ayensu rivers). Scenarios 1 (business as usual) and 2 (protect the Forest Reserve) illustrate that ongoing developments in the buffer zone overall increase by about 7%. In case of complete deforestation this will increase to

NOTE

9 In water management, distinctions are made between green and blue water, where "green" water refers to the water kept in the soil (and is not transported), and "blue" water refers to water in streams, lakes and groundwater reservoirs.

about 37% (Scenario 4 – complete degradation) due to the lower evapotranspiration rates. Restoration of forest conditions in the area would overall result in a slight reduction in overall discharge.

The effect of increased surface runoff due to decreased infiltration and water holding capacity rates of the soil are seen when looking into more detail. Figure 10 gives a five-year record at Pakro between the Baseline situation and Scenario 4 (complete degradation). Here it can be seen that the baseline discharge hydrograph is much smoother compared to the more erratic hydrograph of Scenario 4. This is directly related to the faster surface runoff expected under Scenario 4. Whilst overall discharge may increase by about 37% at Parko (Table 15), in many cases peaks are much more substantially increased compared to the baseline situation. For instance, 30% of the simulated days yielded discharges that were at least double the baseline situation. As the discharge responds very quickly to rainfall events, these higher peaks are important to consider when managing, for instance, reservoirs such as Lake Weija. Here, increased peak inflow can be expected in the business as usual situation, the protection of the reserve only, and the logging and mining of the Atewa Range (scenarios 1, 2 and 4, respectively). Taking into account that the maximum dam water level is 14.33m (World Bank, 1991) and that this water level is increasingly reached, the dam needs to spill more frequently, and greater amounts of water, to the delta. As a result, urban and industrial areas in the Densu delta risk extensive flooding, which can lead to high economic losses and social unrest (Frimpong, 2014; Boamah, 2014). For the communities and industries in the Densu delta, spilling of the Weija Dam has already been a source of conflict towards the Ghana Water Company Limited (GWCL), which is managing the operations of the Weija Dam (WRC, 2007).

It is important to note that whilst it seems that more water becomes available, this refers to blue (flowing) water. In the upstream area (i.e. buffer zone), there will be much lower amounts of water kept in the soil. Correspondingly, the green water resources will be much reduced between rainfall events.

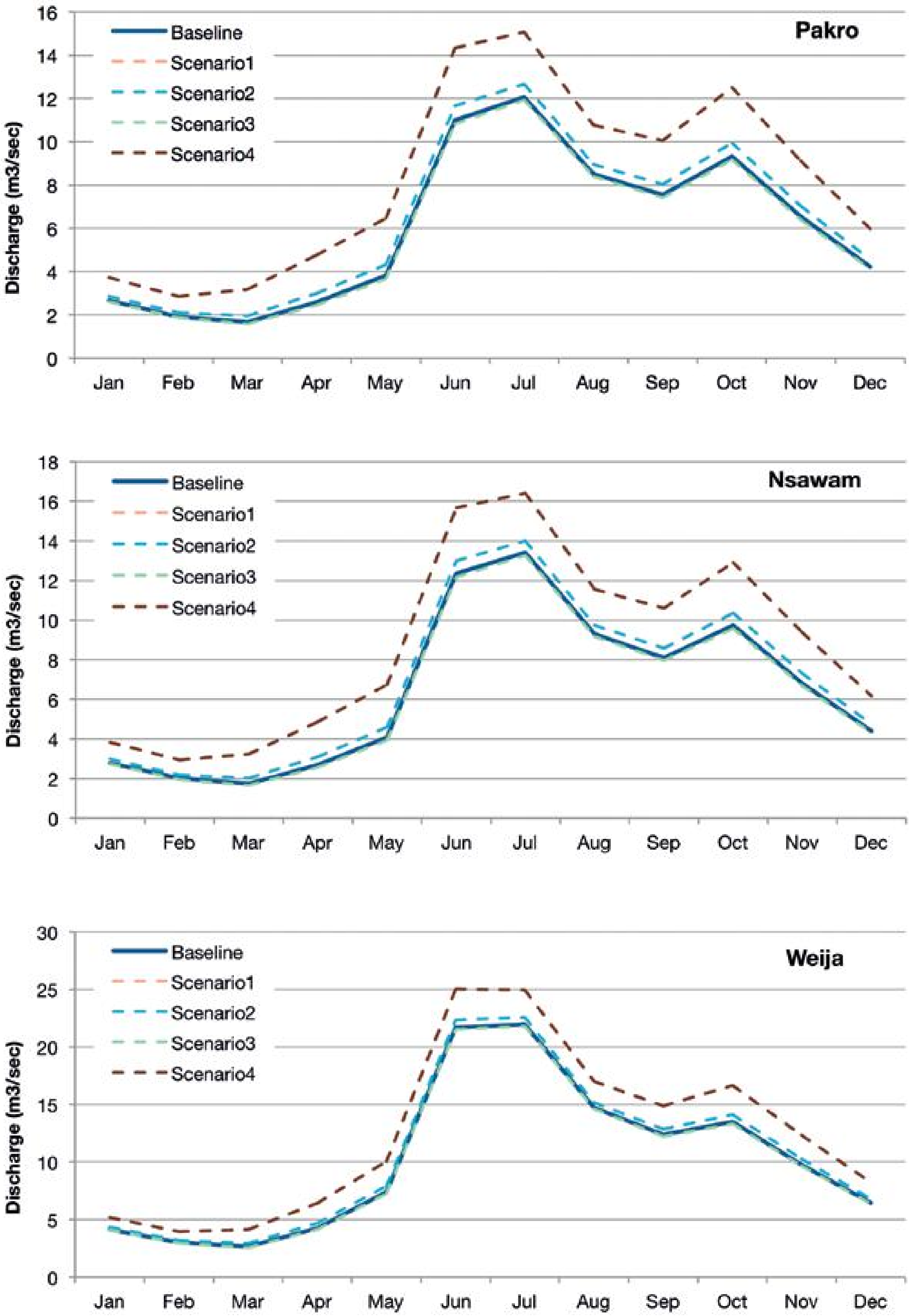

Figure 18 Hydrographs for scenario analyses at three gauging sites (Pakro being most upstream, Weija most downstream)

PAKRO	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC
Jan	2.66	8%	8%	-2%	40%
Feb	1.92	10%	9%	-3%	49%
Mar	1.67	18%	17%	-5%	90%
Apr	2.58	16%	16%	-5%	85%
May	3.82	14%	13%	-4%	70%
Jun	11.01	6%	6%	-2%	30%
Jul	12.07	5%	5%	-1%	25%
Aug	8.52	5%	5%	-1%	27%
Sep	7.55	7%	6%	-2%	33%
Oct	9.33	7%	7%	-2%	34%
Nov	6.54	8%	8%	-2%	39%
Dec	4.22	8%	8%	-2%	42%
Annual avg	**6.01**	**7.4%**	**7.2%**	**-2.0%**	**38%**

Table 15 Simulated average monthly discharge at Pakro and the relative change under the four scenarios

WEIJA	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC	BASELINE M3/SEC
Jan	4.14	5%	5%	-1%	26%
Feb	3.01	6%	6%	-2%	31%
Mar	2.65	11%	11%	-3%	57%
Apr	4.25	10%	10%	-3%	51%
May	7.40	7%	7%	-2%	36%
Jun	21.71	3%	3%	-1%	15%
Jul	21.97	3%	3%	-1%	14%
Aug	14.75	3%	3%	-1%	15%
Sep	12.37	4%	4%	-1%	20%
Oct	13.48	5%	5%	-1%	24%
Nov	9.77	5%	5%	-1%	26%
Dec	6.47	5%	5%	-1%	27%
Annual avg	**10.20**	**4.4%**	**4.2%**	**-1.2%**	**22%**

Table 16 Simulated average monthly discharge at Weija and the relative change under the four scenarios

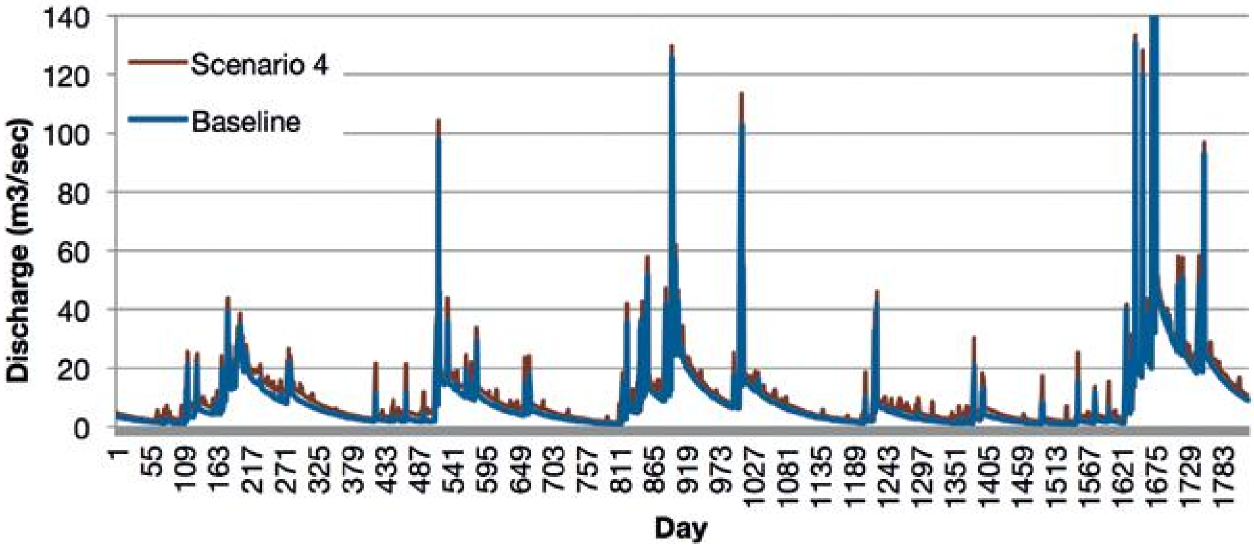

Figure 19 Hydrograph of five years of simulated discharge for the Baseline condition and Scenario 4 (complete degradation)

WEIJA (M3/SEC)	NORMAL	CLOUD 1MM		CLOUD 2MM	
Baseline	12.80	13.27	3.7%	13.94	8.9%
Scenario 4	15.20	15.23	0.2%	15.27	0.5%
	19%	15%		10%	

NSAWAM (M3/SEC)	NORMAL	CLOUD 1MM		CLOUD 2MM	
Baseline	8.01	8.48	5.8%	9.15	14.2%
Scenario 4	10.41	10.44	0.3%	10.48	0.7%
	30%	23%		15%	

PAKRO (M3/SEC)	NORMAL	CLOUD 1MM		CLOUD 2MM	
Baseline	7.37	7.83	6.4%	8.51	15.5%
Scenario 4	9.76	9.79	0.3%	9.84	0.7%
	33%	25%		16%	

Table 17 Results of the sensitivity analysis on the potential effect of cloud forest moisture capturing on the discharge of the Densu River for the Baseline situation and Scenario 4. The numbers indicate average annual discharge, with the percentages denoting the change with respect to the normal situation (columns 4 and 6) or the baseline situation (bottom rows)

Lastly, it should be noted that any feedbacks with the atmospheric system are not part of the model. The Atewa Forest is also typified as a cloud forest, where the highest parts are often shrouded in mist and clouds. These trees can 'strip' more water vapour from wind-blown fog than a landscape without forests. Due to this stripping mechanism, the gain in water yield from the stripping of wind-blown fog by the vegetation may be substantial when it is not raining (up to hundreds of millimetres of water per year), particularly in cloud forests at exposed locations (Critchley & Bruijnzeel, 1996). Cloud forest trees still contribute to evapotranspiration; they can theoretically collect more water than they evaporate or transpire. Such a feedback could result in a lower amount of total water availability under scenarios of tree loss, maybe even offsetting the increase in water resources due to reduced evapotranspiration.

Despite a direct coupling of this effect in the model not being possible, a sensitivity analysis was performed in order to illustrate the order of magnitude impact this effect could have. The exact amount of water that is extracted from the atmosphere is notoriously difficult to measure, and greatly depends on local conditions (i.e. elevation, exposure, wind, proximity to sea, etc.). A review has been performed by Bruijnzeel (2001), showing figures ranging roughly from 0.25 to 2 mm/day. Without specific monitoring studies in Atewa, the exact cloud forest effect is impossible to determine. Moreover, in case of the Densu River, the actual Forest Reserve (the highest part) accounts for only a couple of square kilometres, which is next to nothing compared to the entire catchment. For the sensitivity analysis we therefore depart from the assumption that also the buffer zone acts as a cloud forest (despite its much lower elevation). Furthermore, both open canopy and closed canopy forest are assumed to catch water from the atmosphere. Rates of 1 and 2 mm/day have been used. As these are very optimistic assumptions (large effective area, high efficiency), this should be regarded as an upper estimate of the potential effect. The largest effect is expected in Scenario 4 (complete degradation), which has the largest reduction in forest cover. Hence, the baseline situation and Scenario 4 are explored for this sensitivity analysis. Time series of 25 years of simulated discharge have been used to estimate the average effect.

The results of the sensitivity analysis (Table 17) show that the cloud forest effect on Densu discharge can be substantial (+9% to +16% assuming 2 mm/day), but is considerably lower as compared to the effect of deforestation (Scenario 4 showing increases in discharge of +19% to +33%). Reduction of forest cover would thus lower the water availability due to loss of the cloud forest effect, but increase due to lower evapotranspiration. The combined effect, assuming 2 mm/day, of Scenario 4 remains an increase in water availability (+10% to +16%) in the Densu River. The increase without taking into consideration a possible cloud forest effect is about twice as large. Overall, this would thus not affect the earlier findings.

4.7 SEDIMENTATION

4.7.1 Soil erosion and sedimentation

Soil loss in undisturbed tropical forest is normally less than 0.1 kg / m2, but this figure may rise to 5.0 – 10.0 kg / m2 in forests where the litter layer is removed (Elliot *et al,* 1999). Where forest has been cleared for rain-fed agriculture without proper soil conservation measures, even higher soil losses (up to 20 - 50 kg / m2) have been observed under certain adverse conditions, such as high intense rainfall, steep slopes and erodible soils (Critchley & Bruijnzeel, 1996). For the Atewa Range, this higher figure of soil losses might be applied for activities that relate to the land use pathways, such as illegal encroachment from agricultural expansions, mining activities and chainsaw logging.

There are also land use options that can keep erosion rates in the Atewa Range to a minimum. Productive farmlands can control erosion rates using agroforestry systems with terraced lands at steep surfaces and dense multi-storied canopy layers. Figure 20 illustrates the effects on surface erosion as a function of soil surface and vegetation conditions of a reforested area. Under ideal conditions, erosion rates of agroforestry systems may be reduced by 90 - 95 % (Young, 1989). Also mining operators can keep soil erosion to a minimum through limiting land clearance to the needed area only and re-vegetating disbursed areas as quickly as possible (Asiedu, 2013).

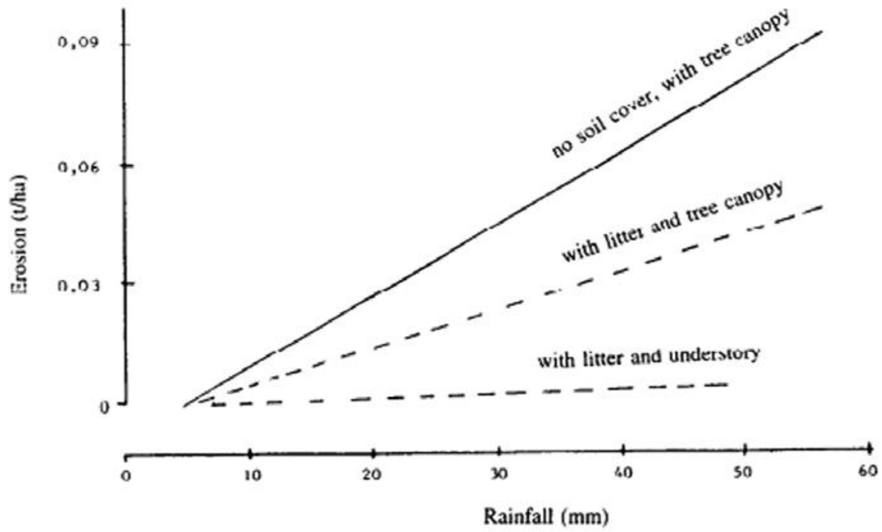

Figure 20 Surface erosion in a young reforested area as a function of various soil surface management options (Wiersum, 1985)

Soil fertility

A negative side-effect of soil erosion is the loss of soil fertility. Soil erosion causes the loss of soil nutrients from the ecosystem in various ways. One of the most significant ways of losing soil nutrients is by nutrients flushing away in eroded sediment (FAO, 1990). Nutrient-rich sediment that is eroded on steep, higher parts of a slope in the Atewa Range may be redeposited in the nearest stream and be carried away until it is eventually being trapped in the Weija Reservoir. Another process via which nutrients are lost upon forest conversion is through enhanced leaching rates. Not only is there a lot more water percolating through the soil after forest clearance diminishes both rainfall interception and water uptake, but there is also a decrease in vegetation causing a decrease in nutrient uptake in the soil. The result is that substantial amounts of nutrients may be washed away directly into the streams and be lost for future productivity. Within the context of the land use pathways, soil fertility could also be decreased through other routes than soil erosion. For instance, the nutrient cycle of the ecosystem breaks when trees are harvested. This is because nutrients in the tropical ecosystem are mainly stored in biomass and not in the soil. Anderson and Spencer (1996) found that 10 - 75 % of all the calcium and phosphorus, 20 – 80 % of the potassium, and 20 – 65% of magnesium present in above- and below-ground biomass plus that is available in the root zone of the soil is stored in the stems of rainforests.

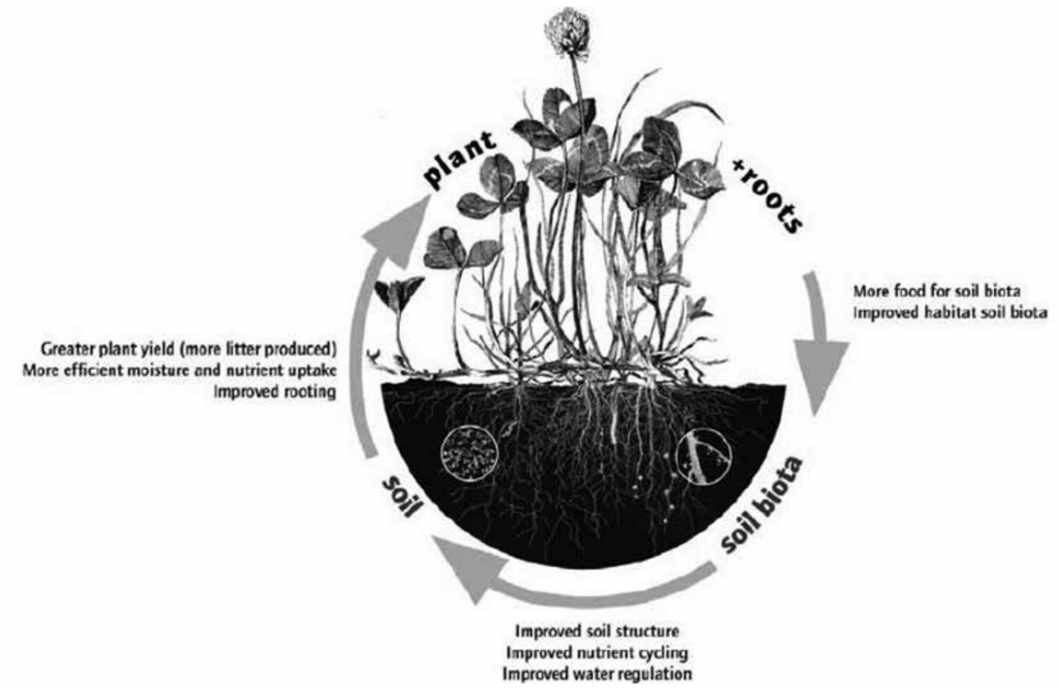

Figure 21 Cyclic interactions from a vegetative cover (van Eekeren *et al.*, 2007)

The various ways in which soil fertility can be lost upon land clearing illustrate that the benefits of cutting down tropical forests in order to convert the nutrient-rich soil into farmland are only short-lived. In the long-term, the new farmland risks becoming so degraded that it becomes uneconomic to farm. There have been many cases in the world where this occurred. For instance, in deforested tropical land in Mexico, soil levels of phosphorus fell by 44 % after three growing cycles, affecting productivity of local farms, which had no financial resources to purchase enough fertilizers for sustaining soil fertility (Lawrence *et al.*, 2007). In addition to the unsustainable short-lived benefits, it may take a long time to recover soil fertility again. Estimates for the period required to compensate overall nutrient losses via nutrient inputs in rainfall and dust are typically in the order of 50 to 60 years (Critchley & Bruijnzeel, 2000).

Hence, vegetation cover and soil provide important supporting services for delivering clean and reliable water resources. Figure 21 summarizes the interaction between above and below ground plant, roots, soil biota and soil properties. These interactions come to a halt when the vegetation cover is removed, and presumably affect other ecosystem services, such as water regulation, erosion and sedimentation, and soil fertility.

Current sedimentation

Water quality indicators that relate to soil erosion include turbidity, total dissolved solids (TDS) and total suspended solids (TSS): Turbidity reflects water clarity; TDS is the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular suspended form; and TSS are solids in water that can be trapped by a filter, such as sediment, decaying plant and animal matter, and industrial wastes. Figure 22 illustrates observed average values with standard deviations of these indicators along the Densu River, together with their guideline values if applicable.

The observed figures show a general trend of increasing values further downstream in the Densu River, until the water discharges in the sink of the Weija Lake. This general trend could be explained by the various land uses in the basin: the relative low values in the upper basin relate to the relatively undisturbed area in and around the Atewa Range; the high values in the middle part of the basin coincide with the relatively high amount of agricultural activities, with elevated erosion rates, along the Densu River in that area; and the low values at the Weija Lake can be explained by the bulk of discharge that causes a decrease in concentration of the solids. More importantly, indicators like turbidity and TSS are already above or close to water quality guidelines that can be used to benchmark. These include indicators from the World Health Organisation (WHO), Environmental Protection Agency (EPA), Ghana Environmental Protection Agency (GEPA) and EU regulations. Threshold values for concentration have been set for turbidity (EPA/WHO: 5 NTU) and TSS (EU: 25 mg/l; GEPA: 50 mg/l).

For average turbidity, the permissible values were exceeded at all the sampling points, especially the middle basin which recorded high values with large outliers. For TSS, the concentrations of TSS reflect an acceptable water quality along the Densu River according to guidelines of GEPA. However, according to EU guidelines, average values at Nsawam, and at some outliers at Mangoase, exceed the maximum permissible level for fisheries and aquatic life, which implies a direct ecosystem loss for fishery services. For TDS, there are no formulated guideline values.

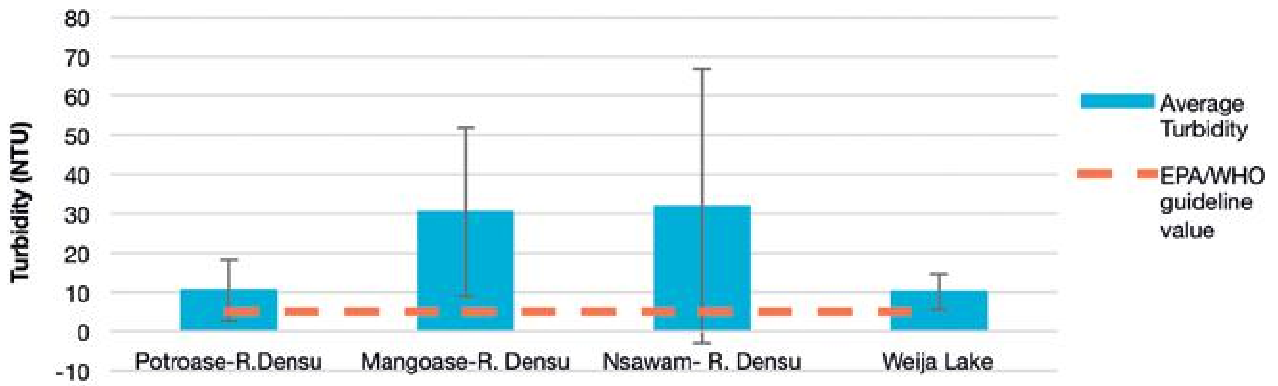

Figure 22 Average turbidity at various sample points along the Densu River

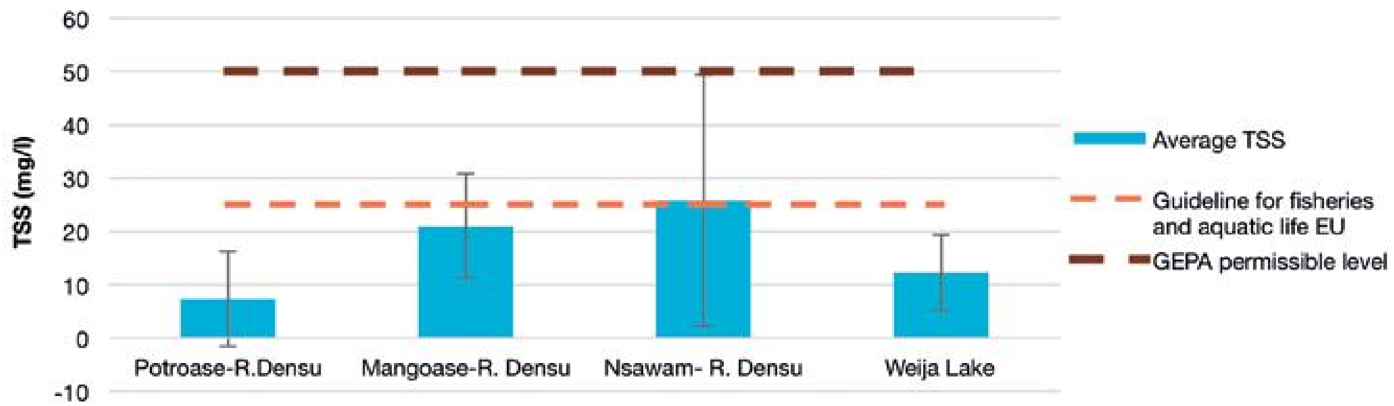

Figure 23 Average concentration of total suspended solids at various sample points along the Densu River

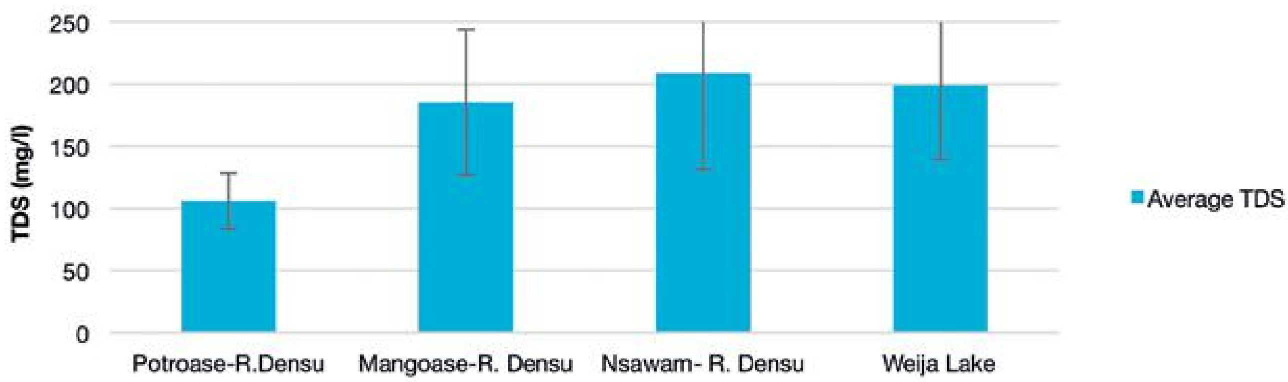

Figure 24 Average concentration of total dissolved solids at various sample points along the Densu River

4.7.2 Siltation in Densu and Weija Reservoir

The Weija Reservoir has a maximum storage capacity of 133 million m^3. The Weija dam spills at a maximum dam reservoir water level of 14.33 m (WRC, 2007). Upstream land clearance and the subsequent increased erosion rates can lead to problems with sediment accumulation downstream. The sediments that enter the Weija Reservoir accumulate in the lake and behind the dam walls and decreases storage capacity. Akuffo (2003) stated that the reservoir is silting up at a rate of 2% per year. GWCL estimated that the average depth of the reservoir has been reduced to 3 m, instead of 5 m when the reservoir was constructed (GWCL, 2015). If the high sediment influx continues, the decrease in storage capacity might lead to water supply problems in Accra. Upstream soil conservation measures or (expensive) dredging of the reservoir could curb this situation.

For the different scenarios, erosion rates have been determined using RUSLE. Overall, the amount of upstream soil erosion determines the magnitude of the siltation at any given place. These results can be found in Table 18. This shows that despite the generally small areas of the Forest Reserve and the buffer zone in the Densu catchment, the changes in land cover there can have substantial impact on siltation. Especially developments in the buffer zone are important for this, illustrated by the difference between Scenario 2 (National Park) and Scenario 3 (National Park and supporting buffer zone), which are as good as equal. Additional protection of the buffer zone (Scenario 3) would avoid an increase in siltation and even result in a small decrease of -1% to -2%. Increased mining activities have the potential to substantially increase the sediment input in the Densu River though, with roughly 8%-14% when considering continued developments (Scenario 1), up to 31%-56% increases if the entire land is cleared of forest (Scenario 4).

	WEIJA	NSAWAM	PAKRO
Scenario 1 (Business as usual)	8%	12%	14%
Scenario 2 (National Park)	8%	12%	14%
Scenario 3 (National Park and supporting buffer zone)	-1%	-1%	-2%
Scenario 4 (Complete degradation)	31%	49%	56%

Table 18 Changes in total upstream erosion potential for three gauging sites and the four scenarios with respect to the baseline

In terms of siltation of the Weija Reservoir, a simple extrapolation can be made from the estimate from GWLC that in 37 years 2 meter of silt has accumulated in the reservoir, leaving an average of 3-meter water depth. If this would continue using such historically estimated rates, the reservoir would be close to filling up in about 55 years. However, if sediment input would increase according to Scenario 1, this would be 4 years quicker, or even 16 years quicker in case of Scenario 4. The change in available water capacity in the reservoir (i.e. the volume not silted up) would reduce with -4% over 20 years as compared to the baseline situation (Table 19).

	SCENARIO 1	SCENARIO 1	SCENARIO 1	SCENARIO 1
Start (1979)	139	139	139	139
Baseline (2015)	53.5	53.5	53.5	53.5
Future (2035)	51.1	51.2	53.8	44.1
Change in %	-4%	-4%	1%	-18%

Table 19 Changes in water capacity (millions of m3) of the Weija Reservoir due to siltation. The changes are with respect to the baseline situation (which assumes same sedimentation rate as in the past)

4.7.3 Pollution by sediment

Effects of increases in sediment load in the river can already be seen in the Birim River, where mining activities in the Kibi region (Figure 25) have resulted in large sediment inputs into the river (Figure 26). To attain the drinking water standards of the WHO and EPA, GWCL has had to invest more in expensive chemicals and filter processes to decrease sediment load. For instance, the cost of water treatment at the plants in Kibi, Anyinam, Bunso and Osino increased more than threefold compared to historical costs when there were no gold mining activities (GWC, 2011). Occasionally, the Birim River is so polluted with sediments that the GWC has to shut down its local treatment plants because it cannot attain to the drinking water standards, no matter the treatment of the water[10]. The river, apart from being polluted, also dries up sometimes because gold miners divert the course of the river to suit their operations, leading to water shortages of communities that depend on the river (Asafo, 2011).

NOTE

10 Agyeman (Page 35, 24 June, 2010): “Birim river bleeds from poisonous chemicals”. Website: http://agyeman6.blogspot.nl/2010/06/birim-river-bleeds-from-poisonous.html

Figure 25 Gold mining activities in the Birim region in March 2016 (Photo: Hans de Moel)

Figure 26 Birim River in the Kibi region in March 2016 (Photo: Hans de Moel)

4.8 WATER QUALITY

For water quality, no specific model has been employed. However, an extensive amount of literature and data has been explored in order to qualitatively say something about the current state and how that relates to the scenarios. The Water Resources Commission uses a combined water quality indicator, combining various ambient water quality parameters (dissolved oxygen, biochemical oxygen demand, ammonia, fecal coliform, pH, nitrate, phosphate, suspended solids, electrical conductivity and temperature) that have been checked against natural or desirable conditions. The index classifies water quality into one of four categories: good, fairly good, poor, and grossly polluted (Table 20). Each category describes the state of water quality compared to objectives that usually represent the natural state. The index thus indicates the degree to which the natural water quality is affected by human activity. The results for 2005 up to 2015 are shown in Figure 27, showing that particularly at Nsawam water is general of poor quality.

CLASS	RANGE	DESCRIPTION
I	> 80	Good -Unpolluted and/or recovering from pollution
II	> 50 - 80	Fairly good
III	25 -50	Poor quality
IV	< 25	Grossly polluted

Table 20 Description of water quality classes

On individual compounds, some monitoring is done with respect to water quality indicators and data from eleven moments in time (between 2006-2008 and 2013-2014) was available to this study. As it concerns snapshots in time, it is not possible to do time series analyses or determine trends. However, they do give a clear indication of the current state. The following section has been split in two sections, addressing water quality issues related to agriculture and mining.

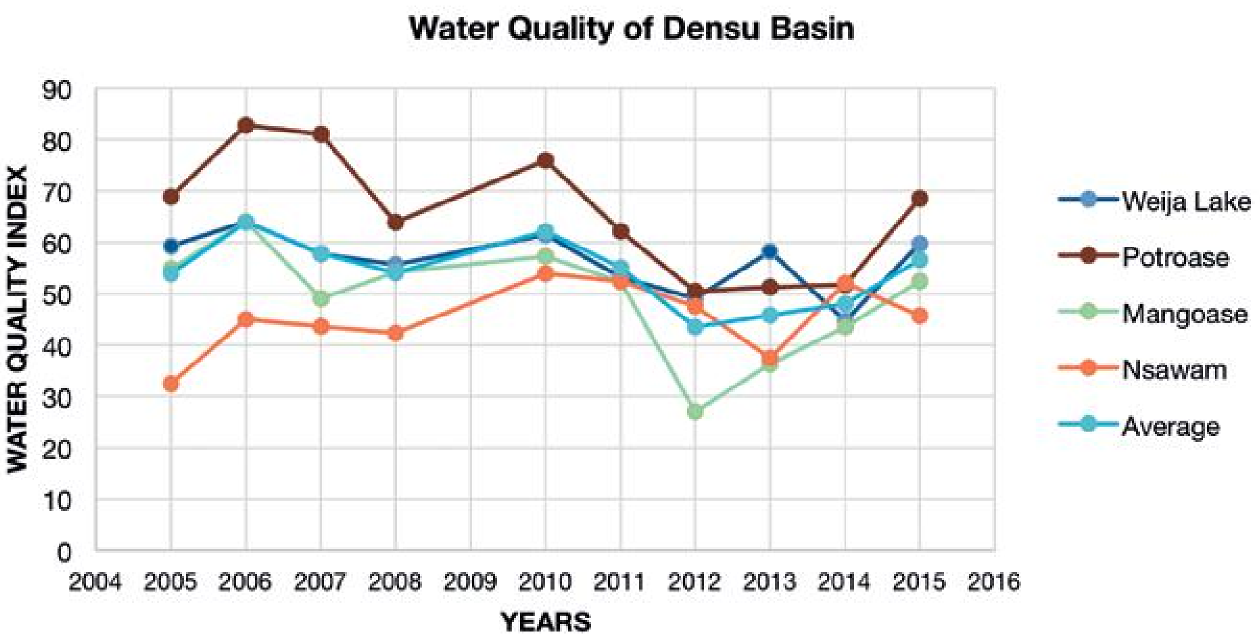

Figure 27 Combined water quality indicator for several gauging stations in the Densu basin from 2005 to 2015

4.9 WATER QUALITY AND AGRICULTURE

Human settlement and land clearance for crops dominate the landscape around the Atewa Forest. The main cultivated crops include cocoa, maize, cassava, sugarcane, vegetables, pineapple and cocoyam (WRC, 2007). Agricultural activities mainly take place along river banks in order to draw water from the river for irrigation. To spur crop growth, agro-chemicals are intensively used. But little attention is given to aquatic hazards associated with their use. In fact, the soil in the Densu Basin is not very suitable for agriculture (CERGIS, 2015), so soil annual uptake efficiencies by crops are relatively poor (e.g. approximately 50 % for nitrogen) causing the surplus of agro-chemicals to be leached, washed and dispersed into the water bodies (Fianko et. al, 2010).

4.9.1 Nutrients

As a result of the surplus of fertilizers that disperses into the rivers, high levels of nutrients fuel algal blooms. This can initially boost dissolved oxygen (DO) levels, but more algae lead to more plant respiration, which draws on the concentration of DO. When the algae die, bacterial decomposition rises, using up most or all of the DO available (Lagasse *et al.*, 2012). As a consequence, the aquatic ecosystem risks becoming hypoxic, causing animals to have more reproduction problems, reduced growth and survival rates, and higher mortality rates (US-EPA, 2000). Coupled with the concentration of DO, the biological oxygen demand (BOD) is also an indicator for the effect of nutrients on water quality: BOD is calculated by measuring the decrease in DO due to decomposition of organic material by aquatic organisms, with the formula BOD = Initial DO - Final DO (US-EPA, 2012).

For water treatment companies that depend on water from the Atewa Forest, the algal blooms increase the costs of water purification. Persistent algal blooms can raise water treatment costs to three times as much compared to a situation without algal blooms (Paintsil & Abrahams, 2008). In order to make water potable again, as much as 60-140 mg/l aluminium sulphate is required to filter out colour and the turbidity (GWCL, 2011). Also for fishermen a low DO or a high BOD is not beneficial, because it likely reduces fish stocks.

The monitoring data show that, despite average levels being acceptable, DO concentrations are sometimes reaching low levels, and sometimes dropping below the threshold for 'minimum growth and activity', especially at Nsawam (Figure 28). Also the BOD is quite high at Nsawam, as at the other sites where some of the measurements are above the threshold for 'polluted water' (Figure 29). Such nutrient levels can occur naturally, but are more often caused by pollution from fertilizer runoff (Chapman, 1996). The nutrient status has been confirmed by observations of occurrence of excessive algal growth in the Densu River and the Weija Lake (Fianko *et al.*, 2010).

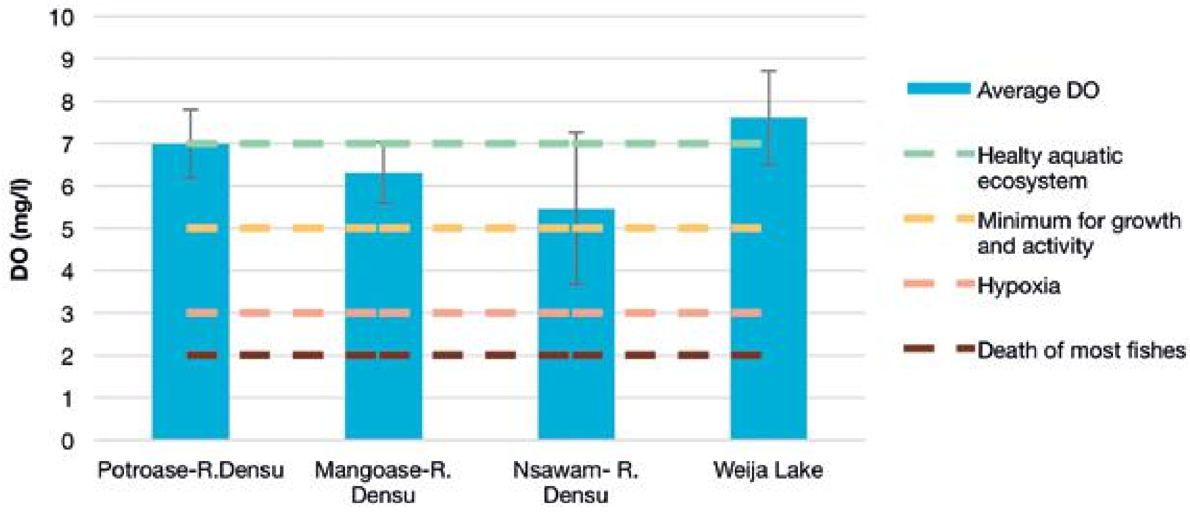

Figure 28 Average dissolved oxygen concentrations at various sampling points in the Densu River

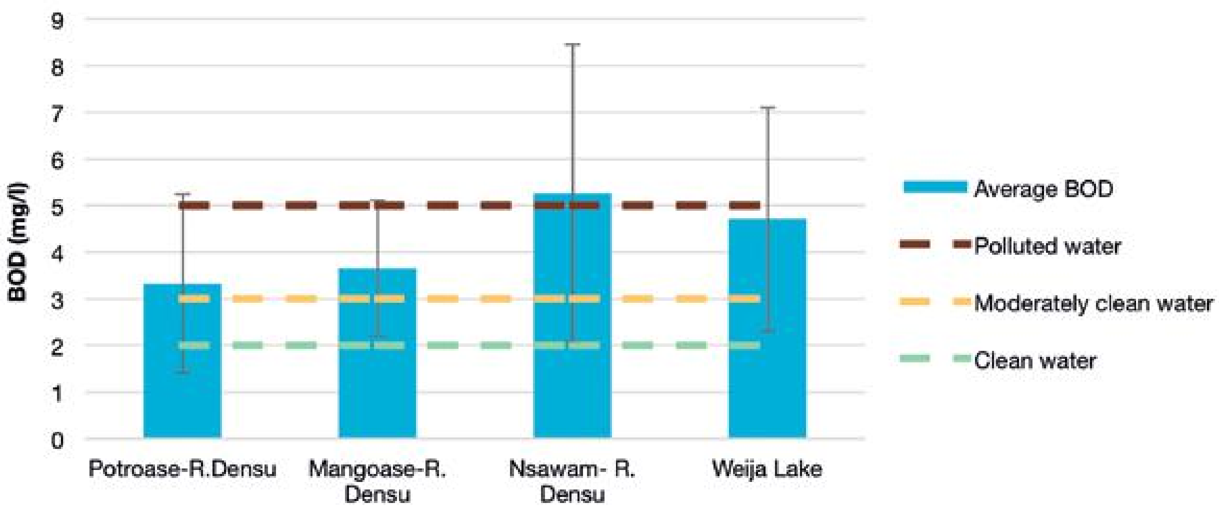

Figure 29 Average biological oxygen demands concentrations at various sampling points in the Densu River

4.9.2 Pesticides

The practice of applying excessive amount of pesticides on crops around the Atewa Range also pressures water quality of the headwaters (Fianko *et al.*, 2010). Pesticides are widely used for the protection against pests; however, the substances of pesticides are toxic to various forms of life. The degree of toxicity depends on the exposure level of the substance and the toxicological, physical and ecological properties of the pesticide. Pesticides accumulate in the food chain and therefore have the potential to be indirectly hazardous for human health when consuming for instance contaminated fish. Pesticides entering the human body can cause disruption of neurological cellular functions, acute and chronic neurotoxicity, tissue or organ damage, irritation and chemical burns (Fianko *et al.*, 2010).

The over-usage of pesticides by farmers is mainly driven by not conscientiously following the procedures recommended for handling the right dosage at the right time of the pesticides (Christian Aid, 2012). An important indirect driver for over-usage is the subsidization of pesticides by the government of Ghana. Spraying is sometimes offered for free to farmers growing cocoa due to their importance to the national economy[11]. Also, these free pesticides, which are specifically designed for cacao, are sometimes misused by farmers because they spray them on their other, non-cacao, crop types to save pesticide expenditures, causing high concentrations of cacao pesticide substances to flow into water streams (Christian Aid, 2012).

With the intensification of agricultural production in Ghana, there has been an increased usage of pesticides. However, no data exists on the amounts of used pesticides at the farmlands of the Densu Basin, though, Kuranchie-Mensah *et al.* (2012) analysed pesticide residues content in the Densu River at Nsawam and Weija Lake. The study revealed that some of the levels of organochlorine pesticides detected in water were relatively high compared to guideline values set by WHO and Australia for drinking water (Hamilton *et al.*, 2003) and thus could be harmful if the trend is not checked (Table 21). Values for Chlordane and Enosulfan sulfate at Weija were higher than WHO or Australian guidelines (bolded values). Values for Gamma-HCH, Delta-HCH, Aldrin and Dieldrin were found to be just a bit higher than the Australian guideline, but still below the WHO guideline value (underlined values).

It is important to know that the concentration of organochlorine pesticides is generally higher in sediment than in water. This is not surprising since the applied pesticides are less soluble in water and favours absorption to sediment particles (Elder and Weber, 1980).

Studies have not been done on the effects of pesticides on the health of the ecosystem in the Densu Basin, although studies by Afful *et al.* (2010) and Fianko *et al.* (2010) and Fianko *et al.* (2013) have recorded residual levels of organochlorine pesticides in fish samples from the Densu River. These studies all found pesticides in the samples. Among the pesticides residues analysed, DDE, alpha-endosulfan, gamma-HCH, delta-HCH, heptachlor and endosulfan sulphate, were predominant in all the samples, sometimes exceeding the reference dose, indicating that consumption of fish and fisheries products from the basin was not at zero risk.

NOTE

11 Bloomberg (2013): “Ghana Cocoa Board to Cut Pesticide Subsidies as Income Falls”. Website: http://www.bloomberg.com/news/articles/2013-08-28/ghana-cocoa-board-to-cut-subsidized-pesticides-as-revenue-falls

PESTICIDE	MEAN CONCENTRATION (µg/L)		WHO GUIDELINE VALUE (µg/L)	AUSTRALIA GUIDELINE VALUE (µg/L)
	WEIJA	NSAWAM		
Gamma-HCH	0.058	0.053	2	0.05
Delta-HCH	0.08	0.13	2	0.05
Heptachlor	0.03	0.02	0.03	0.05
Aldrin	0.016	-	0.03	0.01
Dieldrin	-	0.015	0.03	0.01
Chlordane	**0.037**	-	0.02	0.01
Alpha-endosulfan	0.018	-	-	0.05
Endosulfan sulfate	**0.185**	-	-	0.05
p,p0-DDT	0.018	0.015	2	0.06
p,p0-DDE	0.015	-	2	0.06
Endrin	0.015	0.015	-	-
Endrin aldehyde	0.078	0.11	-	-
Endrin ketone	-	0.013	-	-
Methoxychlor	-	-	20	0.2

Table 21 Comparison of levels of organichlorine pesticides in water with guideline value of WHO and Australia for potable drinking water (adapted from Kuranchie-Mensah *et al.*, 2012). Bold values indicate concentrations above the most stringent guideline, underlined values indicate concentrations above one of the guideline values, but below the other

4.10 WATER QUALITY AND MINING

The Atewa region is known for resources of gold and bauxite. Gold is currently mined in many places, particularly along the Birim River (i.e. in the buffer zone), though gold may be present in other areas as well, including the upstream Densu part (Akulga, 2013). Bauxite is not mined at the moment, though it is known to be present in the Forest Reserve. The exploitation of these resources is sometimes coupled with the use of chemicals, which may then enter the hydrological system. Use is dependent on the type of deposit.

4.10.1 Gold mining

Galamsey operators often do not have the financial resources to invest in expensive machinery and infrastructure such as the large-scale operators, thus use less sophisticated methods to recover gold. The main method for small scale gold mining is gravity panning (Xtra-Gold Resources Corp., 2012). For this, mercury is used to extract gold from rocks, soils, and sediments, which can then leak into water bodies (Emmanuel, 2011). It has been estimated that about 0.5 kg of mercury ends up into water bodies for every 1 kg of gold produced (Asamoah, 2012).

In addition to this mercury influx from galamsey into water bodies, mining in general may disturb heavy metals captured in soil and sediments that may then erode more quickly, releasing more heavy metals than would otherwise have become available from natural erosion. In regions with high precipitation and runoff, such as in the Atewa Range, this source of heavy metal leakage in water bodies is likely to be exacerbated.

Mercury is considered one of the top ten chemicals of major public health concern. Exposure to mercury – even small amounts – may have toxic effects on the nervous, digestive and immune systems, and on lungs, kidneys, skin and eyes (WHO, 2013). The consumption of fish is the main route for mercury exposure in humans and wildlife, although plants and livestock can also contain mercury due to bioconcentration of mercury from freshwater, sediments, soils, and atmosphere, and due to biomagnification by ingesting other mercury-containing organisms (US-EPA, 1997).

Mercury recordings in the Birim River

There are no measurements of mercury in the Densu River, nor is there intensive gold mining taking place in the Densu Basin at the moment. Along the Birim River, on the other hand, extensive mining sites have developed in the last 5-10 years. The effects of small-scale gold mining activities on mercury pollution in the Birim River were analysed in various studies. Osafo (2011) analysed water samples from the Birim River during the dry season near small-scale gold mining areas at Apapam, Kibi, Pano and Bunso (Figure 30). The results of mean mercury concentrations at the sampling sites showed the sequence from high to low: Kibi (0.421 mg/l)> Pano (0.326 mg/l) > Apapam (0.256 mg/l) > Bunso (0.203 mg/l). In approximately the same area, Asamoah (2012) analysed mercury content of water samples during the wet and dry season and found mean concentrations from high to low in the following order: Obronikrom (0.01 mg/l) > Kibi (0.08 mg/l) > Bunso (0.003 mg/l) > Apapam (0.002 mg/l). Attua *et al.* (2015) used a multivariate statistical approach to demonstrate that mercury concentration at fifteen sampling points close to small-scale mining operations in the upper Birim River in the Akyem area ranged from 0.58 to 1.53 mg/l with a mean of 1.06 ± 0.20 mg/l. Nartey *et al.* (2011) recorded mercury concentrations at eleven locations upstream and downstream of the North Birim District in tributaries of the Birim River in the range of 0.045 mg/l and 1.881 mg/l during rainy season and dry season, respectively.

Guideline values for mercury according to the World Health Organisation (WHO) and Environmental Protection Agency (EPA) for safe drinking water are 0.006 mg/l and 0.005 mg/l respectively. Almost all measurements from the Birim were above this level, often quite far above. This implies that Birim River water has become unsafe for domestic use due to mining activities, especially close to mining sites. In the event that mining continues to develop (Scenario 1) and potential zones in the headwaters of the Densu River are mined, such levels of mercury can also be expected in the Densu waters. For Scenario 4 (complete degradation) this would reach extremes, with levels of mercury (and possibly other chemicals related to different mining practices) reaching far above health safety norms, making water unsafe for domestic use. How far this effect would stretch is difficult to gauge, but the findings of Emmanuel (2011) and Asamoah (2012) seem to indicate that effects dwindle when you go downstream (Bunso being the most downstream location). The effects of mercury pollution on humans is not well monitored in Ghana and awareness seems low. However, the potential effects are very severe, including disruption of the nervous system, brain damage, and chromosomal damage (Emmanuel, 2011). In the scenarios, the amount of mercury polluted sediment will therefore be estimated, and linked to reductions in agriculture downstream in floodplains where this sediment settles during high flow events.

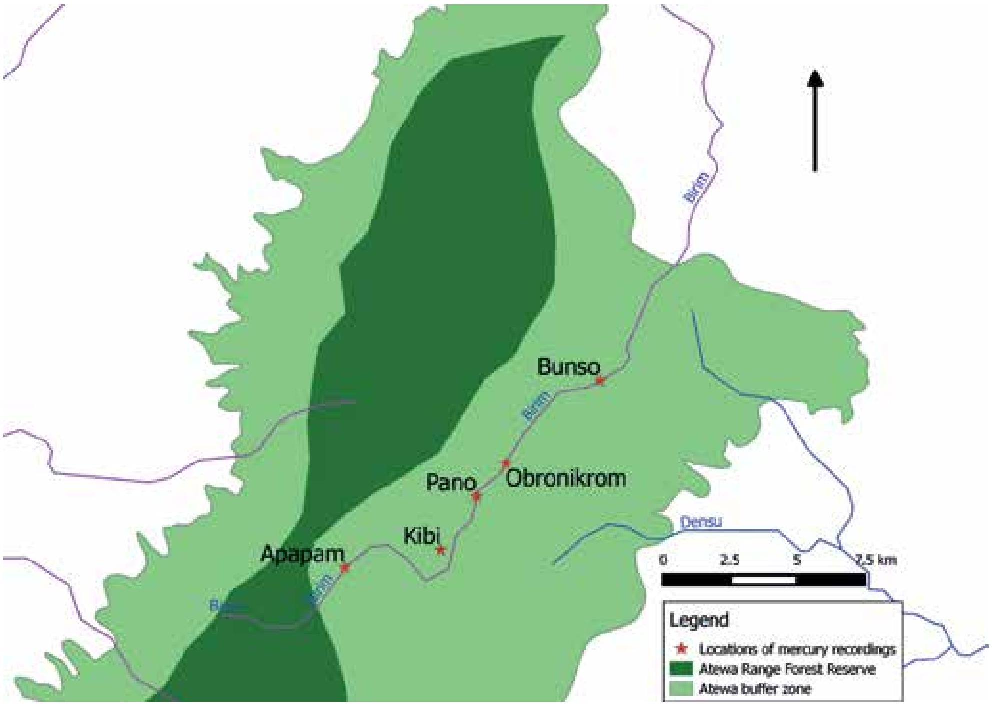

Figure 30 Locations of mercury recordings in the Birim Basin that were used by Osafo (2011) and Asamoah (2012)

The above concerns pollution of the water. However, mercury is also expected to pollute the sediment as it attaches to sediment particles (Domagalski, 2001). This effect may be visible much further downstream, as illustrated by Nartey *et al.* (2011). This study investigated the upstream part of the Pra river, and also analysed sediment on mercury pollution. This showed values reaching far above the US-EPA guideline in the sediment samples (Figure 31), much higher compared to the water samples. Moreover, this was the case throughout all locations, including the most downstream one (PRD).

Hence, mercury may pollute the sediment, which can be transported throughout the entire river basin. To estimate this effect, the extra sediment coming from the mining sites has been determined for the different scenarios (as the difference between the sediment in the Scenario and the Baseline situation). Assuming that all sediment from these sources is polluted, the amount of polluted sediment can be estimated along the stream network. This is given in Table 22.

It should be noted that it is difficult to assess at what point polluted sediment becomes a problem for, for instance, floodplain agriculture dependent on the deposition of sediments by the river. Also, whilst this only concerns the 'new' sediment being deposited by the river, this will accumulate over the years, polluting the soils in the floodplain and consequently affecting possible crops growing on it. Moreover, mercury is known to accumulate in fish tissue, which could directly affect humans feeding on fish from streams or lakes that are impacted by mercury pollution.

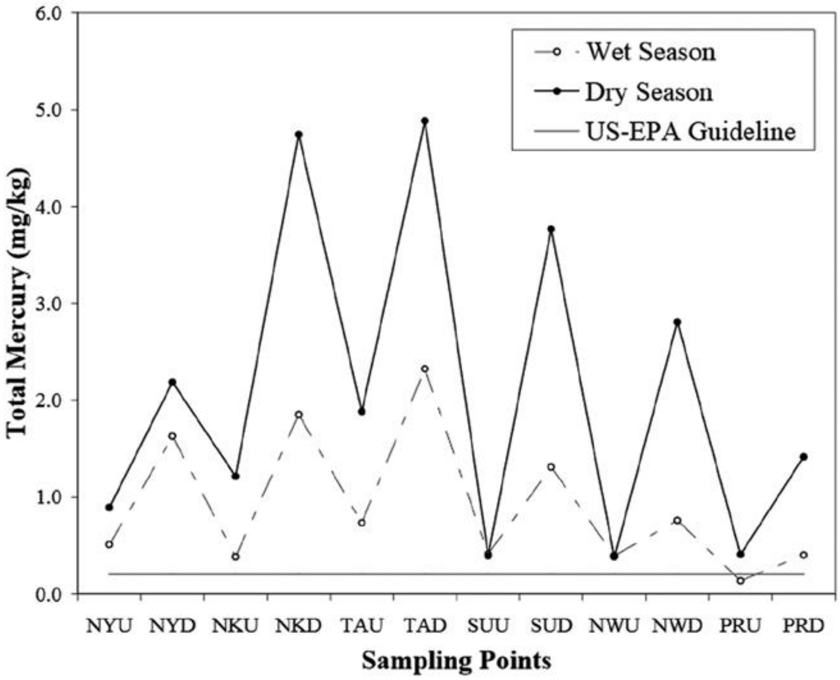

Figure 31 Mercury pollution in sediment for various sampling sites in the Pra river system. (Nartey *et al.*, 2011)

It should be noted that it is difficult to assess at what point polluted sediment becomes a problem for, for instance, floodplain agriculture dependent on the deposition of sediments by the river. Also, whilst this only concerns the 'new' sediment being deposited by the river, this will accumulate over the years, polluting the soils in the floodplain and consequently affecting possible crops growing on it. Moreover, mercury is known to accumulate in fish tissue, which could directly affect humans feeding on fish from streams or lakes that are impacted by mercury pollution.

% POLLUTED SEDIMENT	WEIJA	NSAWAM	PAKRO
Scenario 1 (business as usual)	8%	12%	14%
Scenario 2 (National Park)	7%	11%	12%
Scenario 3 (National Park and supporting buffer zone)	0%	0%	0%
Scenario 4 (complete degradation)	32%	50%	57%

Table 22 Percentage of polluted sediment (resulting from mining activities) along different points in the Densu River

4.10.2 Bauxite mining

The Atewa Range hosts the second largest bauxite deposit in Ghana. It is located on the summits of the mountain ridge (Minerals Commission, 2015). It is the most thoroughly investigated bauxite deposit in Ghana for the feasibility of developing an integrated bauxite/alumina operation in Ghana (Patterson, 1967; Kesse, 1984; Mitchell, 1972; International Bauxite Association, 1977; EPIQ, 1997; Minerex Ltd. of Ireland, 2001). The range of hills on which the bauxite occurs consists of flat or nearly flat-topped hills stretching 14.5 km from Apinamang in the west to Kibi in the east. The bauxite is lateritic in origin and is derived from the steeply dipping Birimian metavolcanic and metasedimentary rocks. The bauxite deposits are covered by a dense tropical forest and 1.5 - 3.0m of thick overburden soil (Minerals Commission, 2015).

In 2011, an international mining company that focuses on the aluminium industry, called Vimetco NV, obtained a prospecting licence for a total area of 468.66 km2 in the Kibi area. Vimetco NV carried out a comprehensive geological survey to map the deposits in that area. According to the feasibility report, the company has blocked out reserves of 152 -180 million tonnes with an average grade of 44.9% Al2O3. The report indicated that it is economically viable to mine the bauxite deposit and to process it into sandy type alumina in a new to build plant in Kibi (Minerals Commission, 2015). This economic analysis, however, did not take into account environmental externalities that are affected by the open pit mine and related infrastructure, such as an increase in soil erosion, sediment load, and land degradation.

4.11 CONCLUSION

In this last section, the findings of the hydrological assessment are made explicit per scenario in Table 23. With respect to overall water availability, the potential water harvesting effect of a cloud forest (providing extra moisture) is not included here, as the sensitivity analysis showed that even in an optimistic situation this would not affect the findings. For siltation, the estimated changes differ between geographic locations, with upstream parts (Pakro) showing larger changes as compared to the downstream part (Weija). Nevertheless, considerable changes are estimated also for the most downstream part. This has been quantified for the Weija Reservoir in terms of how much the water availability of the reservoir (i.e. the volume not silted up) is changed with respect to the baseline situation (siltation as observed in the past).

For water quality, two of the indicators relate to agricultural practices (nutrients from fertilizers, and pesticides). As such, these findings apply to the middle and lower part of the Densu catchment as this is where most of the agriculture is situated. Particularly at Nsawam water quality is currently poor. Future effects are therefore independent of the scenario of what happens upstream in the Atewa Range. For both nutrients and pesticides, current problems are likely exacerbated in the future with increased population growth in the Densu Basin and with it the demand for food. This will result in an increase in agriculture area and/or use of fertilizer and pesticides to increase the crop yield per hectare. The effect of mining on water quality is difficult to assess, though its potential impacts can be very disturbing, even at small quantities. Besides a descriptive analysis resulting from observations currently in the Birim and upstream Pra river (which may happen in the Densu if similar gold mining activities will take place), the percentage of polluted sediment is given (assuming all sediment from mining sites will be polluted). This can be important as this sediment will settle on floodplains where farming may take place, polluting the soil, or may accumulate through the food chain into the tissue of fishes which may be consumed by humans. As with the siltation, percentages are higher for the upstream parts (Pakro, upper end of range) as compared to the downstream parts (Weija, lower end of range).

		SCENARIO 1 BUSINESS AS USUAL (BAU)	SCENARIO 2 NATIONAL PARK	SCENARIO 3 NATIONAL PARK AND SUPPORTING BUFFER ZONE	SCENARIO 4 COMPLETE DEGRADATION
Water quantity	Total water availability (Discharge at Weija)*	+4%	+4%	-1%	+22%
	Spilling at Weija dam**	+8%	+7%	-2%	+38%
Sedimentation	Siltation***	+8 to +14%	+8% to +14%	-1% to -2%	+31 to +56%
	Water availability Weija Reservoir	-4%	-4%	+1%	-18%
Water quality	Nutrients	Increased frequency of breaching threshold for DO and BOD, particularly at Nsawam	Increased frequency of breaching threshold for DO and BOD, particularly at Nsawam	Increased frequency of breaching threshold for DO and BOD, particularly at Nsawam	Increased frequency of breaching threshold for DO and BOD, particularly at Nsawam
	Pesticides	Increased frequency of breaching thresholds for Chlordane and Endosulfan sulfate	Increased frequency of breaching thresholds for Chlordane and Endosulfan sulfate Mercury levels above	Increased frequency of breaching thresholds for Chlordane and Endosulfan sulfate Reduction in	Increased frequency of breaching thresholds for Chlordane and Endosulfan sulfate Contamination of
	Heavy metals	Mercury levels above threshold in Densu Basin. Situation in Birim deteriorates even further.	threshold in Densu Basin. Situation in Birim deteriorates even further.	contamination in Birim region, no contamination in Densu Basin.	mercury and possibly other chemicals in all three Atewa rivers
	% Polluted sediment**	8% - 14%	7% - 12%	0%	32% - 57%

Table 23 Summary table with main findings per scenario from the hydrological assessment.
All numbers/conclusions are as compared with the baseline situation

* Does not include any potential cloud forest effect, which would roughly halve the increases in water availability

** Includes effects of siltation in reservoir as well as variability in incoming discharge in Weija

*** Upper end of changes upstream (Pakro), lower end of changes downstream (Weija)

5 **VALUE** OF ECOSYSTEM SERVICES

The Atewa Range provides benefits to diverse users in the Eastern Region of Ghana, from local communities situated in the range itself to the citizens of Accra in the downstream area. Furthermore, the conservation of the ecosystems in this area is also valued by citizens in other regions of the country and by the global community. With the objective of estimating the value of such benefits, this chapter focuses on the current supply of the main ecosystem services provided by the Atewa Range to the Densu Basin and, in specific cases, to the Ayensu and Birim basins.

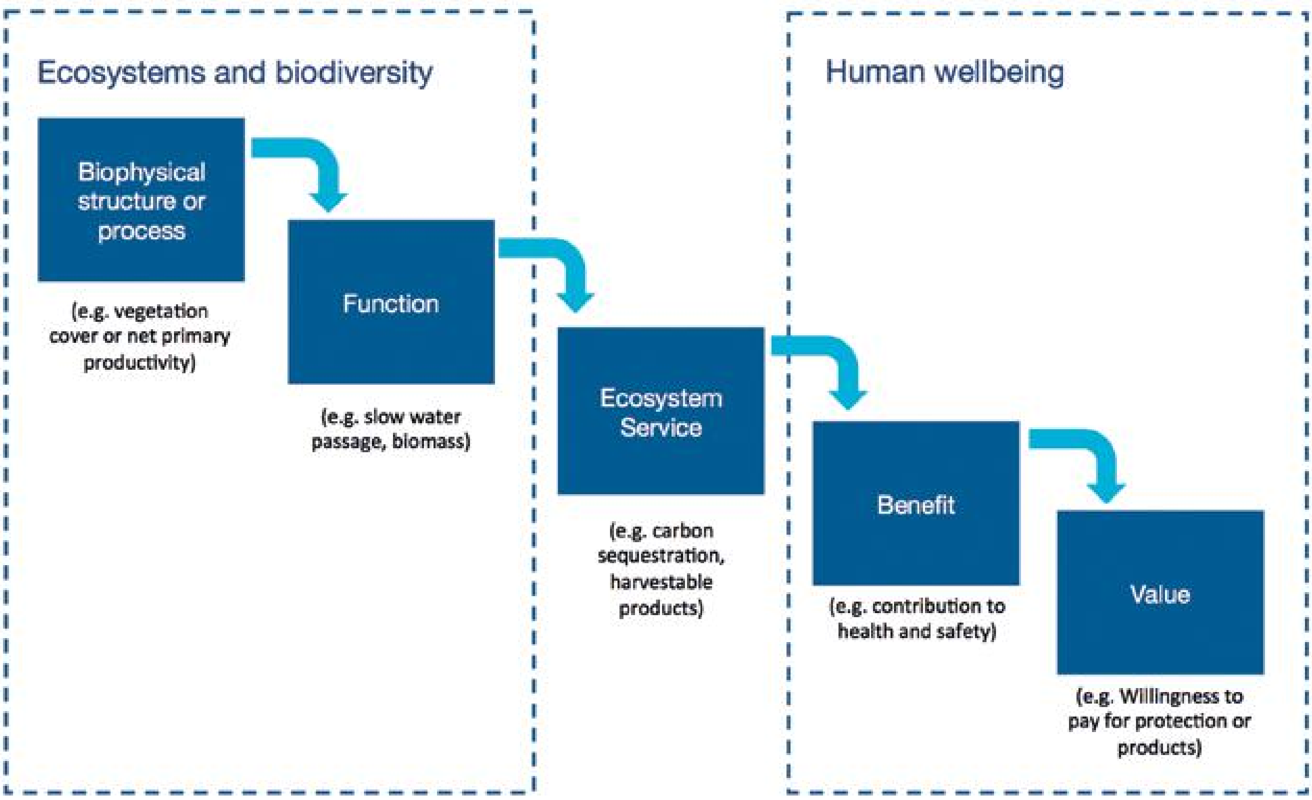

Figure 32 The ecosystem service cascade that depicts the pathway from ecosystem structure and processes to human well-being. Adapted from de Groot *et al.* (2010) and Haines-Young and Potschin (2013)

5.1 METHODOLOGY

By following the TEEB approach, ecosystem services can be defined as the benefits people derive from ecosystems and biodiversity (MA, 2003; 2005; TEEB, 2010). As shown in Figure 32, ecosystem services are originated from ecosystem functions and processes that contribute to human wellbeing (de Groot *et al.*, 2010; Haines-Young and Potschin, 2013). As previously mentioned, at the regional level this chapter focuses on the benefits and the value of the ecosystem services of the Atewa Range to diverse users in the Densu, Ayensu and Birim basins. Additionally, this chapter provides insights into the value of the conservation of the Atewa Range at the national and international scales.

Analysing the value of ecosystem services for specific users requires the identification of a meaningful list of ecosystem services. There are various ecosystem service classification frameworks available (MA, 2005; de Groot *et al.*, 2010; Haines-Young and Potschin, 2013). In this study we use the typology of ecosystem services from The Economics of Ecosystems and Biodiversity (TEEB) initiative (de Groot *et al.*, 2010), which is widely accepted for valuation studies. Although CICES (Haines-Young and Potschin, 2013) has been proposed as an updated classification of ecosystem services, this is still in consultation phase, and hence, it has not been selected for the study due to possible future changes that might affect the comparability of our results.

The categories of ecosystem services considered in this study are: provisioning, regulating, and cultural services (based on de Groot *et al.*, 2010). Provisioning ecosystem services include mainly material outputs from ecosystems; regulating services arise from the role of ecosystems in the regulation of processes; and the cultural services correspond to the broad range of non-material benefits obtained from ecosystems. To identify the most relevant ecosystem services of the Atewa Range, a preliminary list has been compiled in consultation with stakeholders during an inception workshop and the expert meetings held in Ghana in the period from May to June 2015 (Annex A). The ecosystem services included in the analysis have been selected from this list on the basis of available data and their economic importance for the study area. Table 24 presents the resulting list of ecosystem services adapted to match the TEEB typology of provisioning, regulating and cultural services (de Groot *et al.*, 2010). The ecosystem services that were identified during workshop, but excluded from the resulting list are: genetic resources, fisheries, microclimate regulation, erosion control and flood control.

Genetic resources, fisheries and microclimate regulation are not analysed in this study due to lack of data. Flood control and erosion control are partly analysed, but available data are insufficient to estimate their monetary value in this chapter. Flood control is partly explained by the changes in water discharge described in Chapter 4, whereas the contribution of erosion control to water quality and availability is implicitly included in the value of water for agriculture and water for consumption.

To facilitate the analysis, the study area is divided, according to socio-economic and biophysical characteristics, into the following areas (Chapter 1): upstream area (i.e. Atewa Range Forest Reserve and buffer zone), midstream area (i.e. from the buffer zone boundary to the Weija Lake) and downstream area (i.e. Weija Lake, Densu Delta and Accra). For specific ecosystem services, such as water for agriculture and water for consumption, the economic value was extrapolated to include the Ayensu and Birim basins. Besides the specific areas of the Densu River (and other river basins) where benefits are received, Table 24 also summarizes the methodological approach to examine each ecosystem service.

For the majority of the ecosystem services, the monetary value is obtained through market valuation techniques based on current prices. Depending on the service being investigated, secondary data, such as production estimates, current use levels and land cover areas, are also necessary to complete the valuation. Primary data have been additionally collected by surveying over 400 people in Greater Accra with the main purpose of conducting a contingent valuation of the willingness to pay (WTP) for the protection of water for consumption.

Benefits from gold reserves that are currently mined in the Atewa Range are also estimated through market valuation techniques. Although these mineral resources do not represent ecosystem services per-se, they are analysed in this chapter due to their importance in the Atewa Range, and hence as a potential opportunity cost to include in the Cost-Benefit Analysis (CBA) presented in Chapter 6.

	GEOGRAPHICAL RELEVANCE OF BENEFITS				METHODOLOGICAL APPROACH
	GEOGRAPHIC AREA AS DEFINED IN CHAPTER 1			(INTER-) NATIONAL	
	UPSTREAM	MIDSTREAM	DOWNSTREAM		
Provisioning services					
Non-Timber products	X				Market valuation: value of consumption and sales
Timber products	X				Market valuation: value of consumption and sales
Cocoa (farming) **Water for agriculture***	X	X	X		Market valuation: value of cocoa produce Market valuation: net income produced from water
Water for consumption**	X	X	X		Market valuation: current and future production costs and user's expenditure on water Contingent valuation: total and average willingness to pay
Regulating services					
Carbon sequestration***	X	X	X	X	Market valuation: value of changes in carbon stock in the Atewa Range
Cultural services					
Tourism (potential)	X				Benefit transfer: potential income from entry fees and tourist expenditures
Spiritual value	X				Description of non-monetary value
Non-use / existence value	X	X	X	X	Description of non-monetary value
Mineral resources					
Gold	X				Market valuation: market price and production costs
Bauxite (potential)	X				Market valuation: market price and production costs

Table 24 Ecosystem goods and services described in this chapter for the different stages of the Densu River

* Results presented as part of section 5.3 (i.e. midstream area). Economic valuation also includes benefits to the Birim and Ayensu river basins.

** Results presented as part of section 5.4 (i.e. downstream area). Economic valuation also includes benefits to the Birim and Ayensu river basins.

*** Only the quantification of the carbon stock is presented in this chapter. These results are part of section 5.2 (i.e. upstream area). The monetary value of possible future changes in carbon stock is provided in Chapter 6.

The tourism potential in the Atewa Range is the only service analysed with the benefit transfer method, which uses primary information from comparable study sites to estimate benefits in a site with little or no data (Johnston *et al.*, 2015). Tourism potential is, at the same time, the only cultural ecosystem service for which a monetary value was estimated. Other cultural ecosystem services identified in the area (i.e. spiritual and non-use value) are only qualitatively described due to lack of data and the complexity of representing such benefits in monetary and quantitative terms. It is important to stress, that these values are nonetheless of great importance for the wellbeing of local and international communities.

The following sections of this chapter describe the valuation of the most relevant ecosystem services in the up-, mid- and down-stream areas. For each of these sections we provide further details on methodological steps, assumptions and results of the valuation of ecosystem services. The final section of the chapter aggregates the values of those ecosystem services for which monetary valuations are performed, thereby synthetizing the total value of the current supply of ecosystem services by the Atewa Range.

5.2 UPSTREAM AREA: ATEWA RANGE

The upstream area corresponds to the Atewa Range, an area of plateaus with one of the few portions of upland evergreen forests in Ghana (McCullough *et al.*, 2007). Within the Atewa Range, this study estimates the value of ecosystem services supplied by the Forest Reserve and the buffer zone specifically defined for this study.

Table 25 presents the area of the most relevant land cover types for the provision of ecosystem services in the Atewa Range (i.e. Forest Reserve and buffer zone), based on the land-cover data from 2010 made available through the Center of Remote Sensing and Geographic Information Systems of the University of Ghana (CERSGIS). The land cover types from the 2010 classification that are relevant for the ecosystem service valuation correspond to herbaceous cover, open-canopy forest and closed-canopy forest. However, as confirmed in field visits and stakeholder meetings, there is a significant area of the buffer zone covered by cocoa plantations, despite being categorized as forest in the land-cover classification. The area of cocoa in the buffer zone is therefore estimated separately, as explained in the following paragraphs.

The most recent source to estimate the actual area covered by cocoa plantations is the land use map from 2000 (made available through CERSGIS), as this spatial dataset includes the land use categories of cocoa plantations and sub-canopy crops. By intersecting this map with the land cover map from the same year, we estimated that around 87% of the area classified as open-canopy forest and 73% of the closed-canopy forest corresponded to cocoa plantations. These percentages are thus extrapolated to estimate the area of cocoa, closed-canopy forest and open-canopy forest in the buffer zone in 2010 (Table 25). This estimation is only applicable to the buffer zone, as for the sake of simplicity it has been assumed that no cocoa plantations are developed in the Forest Reserve area. The land cover types from 2010, including the area with cocoa, serve as the basis for the estimation of the value of various ecosystem services in the Atewa Range, as described in following sub-sections.

Regarding provisioning services, the forest area in the Atewa Range provides local communities with a broad range of non-timber and timber products. Cocoa plantations also supply part of the non-timber products to local communities, which at the same time benefit from the harvesting of cocoa itself. The herbaceous cover, however, provides suitable conditions for only part of the extensive list of non-timber products provided by forests and in most cases also in smaller amounts. Monetary benefits considered in this section include consumption and sales, and in the case of timber, legal extraction in the buffer zone and illegal logging in the Forest Reserve.

From the Regulating services, the vegetation in the Atewa Range, including forest, cocoa and herbaceous cover, contribute to capturing and storing carbon from the atmosphere. This chapter only presents the estimation of carbon stored in the Atewa Range. The monetary value of carbon sequestration is estimated in Chapter 6 on the basis of future changes in carbon stock under different scenarios.

In addition to provisioning and regulating services, the Atewa Range creates economic opportunities for tourism and, particularly in forested areas, it represents a source of spiritual value and cultural identity. Although tourism potential is not part of the current supply of ecosystem services, future developments can create new revenues from nature, thus being an important value for further analysis of costs and benefits of different scenarios in Chapter 6. The spiritual value of the Atewa Range has diverse manifestations, but monetary valuation techniques are not appropriate to capture its complexity. This value is therefore described only in qualitative terms.

AREA	FOREST		COCOA PLANTATIONS		HERBACEOUS
	CLOSED-CANOPY	OPEN-CANOPY	CLOSED-CANOPY	OPEN-CANOPY	
Forest Reserve (ha)	20,815	4,315	0*	0*	254
Buffer zone (ha)	6,550	2,958	17,890	18,956	2,732
Atewa Range total (ha)	21,470	7,273	17,890	18,956	2,986

Table 25 Land cover categories for the estimation of the value of ecosystem services in the Atewa Range (land cover data obtained through CERSGIS for the year 2010)

* Based on the assumption that no cocoa plantations are developed within the boundaries of the Forest Reserve.

In summary, the ecosystem services that are evaluated in monetary terms within the upstream area (i.e. Atewa Range) are: non-timber products, timber products, cocoa production, and potential for tourism.

In addition to these services, the analysis of the upstream area includes the estimation of the carbon stock in the Atewa Range and the monetary valuation of gold mining and potential bauxite mining benefits, as all these are relevant values to inform the cost-benefit analysis presented in Chapter 6.

5.2.1 Non-timber products

Forest reserves in Ghana are traditionally used as production forests from which local communities obtain a broad variety of non-timber products for consumption and commercial purposes (McCullough *et al.*, 2007). According to previous research, the most used non-timber product in the Atewa Range is bush meat, of which almost 370 tonnes per year are extracted (Ansah, 2014). Other products harvested in large amounts include snails, mushrooms, honey and fruits (Ansah, 2014; Ayivor and Gordon, 2012).

The estimation of the value of non-timber products in the reserve and buffer zone is based on a list of thirteen products adapted from Ansah (2014) (see Table 26). Most of these products can be found in both forest ecosystems and cocoa plantations, although their quantity might differ according to canopy cover and land use type (i.e. open- or closed-canopy; cocoa or natural forest). Regarding the herbaceous type, it is assumed that only a few of the non-timber products can be found in herbaceous areas, and these are provided in smaller amounts than in forests.

To express the differences between land cover types in the calculation of the value of this service, a factor of ecosystem service provision is assigned to each land cover type in the reserve and the buffer zone (Annex D). The factors assigned to the different non-timber products were selected in consultation with experts and validated with representatives of A Rocha Ghana and IUCN.

Local prices and extracted amounts of non-timber products are the basis to estimate the value of the current supply of these products in the Forest Reserve. Local market prices for the majority of the products identified in the Atewa Range were obtained from representatives of A Rocha Ghana. This information was complemented and validated with available literature on specific products (e.g. Bennet and Nozzolillo, 1987; Cobbinah *et al.*, 2008; ITTO, 2013; Lionelle, 2012; Kingdon, 2015; McGowan and Madge, 2010; Nowak, 1999; Opara, 2010), as it is presented in Annex E.

The amount of non-timber products extracted from the Forest Reserve includes household consumption and sales, and it is obtained from yearly estimates derived from approximately 1,950 households of 45 communities investigated by Ansah (2014) in the surroundings of the reserve. These data serve to estimate the total economic value of the current supply of non-timber products in the Forest Reserve. The economic value per hectare and then total economic value of non-timber products in the buffer zone are derived from the factor of ecosystem services provision and the area of each land cover type, as described in the following steps of calculations (where FR: Forest Reserve; BZ: buffer zone; FESP: factor of ecosystem service provision and ha: hectare):

1. $\text{Total economic value (FR)} = \text{Unit price} \times \text{Quantity extracted from the FR}$

2. $$\text{Economic value (ha)} = \frac{\text{Total economic value of the FR}}{\sum(\text{Area of provision [FR]} \times \text{FESP})}$$

3. $$\text{Total economic value (BZ)} = \text{Economic value (ha)} \times \sum(\text{Area of provision [BZ]} \times \text{FESP})$$

Based on these calculations, the total economic value of the annual supply of non-timber products is estimated at approximately US$6.9 million in the Forest Reserve and US$5.4 million in the buffer zone. On average, the provision of non-timber products in one hectare is valued at US$284 (Table 26).

NON-TIMBER PRODUCTS	AVERAGE VALUE PER HECTARE (US$/HA/YEAR)	TOTAL ECONOMIC VALUE FOREST RESERVE (US$/YEAR)*	TOTAL ECONOMIC VALUE BUFFER ZONE (US$/YEAR)*
Snails	$ 65	$ 1,629,000	$ 855,000
Honey	$ 20	$ 499,000	$ 566,000
Mushrooms	$ 11	$ 288,000	$ 151,000
Fruits	$ 2	$ 44,000	$ 68,000
Rattans	$ -	$ -	$ -
Cane	$ 61	$ 1,404,000	$ 491,000
Chewing stick	$ 7	$ 160,000	$ 56,000
Bath Sponge	$ -	$ -	$ -
Chewing sponge	$ 5	$ 12,000	$ 41,000
Spices	$ 14	$ 312,000	$ 295,000
Herbs	$ -	$ -	$ -
Wrapping leaves	$ 3	$ 59,000	$ 91,000
Bush meat	$ 96	$ 2,437,000	$ 2,827,000
Total non-timber products	**$ 284**	**$ 6,950,000**	**$ 5,441,000**

Table 26 Economic value of the current supply of non-timber products in the Atewa Range
* The results are rounded to the nearest thousand

5.2.2 Timber products

The abundant regeneration of trees in the Atewa Forest has historically been a source of timber products for local communities (Hawathorne and Abu-Juam, 1995; McCollough *et al.*, 2007). According to data from local surveys, approximately 350,000 m^3 of timber and about 1,400 tonnes of other timber products are yearly extracted from the Forest Reserve (Ansah, 2014). Other timber products obtained from the forest include firewood, and wood for mortars and pestles (Ansah, 2014; Ayivor and Gordon, 2012). In total, these quantities are extracted for both sale and household consumption.

In this study, the economic value of timber is estimated through market based techniques based on local prices and amount of products extracted.

To reflect differences in the availability of timber products in each land cover type, a factor of ecosystem service provision was selected in consultation with IUCN NL and A Rocha Ghana and assigned to each type of timber product. As cocoa plantations and the herbaceous cover are not considered sources of timber, the factor assigned to these land cover types is 0% (Annex D).

Local prices (Ansah, 2014; A Rocha, pers. comm.) and amounts extracted (Ansah, 2014) are first used to determine the total economic value of timber products for the Forest Reserve. This value, together with the factor of ecosystem services provision is then used to estimate the economic value per hectare of forest, and this result is in turn used to calculate the economic value in the buffer zone. The estimation of the total economic value of timber products for the Forest Reserve and the buffer zone is conducted in the following steps (where FR: Forest Reserve; BZ: buffer zone; FESP: factor of ecosystem service provision and ha: hectare):

1. Total economic value (FR)=Unit price x Quantity extracted from the FR

2. Economic value (ha)= $\frac{\text{Total economic value of the FR}}{\sum(\text{Area of provision [FR]} \times \text{FESP})}$

3. Total economic value (BZ)

= Economic value (ha) x $\sum$ (Area of provision [BZ] × FESP)

Additional sources of data for these calculations, together with the unit conversions utilized to obtain the price of timber per m^3, are presented in Annex E.

As shown in Table 27, the total economic value of the annual supply of timber products is estimated at approximately US$1,392 per hectare, US$30.5 million in the Forest Reserve (from illegal timber logging) and US$10.2 million in the buffer zone. From this amount, timber itself is the main contribution to the economic value, representing approximately 96% of the total.

TIMBER PRODUCTS	ECONOMIC VALUE PER HECTARE (US$/HA/YEAR)	TOTAL ECONOMIC VALUE FOREST RESERVE* (US$/YEAR)**	TOTAL ECONOMIC VALUE BUFFER ZONE (US$/YEAR)**
Timber	$1,336	$29,257,000	$9,741,000
Mortar (Ghanaian)	$49	$1,075,000	$358,000
Pestle (Ghanaian)	$5	$101,000	$34,000
Construction poles	$-	$-	$-
Fire wood	$2	$48,000	$17,000
Total timber products	**$1,392**	**$30,481,000**	**$10,150,000**

Table 27 Economic value of the current supply of timber products in the Atewa Range

* Timber logging in the Forest Reserve is not legally permitted (Ansah, 2014; Abu-Juam *et al.*, 2003).

** The results are rounded to the nearest thousand

5.2.3 Cocoa (farming)

As described in previous sections, a significant part of the buffer zone is covered by cocoa plantations (Table 25, above). The buffer zone, covered by nearly 37,000 ha of these plantations, provides local communities with benefits from cocoa sales and consumption. This section provides a brief overview of the magnitude of these benefits.

The benefits obtained from cocoa sales and consumption in the buffer zone are calculated as the product of the harvested amount and the local price. For the area of cocoa plantations in the buffer zone and a yield of 0.3 tonnes per hectare (FAO, 2004), the total cocoa produce results in around 11,000 tonnes per year. As local price data are not available for this study, we use the average of annual producer prices in Ghana for the period 1991-2011 provided by FAO (FAOSTAT, 2016), calculated at US$844.5 per tonne. Based on these data, the value of the total produce of cocoa in the buffer zone can be estimated at approximately US$9,336,000 per year.

5.2.4 Carbon sequestration

Tropical forests are of global importance for the sequestration of carbon. As forest areas degrade and shrink, the amount of sequestered carbon reduces, ultimately affecting global climate regulation and contributing to ongoing climate change processes. On the other hand, in the case of reforestation the carbon pool in areas with tropical forests, such as the Atewa Range, can be expected to increase.

Unlike other ecosystem services analysed in this study, carbon sequestration does not yield a continuous annual benefit; there is only a change in value in the case of changes in biomass. A decrease in biomass would lead to a negative change in carbon sequestration and additional costs of climate change to society; whereas an increase in biomass would determine a positive change in this service, with the consequent benefits of a more stable climate to society.

Due to lack of a complete baseline to estimate the current average value of carbon sequestration in the Atewa Range, this study does not estimate the current value of this ecosystem service. This section only presents the carbon stock and carbon price used to estimate future carbon sequestration values in the different land-use scenarios analysed in Chapter 6. The carbon stock in the Atewa Range is spatially estimated on the basis of the above ground biomass provided in the Biomass Map of Ghana from 2008-2009 (Asare *et al.*, 2012) and a representative carbon price is selected from the international range of carbon offset prices (Goldstein and Gonzalez, 2014).

Carbon stock in the Atewa Range

According to Asare *et al.* (2012), carbon corresponds to approximately one half of the biomass stored in woody vegetation. Following this conversion rule, we estimate carbon content as half of the above ground biomass (i.e. conversion factor of 0.5). The average carbon content in the Atewa Range is thus calculated between 109 and 130 tonnes per hectare, depending on the land cover type (Table 28). By using the absolute error map of the Biomass Map of Ghana (Asare *et al.*, 2012), an average error of 32.7 tonnes of carbon per hectare is calculated for the Atewa Range.

	FOREST AND COCOA PLANTATIONS		
	CLOSED-CANOPY	OPEN-CANOPY	HERBACEOUS
Average carbon in the Atewa Range (Mg or tonnes/ha)	129.5	114.9	109.0

Table 28 Average carbon content per land cover type in the Atewa Range

In total, it is estimated that the Atewa Range stores 9.3 million tonnes of carbon (Table 29). The spatial distribution of the stored carbon is presented in Figure 33.

	TOTAL BIOMASS (MG OR TONNES)*	TOTAL CARBON (MG OR TONNES)*
Forest Reserve	7,314,000	3,657,000
Buffer zone	11,382,000	5,691,000
Atewa Range	18,696,000	9,348,000

Table 29 Calculation of carbon stored in the Atewa Range
*The results are rounded to the nearest thousand

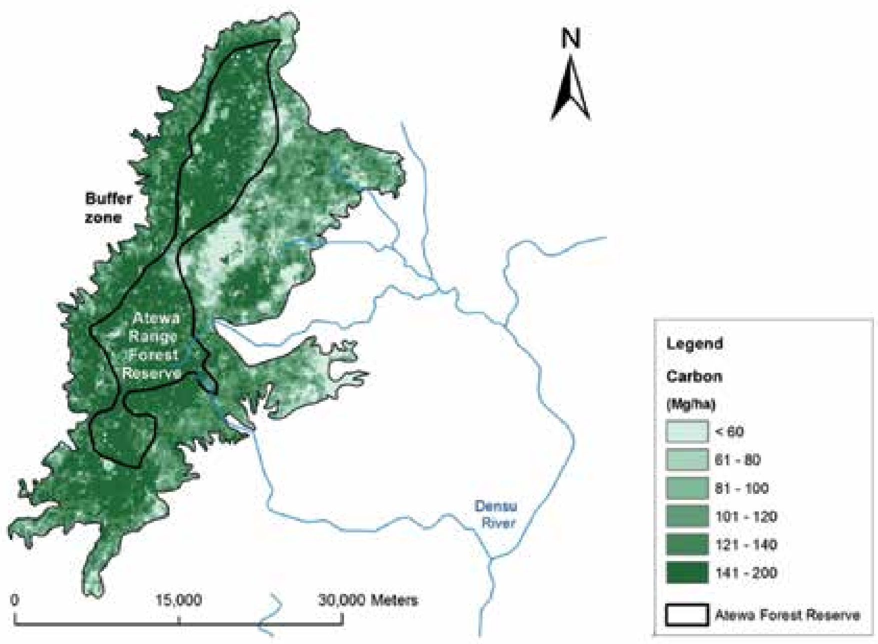

Figure 33 Carbon map of the Atewa Range: Atewa Range Forest Reserve and buffer zone (based on Asare *et al.*, 2012)

Carbon prices

To estimate the economic value of carbon sequestration in the different scenarios analysed in Chapter 6, a carbon price is selected from international pricing mechanisms. Carbon pricing mechanisms differ among countries and regions, varying from taxes to trading mechanisms. Consequently, carbon prices are distributed over a broad range. According to the state and trends report of the World Bank (2014) on carbon pricing, this range covers from under US$1/tCO2 to US$168/tCO2. In the majority of the trading schemes, however, prices are below US$12/tCO2.

Forest Trends analysed 136 forest carbon offset projects in the period 2011-2014, and encountered carbon prices ranging from US$1/tCO2 to over US$100/tCO2. However, the average REDD offset selling price went from US$7.8 /tCO2 in 2012 to US$4.9/tCO2 in 2013 (Goldstein and Gonzalez, 2014). In this study, we use a carbon price of US$6/tCO2 as a representative estimate of existing trading schemes and the REDD offset selling prices. This price is the basis for further calculations of the economic annual value of possible future changes in carbon stock in the Atewa Range presented in Chapter 6.

5.2.5 Potential for tourism

In order to preserve the Atewa Range as well as the quality of the three river basins, alternative income sources for the local population need to be explored. Monetizing ecosystem services by developing tourism is often mentioned by stakeholders as a way to create alternative livelihoods for the local population. The money generated through tourist expenditures as well as the attracted foreign investments can, in theory, be used to protect the surrounding environment and can foster economic development in the region. Ghanaian national parks like Kakum National Park or Mole National Park demonstrate that sustainable economic development is possible through tourism. However, before tourism can generate profits, large investments in the infrastructure of touristic areas have to be made. One of the most crucial factors that adjudicate upon whether an area is worth investing in is the economic return. Although this is not part of the current supply of ecosystem services, potential tourism developments can add revenues arising from nature in the future. Therefore, this section is dedicated to the analysis of the economic potential of tourism in the Atewa Range in order to provide inputs for the cost-benefit analysis described in Chapter 6 for different scenarios.

In the light of this study, Steber (2015) analysed tourist potential of various protected areas in Ghana. Based on the Multi-Criteria Analysis (MCA) it was concluded that of all National Parks and Forest Reserve areas, the Atewa Range is the fourth most suitable area for the development of tourism, after Kakum National Park (most suitable), Digya National Park and Mole National Park (Annex G).

As mentioned above, Kakum National Park provides a great example of how to generate sustainable profits from a protected area in Ghana. Furthermore, Kakum National Park and the Forest Reserve have comparable characteristics in a number of social and environmental criteria. Both locations are situated in Southern Ghana and have similar sizes and landscapes (although different vegetation). Also, both parks show a similar distribution in the number of birds and mammal species. Therefore, it can be assumed that the revenues from entrance fees of Kakum National Park can be taken as a proxy for the potential revenues from entrance fees of the Forest Reserve. Table 30 gives an overview of the social and environmental similarities between both parks.

	KAKUM NATIONAL PARK	KAKUM NATIONAL PARK
Size	350 km^2	232 km^2
Distance from Accra	2h50 / 175 km	1h25 / 93 km
Ecoregion	Eastern Guinea Forest	Eastern Guinea Forest
Mammal species	131	149
Bird species	402	415
Butterflies	405	575

Table 30 Comparison of the Kakum National Park and Atewa Range Forest Reserve

To quantify the tourism potential of the Atewa Range as a tourist destination, it is necessary to estimate the potential number of domestic and international visitors. The latest official data concerning international tourist arrivals is from 2011 and states the arrival of 827,501 international visitors in that year (Ghana Tourism Authority, 2011). If the growth of tourist arrivals continued the trend of the years prior to 2011 (>10%) it is safe to assume that more than one million visitors arrived in Ghana in 2015. Based on statistics from 2009, around 19% of arrivals comprise holiday travels (Ghana Tourism Authority, 2011). Therefore, approximately 190,000 international tourists should have arrived in Ghana in 2015 to spend their holidays in the country. The vast majority of these arrived by plane in Accra and will spend their time in the triangle of Accra – Kumasi – Cape Coast, which forms the core of tourism development and activity within Ghana (Ghana Tourism Authority, 2011).

The Atewa Range Forest Reserve lies within this triangle and is located close to the main route between Accra and Kumasi. Therefore, it has the ideal starting position to attract a large amount of domestic and international tourists. Furthermore, its location allows for daytrips from or to the Ada Foah Bird Sanctuary and the Akosombo Dam. Assuming that the reserve adopts a similar entrance fee structure as the one in the Kakum National Park, the Atewa Range Forest Reserve could generate approximate revenues of US$443,750 from 100,000 visitors per year (compared to 160,000 visitors to Kakum National Park; Table 31).

Additionally, tourist expenditures are a potential source of income that stimulates alternative livelihoods for the local communities around the Forest Reserve. If available, tourists are likely to spend money on souvenirs, food and beverages, accommodation and transport. This means that tourism can contribute significantly to the local economy in the Atewa Range. According to the Ministry of Tourism (2012), international tourists spend on average US$144 per day while in Ghana. For the Cost-Benefit Analysis (CBA) it is assumed that this value will be half for international children (US$72). It is also assumed that both domestic and international tourists stay on average 1.5 days in the Atewa Range. This will result in maximum potential tourist expenditures of US$5.4 million per year.

	VISITORS PER YEAR*		ENTRANCE FEE (US$)	REVENUE (US$/YEAR)
	NUMBER	%**		
Ghanaian adults	15,000	15%	5	75,000
Ghanaian children	55,000	55%	1.25	68,750
International adults	20,000	20%	12.5	250,000
International children	10,000	10%	5	50,000
Total revenue entry fees	100,000	100%		443,750
Maximum potential tourist expenditures				5,400,000

Table 31 Potential Revenue from domestic and international tourism in the Atewa Range Forest Reserve area

* Assuming a third of the domestic and international visitors would visit the Atewa Range.

** Tourism Statistical Factsheet.

5.2.6 Spiritual value of the Atewa Forest

The Atewa Range has great cultural significance and interesting historical recount. The culture of the inhabitants of communities in this area is inextricably linked with the existence of the forest. The forest is locally referred to as Kwaebibirem, which is traditionally regarded as the home of ancestral spirits who provide protection, success and progress to the Abuakwa Stool and the people of the Akyem Abuakwa Traditional Area. Historically, the forest has been conceived as a haven for the people in the traditional area, a belief that is rooted in the wars with the Asante and other tribal groups.

A queen mother of the traditional area and her sister are believed to have died in a river now called Wankobi, whilst digging the riverbed for gold. According to the lore, the queen and her sister were fleeing to the hills from a war with the Asante and stopped to look for gold when they got to the river. The same river, which flows through the eastern side of the Atewa Range is regarded as a shrine and is worshiped by the local population. The river is believed to offer protection and spiritual intervention to those who express their worship to it. It is a taboo to fetch water from the river with any other utensil than a calabash. Also, the water from the river must not be heated or boiled.

Other myths around the Atewa Forest also give rise to particular traditions among locals. On the eastern side of the reserve, for example, it is traditionally a taboo to enter the forest or fetch water from the river on a Thursday.

Historical and cultural resources with a spiritual significance in the area include the Palace of the Okyehene (Ofori Panyin Fie) and the royal mausoleums. These sites, together with other areas of the forest, provide a meaningful space for folktales (e.g. Okomfo Anokye's ram foot and the legend previously described in this section) and numerous manifestations of the local culture and spiritual values, such as festivals, rites, funerals, and music and dance performances.

In 2014, a survey applied to 100 people from ten different communities in the surroundings of the Atewa Range reflected part of the value described above. These results showed that at least 15% of the respondents carried out spiritual activities in the Atewa Forest (Ansah, 2014). People interviewed in these communities acknowledged a close spiritual and cultural connection with the forest. For them, the forest was perceived as the home of their ancestors. Parts of the forest were coherently described as sacred groves and burial places, whilst others were designated as palaces of the chief.

Since the vast spiritual significance of the Atewa Forest might be linked to complex and ancestral interrelations between people and nature, a monetary valuation does not represent a suitable approach to capture the full extent of this value. For this reason, this section has only provided a qualitative description that can serve as a general basis for further investigation of this value.

5.2.7 Mineral resources

Besides providing numerous ecosystem services, the Atewa Range is rich in gold and bauxite, the metal ore from which aluminium is produced. Although extracting these mineral resources poses a serious threat to the ecosystem services described in this chapter, it also provides substantial benefits to local communities and mining companies in three of the four scenarios analysed in this report. This section thus describes the monetary value of gold mining and the potential value of bauxite extraction as a reference for the cost-benefit analysis described in Chapter 6 of the report. The economic value of these products is estimated through market based methods with information about size of the mineral reserves, production costs and average market prices.

Gold mining

Although gold mining has taken place on a very small scale for a long time already, gold production accelerated in the Atewa Range around 2010. Currently, mining activities are concentrated in the Birim River Basin, but mineral resources are also identified in both the Densu and Ayensu basins (see chapter 2).

Xtra Gold (2006) investigated the potential of gold mining in the Atewa Range. Based on the exploration work, the total alluvial gold reserves in the Atewa Range are estimated at a total of almost 14,000 kg. The alluvial gold reserves are located mainly in the buffer zone, with some minor areas in the Forest Reserve area. In total, it is estimated that 50% of the buffer zone would have to be mined to extract the entire gold reserve. Currently, around 2.8% of the buffer zone is mined by both illegal and legally permitted operations (RMSC, 2016). Assuming that the concentration of gold is similar across the entire gold reserve, it is estimated that this mined area relates to roughly 6% of the entire gold reserve. Considering that mining has been going on since 2010, this implies that on average 130 kg of pure gold has been harvested per year over the past 5 years.

For the cost-benefit analysis, the average gold price over the last 10 years is used to estimate the value of gold mining activities. Given an average gold price of US$1,081 per Oz between 2005 and 2015[12], the average gross revenue results in US$4.9 million per year. Costs of the current annual production amount to US$1.9 million for labour and US$0.8 million for capital and energy (Xtra Gold, 2006). The above implies an average net-revenue (before taxes) of US$2.2 million per year for the gold production in the Atewa Range for the past 5 years (Table 32).

Because the gold industry employs people from local communities, labour costs are considered at the same time a local benefit. For this reason, labour costs are not subtracted from the total benefits for the gold industry when estimating the net total value of gold mining in the cost-benefit analysis described in Chapter 6 (Table 32).

NOTE

12 Source: Kitco (2016), retrieved: http://www.kitco.com/scripts/hist_charts/yearly_graphs.plx

Illegal and unregulated gold mining is a serious problem in Ghana. Lack of enforcement of mining regulation creates the opportunity for illegal and mainly small-scale mining activities. Illegal or unregulated operations do not possess the right permits and are not assessed by the Minerals Commission and the Environmental Protection Agency (EPA). National estimates for Ghana indicate that roughly 35% of the gold production in Ghana is illegal or unregulated (Ghana Chamber of Mines, 2014). If this is representative of the situation in the Atewa Range, the total value of illegally mined gold would amount to US$1.4 million (35% of the value used in the cost-benefit analysis), while the remaining benefits from legal gold production would amount to approximately US$2.7 million (Table 32).

Annual Gold production (Oz)	4,560
Average price/OZ from 2005-2015 (US$)	$1,080
Average industrial revenue per year (US$)	$4,929,000
Annual capital costs for the mining industry (US$)	$790,000
Annual wages in the mining industry (US$)	$1,935,000
Average annual profit of the mining industry (US$)	$2,203,000
Value of gold mining used in the cost-benefit analysis in chapter 6 (wages + Average profit)	$4,138,000
% of gold illegal and unregulated production (i.e. small scale)	35%

Table 32 Estimated economic value of annual gold production in the Atewa Range

Bauxite mining

Although only exploratory mining activities have been conducted in the Atewa Range, the idea of developing a bauxite mining site has been present for a long time. Since the first study by Patterson in the late 1960s (Patterson, 1967) various studies have been conducted to estimate the size of the entire Bauxite reserve, which is mainly located in the Forest Reserve area. Table 33 provides an overview of the different studies and the average of their estimates: 142.4 million tonnes of bauxite. According to results of exploratory drilling, the bauxite has an average grade of 44% Alumina (Al_2O_3).

In order to create a lucrative aluminium industry, however, just mining the bauxite will not be sufficient. Large investments need to be made to construct a refinery to produce alumina from the bauxite ore using the Bayer Process, after which the alumina will be smelted to aluminium using the Hall-Heroult process. According to the Minerals Commission (2006), investments for a production plant that will be able to process 600,000 tonnes of bauxite on an annual basis would amount to around US$433 million. This would result in 132,000 tonnes of aluminium per year. Based on a global average, variable costs for the entire process (mine to the final product aluminium) amount to US$1,275 for a ton of aluminium[13]. As this is an energy intensive process, the biggest costs category is energy.

The selling price of bauxite has been quite constant in the last few years between US$1,500 and US$1,600 per metric tonne[14]. This implies an added value of US$275 per metric tonne of aluminium produced. With a capacity of 600,000 tonnes of bauxite, this would result in an annual net value of US$36.3 million (excluding investment costs). This means that it will take almost 12 years to recoup the initial investment (US$433 million) of an alumina production plant.

SOURCE	MILLION TONNES	LOWER BOUND	HIGHER BOUND
Patterson (1967)	60	n/a	n/a
Michell (1972)	120	120	120
International Bauxite Association (1977)	241	182	300
Kesse (1984)	166	152	180
EPIQ (1997)	125	115	135
Average	**142.4**		

Table 33 Estimate of bauxite reserve in the Atewa Range

ALUMINIUM PRODUCTION (TONNES)	PRICE ALUMINIUM (US$ PER TONNE)	VARIABLE COSTS (US$ PER TONNE)	INVESTMENT REFINERY (US$ PER UNIT)
132,000	$1,550	$1,275	$433 million

Table 34 Variables considered for the estimation of the net value of bauxite mining in the Atewa Range

NOTES

13 Information retrieved April 2016: http://aluminuminsider.com/global-aluminum-smelters-production-costs-on-decline/

14 Information retrieved April 2016: http://www.infomine.com/investment/metal-prices/aluminum/all/

5.3 MID-STREAM AREA: AGRICULTURAL LAND IN THE DENSU BASIN

The midstream area includes part of the lower areas of the Atewa Range and the agricultural lands downstream. In the Densu Basin, which is the main focus of this chapter, the downstream area extends southwards, from the buffer zone towards the Weija Lake.

In terms of land cover, the information from 2010 obtained through CERSGIS shows that approximately 40% of the midstream area in the Densu Basin is dominated by open-canopy forest (Table 35). As it was also described for the upstream area, it is likely that the largest part of this area in fact corresponds to rain-fed cocoa and other type of plantations. In following sections, however, cocoa and other type of plantations are excluded from the analysis because their location and crop features indicate that these plantations do not significantly benefit from surface water coming from the Atewa Range.

As presented in Table 35, lands with dense grass and herbaceous cover represent approximately 26% of the midstream area (Table 35). As this classification does not distinguish the use of the land, it is expected that an important part of the area classified in this category actually corresponds to crop lands. Agriculture in the floodplains and irrigated crops of the midstream area obtain direct benefits from the water originated in the upstream area. Water provision for agriculture has consequently been identified as the main ecosystem service supplied by the Atewa Range to the midstream area.

Despite receiving water from the Atewa Range, the Ayensu and Birim basins are not analysed in detail in this study. These two basins are incorporated in the final steps of calculations, but only to illustrate the full extent of the benefits derived from water originated in the Atewa Range. In following sections, water for agriculture is valued at approximately US$1.2 million per year in the Densu Basin and US$3.1 million per year if benefits in the Ayensu and Birim basins are also included through extrapolation.

	BUILT UP/ BARE LAND	WATER	CLOSED CANOPY FOREST	OPEN CANOPY FOREST	DENSE GRASS/ HERBACEOUS COVER	TOTAL
AREA (HA)	31,300	3,000	39,600	99,400	62,100	235,400
%	13%	1%	17%	42%	26%	100%

Table 35 Land cover types in the agricultural area of the Densu Basin (land cover data obtained through CERSGIS for the year 2010)

5.3.1 Water for agriculture

The estimation of the economic value of the current water supply for agriculture in the midstream area derives from its use, as an intermediate good, in crop production. This value is thus assumed to equal the net income (i.e. gross income minus production costs) of crops produced with surface water in the area, as this represents the maximum amount producers might be willing to pay for water as an input (Ward and Michelsen, 2002).

To estimate the net income associated to surface water in the midstream area, or value of water, we firstly estimated the agricultural produce that depends on surface water and the total value of the agricultural production. These figures, together with the costs of production, are then used to estimate the total value of water in the midstream area in the Densu Basin. To obtain the average value of a cubic meter of water for agriculture, the total value is then divided by the amount of water supplied for each crop. All calculations are performed for the Densu Basin, which is the main focus of the analysis. The total value of water, however, is extrapolated to the Ayensu and Birim basins in the final step of the analysis.

Agricultural produce

To estimate the production of crops in the midstream area, average yields are multiplied by the area of each crop. The analysis was limited to areas with crops that depend on surface water, and hence, exclude rain-fed agriculture and crops irrigated with water from boreholes.

Average yields of cocoa are obtained from FAO (2004) and the yields of other crops are estimated as the regional average between 2001 and 2011 (SRID, 2012).

To obtain the area with crops that depend on surface water from the Atewa Range, we focus only on areas that are irrigated with water from the Weija Lake and on agricultural areas in the floodplains of the Densu River. According to the Integrated Water Resource Management Plan for the Densu Basin (WRC, 2007), a total area of approximately 260 ha is irrigated with water from the Weija Lake. Based on spatial identification of agricultural areas with less than 15 degrees of slope that intersect the Densu River, the area of crops in the floodplains of the Densu Basin is additionally estimated at approximately 2,300 hectares (Table 36).

For cocoa, we use the area from the land use map of 2000 (cersgis.org), which in contrast with more recent land use classifications available for this study, includes specific spatial units classified as cocoa and sub-canopy crops. The areas in the floodplains that are covered by these land use types are therefore directly used in subsequent calculations.

Due to the lack of spatial information about other crops, however, we interpolate available figures from the Eastern Region (SRID, 2012) to estimate the area covered specifically by: maize, rice, cassava, yam, cocoyam and plantain. For further calculations, it is assumed that regional percentages of area covered by each of these crops (i.e. regional area of each crop with respect to total area with these crops in the Easter Region) are representative of their distribution in the midstream area.

Table 36 presents the agricultural produce that depends on surface water and provides an overview of the information used to obtain this estimate, including crop yields, percentage of regional area of crops, crops in the irrigated area and area with crops in the floodplains of the Densu River.

CROPS	YIELD (TONNES/HA/YEAR)	% OF THE AREA WITH CROPS IN THE EASTERN REGION	ESTIMATE OF AREA PER CROP (HA)		PRODUCE (TONNES/YEAR)		TOTAL PRODUCE (TONNES)
			IRRIGATED	FLOOD-PLAIN	IRRIGATED	FLOOD-PLAIN	
Maize	1,7	30%	78	493	136	858	994
Rice	2,2	2%	5	34	12	76	88
Cassava	14,7	35%	91	573	1,331	8,417	9,748
Yam	17,1	7%	19	123	331	2,095	2,426
Cocoyam	7,6	10%	26	162	196	1,240	1,437
Plantain	9,2	16%	41	260	377	2,383	2,759
Cocoa*	0,3	-	-	622	-	187	187
Total	-	-	260	2,267	2,383	15,256	17,638

Table 36 Main crops in the Eastern Region and estimation of agricultural produce from surface water in the midstream area of the Densu Basin

* The areas with cocoa were directly estimated from land use data, but due to their spatial location (upstream in the Atewa Range), these were not considered as part of the lands that are irrigated with water from the Weija Lake.

Value of agricultural produce

The agricultural value is estimated as the product of the agricultural produce (Table 36, above) and the local price of each crop. Prices of cocoa and other crops for the period 1991-2011 in Ghana are obtained from the database of average annual prices available on FAOSTAT (2016), and also from local information provided by the West Akim and East Akim District Agricultural Officers of the Ministry of Food & Agriculture.

Additionally, the net producer income is obtained by subtracting costs of production from the total value of the agricultural produce. Costs of production are found in external sources for maize (NAFCO, 2012), rice (NAFCO, 2012), yam (Osei-Adu *et al.*, 2016; Aido *et al.*, 2012) and cocoa (Yahaya *et al.*, 2015), either as an absolute value or as a percentage of the producer price. Since no information could be obtained for cassava and cocoyam, the costs of production are estimated as a percentage of the producer price, based on the average for other crops in the area.

Table 37 presents the prices used in the analysis, the agricultural value in the irrigated and floodplain areas, the costs of production and the net agricultural income that depends on water from the Densu River.

CROP	PRICE (US$ TONNE)	TOTAL (GROSS) VALUE OF AGRICULTURAL PRODUCE (US$/YEAR)		COSTS OF PRODUCTION (US$/TONNE)	COSTS OF PRODUCTION (US$/TONNE)
		IRRIGATED*	FLOOD-PLAIN*		
Maize	$252	$34,000	$216,000	$152	$99,000
Rice	$467	$6,000	$35,000	$223	$21,000
Cassava	$100	$133,000	$841,000	$60	$391,000
Yam	$300	$99,000	$629,000	$198	$248,000
Cocoyam	$234	$46,000	$290,000	$140	$135,000
Plantain	$263	$99,000	$626,000	$157	$291,000
Cocoa*	$845	$-	$158,000	$553	$54,000
Total	-	**$417,000**	**$2,795,000**		**$1,240,000**

Table 37 Value of annual agricultural produce that depends on water from the Densu River
* The results are rounded to the nearest thousand.

Value of water for agriculture

As previously described, the total value of water for agriculture in the midstream area of the Densu Basin corresponds to the net agricultural income, which are estimated at approximately US$1.2 million per year (Table 37). To calculate the amount of water that supports this value, and hence, the average value of a cubic meter of water, we first estimate the water need of each crop under analysis. The obtained values are then multiplied by the respective area of the crops and added up to obtain the total water requirement in the Densu Basin. Due to lack of data to estimate the contribution of other water sources in the floodplains of the Densu River, we assume that agriculture in the floodplains is completely dependent on surface water.

The annual water need of cocoa is directly obtained from external sources (Radersma and Ridder, 1996; Carr and Lockwoods, 2011); while an approximation to the water needs of other crops is estimated according to FAO irrigation and drainage paper 56 (FAO, 1998) and the training manual no. 3 (FAO, 1986) as:

ETc = Kc ETo

In this formula, ETc (mm/ha/day) is the crop evapotranspiration or water need, Kc is the crop coefficient and ETo is the reference evapotranspiration.

The Kc for different growth stages of each crop and the length of these stages in a year (FAO, 1998) are multiplied in order to obtain annual results. This product is then multiplied by the standard ETo suggested in FAO (1986) for humid areas with mean daily temperatures above 25˚C. Based on these calculations, the total water requirement for crops in floodplains and irrigated areas of the Densu Basin is estimated to reach roughly 22.5 million m^3 per year (Table 38). An average value of US$0.064 per m^3 s thus calculated, by dividing the total value of water by the total water requirement in the basin.

CROP	WATER NEED (MM/HA/YEAR)	ESTIMATE OF WATER REQUIREMENT (M3/YEAR)		AVERAGE VALUE OF WATER (US$/ M³)
		IRRIGATED*	FLOODPLAIN*	
Maize	363	283,000	1,788,000	0.05
Rice	1,073	6,000	361,000	0.05
Cassava	861	780,000	4,930,000	0.07
Yam	424	82,000	520,000	0.41
Cocoyam	954	245,000	1,547,000	0.08
Plantain	2,124	874,000	5,525,000	0.05
Cocoa*	878	-	-	0.01
Total	-	**2,320,000**	**20,132,000**	-

Table 38 Water requirement and estimation of the average value of water for agriculture in the Densu Basin

* The results are rounded to the nearest thousand.

To provide a rough estimate of the value of all the water the Atewa Range provides for agricultural use, including the water supplied to the Ayensu and Birim basins, we extrapolate the estimates for the Densu River according to the length of the three rivers. The length of the river is thus assumed to be a suitable indicator of the area of floodplains and agricultural land depending on surface water in the other basins, given that these share physical conditions with the Densu Basin. This coarse assumption is made with the purpose of illustrating the potential increase in benefits if agriculture in other basins was analysed and to provide additional inputs for the cost-benefit analysis presented in Chapter 6. Since the length of the Ayensu River is equivalent to the Densu River and the Birim River corresponds to approximately half this length, the total value of water for agriculture could potentially be around 2.5 times as large as the value calculated in the Densu Basin, being thus estimated at US$3,100,349 per year.

Besides the assumptions to illustrate the increase in value if other basins were included in the analysis, other important aspects to take into account when interpreting the value of water for agriculture presented in this section include: use of regional data on yields and areas, and national data on crop prices; lack of recent land use and irrigation data; lack of information about illegal water abstractions; and lack of specific data on irrigation sources in the floodplains of the Densu River. Furthermore, it is important to notice that the method used in this section to estimate the average value of water gives an indication of value only for the current situation and does not provide additional insights into the contribution of an incremental unit of water. Such purpose would demand the estimation of the marginal value of water (Ward and Michelsen, 2002), for which available data were inadequate.

5.4 DOWNSTREAM AREA: ACCRA

As previously described, the Densu River is one of the main three river systems that originate in the Atewa Range. In its downstream stage, the Densu River supplies water to the Weija Lake, which serves to provide approximately half of the drinking water of Ghana's capital Accra (GA MCA, 2014). Figure 34 presents the area served by water from the Weija Lake.

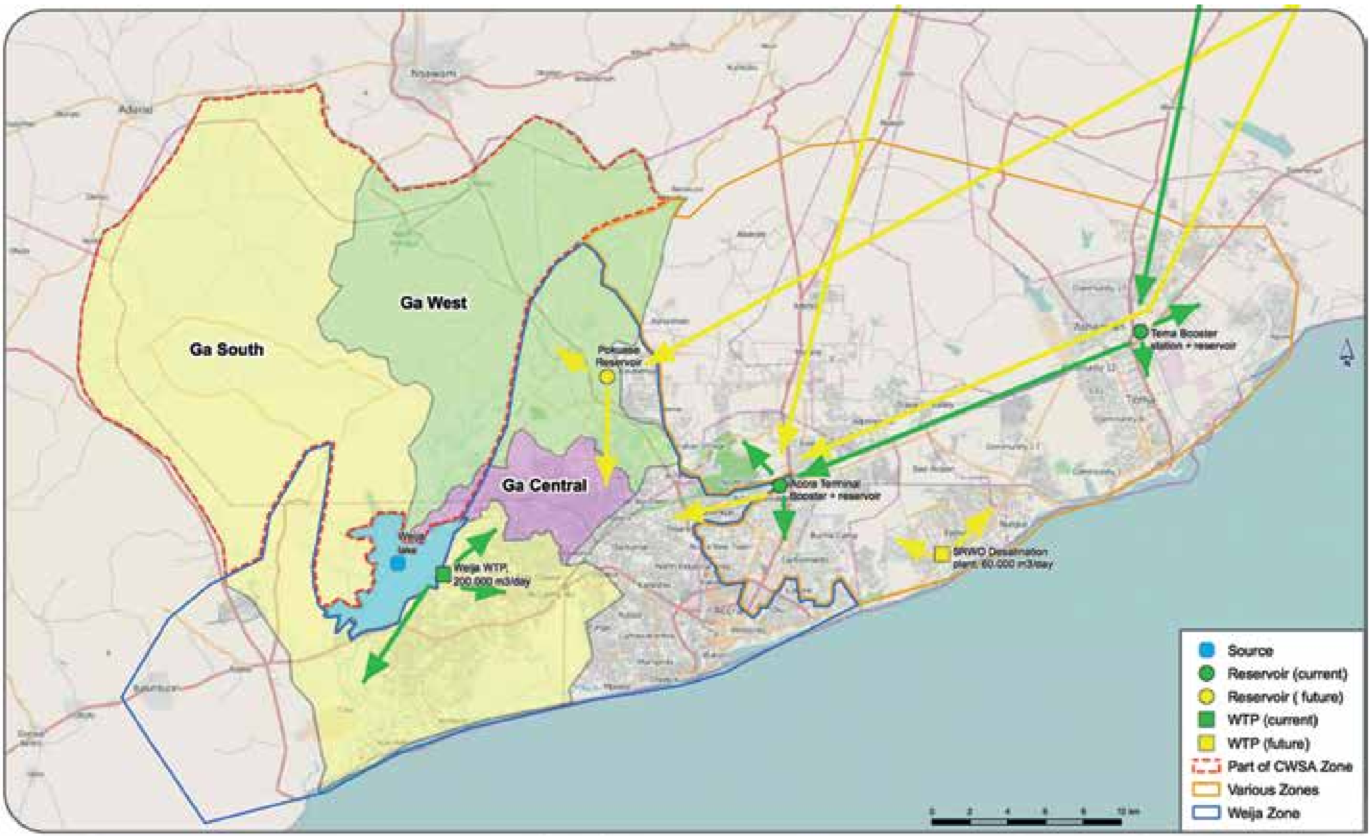

Figure 34 Area served by drinking water from the Weija Lake indicated by blue line (source: GA MCA, 2014)

The estimation of the total value of water for consumption described in subsequent sections focuses mainly on two aspects: supply of drinking water for domestic and industrial use in urban areas; and the willingness to pay for protecting the Atewa Forest and the Densu River as sources of drinking water. The value of the supply of drinking water is estimated through market based valuation techniques based on current use and market prices. The willingness to pay is estimated with the contingent valuation methods on the basis of primary data collected in the period from February to June 2015.

All calculations described in the following sections are performed within the context of the Densu Basin, which is the main focus of this study. For this basin, the benefits from water for consumption amount to US$21.3 million per year. In the final step of the calculations, this estimation is extrapolated to the Ayensu and Birim basins with the purpose of providing an approximation to the full extent of benefits obtained from water transported from the Atewa Range to downstream water users. The total value of water, including this extrapolation, is thus estimated at approximately US$25.1 million per year.

In addition to the water provisioning service for urban areas, this section also examines the existence value (i.e. non-use value) of the Atewa Forest for the citizens of Accra.

5.4.1 Water for consumption

Although drinking water in urban areas in the Densu Basin is delivered from diverse sources, such as independent water providers with own sources, community-managed water supply, and household level systems, this section focuses only on piped schemes that are known to rely on surface water from the Densu River.

The value of water for consumption is calculated as the sum of the producer and consumer surpluses. These values are respectively estimated through market based valuation techniques and a contingent valuation study.

The producer surplus is obtained by subtracting water production costs from expenditures on potable water for domestic and industrial use. Expenditures are estimated from available information about urban water supply, estimates of households served by water schemes and official water tariffs. Production costs, on the other hand, are estimated from production statistics of the Weija Headworks.

In a subsequent step, the consumer surplus was estimated on the basis of a contingent valuation study to elicit the willingness to pay from domestic users to protect the Atewa Forest and the Densu River, as important sources of drinking water. For this study, 417 households were interviewed about water usage, their familiarity with the Atewa Range, and their WTP for a reliable water source (Annex F).

Value of water for domestic and industrial use

As an important part of the value of water, this section describes the estimation of the producer surplus, which represents the expenditure on water for domestic and industrial use minus water production costs.

According to data from the Water Resources Commission (WRC, 2007), approximately 211 million litres of water are daily abstracted in the Densu Basin for urban water supply. Deducting water losses of about 27%, the available amount for urban water supply results in approximately 154 million litres per day (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014). From the available amount of water for urban use, approximately 80% is supplied to domestic users and 20% for industrial purposes (Ga CMA, 2014; GA SMA, 2014; GA WMA, 2014). Based on these figures, it is estimated that the Densu River supplies approximately 123 million litres to domestic users and 30 million for industrial purposes per day (Table 39). It has to be noted that this supply is currently limited by the production capacity of the Ghana Water Company, not by the available water in the Weija reservoir.

DESCRIPTION	ESTIMATE
Water produced for urban supply from the Densu River (i.e. deducting 27% of water losses)	153,898,600 litres per day
Industrial use of water from the Densu River (i.e. approximately 20% of the available water for urban supply)	30,779,720 litres per day
Domestic use of water from the Densu River (i.e. approximately 80% of the available water for urban supply)	123,118,880 litres per day

Table 39 Overview of domestic and industrial use of water from the Densu River

Due to lack of precise information about the number of households served by piped schemes in the Densu Basin, the previous amounts are used as a reference to calculate such figure. As presented in Table 40, the population with water supply in the basin is thus estimated by assuming a unit water demand of 115 litres per capita per day, following the Ghana Netherlands WASH program (Ga CMA, 2014; GA SMA, 2014; GA WMA, 2014). Based on an average household size of 4,01 (Peprah-Asante, 2009), the total number of households served by piped water is thus estimated at 266,969 (Table 40). With the figures of domestic water use and number of households, the average household consumption is calculated as 461 litres per day or 13,835 litres per month (for an average 30-day month).

DESCRIPTION	ESTIMATE
Population served through pipe schemes (Assuming a unit water demand of 115 litres per capita per day)	1,070,599 individuals
Number of households served through piped schemes (Assuming an average household size of 4.01)	266,969 households
Average household water consumption	461 litres per day

Table 40 Overview of the population served with water from the Densu River for domestic use

Available information about approved rates by the Ghana Water Company (GWC) from June 2014 (GA CMA, 2014) is used for obtaining the total expenditure in urban water services, including domestic and industrial users. Calculations for domestic water use are based on rates for a monthly consumption of less than 20,000 litres, which is comparable to the average household consumption. For industrial use, on the other hand, the total expenditure is estimated on the basis of a flat rate (Table 41).

CATEGORY OF SERVICE	APPROVED MONTHLY RATES (US$/1,000 LITRES)
Metered domestic	
0-20,000 litres	$0.36
21,000 litres and above	$0.54
Commercial Industrial (flat rate)	$0.77

Table 41 Tariff structure of the GWC for domestic and industrial users

Based on the previous rates, the yearly expenditure on water from the Densu River represents approximately US$8.7 million for the industrial sector and US$16 million for domestic users in urban areas (Table 42).

	TOTAL EXPENDITURE FOR DOMESTIC USE OF WATER FROM THE DENSU RIVER (US$)*	TOTAL EXPENDITURE FOR INDUSTRIAL USE OF WATER FROM THE DENSU RIVER (US$)*	TOTAL EXPENDITURE IN URBAN WATER SERVICES SUPPLIED BY THE DENSU RIVER (US$)*
PER MONTH	$ 1,340,000	$ 714,000	$ 2,054,000
PER YEAR	$ 16,307,000	$ 8,689,000	$ 24,995,000

Table 42 Expenditures in urban water services for domestic and industrial use
* The results are rounded to the nearest thousand

To estimate the net benefits from water for consumption, water production costs are obtained from the summary of production statistics from the Weija Head Works of the GWC. For the latest year with available data (June 2014 to May 2015), average production costs are estimated at US$0,12 per cubic meter. The total costs are obtained by multiplying such figure by the total abstractions for industrial and domestic use in the Densu Basin (i.e. 210,820 m^3 per day, without deducting water losses). The total costs of production thus results in roughly US$9.2 million per year (Table 43). Consequently, value of water supplied by the Densu River to domestic and industrial users, after deducting production costs is estimated at approximately US$15.8 million per year. As production costs has been subtracted from the total expenditure, this figure represents the producer surplus in the Densu Basin.

	TOTAL EXPENDITURE IN URBAN WATER SERVICES FOR DOMESTIC AND INDUSTRIAL USE (US$)*	TOTAL PRODUCTION COSTS (US$)*	TOTAL ECONOMIC VALUE OF WATER FOR DOMESTIC AND INDUSTRIAL USE (US$)*
PER MONTH	$2,054,000	$754,000	$1,301,000
PER YEAR	$24,995,000	$9,171,000	$15,825,000

Table 43 Economic value of water for urban domestic use in the Densu Basin
* The results are rounded to the nearest thousand

Willingness to pay for the supply of drinking water from the Atewa Forest
The willingness to pay for the protection of the Atewa Forest and the Densu River, and thereby the supply of drinking water to Accra, is investigated through a household survey conducted in the period from February to June 2015. The questionnaire applied to the sample, together with descriptive results, is provided in Annex F.

From a total of 417 respondents, 56% has a pipe connection with the GWC. However, only 36% of the entire sample answers positively when asked if they actually drank the water obtained from the company. An additional 5% of the respondents also gives a positive answer to that question, but stated that it would only drink water from this source if boiled or filtered.

The low percentage of people that uses water piped from the GWC for drinking purposes is confirmed by a vast majority of respondents (i.e. 88% of the sample) that consumes water from other sources, being bottled water the most common alternative drinking source (i.e. for 85% of the respondents).

Among the main water supply problems, approximately 69% of the respondents experienced water quality issues in the last 2 years. The most common problem is dirty water, which affected 59% of the group. Serious problems, such as diseases that could be attributable to water consumed from the tap, affect slightly more than 1% of the interviewees.

Among other issues, water supply is not constant and during the worst months, it has rendered around one fifth of the respondents with no water at all and almost one third with less than 15 days of water provision (Figure 35).

In this context, interviewees were asked about their willingness to pay for protecting the Atewa Forest, the Densu River and thereby the water supply to Accra. Approximately 60% of the sample answered positively to this question and almost 40% responded negatively to it. This second group indicated their incapability to afford it and mistrust of the use of these funds as the main reasons for not willing to pay.

The average willingness to pay of respondents that answered yes to the previous question was US$2.8 on top of the monthly water bill. Table 44 shows the resulting total willingness to pay (or consumer surplus) when these figures are extrapolated to the total number of households that use water from the Densu River for consumption (i.e. 266,969). This figure is estimated at around US$5.5 million per year by assuming that approximately 60% of the total households is willing to pay for the protection of the Atewa Forest for water provision.

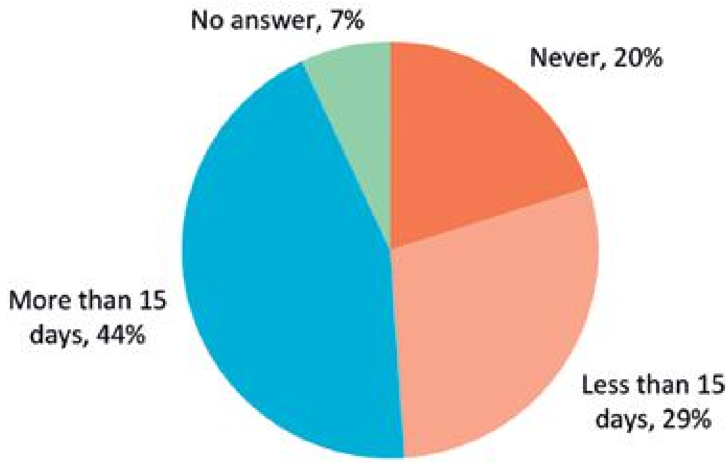

Figure 35 Number of days with water flow from the tap in the month with the worst water supply

The effect of several variables on the willingness to pay was tested, but significant differences in the average values are only found among different income groups. Logistical regression tests, including a pre-selected set of variables that could potentially influence the willingness to pay, do not show a high explanatory capacity. This means that based on the available data the selected variables are insufficient to predict which types of respondents are more likely to be willing to pay for the protection of the Atewa Forest and the Densu River. The variables tested include neighbourhood, gender, educational level, days of water supply in a month, and income.

	WTP PER HOUSEHOLD (US$)*	TOTAL WTP BY ALL HOUSEHOLDS SERVED WITH WATER FROM THE DENSU RIVER (US$)*
PER MONTH	$ 2.8	$ 456,000
PER YEAR	$ 33.7	$ 5,469,000

Table 44 Willingness to pay on top of the water bill for the protection of the Atewa Forest and the Densu River
* The results are rounded to the nearest thousand

Economic value of water for consumption
The total economic value of the current supply of water from the Densu River for human consumption includes the economic value for domestic and industrial use, and the consumer surplus expressed in the willingness to pay an additional amount on top of the household water bill. Based on the previous results, the total economic value of surface water from the Densu River for water consumption is estimated at approximately US$21.3 million per year (Table 45).

Although this study mainly focuses on the Densu Basin, the benefits arising from the consumption of water transported from the Atewa Range to downstream users extend beyond the basin's boundaries, thus including also the Ayensu and Birim basins. Since studying these two basins in detail exceeds the scope of the study, we only provide a rough estimate of the additional benefits delivered to these areas. This value is presented to illustrate the total benefits from water and also serves as an input to the cost-benefit analysis described in Chapter 6.

To obtain the additional benefits to the Ayensu and Birim basins, we extrapolate the total economic value on the basis of urban population figures from official census data (Ghana Statistical Office, 2010): the urban population in the Ayensu and Birim basins roughly represents 13% and 5% of the urban population in the Densu Basin, respectively. By adding this percentage of benefits to the estimates for the Densu Basin, the total economic value of water for consumption in the three basins resulted in US$2.1 million per month and US$25.1 million per year.

	TOTAL ECONOMIC VALUE OF WATER FOR DOMESTIC AND INDUSTRIAL USE (US$)*	TOTAL WTP BY ALL HOUSEHOLDS SERVED WITH WATER FROM THE DENSU RIVER (US$)*	TOTAL ECONOMIC VALUE OF WATER FOR CONSUMPTION IN THE DENSU RIVER (US$)*
PER MONTH	$ 1,301,000	$ 456,000	$ 1,756,000
PER YEAR	$ 15,825,000	$ 5,469,000	$ 21,294,000

Table 45 Estimation of the total economic value of the current water supply for human consumption
* The results are rounded to the nearest thousand

5.4.2 Non-use or existence value of the Atewa Range

Biodiversity is generally valued by an international audience (MEA, 2005). Various Ghanaian and international organizations spend resources to protect the existence of unique Atewa Forest ecosystem in line with the Convention on Biological Diversity (CBD). Furthermore, this ecosystem provides habitat to many endangered species that are listed on the IUCN red list or are otherwise recognized for its uniqueness (for more information see Chapter 2). International sponsors supply funding to protect this ecosystem because of their motivation to conserve biodiversity. However, it remains impossible to estimate this value in monetary terms, since the total amount spent in the conservation of the Forest Reserve is unknown.

Another component of the existence value is the value assigned to the Atewa Range by Ghanaians. Although many people in Ghana are not likely to visit the Forest Reserve, they might still value the existence of this area. Therefore, part of the willingness to pay of the population of Accra for the conservation of the Atewa Forest may be theoretically attributed to this existence value. The results of the survey in Accra, however, suggest that the existence value might represent only a small part of the total willingness to pay. This survey showed that 73% of the 417 respondents in Accra were not familiar with the Atewa Range and the willingness to pay for conservation of the Atewa Range was not significantly higher for people that were in fact familiar with the forest.

Giving an indication of the absolute importance of the non-use or existence value of the Atewa Range results impossible with the available information. However, Chapter 6 provides an indication of potential changes in this value in qualitative terms, based on the conditions defined in different land use scenarios. In such chapter, this value is examined together with all other ecosystem goods and services that has been previously described.

5.5 OVERVIEW OF THE ECONOMIC VALUE OF ECOSYSTEM SERVICES FROM THE ATEWA RANGE

As a summary of the estimates resulting from this chapter, Table 46 presents the ecosystem services from the Atewa Range for which a monetary value was calculated. These results encompass the economic value of the current supply of five ecosystem services, potential benefits from tourism, and benefits from gold and (potentially from) bauxite mining.

The total area of supply in Table 46 correspond to the relevant geographic areas described in the beginning of this chapter (Table 24). The upstream area (Forest Reserve and buffer zone) represents the total supply area of: non-timber products, timber products, gold, bauxite (potential) and tourism (potential) benefits.

The midstream and downstream areas, on the other hand, receive benefits from water for agriculture and water for consumption. The area of supply of water for agriculture includes the irrigated lands and floodplain areas that extend from the buffer zone to the mid- and downstream stages of the Densu, Ayensu and Birim basins. The supply of water for consumption includes urban residents and industrial users that are situated in the mid- and down-stream areas of the Densu, Ayensu and Birim basins.

Besides the total economic value, Table 46 also presents the economic value per hectare for ecosystem services supplied in the upstream area (i.e. Forest Reserve and buffer zone), where the link between area and the provision of the service is directly observable.

ECOSYSTEM SERVICES AND OTHER BENEFITS FROM THE ATEWA RANGE	ECONOMIC VALUE	
	IN THE TOTAL AREA OF SUPPLY (US$/YEAR)	IN ONE HECTARE (US$/HA/YEAR)
Provisioning services		
Non-timber products	$ 12,390,228	$ 284
Timber products (legally permitted activities in the buffer zone)	$ 10,150,000	$ 1,392
Timber products (illegal timber logging in the Forest Reserve)	$ 30,481,000	$ 1,392
Cocoa (farming)	$ 9,336,000	$ 253
Water for agriculture*	$ 3,100,000	n/a
Water for consumption*	$ 25,100,000	n/a
Cultural services		
Tourism (potential revenues and expenditures)	$ 5,844,000	n/a
Other goods and services		
Mineral resources		
Gold (legally permitted)	$ 2,700,000	n/a
Gold (illegal and unregulated)	$ 1,400,000	n/a
Bauxite (potential net value, excluding investment costs)	$ 36,300,000	n/a

Table 46 Overview of the economic value of the current supply of ecosystem services and other benefits from the Atewa Range

* The economic value of water for agriculture and consumption includes actual estimates for the Densu Basin and extrapolated values for the Ayensu and Birim basins

From the analysed services, timber products represent the highest economic value per year, with approximately US$40.6 million, respectively. This value reflects the dependence of local communities on timber for both consumption and sales. It is important to notice, however, that an important part of the timber benefits is illegally, and potentially unsustainably, obtained from the Forest Reserve. For the purpose of this analysis, it is estimated that all the economic benefits obtained from timber harvested in the Forest Reserve correspond to illegal and unregulated activities, which provide approximately US$30 million per year (75% of the total economic benefits from timber).

Also in the upstream area, cocoa farming in the buffer zone provides additional benefits to local communities that amount to around US$9.3 million per year. Part of the cocoa production might also come from illegal activities (McCullough *et al.*, 2007), but the available information does not allow to estimate the percentage of these benefits that can be linked to these activities.

The valuation of water for consumption shows that the industrial sector and domestic households in the Densu, Ayensu and Birim basins might obtain combined economic benefits of approximately US$25 million per year. Furthermore, water for agriculture provides benefits that account for approximately US$3.1 million per year in the irrigated lands and floodplains of these basins.

In addition to the current supply of the ecosystem services described above, the potential for tourism of the Forest Reserve is estimated at approximately US$5,844,000 from 100,000 visitors.

The combination of profits and wages earned in the gold mining industry sum up to US$4.1 million per year. According to estimates from the Ghana Chamber of Mines (2014), around 35% of the gold production in the country comes from illegal or unregulated small-scale mining activities. If this is representative of the situation in the Atewa Range, the total value of gold illegally mined would amount to US$1.4 million. Although bauxite mining has not been developed, the potential annual value of a bauxite mining industry is estimated at US$36.3 million per year (excluding investments in the alumina refinery).

It is important to notice that the results presented in this chapter must be interpreted only as a part of the total monetary value of the Atewa Range. Previous sections of this chapter describe the spiritual value and existence value of the Atewa Range only in qualitative terms. An approximation to the carbon sequestration value is only given in terms of carbon stock. Other services, such as flood regulation, were previously described in Chapter 4, but not included in this chapter due to lack of data to perform additional quantitative or monetary estimations. To avoid significant information gaps in the results of the cost-benefit analysis, all these benefits are further dealt with in Chapter 6.

6 COST-BENEFIT ANALYSIS OF LAND USE CHANGE SCENARIOS IN THE ATEWA RANGE

The main goal of this chapter is to provide insights into the strengths and weaknesses of alternative development paths in the Atewa Range (i.e. Forest Reserve and buffer zone) from an economic perspective. The analysis presented in this chapter consequently focuses on changes in the value of ecosystem services provided by the Atewa Range under four land use scenarios, which were previously defined in Chapter 3 of this study.

Effects of changes in the supply of ecosystem services in the different scenarios are expressed as monetary and non-monetary costs and benefits. The starting point to analyse such changes is the value of the current supply of ecosystem services estimated in Chapter 5. Changes in monetary values are firstly investigated here through a cost-benefit analysis (CBA) for a period of 30 years. This is an additional 10 years compared to the timeframe of the hydrological model. This time frame was chosen to emphasize the long term effects of land conversion. Based on the results of this CBA and further analysis of non-monetary values, this chapter also examines the allocation of costs and benefits to different stakeholders.

6.1 METHODOLOGY

This section describes the methodological steps to analyse the costs and benefits of the land use scenarios of the study over a 30-year period, starting in 2016. This is done by firstly defining the specific changes in ecosystem services that are likely to occur under each scenario including the specific assumptions that are necessary for subsequent calculations. Next, we describe the main procedure to estimate the annual value and the net present value (NPV) of the different scenarios in monetary terms. Finally, the steps to allocate these monetary values and other non-monetary costs and benefits to different stakeholders are also described.

6.1.1 Changes in costs and benefits in different land use scenarios

As described in Chapter 3, for this study we have specified four land use scenarios, namely: business as usual (Scenario 1), National Park (Scenario 2), National Park and supporting buffer zone (Scenario

3) and complete degradation (Scenario 4). Changes in land cover that are expected to occur in each scenario have been previously detailed in Chapter 3. Similarly, Chapter 4 has provided insights into the outcomes of these scenarios in terms of water quantity, sedimentation and water quality.

For the CBA and stakeholder analysis, the link between these outcomes and the provision of ecosystem services was carefully analysed in order to estimate the effect of the land use scenarios on the economic benefits that different stakeholders derive from the Atewa Range.

Land cover changes directly affect the estimated monetary value of the following ecosystem services: non-timber products, timber products, cocoa production and carbon sequestration. These changes also affect the value of ecosystem services, such as flood and drought control, for which available data did not allow to estimate their monetary value. Non-monetary benefits, such as the spiritual value and existence value, are also likely to be affected by land cover changes in different scenarios.

Changes in the land use are furthermore expected to have effects on the water quantity, sedimentation and water quality downstream. These effects on the hydrological regime of the basin, are at the same time likely to affect provisioning ecosystem services, such as water for agriculture and water for consumption.

Besides the differences in land-cover and water-regime, there are several parameters that can drive changes in benefits and costs in each scenario. For instance, benefits arising from tourism will depend on the creation of a National Park and mining profits might change according to legal restrictions and enforcement.

The scenarios proposed in Chapter 3 illustrate a future end-point irrespective of any specific time frame. Therefore, several assumptions were necessary to represent quantitative changes in value and thus enable the comparison of the scenarios over a time frame of 30 years.

The following paragraphs and tables explain the approach adopted in the CBA to quantify the changes in the monetary benefits and costs that are linked to changes in land-cover, water-regime and other parameters of each scenario. Non-monetary values are not further addressed in this section, since these are analysed according to the steps described in the final section of the methodology (stakeholder analysis).

Scenario 1 – Business as usual
As a future perspective based on continued developments in the Forest Reserve and the buffer zone, this scenario considers the following changes: decrease in the forest area in the Atewa Range; forest degradation; conversion from closed- to open-canopy forest; increase in the mining area; slight increase in water availability in the Weija Lake; sediment pollution and increase in water pollution. In addition to these changes, this scenario considers a population growth rate of 3.1% based on the estimates of the Ghana Netherlands WASH programme (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014).

Based on these changes, Table 47 describes how the different ecosystem services of the Atewa Range and the additional park management costs develop in the business as usual scenario. The assumptions described in the table served as the basis to estimate the monetary costs and benefits in the CBA, which is separately described in the next section of the methodology.

ECOSYSTEM SERVICES AND ADDITIONAL COSTS	EXPECTED DEVELOPMENT IN THE BUSINESS AS USUAL SCENARIO
Non-timber products	Expected development in the business as usual scenario Non-timber products are harvested in suitable land cover types (i.e. closed- and open-canopy forest, cocoa plantations and herbaceous cover).
Timber products	Timber products are obtained from suitable land cover types (i.e. closed- and open-canopy forest). Timber yields decrease due to unsustainable use and degradation of the forest (see further information in Box 3). Yields have linearly decreased by 75% in the first two decades. This linear and decreasing trend continues in the subsequent years of the analysis
Cocoa production and sub canopy farming	Rain-fed cocoa plantations and sub canopy crops in the buffer zone are normally harvested.
Water for agriculture	50% crop failure in the floodplain due to sediment pollution (i.e. 10-14% of the sediment is polluted).
Water for consumption	Population growth of 3.1% per year. Urban consumption and industrial use increase accordingly. Additional water treatment costs for mercury are considered.
Carbon sequestration	The rate of change in carbon stock is given by the change in land cover defined for the first 20 years. Based on the results from the economic valuation, the annual value for carbon sequestration is calculated as follows: Carbon sequestration = $\Delta CS_n = CS_{n+1} - CS_n$ Where CS_n represents the total Carbon Stock (CS) of the Atewa Range in year n of the analysis.[15]
Tourism (potential)	No tourism.
Bauxite alumina	No Bauxite extraction.
Gold	24% of the gold reserve is depleted, at a constant rate, in 20 years. Most of this gold is extracted from the buffer zone. In the Forest Reserve, 1% of the area is used for illegal and unregulated mining.
Park management costs	No additional management costs.

Table 47 Development of the supply of ecosystem services and the additional management costs in the business as usual scenario

NOTE

15 Please note that if the total carbon stock decreases over the course of a year (i.e. $CS_{n+1} < CS_n$), the annual value for carbon sequestration will be negative ($\Delta CS_n < 0$)

As the land cover classification available for this study (CERSGIS, 1990, 2000, 2010) is based on broad definitions of closed and open canopy forests, it does not provide sufficiently detailed information to estimate forest degradation in the analysis timeframe.

To account for degradation processes, this analysis is consequently based on the assumption of decreasing timber yields in areas with continued unregulated extraction. The importance of incorporating this aspect into the analysis is given by the rationale described in Box 3.

Box 3 Supporting information on decreasing timber yields in forest areas

BOX 3 The following aspects are considered to support the assumption on decreasing timber yields in areas with continued timber extraction over time:

1. Forest degradation on the edges of the Forest Reserve forces loggers to venture deep into the forest. Given the mountainous landscape and steep slopes on the edges of the reserve, this implies much higher logging costs and consequently decreasing benefits for loggers. As a result, monetary benefits from logging practices might decrease over time (Van Beukering *et al.* 2003).

2. In the land-cover data available for this study (CERSGIS, 1990, 2000, 2010), the closed canopy forest is defined as forest with a canopy cover between 60% and 100%. This definition may include both undisturbed and disturbed forest types. Although it is likely that areas that suffered from illegal selective logging practices have lost economically interesting timber species, these may still be classified as closed-canopy forest areas. This implies that the average quality of closed-canopy forest areas may decrease over time without being classified in a different land-cover category. Therefore, the assumption of decreasing timber yields accounts for degradation processes that are not reflected in land-cover changes from closed canopy forest to other categories.

3. Previous studies have emphasized that the forest definitions underlying the data available for this study may lead to the erroneous classification of areas with more than 10% tree cover as open-canopy forest (Indufor Oy, 2013). The open canopy category includes forests with a canopy cover between 10% and 60% and represents a broad range of forest types that may differ in terms of density and species composition. Timber yields are thus likely to vary within areas classified as open-canopy forest. Therefore, the assumption of decreasing timber yields also reflects degradation processes in open-canopy forests that are not accounted for in the available land-cover data.

ECOSYSTEM SERVICES AND ADDITIONAL COSTS	EXPECTED DEVELOPMENT IN SCENARIO 2 (NATIONAL PARK)
Non-timber products	Restrictions apply to the NP area (former Forest Reserve) as of year 4: the use of non-timber products is prohibited. In the buffer zone, non-timber products are harvested in suitable land cover types (i.e. closed- and open-canopy forest, cocoa plantations and herbaceous cover).
Timber products	Restrictions apply to the NP area (former Forest Reserve) as of year 4: the use of timber products is prohibited. In the buffer zone, timber products are obtained from suitable land cover types (i.e. closed- and open-canopy forest) In the buffer zone, timber yields decrease due to unsustainable use and degradation of the forest (Box 3, above). Yields have linearly decreased by 75% in the first two decades. This linear and decreasing trend continues in the subsequent years of the analysis..
Cocoa production and sub canopy farming	Rain-fed cocoa plantations and sub canopy crops in the buffer zone are normally harvested.
Water for agriculture	50% crop failure in the floodplain area due to sediment pollution (i.e. above 10-20% of the sediment is polluted).
Water for consumption	Population growth of 3.1% per year. Urban consumption and industrial use increase accordingly. Additional water treatment costs for mercury are considered.
Carbon sequestration	The rate of change in carbon stock is given by the change in land cover defined for the first 20 years. Based on the results from the economic valuation, the annual carbon sequestration is calculated as follows: Carbon sequestration = $\Delta CS_n = CS_{n+1} - CS_n$ Where CS_n represents the total Carbon Stock (CS) of the Atewa Range in year n of the analysis.[12]
Tourism (potential)	50,000 people visit the national park every year (national and international visitors)
Bauxite alumina	No additional expenditures in tourism products and services occur in the buffer zone. It takes five years to reach the full tourism potential. No Bauxite extraction.
Gold	Gold extraction in the Forest Reserve occurs only in the first three years of analysis, prior to the effective implementation of the National Park. Gold extraction in the buffer zone occurs during the entire timeframe. 24% of the gold reserve is depleted, at a constant rate, in 20 years.
Park management costs	Additional costs only in the NP. Average management costs per hectare were estimated at US$3.6 per year based on Kwabena (2015). No change in current management costs for the Forestry Services Division, but additional costs are incurred by the Wildlife Division.

Table 48 Development of the supply of ecosystem services and the additional management costs in Scenario 2 (National Park)

Scenario 2 – National Park

Scenario 2 assumes that the Forest Reserve becomes a National Park (NP). This entails increased efforts to preserve and partially restore degraded areas, as well as additional enforcement efforts to stop illegal and unregulated mining activities within the boundaries of the NP. For the CBA, it was assumed that the National Park is effectively implemented in year 4 of the analysis. In the buffer zone, land cover follows the same trend as described for the business as usual scenario. The area of the National Park (former Forest Reserve), however, has an increase in forest cover in general and most of it becomes closed-canopy forest. In terms of water availability, this scenario is similar to the business as usual scenario, but it entails a slight increase in water quality if compared with the business as usual situation.

The population growth rate in this scenario is also estimated at 3.1% (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014).

Based on the main characteristics of the National Park scenario, Table 48 describes how the different ecosystem services of the Atewa Range and the additional park management costs in this scenario would develop in the future. The next section of the methodology describes how the assumptions of this and the other scenarios are used to estimate the monetary costs and benefits in the CBA.

Scenario 3 – National Park and supporting buffer zone

This scenario entails the same changes in the Forest Reserve area as the previous scenario, as it also becomes a NP. Scenario 3, however, includes additional efforts to promote compatible land use and support restoration of degraded areas in the buffer zone. The restoration of the buffer zone results in an increase in the area covered by forests and a higher percentage of closed-canopy forest. These changes determine an increase in the water availability in the Weija Lake, improvements in water quality and no sediment pollution.

ECOSYSTEM SERVICES AND ADDITIONAL COSTS	EXPECTED DEVELOPMENT IN SCENARIO 3 (NATIONAL PARK AND SUPPORTING BUFFER ZONE)
Non-timber products	Restrictions apply to the National Park (NP) area (former area of the Forest Reserve) as of year 4: the use of non-timber products is prohibited. In the buffer zone, the use of non-timber products is still allowed
Timber products	Timber extraction is prohibited in the NP (former Forest Reserve) area as of year 4. During the first three years, timber yields in the buffer zone decrease at the same rates as in scenarios 1 and 2 (Box 3, above). As of year 4, timber products are sustainably harvested only from open-canopy forests in the buffer zone. Timber yields in the buffer zone remain constant during the rest of the timeframe due to the effective implementation of sustainable forest management in all the areas where the extraction is permitted
Cocoa production and sub canopy farming	Rain-fed cocoa plantations in the buffer zone are normally harvested. Restoration activities include agroforestry: sub canopy cropping. Therefore, the area of cocoa plantations increases in the same proportion as the forest does in the buffer zone. Sustainable practices are assumed to minimize impacts on soil and water.
Water for agriculture	Agricultural production derived from water from the Densu, Ayensu and Birim rivers remains constant. No crop failure.
Water for consumption	Population growth of 3.1% per year. Urban consumption and industrial use increase accordingly.
Carbon sequestration	The rate of change in carbon stock is given by the change in land cover defined for the first 20 years. Based on the results from the economic valuation, the annual carbon sequestration is calculated as follows: Carbon sequestration = $\Delta CS_n = CS_{n+1} - CS_n$ Where CS_n represents the total Carbon Stock (CS) of the Atewa Range in year n of the analysis.[15]
Tourism (potential)	100,000 people visit the NP, of which 70% are domestic and 30% international visitors. An average daily expenditure of US$144 per visitor is estimated for international adults and half of this amount is assumed for international children. It takes five years to achieve the full tourism potential.
Bauxite alumina	No Bauxite extraction.
Gold	Gold extraction occurs in the first three years, prior to the effective implementation of the National Park and further conservation measures in the supporting buffer zone.
Park management costs	Average management costs per hectare in the NP were estimated at US$3.6 per year based on Kwabena (2015). Besides the costs of managing the NP, additional costs per hectare in the buffer zone (US$1.8 per hectare per year) were assumed to be half of those in the NP. No change in current management costs for the Forestry Services Division, but new costs are added to the Wildlife Division.

Table 49 Development of the supply of ecosystem services and the additional manage-ment costs in Scenario 3 (National Park and supporting buffer zone)

ECOSYSTEM SERVICES AND ADDITIONAL COSTS	EXPECTED DEVELOPMENT IN SCENARIO 4 (COMPLETE DEGRADATION)
Non-timber products	Non-timber products are harvested in suitable land cover types (i.e. closed- and open-canopy forest, cocoa plantations and herbaceous cover).
Timber products	Timber products are obtained from suitable land cover types (i.e. closed- and open-canopy forest). In year 20, all forest has been lost and cocoa plantations have been replaced by mining activities or have become herbaceous areas.
Cocoa production and sub canopy farming	Rain-fed cocoa plantations and sub canopy crops in the buffer zone are harvested until year 20, when the entire area has been degraded or replaced. Degradation and conversion into mining areas occur at a constant rate between years 1 and 20.
Water for agriculture	100% crop failure in the floodplain due to sediment pollution (i.e. above 50% of the sediment is polluted)
Water for consumption	Population growth of 3.1% per year. Urban consumption and industrial use increase accordingly. Additional water treatment costs for mercury are considered.
Carbon sequestration	The rate of change in carbon stock is given by the change in land cover defined for the first 20 years. Based on the results from the economic valuation, the annual carbon sequestration is calculated as follows: Carbon sequestration = $\Delta CS_n = CS_{n+1} - CS_n$ Where CS_n represents the total Carbon Stock (CS) of the Atewa Range in year n of the analysis.[15]
Tourism (potential)	No tourism.
Bauxite alumina	Bauxite production occurs with an extraction rate based on the capacity of the proposed alumina smelter.
Gold	All investment costs are evenly distributed between the second and fourth year of analysis (2017-2019). All the gold reserve is depleted in 20 years. The extraction rate is constant.
Park management costs	No additional management costs.

Table 50 Development of the supply of ecosystem services and additional management costs in Scenario 4 (complete degradation)

As in previous scenarios, the population growth rate is assumed at 3.1% (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014).

Based on the additional conservation efforts incorporated into this scenario, Table 49 explains the future development of different ecosystem services of the Atewa Range and the additional park management costs, given that the NP and the supporting buffer zone are successfully established.

Scenario 4 – Complete degradation

As an extreme case, the complete degradation scenario assumes the complete deforestation and degradation of the Atewa Range. This is due mainly to logging and mining. In this scenario, 50% of the Atewa Range is transformed to herbaceous areas. The remaining area is almost completely occupied by mining activities. This scenario entails an increase in water discharge, but also a significant increase in the spilling at the Weija Dam. Together with a significant increase in siltation, this determines a reduction in the available water in the Weija Lake. Water quality is also negatively affected to a significant extent.

The population in this scenario is also assumed to grow at 3.1% rate (GA CMA, 2014; GA SMA, 2014; GA WMA, 2014).

Table 50 describes the main effects of this scenario on the different ecosystem services in the Atewa Range. These considerations were used as an input for the CBA, as described in the subsequent section of the methodology.

6.1.2 Cost-benefit analysis

The estimation of monetary costs and benefits arising from management interventions, water regime and land-cover change in different scenarios is primarily based on the economic value of ecosystem services presented in Chapter 5. Building upon the current values estimated in that chapter, this analysis focuses on future yearly changes. Furthermore, we estimate additional management costs and benefits arising from the different development paths adopted in each scenario. This CBA thus provides general trends in the monetary value and the total net present value (NPV) of the different land use scenarios.

In this study, the NPV consists of the accumulated net benefits over a pre-defined time frame of 30 years. In general, the results of the economic valuation of current supply of ecosystem services (Chapter 5) were used as the starting point for estimating costs and benefits in the first year of the analysis. The end point was derived from the changes in land cover predicted for each scenario (Chapter 3).

For the CBA, we assumed that the outcomes of each scenario, such as land cover and water discharge, will be observed after 20 years (similar to the timeframe in the hydrological assessment). The last decade of the analysis (from year 21 to 30) thus corresponds to a linear extrapolation of the previous trends.

For benefits that are directly linked to land cover, such as timber and non-timber products, the change from the current situation to the end point of each scenario was assumed to occur at a constant annual rate. These rates of change in land cover served to estimate annual benefits during the entire time frame. Changes in the water regime, water quality and other parameters were additionally considered to adjust the estimates according to the expected development path of each scenario (see from Table 47 to Table 50 in the previous section of the methodology). For benefits and costs that are not directly linked to land cover areas, such as tourism potential and water for consumption, the estimation of annual change was based on the specific parameters and assumptions described in the previous section of the methodology (from Table 47 to Table 50).

For calculation purposes, all investments associated to bauxite mining in Scenario 4 (complete degradation) were evenly distributed between the second and the fourth year of analysis (2017-2019). In Scenario 2 (National Park) and Scenario 3 (National Park and supporting buffer zone), the implementation of the National Park was assumed to start in the first year of the analysis, but it its effective implementation was assumed to be complete in year four. Management costs are therefore accounted for from the first year. All gains and losses in other ecosystem services due to management and restrictions arising from this new status are included as of the fourth year of analysis..

Annual values for each ecosystem service over the period of 30 years were estimated on the basis of the starting value (current supply), land cover change, change in water regime and quality, specific assumptions for each scenario and extrapolated trends described in previous paragraphs.

A discount rate is used to reflect time preferences and therefore implies that a higher weight is assigned to the costs incurred and the benefits obtained in the present rather than those in the long term. The sum of annual discounted values was calculated over the 30-year period to obtain the total NPV, which is the main indicator

of monetary value for each scenario. The steps to calculate the total NPV are synthetized in the following formula:

$$Total\ NPV = \sum_{i=0}^{n} \frac{B_i - C_i}{(1 - r)^i}$$

In the formula, *Bi* corresponds to the benefits in year *i*, *Ci* represents the costs in year *i*, *r* is the discount rate and *i* is the year of analysis, assuming that the present year corresponds to 0. For this study, the costs and benefits were discounted at a rate of 5% (r=0.05).

Besides the total NPV, this chapter also presents the trends in annual value for the different scenarios as an additional indicator to support the analysis.

To analyse the effects that changes in specific parameters would have on the overall results, we conducted a sensitivity analysis of different discount rates, and different yields in timber and non-timber products. The selection of these parameters was, respectively, based on the arbitrary character of choosing a discount rate and the impossibility to reflect the effect of ecosystem degradation and biodiversity differences on the value of timber and non-timber products, given the existing data constraints.

6.1.3 Stakeholder analysis

The stakeholder analysis presented in this chapter aims to provide insights into the allocation of costs and benefits to different stakeholders in the various scenarios described in the study. The selection of the relevant stakeholders for this analysis was based on the inception workshop and subsequent meetings with A Rocha Ghana, the IUCN NL and local experts and stakeholders. Based on the information gathered in the meetings, the stakeholders chosen for the analysis were: local communities, licensed mining companies (bauxite and gold mining), downstream urban residents, farmers, the international community and the Forestry Commission of Ghana as governmental institution.

The monetary analysis was limited to the year 30 (2045) of the analysis. This year was chosen to provide insight into the end-point situation of the scenarios. In the context of the stakeholder analysis, we used the annual value, as this estimate conveys a meaningful insight in the future wellbeing of a broader range of stakeholders compared to the NPV, which is relevant mainly for companies and the government.

The monetary value previously estimated for year 30 was allocated among the different stakeholders according to the percentages presented in Annex I. In general, the assignation of percentages was rather straightforward, since in most cases a specific type of cost or benefit was entirely attributed to an individual category of stakeholder. Only in the case of mining, the present value was distributed among two stakeholders: mining companies and local communities. In this case, the allocation of a percentage of costs and benefits from gold mining followed the Ghana Chamber of Mines (2014), which determined that 35% of the gold mining corresponds to (illegal or unregulated) small scale mining (i.e. Galamsey).

Values that were not monetarily estimated in Chapter 5, were included in the analysis in a qualitative way, through a three level scale to describe the effect (neutral, positive and negative) of the differences of the scenarios on such values. For flood control and drought mitigation, lack of data did not allow to estimate a monetary value. The results presented in Chapter 4, however, provided sufficient information to classify the expected effects on the value of these services in the three-level scale for the relevant stakeholders (i.e. negative effects, no effects and positive effects).

Non-monetary benefits, such as spiritual and existence values, derived from cultural ecosystem services, were classified according to the same scale. In this case, the qualitative descriptions provided in Chapter 5 were used as the main input to determine the effect of the different scenarios on these ecosystem services.

6.2 RESULTS

6.2.1 Overview of costs and benefits in the different land use scenarios

The results presented in this and the remaining sections of this chapter describe the main costs and benefits of the four different land use scenarios described for the Atewa Range. Monetary costs and benefits are synthetized in two estimates of value, namely: net present value (NPV) and annual value in the last year of the analysis. The expected implications for costs and benefits that are not estimated in monetary terms, are qualitatively described as positive, negative or neutral effects on value. Table 51 summarizes the results of this analysis.

In the table, the total NPV and the total annual value are firstly presented as the sum of all monetary costs and benefits, including those arising from legally permitted activities and also illegal or unregulated activities such as timber logging and informal small-scale mining. Besides these estimates, Table 51 also compares the percentage of the total value that can be associated to illegal or unregulated activities in the Atewa Range. Further details on the value arising from activities that are not allowed in the Atewa Range are presented in subsequent sections of this chapter.

On the basis of the results presented in Table 51 and Figure 36, the following paragraphs describe the ranking of each scenario and compare the benefits between legally permitted and illegal or unregulated activities in the Atewa Range.

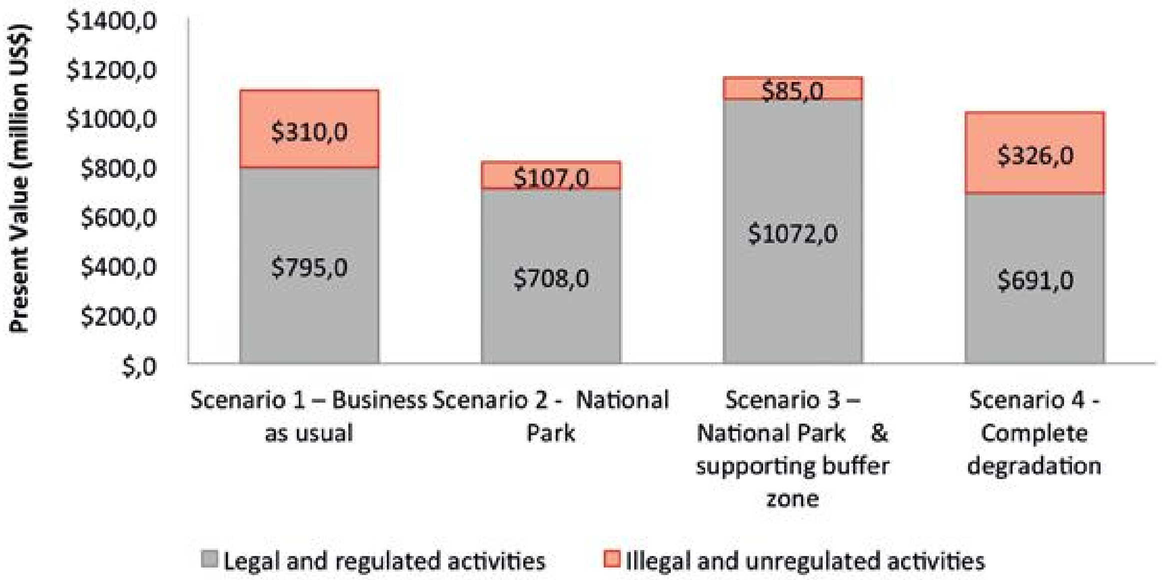

Figure 36 Net present value of different scenarios, including legally permitted and illegal and unregulated activities (millions US$, 30-year period and discount rate of 5%)

	SCENARIO 1 BUSINESS AS USUAL	SCENARIO 2 NATIONAL PARK	SCENARIO 3 NATIONAL PARK AND SUPPORTING BUFFER ZONE	SCENARIO 4 COMPLETE DEGRADATION
Total NPV (including legally permitted, illegal and unregulated activities)	$ 1,105	$ 815	$1,157	$ 1,017
% of NPV associated to illegal and unregulated activities	28%	13%	7%	32%
Annual value in year 30 (including legally permitted, unregulated and illegal activities)	$ 36	$ 26	$ 93	$ 37
% of annual value (year 30) associated to illegal and unregulated activities	11%	6%	0%	0%
Effect on regulating ecosystem services not included in the monetary valuation	–	–	o	–
Effect on cultural ecosystem services not included in the monetary valuation	–	+	+	–

Table 51 Costs and benefits of different scenarios (monetary values are expressed in millions US$; NPV is estimated over a 30-year period and with a discount rate of 5%)
o neutral effect; + positive effect; – negative effect

Costs and benefits in Scenario 1 – Business as usual

Scenario 1 (business as usual) occupies a higher position in the ranking of monetary benefits than other scenarios, but at the same time it allows for many illegal and unregulated activities. In terms of total NPV, the business as usual situation provides larger monetary benefits and higher annual value than the Scenario 2 (National Park) in year 30. The benefits in Scenario 1, however, are largely obtained from illegal and unregulated activities such as timber logging in the Forest Reserve and informal small-scale mining (Table 51 and Figure 39). It is estimated that 28% of the NPV and 11% of the annual value in year 30 would arise from illegal or unregulated activities, being these some of the highest percentages of this type of benefits among the scenarios under analysis. It is thus likely that the lack of control over these activities, together with changes in the water regime, will have negative effects on regulating ecosystem services such as flood and drought mitigation in downstream areas. Furthermore, forest degradation, land-cover change, and hunting are expected to have a negative impact on spiritual and existence values associated to the biodiversity of the Atewa Range.

Costs and benefits of Scenario 2 – National Park

Scenario 2 (National Park) is favourable for cultural values of the Atewa Range, and entails strengthened control of illegal, unregulated and unsustainable activities within the boundaries of the National Park (former Forest Reserve area). Despite this, Scenario 2 is less attractive than others in monetary terms. In comparison with scenarios 1 (business as usual) and 4 (complete degradation), Scenario 2 has a stronger enforcement of regulations to prevent illegal timber logging and illegal or unregulated gold mining in the National Park area. This favours the recovery of the forest cover and leads to a decrease in illegal and unregulated revenues. However, this scenario consequently offers lower annual and present values than scenarios 1 and 4, where illegal or unregulated activities still make a big contribution in monetary terms (Table 51 and Figure 39). As land-cover change and ecosystem degradation still take place in the buffer zone, Scenario 2 provides lower monetary benefits compared to Scenario 3, in which the buffer zone is restored and managed sustainably. Ecosystem restoration within the National Park boundaries in Scenario 2 represents an improvement with respect to scenarios 1 (business as usual) and 4 (complete degradation) in terms of the cultural and regulating services for which a monetary value is not assigned this study, but this improvement is limited in comparison with Scenario 3 (National Park and supporting buffer zone).

Costs and benefits of Scenario 3 – National Park and supporting buffer zone

Scenario 3 (National Park and supporting buffer zone) offers high monetary benefits with a low participation of illegal and unregulated activities in comparison with other scenarios. Furthermore, this scenario has potentially favourable effects on benefits that have not been valued in monetary terms. Scenario 3 has the highest annual monetary value in year 30 and occupies the highest position in terms of NPV. Over the 30-year timeframe, illegal and unregulated activities are estimated to contribute with only 7% to the total NPV of this scenario. In year 30, it is expected that all the benefits from the Atewa Range will be obtained from legally permitted activities. Since deforestation is effectively controlled in this scenario, it is likely to observe a neutral (and possibly positive) effect on the ecosystem services that are not included in the monetary value, such as drought and flood control. Furthermore, additional protection and restoration of ecosystems in the entire Atewa Range area is likely to have a positive effect on cultural ecosystem services related to spiritual and existence values.

Costs and benefits of Scenario 4 – Complete degradation

Scenario 4 (complete degradation) ranks as the second least favourable scenario in terms of total NPV and the annual monetary value in year 30 is similar to the one obtained in the business as usual situation (Scenario 1). As observed in Table 51 and Figure 36, the total NPV is obtained to a large extent from illegal and unregulated activities (32% of the total value). The absence of benefits from illegal and unregulated activities in the total annual value in year 30 is explained by the depletion of timber and gold due to their extraction in prior years. The exhaustion of the majority of these and other resources, such as non-timber products, also determines a low annual value in year 30 in comparison with Scenario 3. Land-cover change and forest degradation in this scenario will most likely have negative effects in cultural and regulating services that were not quantified in monetary terms in this study.

6.2.2 Analysis of monetary costs and benefits

This section focuses on the specific monetary values in each of the different land use scenarios. Table 52 shows the net present value, or NPV, calculated for each scenario over the entire 30-year period. The monetary benefits considered in the analysis include provisioning, regulating and cultural services of the Atewa Range, and also local benefits obtained from mining activities. All these values are estimated as net benefits, and hence, their associated costs have been already deducted from the results presented in the table. The only additional costs that are separately analysed arise from enhanced management of the ecosystems in the area.

The benefits and costs described above are affected in different ways in each scenario. Section 6.2.1. of the methodology provides a descriptive overview of the expected development of costs and benefits included in the total annual value and, therefore, in the total NPV. Based on these particular development paths, the results of the total NPV (i.e. sum of annual values over 30 years, discounted with a 5% rate) are summarized in the subsequent paragraphs according to the results presented in Table 52, below.

Provisioning ecosystem services related to legally permitted activities in the upstream area

The consumption and sale of non-timber products from the Forest Reserve and the buffer zone has the highest net present value in Scenario 1 (business as usual) with approximately US$189 million. Scenario 4 (complete degradation) has the second highest present value of non-timber products (approximately US$112 million), yet this value can be explained by the high and most likely unsustainable rates of extraction assumed under this scenario. Although Scenario 3 (National Park and supporting buffer zone) considers further restrictions in the Forest Reserve area, the restoration and sustainable use of the buffer zone is likely to compensate for this potential loss of monetary benefits. Scenario 3 is thus close to the second position in terms of NPV of non-timber products, with around US$108 million.

The legal extraction of timber products in the buffer zone provides the largest benefits in scenarios 1 (business as usual) and 2 (National Park) than in other scenarios, with NPVs estimated at approximately US$90 and US$94 million, respectively. Lower net present values of timber products in other scenarios can be explained by more sustainable use of timber in the supporting buffer zone in Scenario 3 (National Park and supporting buffer zone) and a rapid ecosystem degradation in Scenario 4 (complete degradation).

For cocoa farming, the net present values in scenarios 1, 2 and 3 (US$140, US$140 and US$156 million, respectively) do not suggest major differences between the effects of these scenarios on the net value of cocoa production. Although the value increases somewhat in scenario 3 due to an increase in agroforestry in the buffer zone. In Scenario 4 (complete degradation), however, the effect of mining and logging is likely to decrease the present value of this crop to approximately US$71 million, which represent approximately half of the value obtained in the other scenarios in the Atewa Range.

Provisioning ecosystem services related to illegal and unregulated activities in the upstream area

Illegal logging in the Forest Reserve is an important source of timber in all scenarios. The largest monetary benefits from illegal logging are observed in Scenario 1 (business as usual), which offers a net present value of over US$480 million from the timber extracted in the Forest Reserve over the 30-year period. In Scenario 4 (complete degradation), the net present value of illegally obtained timber is lower than in the previous scenario, but still significant (approximately US$230 million). This lower value in Scenario 4 can be explained by the extreme assumption of complete deforestation of the Atewa Range by the year 20 of the analysis. This assumption implies that during the last decade of analysis no illegal-timber benefits are taken into account in this scenario.

As the National Park in scenarios 2 (National Park) and 3 (National Park and supporting buffer zone) entail further control of illegal or currently unregulated activities, the net present value of illegally obtained timber only represents benefits that would be obtained in the first three years of analysis, prior to the complete and effective implementation of the new protected area.

Provisioning ecosystem services downstream the Atewa Range (Densu, Ayensu and Birim basins)

Water for agriculture has the highest net present value in the scenario with the National Park and the supporting buffer zone (Scenario 3), being estimated at approximately US$50 million. The highest net present value of water for consumption in downstream areas in the Densu, Birim and Ayensu basins is also observed in Scenario 3 (with around US$582 million for the three basins). The substantial value of water provision in this scenario is associated to the restoration of the vegetation cover, the decrease in mining activities and more sustainable activities in the Atewa Range. As described in Chapter 4, these conditions have a favourable effect in water discharge and quality for downstream users.

Scenarios 1 (business as usual) and 2 (National Park) represent the second best options for water provision with net present values of around US$38 million for agriculture and approximately US$296 million for consumption. The similarities between these two scenarios can be explained by land-cover and water-regime changes driven by mining, logging and other unsustainable activities in the buffer zone that are comparable in both scenarios.

As described in chapters 4 and 5, and in Annex J, water discharge does not represent a significant limitation in any of the scenarios. In Scenario 4 (complete degradation), however, water quality becomes a constraint that in turn negatively affects the water availability for all users in the area. As a consequence of this decline in water quality, the net present value of water in this scenario decreases to approximately US$220 million (including agriculture and consumption), which represents 35% of the net present value of water in Scenario 3 (National park and supporting buffer zone) and 65% of the net present value in scenarios 1 (business as usual) and 2 (National Park).

Regulating ecosystem services

The only regulating ecosystem service estimated in monetary terms corresponds to carbon sequestration. Based on the expected changes in biomass in the different scenarios, the cost-benefit analysis focuses on the net present value of changes in the total carbon stock of the Atewa Range. According to this analysis, the carbon storage capacity, and hence the monetary value of carbon sequestration, is negatively affected by land-cover change in all scenarios

The main losses of carbon stock are observed in Scenario 4 (complete degradation) and have a net present value of approximately US$-23 million. This is explained by the total loss of the forest and the consequent loss of biomass in the Atewa Range considered in this scenario. The effective implementation of the National Park and the supporting buffer zone (Scenario 3), on the other hand, leads to minimum losses, with a net present value estimated at US$-0.1 million. Although an increase in carbon stock is observed over the entire time frame in Scenario 3, a decrease of carbon stock in the first few years still results in a negative NPV. This means that the present value of the carbon losses that would occur before the effective implementation of the National Park would outweigh the gains in sequestered carbon over the period between its implementation and the year 30. The greater weight assigned to the first years of analysis by the use of a discount rate (5%) further exacerbates the negative effect of carbon losses during this period on the overall estimation of the NPV.

Scenarios 1 (business as usual) and 2 (National Park) provide similar net present values of the losses in carbon stock (US$3.9 and US$3.5 million, respectively). This difference suggests that further protection and restoration of the Forest Reserve area only (Scenario 2) would not lead to substantial changes in the monetary value of carbon sequestration in the Atewa Range with respect to the business as usual situation (Scenario 1).

Cultural ecosystem services

As previously described, it has been assumed that tourism will only be developed in scenarios 2 and 3, in which the Forest Reserve becomes a National Park. In Scenario 2 (National Park), the collection of entry fees for 30 years provides accumulated benefits with a present value of around US$3 million. In Scenario 3 (National Park and supporting buffer zone), these benefits could result in a net present value of US$76 million, which additionally includes visitor expenditures associated to tourism development in the supporting buffer zone. The difference between the values obtained in both scenarios reflects the supplementary benefits that could be observed if further efforts were put into the sustainable use of the supporting buffer zone, besides the creation of the National Park.

Mining benefits

Mining benefits described in this paragraph include gold and, in Scenario 4, also bauxite extraction. As official estimates indicate that approximately 65% of the gold produced in the country comes from legally permitted activities (Ghana Chamber of Mines, 2014), the net present values described here were calculated according to national average. Benefits from illegal or unregulated gold mining are quantified in a separate section below.

The highest net present value of mining benefits is observed in Scenario 4 (complete degradation), in which all suitable areas in the Atewa Range are mined, either for gold (around US$173 million are attributed to legally permitted extraction) or bauxite (approximately US$58 million). Gold extraction in scenarios 1 (business as usual) and 2 (National Park) have a present value of around US$47 and US$44 million, respectively.

In Scenario 3 (National Park and supporting buffer zone), gold extraction is only allowed during the first three years of analysis, prior to the creation of the National Park and the implementation of additional conservation measures in the buffer zone. The net present value arising from legally allowed mining activities in Scenario 3 is consequently the lowest (around US$2 million).

Illegal and unregulated mining benefits

According to the Ghana Chamber of Mines (2014), nearly 35% of the gold produced in Ghana can be attributed to illegal activities. To provide an indication of the benefits that are illegally obtained from gold mining in the Atewa Range, we used this percentage as a reference. Based on this estimation, the net present value of illegal gold extraction would amount approximately US$93 million in Scenario 4 (complete degradation), US$25 million in Scenario 1 (business as usual), US$24 million in Scenario 2 (National Park), and US$1 million in Scenario 3 (National Park and supporting buffer zone). In Scenario 2 (National Park), the net present value includes illegal mining benefits from the buffer zone and Forest Reserve area during the first three years of analysis. From year 4 onwards (i.e. effective implementation of the National Park), the net present value in this scenario only considered illegal mining benefits obtained from the buffer zone.

The net present value of illegal gold in Scenario 3 (National Park and supporting buffer zone) includes benefits from the entire Atewa Range, but only from the first three years of analysis, before the National Park and additional conservation measures in the buffer zone are effectively implemented.

Management costs

Additional costs of managing the new National Park and protecting the buffer zone are only estimated for scenarios 2 (National Park) and 3 (National Park and supporting buffer zone). In Scenario 2, the present value of these costs corresponds to US$-1.5 million and in Scenario 3, this value is estimated at US$-2.9 million.

Total net present value

Based on the results described above, the total NPV presented in Table 52 is calculated as the sum of the present value of all benefits and costs. For the 30-year period, the implementation of the National Park and a supporting buffer zone described in Scenario 3 yields the highest total NPV (approximately US$1.2 billion). This scenario is followed by Scenario 1 (business as usual), which yields US$1.1 billion, Scenario 4 (complete degradation; US$1 billion) and Scenario 2 (National Park; US$0.8 billion).

If illegal and unregulated activities are excluded from the analysis, Scenario 3 (National Park and supporting buffer zone) still ranks as the scenario with the highest NPV. The largest decrease in NPV, on the other hand, is observed in scenarios 1 (business as usual) and 4 (complete degradation), since illegal timber logging and gold mining play a significant role in their expected development.

Total annual value in year 30

As previously described in the methodology section, the total annual value was estimated as the sum of all yearly benefits and costs of each scenario. Table 52 presents the total annual value estimated in year 30, as this point in time can serve as an indication of the outcome of the scenarios after the entire period considered in the CBA.

By the end of the period of analysis (year 30), Scenario 3 (National Park and supporting buffer zone) offers the highest total annual value of all the scenarios, with approximately US$93 million per year.

Scenarios 4 (complete degradation), 1 (business as usual) and 2 (National Park) offer US$37, US$35 and US$25 million, respectively. The fact that the annual value of each of these scenarios in year 30 represents around one third of the monetary benefits expected in Scenario 3 suggests that these scenarios are less attractive than the National Park with a supporting buffer zone in the long term.

Regarding benefits from illegal and unregulated activities, Table 52 shows that by the 30th year of analysis the annual values in scenarios 1 (business as usual) and 2 (National Park) would be the most dependent ones on this type of benefits. In Scenario

3, illegal and unregulated activities are expected to be successfully controlled through effective legal enforcement. In Scenario 4, on the other hand, it is assumed that the natural resources extracted in an illegal manner will be depleted before the end of the analysis timeframe, and hence, these will not generate further monetary benefits in year 30.

	SCENARIO 1 BUSINESS AS USUAL	SCENARIO 2 NATIONAL PARK	SCENARIO 3 NATIONAL PARK AND SUPPORTING BUFFER ZONE	SCENARIO 4 COMPLETE DEGRADATION
PROVISIONING SERVICES				
Non-timber products	$ 189.1	$ 98.8	$ 107.51	$ 111.9
Timber products (legally permitted timber logging in the buffer zone)	$ 89.2	$ 93.6	$ 91.9	$ 77.6
Timber products (illegal timber logging in the Forest Reserve)	$ 285.2	$ 83.8	$ 83.7	$ 232.9
Cocoa farming	$ 140.1	$ 140.1	$ 156.5	$ 71.3
Water for agriculture	$ 37.8	$ 38.1	$ 49.8	$ 27.1
Water for consumption	$ 295.6	$ 295.6	$ 581.5	$ 194.6
REGULATING SERVICES				
Carbon sequestration	$ -3.9	$ -3.5	$ -0.1	$ -23.2
CULTURAL SERVICES				
Tourism (potential)	$ -	$ 2.8	$ 76.4	$ -
MINING BENEFITS				
Bauxite alumina	$ -	$ -	$ 12.4	$ 58.0
Gold (legal extraction)	$ 46.6	$ 43.6	$ 1.9	$ 173.4
Gold (illegal and unregulated extraction)	$ 25.1	$ 23.5	$ 1.0	$ 93.4
MANAGEMENT COSTS				
Additional park management costs	$ -	$ -1.5	$ -2.9	$ -
TOTAL NPV 30 YEARS				
Including illegal and unregulated activities	$ 1,104.8	$ 814.9	$ 1,156.6	$ 1,017.1
Excluding illegal and unregulated activities	$ 794.5	$ 707.6	$ 1,071.8	$ 690.8
ANNUAL VALUE IN YEAR 30				
Including illegal and unregulated activities	$ 35.4	$ 26.1	$ 92.7	$ 37.2
Excluding illegal and unregulated activities	$ 31.4	$ 24.6	$ 92.7	$ 37.2

Table 52 Net Present Value (NPV) for various scenarios in the Atewa Range (millions US$, 30-year period and discount rate of 5%)

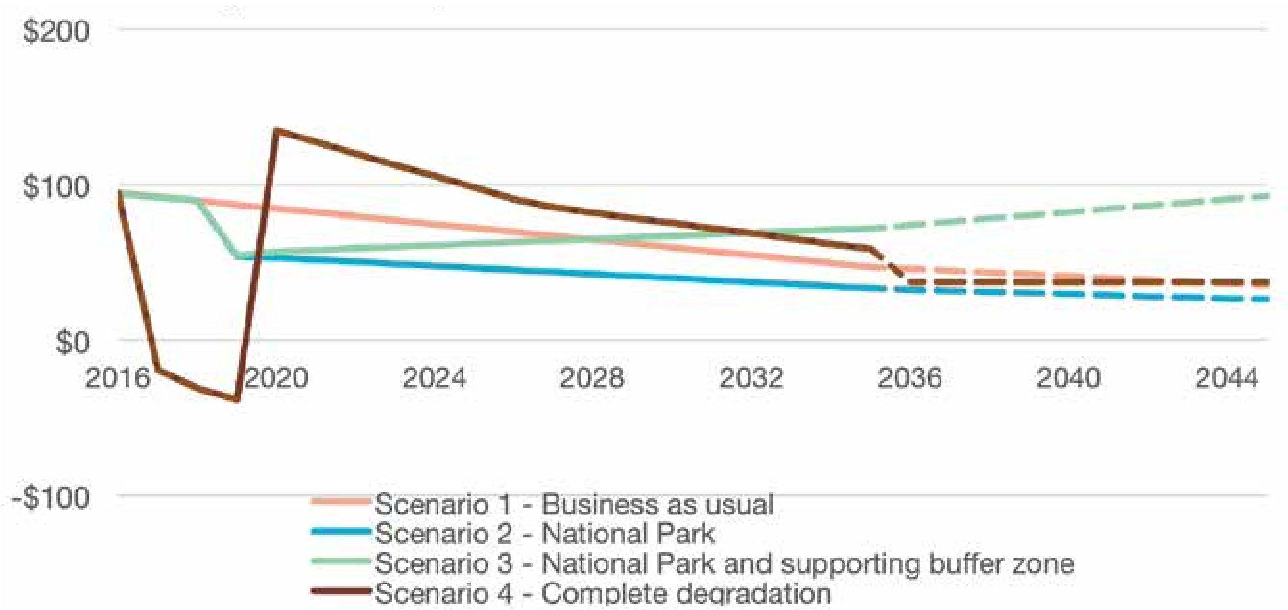

Figure 37 Annual value in different scenarios for a 30-year period (millions US$). Annual value in period 2036-2045 is based on extrapolation of hydrological model outcomes and land cover change

Trends in total annual value

Figure 37 (above) depicts the development and main trends in total annual value in each scenario, including all costs and benefits with no discount applied.

Before 2020, the decline in annual value observed in scenarios 2 (National Park) and 3 (National Park and supporting buffer zone) is linked to the restrictions on the use of timber, non-timber products and mineral resources, that will be effectively implemented within the National Park by the 4th year. As observed in the figure, before the creation of the National Park, the annual values in these two scenarios are equivalent to the annual values in the business as usual situation (Scenario 1).

In the same initial period, a steeper decline in the annual value from Scenario 4 (complete degradation) is associated to first investments for bauxite mining.

When analysing the main trends over the first 20 years of analysis (solid line), only Scenario 3 (National Park and supporting buffer zone) provides increasing annual benefits. All the other scenarios follow a decreasing trend (Figure 37).

In the subsequent decade (from year 21 to year 30, depicted as a dashed line), based on the extrapolation of land cover changes and the outcomes of the hydrological model, the main trend remains the same for scenarios 1 (business as usual), 2 (National Park) and 3 (National Park and supporting buffer zone). In Scenario 4 (complete degradation), however, the annual value becomes constant, instead of following the decreasing trend of the previous decade. In this specific case, this trend reflects that the constant revenues from bauxite extraction become by far the main source of benefits in the Atewa Range after the depletion of gold reserves and forest products (Figure 37).

6.2.3 Changes in monetary and non-monetary values for different stakeholders

The values estimated in previous sections correspond to the total monetary costs and benefits of each scenario and hence, these do not illustrate differences between stakeholders. In order to support and complement the results of the CBA, this section elaborates on the distribution of costs and benefits among different stakeholders, and also on the values that were not quantified monetarily in the previous section. As described in the methodology section, the analysis of stakeholders uses the annual value in year 30 (2045) as a reference for all monetary comparisons.

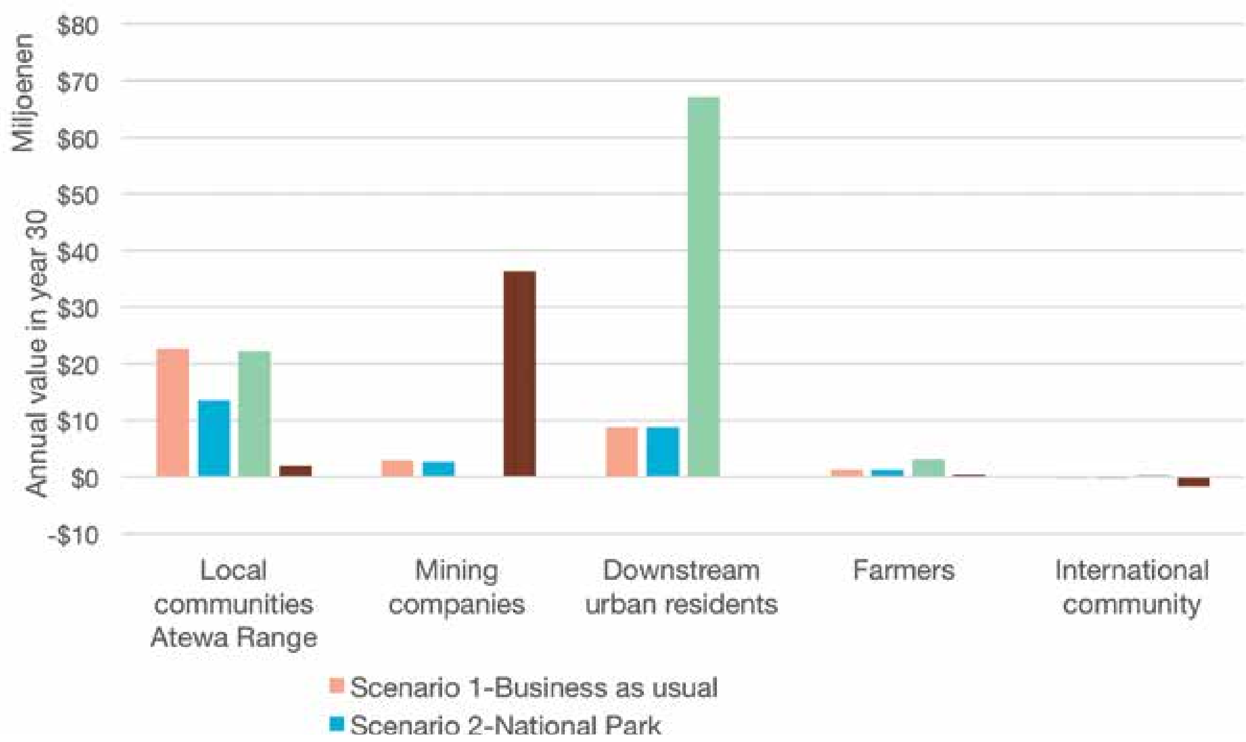

Figure 38 Annual value allocated to key stakeholders in different scenarios (millions US$, year 30). The Forestry Commission is not included in this figure; please refer to Table 53 for further information about this stakeholder

	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4
LOCAL COMMUNITIES ATEWA RANGE				
Annual value of non-timber products	$ 10.6	$4.0	$ 5.7	$ 2.0
Annual value of timber products (timber logging in the buffer zone)	$ 0.4	$0.4	$ 0.3	$ -
Annual value of timber products (illegal and unregulated logging in the Forest Reserve)	$ 2.5	$ -	$ -	$ -
Annual value of cocoa farming	$ 7.6	$ 7.6	$ 10.8	$ -
Annual tourism benefits (in the buffer zone)	$ -	$ -	$ 5.4	$ -
Annual value of gold mining (illegal and unregulated galamsey)	$ 1.6	$ 1.4	$ -	$ -
Spiritual value	-	+	+	-
MINING COMPANIES				
Annual value of gold and bauxite production	$ 2.9	$ 2.7	$ -	$ 36.3
FARMERS				
Annual value water for agriculture	$ 1.2	$ 1.2	$ 3.1	$ 0.4
Flood and drought risk reduction	-	-	o	-
DOWNSTREAM URBAN RESIDENTS				
Annual value of water for consumption	$ 8.8	$ 8.8	$ 67.2	$ -
Flood control in the Densu Delta	-	-	o	-
Existence value	-	+	+	-
INTERNATIONAL COMMUNITY				
Annual value of carbon sequestration	$ -0.2	$ -0.2	$ 0.04	$ -1.5
Existence value	-	+	+	-
FORESTRY COMMISSION				
Annual value of tourism	$ -	$ 0.2	$ 0.4	$ -
Additional NP management costs	$ -	$ -0.1	$ -0.2	$ -

Table 53 Total annual value, non-monetary values and other benefits allocated to main stakeholders in the different scenarios (millions US$, year 30)

o neutral effect; + positive effect; - negative effect

This analysis focuses on six categories of stakeholders, namely: local communities, licensed mining companies (bauxite and gold mining), farmers, downstream urban residents, international community and the Forestry Commission of Ghana as the governmental institution responsible for managing the Forest Reserve area. As previously explained, annual costs and benefits are allocated to the different stakeholder categories according to the percentages shown in Annex I. In most cases, a specific type of cost or benefit was entirely attributed to an individual category of stakeholder. Only in the case of mining, the annual value was distributed among two stakeholders: 35% of mining benefits to the (illegal and unregulated) small scale mining, or Galamsey, carried out by part of the local communities; and 65% to mining companies (Ghana Chamber of Mines, 2014).

Local communities

As observed in Table 53, local communities in the Atewa Range are the beneficiaries of timber and non-timber products, cocoa farming, and part of the gold mining benefits. Furthermore, if tourism was developed in the area, these communities would be able to create additional revenues from this activity.

The total monetary value for local communities is differently affected in the various scenarios (Figure 38). Scenarios 3 (National Park and supporting buffer zone) and 1 (business as usual) offer the highest monetary value in year 30 (including benefits from illegal and unregulated timber harvesting). In Scenario 3 local communities benefit from multiple sustainable uses that impede the degradation of the Atewa Range. In Scenario 1, on the other hand, they benefit from continued developments, as well as illegal and unregulated activities.

Scenario 4 (complete degradation) is the least favourable scenario for this group, mainly due to the degradation caused by logging and mining activities. If all benefits are considered, the difference between the annual value for local communities in Scenario 4 and the ones that rank as the first alternatives is substantial. In year 30, annual benefits of scenarios 1 and 3 are more than 10 times as large as the annual benefits of Scenario 4.

As shown in Table 53, part of the actual monetary value attributed to local communities corresponds to timber from the Forest Reserve. Since timber logging in the Forest Reserve is an illegal activity (Ansah, 2014; Abu-Juam *et al.*, 2003), however, the information to determine the distribution of these benefits among local households is extremely scarce. Previous research suggests that some timber benefits are concentrated in few illegal chainsaw operators with the capacity to harvest large amounts, thus benefiting only part of the local households (Ansah, 2014). A comparable situation can be expected for other activities, such as: unregulated small-scale gold mining (Galamsey); hunting legally protected species, such as big mammals that might be consumed or sold as bush meat; and part of the cocoa production (McCullough *et al.*, 2007).

At the time of this analysis no data were available to estimate the unregulated or illegal bush meat and cocoa harvests, or to distinguish other categories of stakeholders that could benefit from unregulated extraction of gold and timber. Therefore, all these benefits were included in the annual value for local communities.

Besides the monetary value, local communities also assign a spiritual value to the Atewa Forest. Due to land-cover change and deforestation, it is likely that this value will be negatively affected in scenarios 1 (business as usual) and 4 (complete degradation), as these entail fewer forest protection measures than the other scenarios.

Mining companies

Situated also in the Atewa Range, mining companies share costs and benefits of gold mining with local communities. Additionally, these companies are likely to benefit from the extraction and processing of bauxite, if the suitable conditions were in place. Not surprisingly, Scenario 4 (complete degradation) is by far the most encouraging scenario for this category of stakeholders, since it assumes that mining activities are allowed in the entire range.

Farmers

Downstream the Atewa Range, in the floodplains of the Densu River and in the surroundings of the Weija Dam, farmers benefit from the use of water for the irrigation of various crops. For the analysis, it has been assumed that this situation is comparable to the Ayensu and Birim basins.

Especially in floodplain areas, the Atewa Forest also helps regulate water flows and therefore minimize flood and drought risks for farmers. Although this ecosystem service was not analysed in monetary terms, due to lack of data, Table 53 presents possible effects on the value of flood and drought reduction for farmers situated downstream the Atewa Range. As presented in Figure 38, the most convenient situation for this type of stakeholders is the one provided by Scenario 3 (National Park and supporting buffer zone), while the least favourable for this group is presented in Scenario 4 (complete degradation).

Downstream urban residents

Urban residents benefit from the consumption of water originated in the Atewa Range and transported to downstream areas through the Densu, Ayensu and Birim rivers. For these residents, the highest value of the provision of water for consumption is clearly observed in Scenario 3 (National Park and supporting buffer zone), which entails higher ecosystem restoration and conservation efforts in the Atewa Range. Scenarios 1 and 2 provide low monetary benefits related to water consumption in comparison with Scenario 3. Scenario 4, on the other hand, is without a doubt the worst case, since it provides no monetary benefits at all, mainly due to complete forest degradation and high levels of contamination due to increased mining activities (Table 53).

For urban residents, the Atewa Forest also helps regulate the water discharge, thereby minimizing flood events. Although it was not estimated in monetary terms, it is likely that the value of this service will be negatively affected in scenario 4, due to complete degradation, and to a lesser extent in scenarios 1 (business as usual) and 2 (National Park). The effect of Scenario 3 (National Park and supporting buffer zone) on flood control was classified as neutral, since the conditions described in these case do not suggest possible negative effects (Table 53).

In addition to the described monetary benefits, some citizens of Accra attach value to the existence of the Atewa Forest, regardless of the use they might possibly make of this forest in the future. According to this existence value, scenarios 2 (National Park) and 3 (National Park and supporting buffer zone) would represent the best scenarios.

International community

The international community assigns value to the existence of the Atewa Forest as a shelter for biodiversity and habitat for several endangered species. This value is reflected in the financial support from international sponsors for the protection of the Atewa Forest, for which available data do not allow to obtain monetary estimates. However, it is likely that scenarios 2 (National Park) and 3 (National Park and supporting buffer zone) would represent the best scenarios from this perspective (Table 53).

In this study, the change in the carbon sequestration value is also allocated to the international community, as this is the main party that could be willing to pay for this service through market based mechanisms. As the change in carbon sequestration value is related to the available biomass in the area and additional protection measures can ensure the existence of the forest in a longer term, Scenario 3 (National Park and supporting buffer zone) provides the best conditions from this perspective (Table 53).

Forestry Commission of Ghana

The Forestry Commission is also a relevant stakeholder, as it is responsible for the management of the Forest Reserve and, in the corresponding scenarios, of the National Park. For this government body, scenarios 2 (National Park) and 3 (National Park and supporting buffer zone) would entail the creation of new revenue streams from the development of tourism, but would at the same time create additional park management costs (Table 53). Please note that other governmental bodies, such as the Minerals Commission, Water Resources Commission and the Ministry of Food and Agriculture are also relevant stakeholders in the buffer zone. However, considering that there is currently no management of this area, further information regarding gains and losses for these governmental bodies cannot be provided.

6.2.4 Sensitivity analysis

The robustness of the monetary CBA was examined by evaluating the effects of changes in specific parameters on the overall results. This sensitivity analysis considered different discount rates, and different yields in timber and non-timber products. These parameters were selected on the basis of their potential to influence the main results and the uncertainty around the estimation of their actual value.

Discount rate

The use of high discount rates to guide environmental decisions is generally expected to lead to long-term degradation of ecosystems. Consequently, selecting an appropriate discount rate renders plenty of room for debate around the ethical nature of such choice (for further information refer to Gowdy *et al.*, 2010). Although the scope of this study does not allow to discuss ethical implications of a specific discount rate, a sensitivity analysis of discount rates between 0% and 15% (with intermediate steps of 2.5%) has been used to illustrate the effects this choice can have on the total NPV (Table 54).

	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4
0%	$ 1,823	$ 1,310	$ 2,196	$ 1,813
2.5%	$ 1,388	$ 1,009	$ 1,550	$ 1,334
5%	$ 1,105	$ 815	$ 1,157	$ 1,017
7.5%	$ 912	$ 683	$ 907	$ 800
10%	$ 775	$ 590	$ 743	$ 646
12.5%	$ 675	$ 522	$ 629	$ 534
15%	$ 599	$ 471	$ 548	$ 450

Table 54 Results of the sensitivity analysis of the effect of different discount rates on the Net Present Value (NPV) over a 30-year period (millions US$)

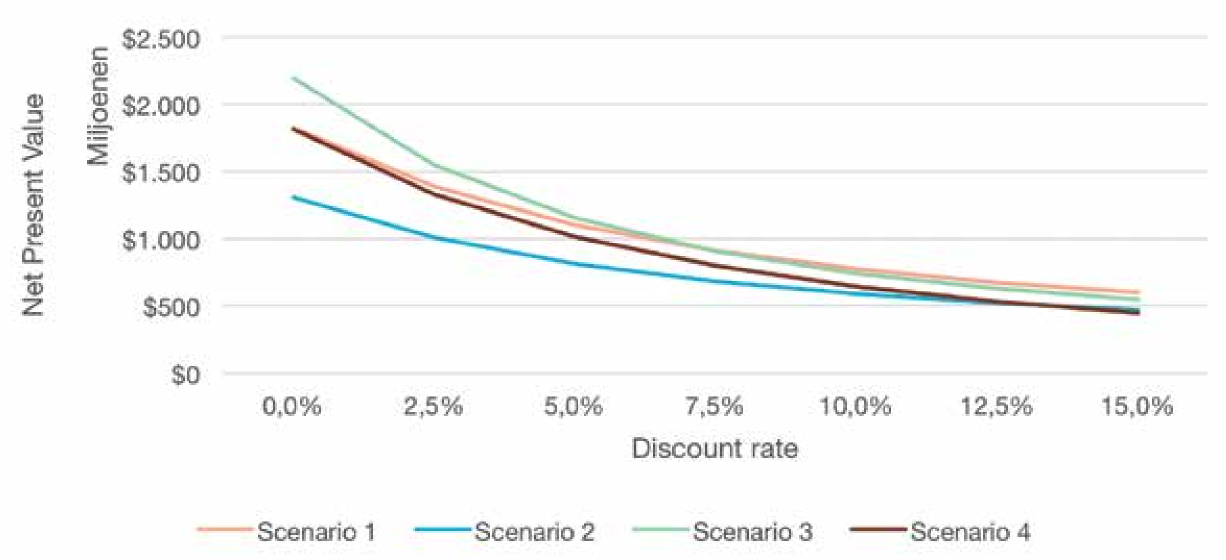

Figure 39 Effect of changes in discount rate on the Net Present Value (NPV) of different scenarios over a 30-year period (millions US$)

This analysis shows that different discount rates determine some changes in the ranking of NPVs among scenarios (Table 54 and Figure 39). With low discount rates (<7.5%), the scenarios are ranked, from the highest to the lowest NPV, in the following order: Scenario 3 (National Park and supporting buffer zone), Scenario 1 (business as usual), Scenario 4 (complete degradation) and Scenario 2 (National Park). However, if higher discount rates are used, the NPV of Scenario 3 falls to the second position. With a discount rate of 15%, on the other hand, Scenario 2 climbs to the third position, while Scenario 4 becomes the lowest in the ranking of NPV.

Yield of timber products

The economic benefits from timber products represent a substantial part of the total economic value. In the business as usual situation (Scenario 1), for example, timber provides almost 35% of the total NPV in the Atewa Range, thus being the largest benefit estimated over the 30-year period.

Although the estimates of timber consider land cover change, available data do not provide specific insight into the changes in yield (US$/ha) that occur as a consequence of less evident processes of ecosystem degradation or changes in biodiversity.

Given the significant amount of timber that is currently extracted, it is reasonable to assume that lower yields, caused by ecosystem degradation or changes in biodiversity, would significantly affect the total NPV estimated for the Atewa Range. This study therefore assumes that timber yields would decrease to 25% of the original yield in the first 20 years and this decreasing trend would continue linearly in the subsequent decade under analysis as a consequence of forest degradation. This situation is particularly relevant in scenarios 1, 2 and 4, in which timber logging and other unsustainable activities threaten the availability of timber products in the Forest Reserve and/or the buffer zone.

Given the substantial contribution of timber benefits to the total NPV of all scenarios, this assumption might potentially affect the robustness of the overall results. Timber yield is therefore an interesting and suitable parameter for the sensitivity analysis.

In this sensitivity analysis, the assumption that timber yields per hectare decrease over time is tested. By comparing the total NPV estimated in the CBA with the total NPV estimated with alternative changes in timber yield, the robustness of the CBA results is assessed. Whereas the CBA is based on the assumption of 25% of the original timber yield per hectare in year 20, this analysis includes 50% and 5% of yield in year 20 as parameters of comparison. The decrease in timber yield is linearly estimated for the entire 30-year period. With the linear decrease of 50% after 20 years, timber yields would be extrapolated to 25% of the current yields in year 30. On the other hand, if timber yields decreased to 25% and 5% in year 20, a linear extrapolation would lead to no yields (or 0%) in the years 27 and 21, respectively. The results of the sensitivity analysis based on these changes in timber yield are shown in Table 55 and Figure 40.

Although it may be rather predictable that lower yields of timber would determine lower NPVs, this change has a greater effect on the NPV of Scenario 1 (business as usual) than in the other scenarios. In Scenario 1, the difference between 50% and 5% yields in year 20 (and 25% and 0% in year 30 respectively) corresponds to around 10% decrease in the total NPV (from US$1,276 to US$1,154 million). In Scenario 2, this difference is only around 2% and in scenarios 3 and 4, this assumption does not determine observable differences (Table 55).

In Scenario 3, decreasing yields are only expected over a limited period of time, before the effective implementation of the National Park and the additional protection measures in the buffer zone. Therefore, decreasing yields in this scenario do not lead to major changes in terms of NPV. In Scenario 4, the Atewa Range is completely degraded by year 20 as a consequence of higher degradation rates than the ones used in this sensitivity analysis. This implies that the decreasing timber yields used in this analysis have no effect on the NPV of Scenario 4 (Table 55).

Figure 40 additionally illustrates that using a higher decrease in timber yield determines slightly lower NPVs in Scenario 1 (business as usual) and higher NPVs in Scenario 3 (National Park and supporting buffer zone). If timber yields decrease linearly and are set at 50% in year 20, then scenarios 1 and 3 have approximately the same NPV. On the other hand, with a linear decrease of timber yields to 25% and 5% in year 20 Scenario 3 offers the highest NPV.

The differences described above reveal the potential effect of the assumption of decreasing timber yields on the total NPV. The results of this sensitivity analysis suggest that this effect is particularly relevant in scenarios where unsustainable timber extraction is an important source of economic benefits over the 30-year period (i.e. Scenario 1). However, this factor is unlikely to change the overall ranking of scenarios significantly in terms of NPV.

PERCENTAGE OF TIMBER YIELD IN YEAR 20 (LINEAR DECREASE CONTINUES BETWEEN YEAR 20 AND 30)	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4
50% in year 20 (25% in year 30)	**$ 1,175**	**$ 827**	**$ 1,158**	**$ 1,017**
25% in year 20 (0% as of year 27)	$ 1,105	$ 815	$ 1,157	$ 1,017
5% in year 20 (0% as of year 21)	$ 1,053	$ 806	$ 1,156	$ 1,017

Table 55 Results of the sensitivity analysis of the effect of decreasing timber yields of potentially degraded forest areas on the Net Present Value (millions US$, 5% discount rate, calculated over a 30-year period)

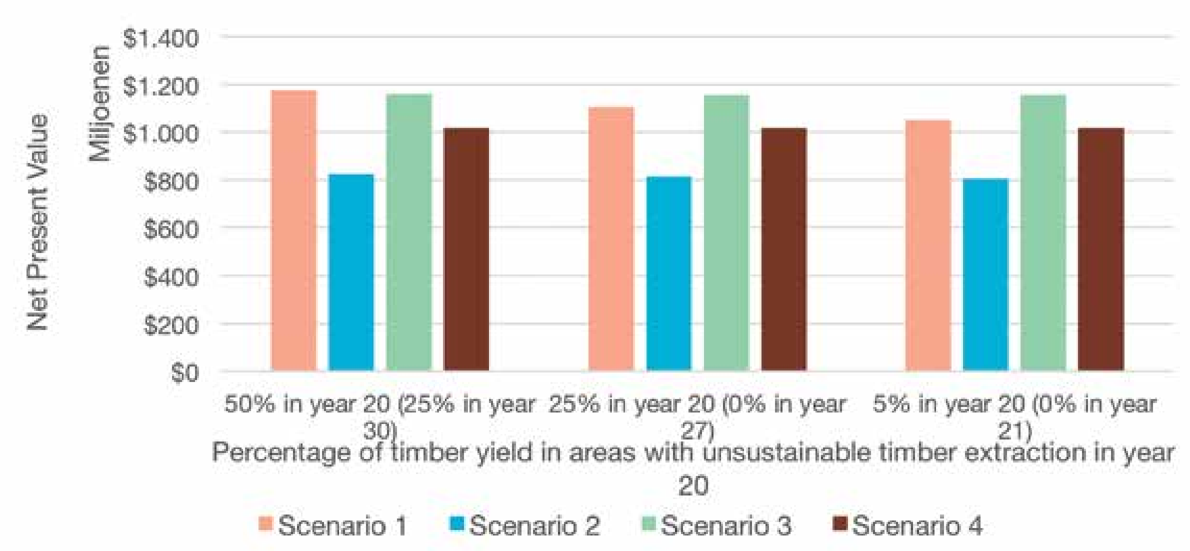

Figure 40 Effect of timber yields of potentially degraded forest areas on the Total Net Present Value (NPV) of different scenarios over a 30-year period (millions US$, 5% discount rate)

Yield of non-timber products

The economic benefits from non-timber products also represent an important part of the total economic value. Non-timber products provide between 10% and 17% of the total NPV depending upon the conditions and assumptions of each scenario.

Although the estimates of non-timber products consider land cover change, the diverse nature of these products and the lack of specific data do not allow to analyse changes in yield (US$/ha) that occur as a consequence of less evident processes of ecosystem degradation or changes in biodiversity. Given the significant amount of non-timber products that is currently extracted in the Atewa Range, it is reasonable to assume that lower yields, caused by ecosystem degradation or changes in biodiversity, would significantly affect the total NPV estimated for the different scenarios.

In this sensitivity analysis, the total NPV estimated in the CBA is compared with the total NPV estimated with lower yields of non-timber products (-25% and -50% yield per hectare). The results of this analysis are presented in Table 56 and Figure 41.

As it may be expected, lower yields of non-timber products determine lower NPVs in all scenarios. The effect of this change is the largest on Scenario 1 (business as usual), in which 50% lower yields cause around 9% decrease in total NPV (from US$1,105 to US$1,010 million). Scenario 3, on the other hand, is the least affected by changes in yield, and the same 50% reduction in yield is equivalent to approximately 5% decrease in total NPV (from US$1,1157 to US$1,103 million) (Table 56).

As illustrated in Figure 41, a decrease in the yields of non-timber products would not determine any changes in the overall ranking of scenarios in terms of NPV. However, the difference between the NPV in Scenario 1 (business as usual) and Scenario 3 (National Park and supporting buffer zone) slightly increases if lower yields of non-timber products are used in the analysis.

The differences described above show that using lower yields of non-timber products in the estimation of the NPV would not affect the overall results of the CBA. Despite the uncertainty around the actual yields of non-timber products, this analysis thus suggests that this parameter in particular does not affect the robustness of the main results of the study. Therefore, new data on the yields of non-timber products in the Atewa Range might help improve the accuracy of the analysis, but it is unlikely to determine significant changes in the ranking of scenarios.

CHANGE IN YIELD OF NON-TIMBER PRODUCTS (%)	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4
0%	$ 1,105	$ 815	$ 1,157	$ 1,017
-25%	$ 1,058	$ 790	$ 1,130	$ 989
-50%	$ 1,010	$ 765	$ 1,103	$ 961

Table 56 Results of the sensitivity analysis of the effect of changes in the yields of non-timber products on the Net Present Value (millions US$, 5% discount rate, calculated over a 30-year period)

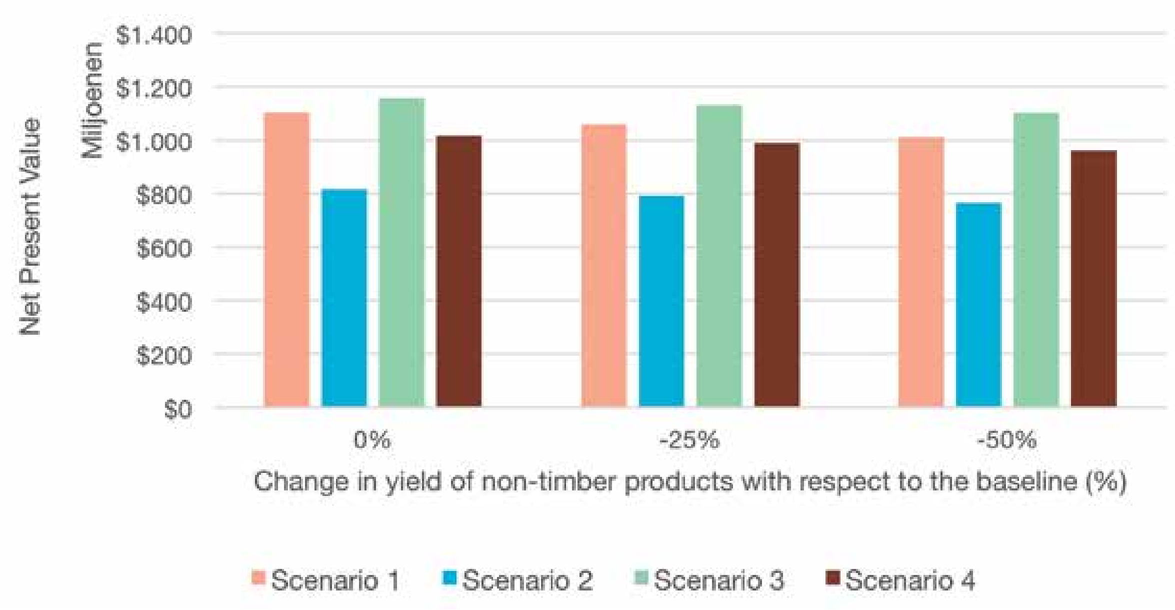

Figure 41 Effect of changes in the yields of non-timber products on the Net Present Value (millions US$, 5% discount rate, calculated over a 30-year period)

6.3 INTERPRETATION OF THE CBA RESULTS

6.3.1 Discussion of results

The cost-benefit analysis presented in this chapter described monetary and non-monetary values of four land use scenario. The purpose of this analysis was to provide insights into the strengths and weaknesses of these scenarios from an economic perspective. Therefore, rather than finding the best scenario, this chapter reveals the different outcomes of extreme and intermediate scenarios in terms of benefits and costs for various stakeholders. As such, the intended use of these results is to guide decision-makers and other relevant parties in the search of a tailor-made sustainable development path for the Atewa Range.

According to the results of the analysis, Scenario 1 (business as usual) ranks in a high position from a monetary perspective, but at the same time entails negative impacts on water provision, cultural values, and regulating ecosystem services. In addition to this, the monetary benefits in this scenario would be created to a great extent by illegal or unregulated activities. Due to these undesirable effects, this scenario would not be particularly attractive to downstream residents, farmers and the international community. And although this scenario might generate high values for local communities, these benefits might not be sustainable in the long run.

Scenario 2 (National Park) favours the protection of cultural values and several ecosystem services of the Forest Reserve, but it is less attractive than other scenarios in monetary terms. The results presented in this chapter reveal that additional restoration and conservation efforts only in the Forest Reserve area (Scenario 2 – National Park) would not substantially increase the benefits obtained from the Atewa Range with respect to the business as usual situation (Scenario 1). In monetary terms, Scenario 2 is as attractive as the business as usual scenario for mining companies, downstream urban residents and farmers.

It is important to notice, however, that Scenario 2 (National Park) entails strengthened control of unregulated and unsustainable activities within the boundaries of the National Park (former Forest Reserve area), thus protecting the biological diversity and the cultural values of the Atewa Range.

Scenario 3 (National Park and supporting buffer zone) can be perceived as the most attractive alternative in terms of ecosystem service provision, because it would entail the highest monetary benefits and also favourable effects on cultural values and regulating services that were not quantified in the analysis. The implementation of this scenario, however, might represent an important challenge as it considers strengthened legal enforcement in the Forest Reserve area and potentially substantial interventions to improve the sustainability of all the activities in the buffer zone. If these conditions were met, this scenario would consequently provide the lowest participation of illegal, unregulated and unsustainable activities in the Atewa Range compared with the other scenarios. The main beneficiaries of the outcomes of this scenario would be the downstream residents and farmers of the Densu, Ayensu and Birim basins. In the Atewa Range, Scenario 3 also represents an attractive alternative for local communities, although it provides unfavourable conditions for mining.

Scenario 4 (complete degradation) provides the largest mining benefits from gold and bauxite among all the scenarios, but still does not rank as the best alternative in terms of NPV or annual value in year 30. The conditions defined in this scenario would have detrimental effects on cultural values and adverse impacts on regulating ecosystem services. Together with these negative effects, impacts on water quality would make this situation the least favourable for local communities and downstream residents and farmers, leaving mining companies as the only significant beneficiaries from this scenario.

Overall, this analysis has revealed that shifting from the business as usual situation towards additional conservation efforts in the Atewa Range has the potential to protect cultural values and provide economic benefits for various stakeholders. This potential, however, can be fully achieved only if this gradual shift considers ecosystem restoration and sustainable activities in the buffer zone, in addition to the strengthened protection of the Forest Reserve area.

6.3.2 Dealing with information gaps

The valuation of ecosystem services and their development over a long future timeframe involves an interdisciplinary research effort that relies on available economic, ecological and (in this case) hydrological data and reports. As in every study, the results of the analysis are only as robust as the data that forms its basis. As expected in a study with such a broad scope, the research team dealt with several data gaps. Occasionally, time series data were not available to estimate trends in ecosystem services or economic indicators. Especially with regard to the change in biodiversity within the Atewa Range, this proved to limit the research team in its ability to draw solid conclusions.

For some ecosystem services no data was available at all, so these had to be excluded from the quantitative analysis. An important example are the fisheries in the Densu Basin and Weija lake. In the case of mercury pollution, fisheries are one of the most vulnerable economic sectors due to the accumulation of mercury in fish stocks. Another example is the existence value of a biodiverse area such as the Atewa Range. This value is potentially large but could not be included in the CBA. Due to a lack of data on biodiversity and the willingness-to-pay of the international community for the conservation of the Atewa Range it is currently impossible to incorporate this value in the overall economic analysis. Effects of the different scenarios on the regulation of floods in the Densu delta were also analysed from a qualitative perspective due to lack of data to estimate monetary values.

A structural problem that the research team encountered is the fact that many of the environmentally harmful activities in and around the Atewa Range Forest Reserve are not regulated and therefore poorly documented. This among others resulted in difficulties in the estimation of the amount of harvested timber and NTFPs. To compensate for this information gap, the research team conducted a sensitivity analysis in Chapter 6.

Another gap is the lack of water measurements that can be used to estimate the downstream effect of mining activities. Upstream measurements in the Birim indicate a very serious pollution problem, but little is known about levels of mercury and cyanide in the downstream areas. Monitoring of these values in the future will be paramount to safeguard the wellbeing of downstream beneficiaries if mining practices continue.

Bauxite mining is the most relevant benefit in the fourth scenario (complete logging and mining) and has an important impact on the outcome of the NPV. Although various studies have estimated the size of the Bauxite reserves in the Atewa Range there has been little research on the economic feasibility of mining it (e.g. required investments, operating costs, etc.). In any case, Bauxite mining in the Atewa Range would require substantial investments that have not been elaborately investigated.

Because of the data gaps described above, the results of the CBA should be used with great care and the costs and benefits stated in this report should be interpreted as a rough indication of the actual values. Despite these limitations, the trends in each scenario provide a useful input to the integrated management of the forest and its river basins.

7 CONCLUSION AND RECOMMENDATIONS

The final step of this study links the results of the cost-benefit analysis (CBA) to actual policy processes regarding the land use management of the Atewa Range. In previous chapters, the different values of ecosystem services provided by the Atewa Range were identified and quantified. These services benefit a wide range of stakeholders in the upstream, midstream and downstream sections of the Densu, Birim and Ayensu rivers. By assessing the change in values in different future scenarios, this study provides insight into how beneficiaries are affected by alternative management regimes in the Atewa Range. In this chapter, the overall conclusion of this research is put in the context of the Ghanaian governance setting to shed light on policy implications of the scenarios under the analysis.

7.1 OVERALL CONCLUSION

In this study, the effects of four different land use scenarios in the Atewa Range were investigated by assessing changes in the value of ecosystem services. The results of an 'extended' cost-benefit analysis indicate that increasing protection in the existing Forest Reserve and managing a buffer zone around it more sustainably (Scenario 3) would yield the highest benefits for the people that depend on the Atewa Forest and the Densu, Ayensu and Birim rivers.

These results reveal that a shift from the business as usual approach towards additional conservation efforts in the entire Atewa Range has the potential to provide economic benefits and protect cultural values for various stakeholders.
In economic terms, only the conditions provided by the National Park and the supporting buffer zone (Scenario 3) would lead to an increasing trend in the annual net value. Furthermore, this setting would offer the highest net present value over a 30-year period and by far the highest annual value by the end of this period.

Also in terms of non-monetary values Scenario 3 seems more favourable than the other options analysed. The implementation of the National Park would strengthen the protection of culturally significant areas, while additional management efforts in the buffer zone would ensure that traditional activities of local communities continue to develop in a sustainable manner. At the same time, these conservation efforts would protect the existence value that the Atewa Forest has for people in other areas of Ghana and for the international community.

In addition to the monetary and non-monetary benefits described, Scenario 3 has the potential to create jobs in the tourism sector and for the management of the National Park. In this scenario, the new status of the area would bring multiple local benefits such as new opportunities for the local economy, for awareness raising and education, and for the local livelihoods.

In contrast to the conditions offered in Scenario 3 (National Park and supporting buffer zone), the cost-benefit analysis suggests that the total value of ecosystem services would steadily depreciate if unsustainable practices remained in place. In fact, Scenarios 1 (business as usual), 2 (National Park) and 4 (complete degradation) all face decreasing benefits in the long run due to the maintained extractive activities in the buffer zone. In scenarios 1 (business as usual) and 2 (National Park), forest degrading practices in the Forest Reserve and/or the buffer zone hamper the implementation a sustainable solution for the management of the Atewa Range in the long run.

Although the hydrological model has shown that losing part of the vegetation cover in the Atewa Range might slightly increase the annual water availability in the Densu River, this situation would also determine a higher variability in the water discharge, which in turn would lead to a higher probability of facing droughts and floods. Furthermore, despite the uncertainty of quantitative change in downstream effects, it is almost certain that households and industries downstream will be negatively affected by an increase in pollution and sediment in the water bodies in scenarios with intensive and extractive activities in the buffer zone (Scenarios 1, 2 and 4). Decreased water quality in these scenarios will potentially affect the provision of fresh water, increase health costs and worsen the burden of water from other sources (e.g. sachet).

It has to be noted that benefits from downstream fisheries, microclimate regulation and genetic diversity are not included in the analysis due to a lack of data. However, as these ecosystem services also depend on a healthy Atewa Range and would be negatively affected by deforestation, additional data would most certainly confirm Scenario 3 (National Park and supporting buffer zone) as the option with the highest long-term value.
In terms of beneficiaries, the CBA revealed substantial differences in benefits between the up- and down-stream areas in the different scenarios. On the one hand, conservation efforts upstream have consequences for the livelihoods of fringe communities, which currently benefit from extractive land use activities. On the other hand, downstream beneficiaries would be negatively affected if intensive and extractive activities took place upstream in the Atewa Range.

An integrated management approach, including land use zoning with different management regimes, will be needed to achieve the transition towards sustainable use and conservation of the Atewa Range. Within the Ghanaian government it is important that the Forestry Commission, Minerals Commission, Water Resources Commission and District Assemblies work closely together to align policies. Externally, local communities and civil society need to be involved to develop an inclusive management plan in which the all stakeholders are considered. The involvement of all relevant actors in the planning process can help ensure sustainable forest management, minimize costs, create trust, empower local stakeholders and build local capacities. Only with strong, inclusive stakeholder involvement can an equitable development of the Atewa Range and its downstream river basins be achieved.

7.2 GOVERNANCE IMPLICATIONS AND RECOMMENDATIONS

The current study should be seen as a first step towards optimizing the sustainable use of the Atewa Range and its downstream river basins. To achieve this ambitious goal, this study represents a comprehensive knowledge basis, as it provides insight into the change in costs and benefits for various stakeholders in different land use management scenarios. However, it does not cover all the relevant elements to take into account for achieving sustainable management in the Atewa Range. Other aspects to increase sustainability in the area that are not part of the scope of this study can include: the development goals of the Ghanaian government; the ecological limits to the ecological and hydrological systems; and the capability of stakeholders to adapt to new conditions.

In order to achieve the sustainable management of the Atewa Range, interaction and engagement is required between the relevant stakeholders. Figure 42 visualizes the governance setting in which the different stakeholders interact according to their interests and responsibilities. Strategies for improving the governance setting to support sustainable management were discussed during the inception workshop of this TEEB study on 28 May 2015 (Annex A) and the validation workshop on 25 August 2016 (Annex K).

The remainder of this section describes the implications of the TEEB study results for the following aspects visualized in Figure 42: land use planning; cooperation within the Ghanaian government; regulation and monitoring; the development of alternative livelihoods; raising awareness and payment schemes for ecosystem services.

Land use planning and decision-making
Although the Forest Reserve is officially protected, this status is not enough to generate sufficient funds for effective management. In order to increase the level of protection, the Forestry Commission has the intention to update the current status of the Forest Reserve to that of a National Park. Indeed, this update would lead to more stringent management objectives for the current reserve area and is likely to be an effective step towards the conservation of Atewa's ecosystem services.

However, simply increasing the protection of the Forest Reserve in a top-down manner is not likely to improve the wellbeing of the local communities in the range. The results of the CBA indicate the high dependence of local households on the forest for their livelihoods. Simply forbidding local communities to exploit the forest ecosystem will not be adequate. Close cooperation between the central government, political districts and community leaders is fundamental to define the new management objectives of a National Park, and also to create and sustainably manage a surrounding buffer zone.

A similar legal approach as for Mole National Park could be applied to manage the National Park and the buffer zone, by pursuing inclusive, collaborative management , such as: Community Resource Management Area (CREMA). CREMA is a newly developed legal framework in Ghana for community based management of natural resources. This framework provides the conditions and rules that enables communities to co-benefit from sustainable natural resource use and as such promotes community rights and local ownership. By simultaneously including local residents in the management of the protected area and providing microcredits for alternative livelihood investments, the framework is intended to divert communities from harmful activities to ecosystems. The implementation of a legal management framework, such as CREMA, should consider adequate and realistic compensation and relocation mechanisms if forested lands are acquired by the state and current livelihoods of local communities are compromised.

In view of the current level and trend of forest degradation in the Atewa Range, to a high extent in the surrounding buffer zone and also to some extent within the Forest Reserve itself, it is recommended to invest in forest restoration, through public, private and blended financing (for instance through the Ghana Forest Investment Program).

Monitoring and enforcement of regulations
Paramount to effective land use management is the enforcement of regulations. It should be noted that the regulation currently in place should already tackle a substantial number of threats to the Atewa Forest. The Forest Reserve is classified as Category A, which means that no extractive use is allowed except for some NTFPs. Despite this restriction, timber is illegally harvested and bushmeat species are hunted in large numbers, thus threatening a great extent of the forest ecosystems in the Atewa Range.

The change in status from a Forest Reserve to a National Park will help tackle the existing issues in the Forest Reserve, but further actions in terms of enforcement are still required to assure that this upgrade will achieve the expected results. Additional measures and management arrangements need to be established in relation to the buffer zone. The Forest Services Division (FSD), responsible for the management of the Forest Reserve, faces lack of staff capacity, discontinuity of funding, and logistical limitations. Even though various of the current threats to the Atewa Range – at least the threats within the Forest Reserve itself - are in principle addressed by the status of a Forest Reserve and/or National Park, the described issues faced by the FSD pose challenges for enforceability of existing regulations.

Strategies to ensure effective enforcement can include: raising awareness and educating local stakeholders in terms of the legal framework in place; training the FSD staff (or Wildlife Division staff in the case of an update to a National Park) and prosecutors; increasing the presence of the FSD staff on the ground; and providing adequate logistical support to the FSD. Key actors to support this process include the District Assembly, the traditional authorities, non-governmental organizations, the judicial authority, the police and the Forestry Commission.

The development of alternative and supplementary livelihoods
The implementation of the National Park status would imply that local communities lose access to many extractive resources in the Forest Reserve and the buffer areas (MLNR, 2012). According to the CBA results, local communities can lose part of their benefits from the extraction of non-timber and timber products in the situation with a National Park (scenarios 2 and 3). However, the overall benefits in the latter (Scenario 3) exceed the ones obtained in the business as usual situation (Scenario 1).

The results of the CBA include the future development of a flourishing tourism sector and an increase in traditional cocoa and agroforestry schemes. However, ecotourism and traditional farming might not be the only adequate alternatives to provide the communities of the Atewa Range with sufficient means to make up for the profits from the extraction of timber, NTFPs and gold. It is extremely relevant that alternative and supplementary income sources are developed and sustainable extraction levels ensured. Alternative and supplementary livelihoods must be researched and tailored to suit the needs of the local communities. Sufficient incentives should furthermore be put in place and an increased awareness of the monetary and non-monetary gains of protecting the forest must be promoted.

Some efforts have been undertaken by A Rocha Ghana to develop alternative and supplementary livelihoods in the Atewa Range[16]. Rearing of grasscutters and snails, and the growing of mushrooms are examples of the organization's efforts and stand out as potential alternatives and supplementary sources of income to similar products that are traditionally harvested from the forest. This means that there are already markets in place for

NOTE
16 http://ghana.arocha.org/projects/protecting-atewa-forest/

these products and that the need to harvest these products from the wild will diminish. Unfortunately, these supplementary activities have just been introduced to the local population and are not yet sufficiently developed to compensate for a potential income drop faced by sudden restrictions in land use activities. It can be concluded that substantial investments for green value chains need to be identified and supported in order to prepare the local population for an update to a National Park.

A system for the payment for ecosystem services

The CBA results show that downstream beneficiaries and the international community also benefit from ecosystem services in the form of water provisioning, carbon sequestration and the conservation of biodiversity. However, these stakeholders do not contribute directly to the sustainable management of the Atewa Range at the moment. This means that in a scenario with additional conservation efforts, the upstream communities might benefit but also face restrictions on their activities, while downstream beneficiaries and the international community would only benefit from this scenario. A possible mechanism to compensate local communities is to develop a payment for ecosystem services (PES) framework (Tacconi, 2012). Note that a PES system is not currently in place, and hence, this potential interaction is depicted with a dashed line in Figure 42.

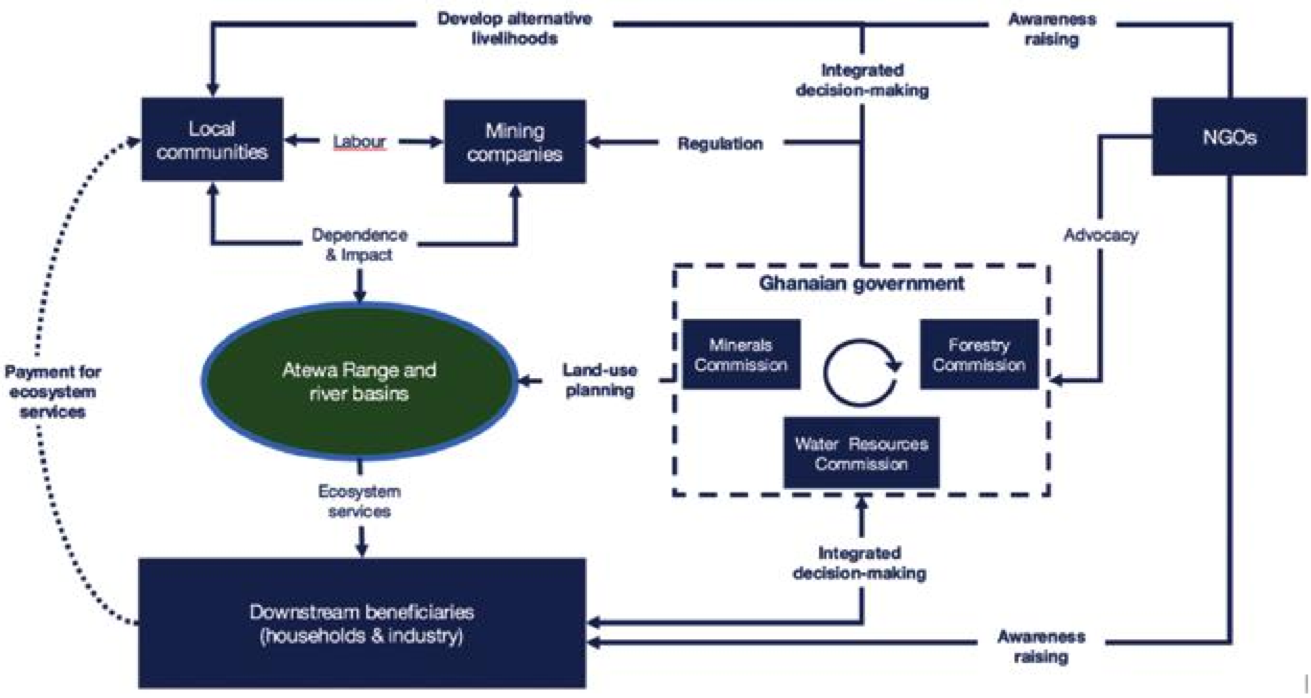

Figure 42 Governance setting with regard to the integrated management of the Atewa Range.

Figure 43 presents a potential PES-framework that could be suitable for the integrated management of the Atewa Range. The rationale behind this scheme is that in exchange for a reduced impact on the Atewa Range and river ecosystems, the downstream beneficiaries in Accra (or other downstream areas) and the international community contribute to a fund that supports the local community in the development of alternative and supplementary livelihoods. This can be done, for example, in the form of microcredits in the case stakeholders opt for a CREMA approach.

A payment for ecosystem services scheme can potentially be used to maintain the quality of downstream ecosystem services and catalyse the transition of fringe communities towards alternative and supplementary livelihoods. This scheme will potentially provide supplementary income during lean season and additional incentives to prevent illegal and unregulated activities that affect the forest.

The household survey conducted in the light of this study identified a positive willingness to pay for an environmental tax that is used to increase the protection of the Atewa Range as a water source. Downstream residents that depend on the water from Atewa are on average willing to pay about 3.3 million USD (12.7 million GHS) for the conservation of their water source (see Chapter 5).

A potential option to capitalize the willingness to pay (WTP) of water users is by levying an earmarked environmental tax on the monthly water bill of the Ghana Water Company. The revenues collected through a PES-scheme can be added to the common fund of the relevant Metropolitan, Municipal and District Assemblies (MMDAs) to be managed and used for PES ventures for the protection of the forest.

Despite the potential this type of scheme has in the Atewa Range, care must be taken to: ensure the sustainable management of the fund; prevent the rise of unrealistic expectations among local communities; develop investment alternatives that reflect the needs of local communities; and identify the specific and most relevant local actors that will be compensated for the additional protection of the forest. Additionally, the effective implementation of a PES-scheme will require awareness raising among industries and households in the upstream, midstream and downstream areas of the basin.

As part of the Living Waters project, a mapping and scoping assessment of private sector companies reliant on water in the Densu Basin was carried out. The assessment surveyed 20 companies from 3 sectors and identified that reliable water quantity and high quality were key business risks. According to Ghana Water Company Limited, tariffs are currently undergoing review by PURC, and a potential 100% increase is being discussed. The increase, similar to increase in electricity tariffs, are to better cover utility costs, such as maintaining water quality standards. Most respondents to the survey recognised the importance of forests and ecosystem services for continued business success. An Atewa Private Sector Working Group has been established by IUCN Ghana to enable businesses to contribute to improved management of Atewa and the river basins. The group has 13 members, both large and small businesses, from various sectors. The group will work towards delivering some concrete recommendations in 2016.

As a supplementary alternative to the payment scheme for water provision, Permian Global is currently investigating the potential of Voluntary Carbon Units (VCUs). VCUs are credits that can be issued for conserved forest areas in which carbon is sequestered. After certification, credits can be sold on international markets and revenues can be used for the conservation of the forest area for which the credits are issued.

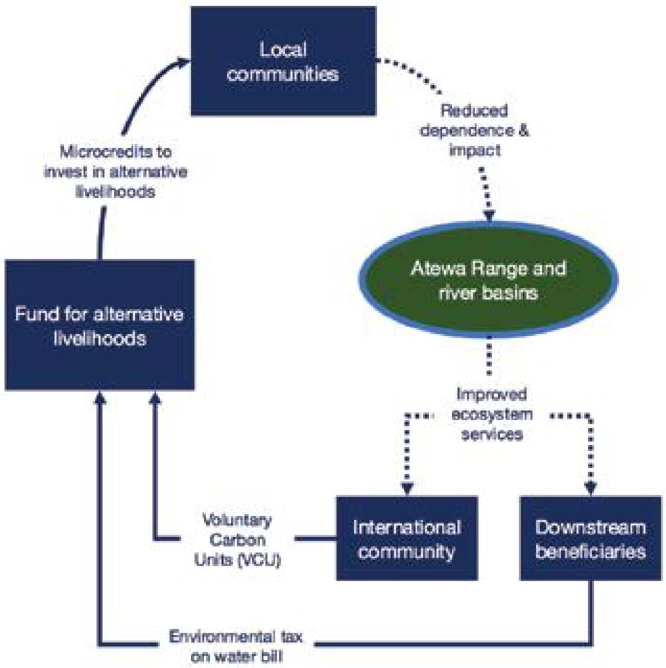

Figure 43 Potential framework for the payment of ecosystem services. Please note that there are currently plans for the development of Voluntary Carbon Units (VCUs) by Permian Global

Cooperation within the national government

The CBA results indicate that merely updating the status of the Forest Reserve to that of a National Park will not be sufficient to protect the ecosystem services provided by the Atewa Range. The combination of additional protection within the Forest Reserve and sustainable management of the buffer zone will, however, contribute to the sustainability of these benefits. Developing and enforcing conservation policies in the buffer zone implies that management efforts will exceed the jurisdiction of the Forestry Commission. Considering that most impacts of gold mining affect river basins under the jurisdiction of the Water Resources Commission, and that concessions have to be issued by the Minerals Commission, more intensive cooperation will be required within the central government of Ghana.

Coordination between the Forestry Commission and the Minerals Commission, however, has not proven to be always effective in the past. The Minerals Commission has issued licenses for exploratory drilling to investigate bauxite reserves in the Forest Reserve, although this is not in line with the current Forest Reserve regulations. Also one of the gold mining concessions issued by the commission overlaps with the Forest Reserve boundaries, resulting in conflicting policy. An integrated management approach based on multi-stakeholder participation can be undertaken in order to deal with these issues at a multi sectorial level. This would require a specific model for the Atewa Range, including mechanisms to handle conflicting interests in the Forest Reserve and the buffer zone.

Key actors for the implementation of an integrated management approach in the Atewa Range include the Environmental Protection Agency, the Forestry Commission, the Forestry Research Institute of Ghana (FORIG), the Ministry of Local Government and Rural Development, the Ministry of Lands and Natural Resources, the Minerals Commission, the Ministry of Food and Agriculture, the District Assemblies and the Traditional Authorities.

Cooperation in environmental management at the District Level

Political districts have the mandate to enact and enforce local byelaws on the environment. An issue beyond the scope of this study, but relevant to sustaining the value of water provisioning at the Weija level is that water pollution along the midstream and downstream stages of the Densu River might raise the costs of the Ghana Water Company on water treatment and affect other stakeholders, such as fishermen. This is an environmental debt tending to reduce the value of this ecosystem service where the producer absorbs the increased cost.

Where the GWC passes on the cost to urban water users, the market price is distorted. Restoring the real value of the ecosystem service can be effectively done by imposing an environmental tax on polluters to the extent that the tax is higher than the cost of abating the environmental damage. The Environmental Protection Agency of Ghana led District Level Strategic Environment Assessments with lessons to support cooperation with the central government and research on enforcing district level environmental regulation through the institution of an appropriate environmental tax-compensation payment system. The insight gained through these studies can help achieve successful cooperation at the District Level to protect ecosystem services provided to downstream users by the Atewa Range.
Raising awareness
Last but not least, raising awareness about the importance of the Atewa Range as the source of a wide range of ecosystems can be an important factor to support the sustainable management of the Forest Reserve and the buffer zone. Greater awareness is relevant for stakeholders in the up- and downstream areas. The household survey conducted in the context of this study in Accra showed that only part of the downstream beneficiaries are aware of the Atewa Range.

Raising awareness

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A better understanding of the relation between the Atewa Range and the water supply of western Accra can increase the pressure on the national government to pursue the sustainable development of the area. Awareness raising should focus on the importance of the Atewa Range for water quantity and quality downstream. It is also imperative to include monetary and non-monetary benefits of increasing protection of the Forest Reserve and integrated management of the buffer zone.

In the upstream area, awareness and education can create a better understanding of the relation between extractive activities and the state of the forest and river ecosystems. Awareness must be created among all stakeholders, including local communities, farmers and industries. The effectiveness of awareness raising campaigns can be increased by targeting specific groups, such as school children. A better understanding is likely to result in more support for conservation activities within the Atewa Range itself.

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ANNEX A • K

Mining, Photo Jan Willem den Besten

ANNEX A OUTCOME OF STAKEHOLDER CONSULTATION IN SCOPING PHASE

Inception workshop and stakeholder meetings

On 28 May 2015, a one-day workshop was organized in the Alisa Hotel in Accra to introduce the study. During that workshop stakeholders identified important ecosystem services, threats and solutions. Based on the workshop and meetings with stakeholders in the following period, researchers were able to define the scope of the research. The following paragraphs provide an overview of the relevant ecosystem, ecosystem services, pressures and possible interventions.

Ecosystems and ecosystem services

Table 57 lists the important ecosystems and services that are provided by the Atewa Range. These services were selected on the basis of the inception workshop and meetings with stakeholders. The relevant ecosystems are the tropical 'upland' forest itself and the three rivers that flow from it. Although all rivers are taken into account in the research, focus lies on the Densu Basin, for which specific sub-ecosystems have been identified. Parts of the river identified are the agricultural area between the forest and the Weija lake; the Weija lake itself; and the Densu Delta, which is considered an important wetland area and has the status of a Ramsar site. The ecosystem services are classified under the framework provided by the Millennium Ecosystem Assessment (MA, 2005).

1. ECOSYSTEMS	2. ECOSYSTEM SERVICES
• Atewa Range:	**PROVISIONING SERVICES**
• Atewa Range Forest Reserve	• Non-Timber Forest Products
• Rest of the Atewa Range	• Timber
• Rivers:	• Fuel wood
• Birim	• Bush meat
• Ayensu	• Fisheries
• Densu	• Mineral resources
• Densu river:	• Water for agriculture
• Agricultural area	• Water for consumption
• Weija lake	• Herbal medicine
• Densu Delta	**REGULATING SERVICES**
	• Erosion prevention
	• Microclimate regulation
	• Carbon sequestration
	• Flood control
	• Watershed regulation
	CULTURAL SERVICES
	• Spiritual value of Atewa Forest
	• Non-use / existence value
	• Research
	• Recreational activities
	• Potential for tourism
	SUPPORTING SERVICES
	• Genetic resources
	• Wildlife habitat

Table 57 Ecosystems and ecosystem services identified during the stakeholder consultation. This list has been used as a reference to select the relevant ecosystem services for the final analysis

ANNEX B STUDIES ON SPECIES ABUNDANCE IN THE ATEWA RANGE

The following table presents the results of various ecological surveys that have been conducted in the Atewa Range Forest Reserve. Unfortunately, due to a lack of ecosystem consistency between surveys, accurate trend analysis is not possible.

Sources: Hawthorne and Abu-Juam (1995), McCullough *et al.* (2007) and RMSC

DATE	NO. OF SPECIES	ELEVATION	GHI	PIONEER INDEX	REMARKS	SOURCE
01/04/1970	96	500	62	75	Student survey	Hawthorne and Abu-Juam (1995)
01/04/1970	40	600	115	62	Student survey	do
01/04/1970	34	800	90	68	Student survey	do
25/11/1971	129	540	62	37	Near bauxite survey road	do
25/01/1972	86	760	93	39	Near survey road	do
19/12/1972	56	720	77	28	30% slope near ridge	do
02/03/1973	124	540	90	29	Ridge 2km NW Apapam	do
02/03/1973	39		8	71	Just outside near Apapa	do
17/03/1973	64	750	92	53	Summit plateau	do
27/04/1973	102	770	75	42	Summit	
10/04/1990	245		127	92	In and around bauxite quarry plot on ridge (35 tree species): ATETH1	do
10/04/1990	126		109	55	Undisturbed forest adjacent ATETH1; dark loam, many loose rocks; ATETH2	do
09/04/1990	22		100	14	Miscellaneous specimen from slopes and ridge top	do
23/08/1991	197	480-490	79	91	Hill top 3km from Boundary Pillars 100-101	do
22/01/1992	34		46	77	Ridge top raphia swamp on dark clay	do
26/01/1992	30	590	123	59	25m x 25m ridge top; swamp 590 above Kibi; dark clay	do
28/3/1992 – 10/4/1992	213				Permanent sample Plots data. A total of 7 plots sampled	RMSC
20/5/1994 – 26/8/1994	215				Permanent sample Plots data. A total of 9 plots sampled	RMSC
20/1/1998 – 24/2/1998	181				Permanent sample Plots data. A total of 4 plots sampled	RMSC
2006	314				Rap Assessment Program	McCullough et al. (2007)

ANNEX C RELEVANT INDICATOR SPECIES FOR THE ATEWA RANGE ECOSYSTEM

Butterflies

Butterflies are extremely sensitive to changes in vegetation composition and structure (Dennis and Sparks, 2006). Studies conducted on Butterfly diversity and richness in the Atewa Range found a positive correlation between habitat disturbance and butterfly diversity (Table 58; Addo - Fordjour et. al. in 2015). A significant correlations of butterfly abundance with plant species richness and canopy cover of the forests was recorded in these studies, suggesting that forest vegetation is an important determinant of butterfly abundance.

	NDF	MDF	HDF
SPECIES RICHNESS	$36.6^{a}\pm2.1$	$29.5^{b}\pm1.06$	$23.5^{c}\pm0.73$
DIVERSITY	$3.36^{a}\pm0.05$	$3.27^{a}\pm0.04$	$2.93^{b}\pm0.03$
ABUNDANCE	$75.8^{a}\pm4.66$	$51.7^{a}\pm1.08$	$39.7^{b}\pm1.93$

Table 58 Butterfly diversity and abundance in the non-disturbed (NDF), moderately disturbed (MDF) and highly disturbed (HDF) forests in the Atewa Range Forest Reserve (± Standard error of mean). Means in the same row that have different superscripts are significantly different at $\alpha = 5$ %

ANNEX D FACTOR OF ECOSYSTEM PROVISION

Factor of Ecosystem Service Provision

	Factor of ecosystem services provision [assumption on average % of provision per land cover type]				
	FOREST		COCOA PLANTATIONS		
	CLOSED CANOPY	OPEN CANOPY	CLOSED CANOPY	OPEN CANOPY	HERBACEOUS
NON-TIMBER PRODUCTS:					
Snails	100%	100%	10%	10%	0%
Honey	100%	100%	50%	50%	25%
Mushrooms	100%	100%	10%	10%	0%
Fruits	100%	50%	100%	50%	0%
Rattans	100%	0%	100%	0%	0%
Cane	100%	50%	0%	0%	0%
Chewing stick	100%	50%	0%	0%	0%
Bath Sponge	100%	50%	100%	50%	0%
Chewing sponge	100%	50%	0%	0%	0%
Spices	100%	50%	50%	25%	0%
Herbs	100%	50%	100%	50%	0%
Wrapping leaves	100%	50%	100%	50%	0%
Bush meat	100%	100%	50%	50%	50%
TIMBER PRODUCTS:					
Timber	100%	25%	0%	0%	0%
Mortar (Ghanaian)	100%	25%	0%	0%	0%
Pestle (Ghanaian)	100%	25%	0%	0%	0%
Construction poles	100%	25%	0%	0%	0%
Fire wood	100%	50%	0%	0%	0%

ANNEX E PRICE ESTIMATION OF NON-TIMBER AND TIMBER PRODUCTS

	Price per unit (GhȻ)	Unit of measurement	Estimated amount (kg or m3 per unit)	Price (GhȻ per kg or m3)	Price (US$ per kg or m3)	REMARKS AND ASSUMPTIONS FOR UNIT CONVERSIONS
	A ROCHA (PERS. COMM., 2016)					
NON- TIMBER PRODUCTS						
Snails	70	5 litre plastic paint rubber	2.5 kg	28.0	7.3	Assumption: average snail weighs 250 g, with a shell length of 10 cm (based on Cobbinah *et al.*, 2008). Therefore, 5 litres paint rubber contains approximately 10 snails. Total weight in each rubber is 2.5 kg.
Honey	30	600 ml bottle	0.85 kg	35.3	9.3	Assumption: density of 1.42 kg/litre, 0.85 kg per bottle.
Mushrooms	5	Per pack	0.35 kg	14.3	3.7	Assumption: weight of a pack of mushrooms, based on pictures from local observations, is approximately 350 g (0.35 kg) per pack.
Fruits:	-	-	-	2.9	0.8	Average price (this estimate is used for further calculations based on fruits).
• Breadfruit	0.2	Per bunch of boiled seeds (about 10 per serving)	0.059 kg	3.4	0.9	Assumption: Average number of seeds in a fruit is 59 with an average weight of 350 g. A bunch of 10 seeds is assumed to weigh approximately 59 g (0.059 kg). Based on pictures from local observations and Bennett and Nozzolillo (1987).
• Asana (Chrysophyllum albidum)	0.5	Per fruit	0.2 kg	2.5	0.7	Assumption: 0.2 kg per fruit (based on local observations).
RATTANS	-	-	-	-	-	-
Cane (mfia)	1	1.5 m piece	0.00558 kg	179.2	47.0	Assumption: A cane piece of 152.4 m (500’) long is estimated to weigh approximately 567g (1 1/4 lbs) (based on information from online sellers). Therefore, a 1.5 m piece weighs approximately 5.58 g (0.00558 kg)
Chewing stick	1	Per bundle (5 sticks)	0.03 kg	33.3	8.7	Assumption: weight of a bundle is approximately 0.03 kg (based on information from online sellers)
Bath Sponge	15	Per bunch	-	-	-	No information about weight. Local observations indicate that it is not common in local markets anymore (A Rocha, pers. comm.)
Chewing sponge	5	Per bunch	0.2 kg	22.2	5.8	Assumption: between 0.2 - 0.25 kg per bundle, average 0.225 kg (based on local market observations)
Spices:	-	-	-	47.6	12.5	Average price (this estimate is used for further calculations based on spices).
• Soro wisa (Piper guineense)	10	Per 500 m	0.3 kg	40.0	10.5	Assumption: Based on the estimated density of black pepper (approximately 500 g/l), the weight of 500 ml of Soro wisa is calculated as 250 g (0.25 kg)

	Price per unit (Gh₵)	Unit of measurement	Estimated amount (kg or m^3 per unit)	Price (Gh₵ per kg or m^3)	Price (US$ per kg or m^3)	REMARKS AND ASSUMPTIONS FOR UNIT CONVERSIONS
	A ROCHA (PERS. COMM., 2016)					
• Fom wisa (Aframomum melegueta)	24	Per 500 ml	0.3 kg	96.0	25.2	Assumption: Based on the estimated density of black pepper (approximately 500 g/l), the weight of 500 ml of Fom wisa is calculated as 250 g (0.25 kg)
• Prekese (Tetrapleura tetraptera)	1	Bunch of three	0.2 kg	6.7	1.7	Assumption: Pods weigh roughly about 50 g each. Three pods weigh 150 g (0.15 kg) (based on local market observations)
HERBS						
Wrapping leaves	2	Per bundle	0.2 kg	8.9	2.3	Assumption: weight of 0.2 - 0.25 kg per bundle, average: 0.225 kg (based on local market observations)
Bush meat:				35.9	9.4	Average price (this estimate is used for further calculations on bush meat).
• Grasscutter	200	Full grown animal	3.8 kg	53.3	14.0	Assumption: average weight female 3 kg and male 4.5. Average weight for calculations 3.75 kg (based on Lionelle, 2012; Opara, 2010)
• African giant rat	30	Full grown animal	1.3 kg	24.0	6.3	Assumption: Average weight 1.25 kg (based on Nowak, 1999; Kingdon, 2015)
• Maxwell's Duiker	200	Full grown animal	8.0 kg	25.0	6.6	Assumption: Average weight 8 kg (based on Kingdon, 2015)
• Tree Pangolin	100	Full grown animal	2.3 kg	43.5	11.4	Assumption: Average weight 2.3 kg (based on Kingdon, 2015)
• Brush-tailed Porcupine	120	Full grown animal	3.3 kg	36.9	9.7	Assumption: Average weight 3.25 kg (based on Kingdon, 2015)
• Monkey spp.	150	Full grown animal	7.8 kg	19.4	5.1	Assumption: Average weight 7.75 kg (based on Kingdon, 2015)
• Ahanta francolin (akokohwedie)	25	Full grown animal	0.5 kg	49.0	12.9	Assumption: Average weight 0.51 (based on McGowan and Madge, 2010)
TIMBER FOREST PRODUCTS:						
Timber	-	-	1 m3	629.4	165.0	Assumption: average domestic price of timber is estimated as 165 US$m3 (Based on information from ITTO, 2013)
Mortar (Ghanaian)	65	Per small size - Per big size	1,5 kg	97.5	25.6	Assumption: average weight of mortar (small and big size) estimated as 1.5 kg (based on local market observations). Average price is estimated at Gh₵65 (50 for small size and 80 for a big size mortar; A Rocha and K. Ansah; pers. comm.)
Pestle (Ghanaian)	8.5	Per tree sapling	0.4 kg	3.4	0.9	Assumption: average weight of mortar (small and big size) estimated as 0.4 kg (based on field observations and online shipping details of similar products)
Construction poles	-	-	-	-	0.0	-
Fuel wood	10	Per bundle	40 kg	0.3	0.1	Assumption: weight of one bundle of about 40 kg (based on local market observations)

ANNEX F TYPES OF DATA USED

Relevant data for the study were collected in the period from June till November 2015. The data collection process included both, secondary and primary information, as described below.

Secondary data

The research team consulted numerous knowledgeable stakeholders and research institutes to discuss the data availability within the scope of the study. The collection of secondary data resulted in an archive containing structured available data sources for environmental management that will serve to facilitate future research in the area.
Secondary data was collected within the following fields:

- Relevant **ecological data** was collected to assess the status and trends of important ecosystems and threats to these ecosystems. The collected data consists of habitat maps, species abundance, trends in ecosystem quality and environmental threats to the ecosystems within the study scope. The ecological data form the basis for the ecological assessment in chapter 2 of the study. Furthermore, the ecosystem quality and trends will form the link between the land use scenarios and ecosystem services in the Atewa Range.

- To develop the hydrological analysis, the team collected **hydrological data** for the Densu River Basin. Important threats to water quality, such as gold mining, and water abstraction rates were identified and quantified. Meteorological and geophysical data was collected to support the development of the hydrological model.

- **Socioeconomic data** and policy documents were collected to support the valuation of ecosystem services (chapter 5) and to develop policy recommendations. The team collected information on relevant economic activities and ecosystem benefits related to the ecosystem services of the Atewa Range, such as drinking water, water for agriculture, timber and non-timber products, carbon sequestration and tourism. Population statistics were important to support the scenario development.

As it is common in transdisciplinary ecosystem service valuation studies, such as this one, the team faced serious data gaps. Although the data collection process generated relevant information, these data gaps represented an important challenge for the final analysis. To overcome this limitation, researchers consulted the international literature to make well founded assumptions.

The available data, the data gaps and the assumptions associated to the different steps in the analysis are elaborately described in the corresponding chapters of the report.

Primary data: survey on water provisioning in Greater Accra

An important gap in the already available data for the study was the lack of information about the water use by downstream households and their willingness to pay for reliable water from the Atewa Range. This limitation was tackled by conducting a household survey to assess the importance of water provided by the Atewa Forest, people's awareness about their water source and their support to protect it.

Approximately 400 households were interviewed by students of the KNUST University in the western area of Accra that is served with water coming from the Weija Lake. The results of the survey enabled researchers to quantify the importance attributed by the population in Accra to the Atewa Range and their willingness to pay for its protection as a source of water.

Questionnaire on water provisioning in Greater Accra

SURVEY ON WATER PROVISIONING IN GREATER ACCRA

Name Interviewer:		**Interview ID no.:**
Date of interview:		
District / Neighbourhood:	Rural / Urban:	
Start time/end time of interview	Start time:	End time:

HELLO MY NAME IS.............................. AND I AM HELPING THE GHANAIAN FORESTRY AND WATER RESOURCE COMMISSION WITH THEIR RESEARCH ON THE QUALITY OF THE WATER SUPPLY IN GREATER ACCRA. WE ARE INTERESTED IN YOUR OPINION. **EVERYTHING THAT YOU TELL US WILL BE KEPT STRICTLY CONFIDENTIAL**. THE INTERVIEW WILL TAKE ABOUT **20 MINUTES**. WOULD YOU BE WILLING TO PARTICIPATE?

A.GENERAL QUESTIONS

1. In which neighbourhood of Accra do you live?

1) Dansoman and immediate surrounding areas	☐
2) Bortianor and immediate surrounding areas	☐
3) Mallam and immediate surrounding areas	☐
4) Kasoa and immediate surrounding areas	☐
5) Achimota and immediate surrounding areas	☐
6) Ofankor and immediate surrounding areas	☐
7) Other, please specify:	

2. Can you specify the number of adults (including yourself) and the number of children in your household that you share your expenses with?

1) Number of adults (above 18)	....
2) Number of children (under 18)	....

B.WATER SOURCE, USE AND EXPENDITURE

3. Do you have a pipe connection with the Ghana Water Company for your water supply?

Yes	☐
My neigbourhood has a standing pipe connection	☐
No *(continue with question 8)*	☐

(INTERVIEWER: CAN WE ASK TO KEEP YOUR WATER BILL OF LAST MONTH IN MIND TO EASILY RESPOND TO OUR QUESTIONS?)

4. What is your water consumption per month from your Ghana Water Company connection? ....Liters (or different unit of measure, specify and convert to an estimate in liters: ....)

5. Do you share your water connection with other households?

Yes	☐
No	☐

6. How much did you pay for the Ghana Water Company pipe connection last month (if your share your water bill, mention your own contribution)? ....Cedis

7.Do you or your family drink the water coming from the Ghana Water Company?

Yes	☐
Yes, but I filter/boil it first	☐
No	☐

8. Do you make use of other water resources and what do you use these for?

Source	Drinking water	Personal hygiene	Household chores	Other, specify:
a. Water truck	☐	☐	☐	☐
b. Borehole	☐	☐	☐	☐
c. Lake, river, rain	☐	☐	☐	☐
d. Bottled / sachet water	☐	☐	☐	☐
e. Neighbour's connection	☐	☐	☐	☐
f. Others, pls. specify:	☐	☐	☐	☐

9. If water FROM OTHER WATER SOURCE is bought, how much additional money do you spend PER MONTH, on average? .... Cedis

C. WATER QUALITY AND QUANTITY CONCERNS

10. Did you in the last 2 years experience problems with the water quality? *(multiple answers possible)*

☐ Dirty water (taste, colour, and smell)
☐ Diseases caused by water supply (e.g. diarrhoea)
☐ Others, please specify:

11. How many days per month can you get water from your faucet/tap in the month with the worst water supply? *(please check ONE)*

☐ Never
☐ 1 - 5 days per month
☐ 6 - 15 days per month
☐ 15 - 25 days per month
☐ 25 - all days per month

12. Do you have a water tank or other means to store water?

☐ Yes
☐ No *(go to question 14)*

13. How many days can your water storage provide your household with water?

.... Days

14. What do you think is the main cause of water supply problems in Accra (choose 1)?

1) Busted pipes	☐
2) Insufficient raw water during the dry season	☐
3) Management by Ghana Water Company	☐
4) Too many water users	☐
5) Deforestation or other environmental issues	☐
6) Others, please specify:	☐

D. WATER SUPPLY SOURCE

15. Where do you think that the Ghana Water Company gets the water it is distributing to your household? *(multiple answers possible)*

Rainwater	☐
Volta Lake	☐
Densu River / Weija Lake	☐
Seawater	☐
Well / Groundwater	☐
Others, pls. specify:	☐
I don't know	☐

16. Are you familiar with the Atewa Range Forest Reserve?

Yes	☐
Somewhat familiar	☐
No *(continue with question 19)*	☐

17. What do you know about the Atewa Range? The Atewa Range is a… *(multiple answers possible)*

Source for bush meat	☐
Source for timber	☐
Gold mining area	☐
Potential bauxite mining area	☐
Wildlife area	☐
Microclimate	☐
Tourist attraction	☐
Water source for important rivers	☐
Forest Reserve	☐
I don't know	☐
Others, please specify:	☐

18. Which of the following threats facing the Atewa Forest, the Densu River and Weija lake do you consider the most important? *(Choose one)*

1) Farming activities	☐
2) Gold and bauxite mining	☐
3) Waste / pollution	☐
4) Industrial activities / factory's	☐
5) Sewerage	☐
6) Chainsaw logging	☐
7) Hunting	☐
8) Other, specify:	☐
	☐

19. Are you aware that the Atewa Forest is the source for the water in the Densu River and the Weija Lake?

Yes	☐
Somewhat aware	☐
No	☐

20. Do you agree with the following statements? *(1. Completely disagree - 5. Completely agree)*

	Completely disagree		Neutral		Completely agree	Don't know
	1	2	3	4	5	
1) The Densu River and Weija Lake are well managed	☐	☐	☐	☐	☐	
2) The Atewa Range Forest Reserve should become a National Park	☐	☐	☐	☐	☐	

E. ADDITIONAL MANAGEMENT

(PLEASE READ THE FOLLOWING TEXT OUT LOUD)

The Ghana Water Company currently uses the Weija lake in the Densu River as an important source for the water supply in Accra. The Atewa Range Forest Reserve is the source for the water in the Densu River and Weija Lake.

Unfortunately, the Atewa Range Forest Reserve experiences deforestation due to a number of pressures: an increase in farming, gold mining, timber exploitation, and trade in forest products. Also, there is a potential but serious threat to the forest because of the possibility for large-scale bauxite mining.

Degradation of the Atewa Range Forest Reserve threatens the quality and quantity of the water supply of Accra.

Protecting the Atewa Forest and the Densu river from these threats requires financial resources. **An environmental tax on top of your monthly water bill** could support the protection of the Atewa Forest, Densu River and Weija Lake, thereby securing the water supply for Accra.

21. Are you in principle willing to pay an additional amount on top of your monthly water bill to protect Atewa Forest, the Densu River and thereby the water supply of Accra?

1) Yes *(continue with question 23)*	☐
2) No *(continue with next question)*	☐

22. If you are not willing to pay for protection, what is your main reason? *(After this question, continue with the Choice Experiment)*

1) I do not care enough about the water supply of Accra or the Atewa forest	☐
2) I cannot financially afford to contribute	☐
3) I do not cause problems to the Atewa Forest or the Densu River and am not responsible for solving them	☐
4) I do not trust that the funds will be spend wisely	☐
5) Other, specify:	☐

23. If you are willing to pay, what is the maximum amount you are willing to pay per month? This amount would be charged on top of your monthly water bill? The funds will be used to pay for protection of the Atewa Forest and the Densu River? (Carefully take into account whether you can and are willing to pay this amount given your current income level)

0 Cedis	5 Cedis	12 Cedis	25 Cedis	50 Cedis	100 Cedis	250 Cedis	1000 Cedis
1 Cedis	7 Cedis	15 Cedis	30 Cedis	65 Cedis	125 Cedis	350 Cedis	More than 1000 Cedis
3 Cedis	9 Cedis	20 Cedis	40 Cedis	80 Cedis	150 Cedis	500 Cedis	Don't know

You can fill an amount from the table below or any other amount in this box: ....**Cedis** per month

24. Indicate on a scale between 1 to 5 how certain you are about your choice of the amount: 1 means *"not certain at all"* and 5 *"fully certain"*

Uncertain	←		→	Certain
1	2	3	4	5

F. CHOICE EXPERIMENT

IMPORTANT: FILL VERSION NUMBER ....

REFER TO THE INTERVIEW PROTOCOL
[REMIND THE RESPONDENT THAT THIS IS AN ANONYMOUS QUESTIONNAIRE AND THAT THIS EXPIREMENT IS HYPOTHETICAL AND THAT THEY SHOULD CHOOSE THE SCENARIOS REGARDLESS OF WHO IS MANAGING THE FUNDS]

SHOW THE EXAMPLE CHOICE CARD HERE

The following questions ask you to make a choice between three scenarios for the future state of the Atewa Forest and the water supply of Accra. The scenarios are described in terms of the following aspects:

- **Water availability** refers to the amount of days per month that water is available from your Ghana Water Company connection.

- **Water quality** refers to whether you can drink the water. If the quality is high, it is potable straight from the tap. If not, it has to be boiled or treated at home with filters before drinking.

- **Atewa forest management** refers to the level of protection of the Atewa Range. The Atewa Range can become a National Park, or remain the forest reserve that it currently is. Becoming a National Park will increase the level of protection significantly.

- An additional payment in the form of an **environmental tax** per month on your water bill. This payment will be strictly used for management of the Atewa Range, Densu River and Weija Lake.

(SHOW ON THE EXAMPLE CHOICE CARD THAT THE ITEMS FOR ONE SCENARIO BELONG TOGETHER AND INDICATE THAT HE/SHE SHOULD CHOOSE ONE OF THE THREE SCENARIOS). Be aware that none of the choices has a clear-cut best scenario and that you will need to make trade-offs between the different aspects. There are no wrong answers - we are only interested in your opinion!

Please look at the 3 options shown in the example card. To make a choice between the 3 options you should look at all of the items that shape the option (water availability, water quality, Atewa forest management, environmental tax,)

- **In Option A** water is available from you Ghana Water Company connection every day of the month. The water from the tap is potable (drinkable). Atewa Forest is protected. The environmental tax on top of your water bill is 200 Cedis per month.

- **In Option B** water is available from you Ghana Water Company connection for 15 days per month. The water from the tap is potable (drinkable). Atewa Forest is not protected. The environmental tax on top of your water bill is 50 Cedis per month.

- **In Option C** water is available from you Ghana Water Company connection on 5 days of the month. The water from the tap is not potable (drinkable). Atewa Forest is not protected. There is no environmental tax on your water bill. Option C will remain the same in each choice card.

You will be asked to make a choice **seven times**. In each question, the options on offer will be different. Try to imagine in which situation you would prefer to be, taking into account the payment, and then choose that option. Options A and B are different in each question. Please note that none of the options will be perfect from your point of view and that some decisions may be difficult. Every card represents a new choice and has nothing to do with the previous choice.

(FOR THE FIRST CHOICE CARD TRY NOT TO HELP THE RESPONDENT TOO MUCH, UNLESS HE REALLY DOESN'T UNDERSTAND. JUST BRIEFLY POINT OUT THE DIFFERENCES BETWEEN THE OPTIONS IF NECESSARY BUT TRY TO GIVE A BALANCED PRESENTATION. DO NOT LET YOUR VALUES AND PREFERENCES INFLUENCE THE RESPONDENT'S CHOICE!! AFTER ALL CHOICES ARE MADE, ASK THE RESPONDENT THE FOLLOW UP QUESTIONS. IF THE RESPONDENT REFUSES TO MAKE A CHOICE, TRY TO FIND OUT WHY.)

25. Record the respondent's answers to each choice question and the certainty of the choice in the table below *(Check only one box per row)*.

VERSION:	Option A	Option B	Option C	Declined to answer
Choice Card 1				
Choice Card 2				
Choice Card 3				
Choice Card 4				
Choice Card 5				
Choice Card 6				
Choice Card 7				

26. Please indicate on a scale from 1 to 5 how certain you are about the choices you just made.

Uncertain ←			→	Certain
1	2	3	4	5

(ONLY ASK THE FOLLOWING QUESTION IF THE RESPONDENT HAS CHOSEN OPTION C EACH TIME OR DECLINED TO ANSWER, OTHERWISE GO TO QUESTION 28)

27. You have chosen the option C in each card or declined to answer. Can you explain why? (Check only one)

1) I do not think that additional protection is worth doing	☐
2) I am not confident that the money will be used as specified	☐
3) The issues are more complex than these questions suggest	☐
4) I cannot afford it / The costs were too high	☐
5) I couldn't understand the questions/ Too hard to make the choices	☐
6) The choices weren't relevant to me / Didn't describe what matters to me	☐
7) Don't know / Refuse to answer	☐
8) Other, specify...	☐

28. In making your choices, how important were the following attributes to you? *(1 being not important and 5 being very important)*

	Not important 1	2	Neutral 3	4	Very important 5
1) Water availability	☐	☐	☐	☐	☐
2) Water quality	☐	☐	☐	☐	☐
3) Atewa Forest management	☐	☐	☐	☐	☐
5) Environmental tax	☐	☐	☐	☐	☐

G. DEMOGRAPHICS

(REMINDER: THE FOLLOWING QUESTIONS ARE FOR STATISTICAL PURPOSES ONLY)

29. Gender:

1) Male	☐
2) Female	☐

30. How old are you?

1) 18-19	☐	7) 45-49	☐
2) 20-24	☐	8) 50-54	☐
3) 25-29	☐	9) 55-59	☐
4) 30-34	☐	10) 60-64	☐
5) 35-39	☐	11) 65-69	☐
6) 40-44	☐	12) 70+	☐

31. In which field are you employed?

1) Self-employed	☐
2) Skilled labourer	☐
3) Government employee	☐
5) Scientific, technical activities	☐
7) Unemployed	☐
8) Other, please specify:	☐

32. What is the highest level of education that you have completed?

1) None	☐
2) Primary school	☐
3) Secondary school / middle school	☐
4) Vocational / technical training	☐
5) University / Bachelor's degree	☐
6) University / Master's degree or other post-graduate	☐
7) Declined to answer	☐
8) Other, specify:	☐

33. What is the income earned in your household after taxes in Cedis last month?

(REFER TO INCOME CARD AND REMIND THE RESPONDENT THAT YOU ARE NOT AWARE OF THE MEANING OF THE INCOME CATEGORIES DUE TO THE RANDOM LETTERING)

LETTER: ....

34. (FOR THE INTERVIEWER): DID YOU HAVE TO TRANSLATE FOR THE RESPONDENT?

1) Yes, everything	☐
2) Yes, some words	☐
3) No, nothing	☐

35. If you have any other comments, please leave them in the box below:

(IF THE RESPONDENT WANTS TO LEAVE HIS OR HER PERSONAL INFORMATION IN ORDER TO RECEIVE INFORMATION OF THE REPORT, ASK HIM OR HER TO DO SO NOW AND RECORD IT)

Name (optional):
Phone (optional):
E-mail (optional):

THIS IS THE END OF THE QUESTIONNAIRE; THANK THE RESPONDENT FOR HIS/HER TIME AND PATIENCE!!!

General results of household survey in greater Accra

This appendix summarizes the responses to the household survey conducted in Accra in the period of February – June 2015. The survey was answered by a total of 417 people. The results provided below include valid answers to the most relevant questions to describe the demographics, use of water, water quality and quantity issues, perception of the Atewa Range and opinion on the Forest Reserve's management of the surveyed population.

Demographics and general questions

The tables below present the main variables that describe the population analysed in the survey. In general, the majority of respondents are between 20 and 39 years old, are self-employed and most of them has at least secondary education.

GENDER	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL
Male	177	43%
Female	235	57%
Total	**412**	

Table 59 Gender of the surveyed population

AGE	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL
18-19	17	4%
20-24	55	14%
25-29	69	17%
30-34	61	15%
35-39	48	12%
40-44	28	7%
45-49	37	9%
50-54	32	8%
55-59	30	7%
60-64	12	3%
65-69	10	2%
70+	8	2%
Total	**407**	

Table 60 Age of the respondents to the survey

TYPE OF EMPLOYMENT	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL
Self-employed	228	58%
Skilled labourer	54	13%
Government employee	31	8%
Scientific, technical activities	18	4%
Unemployed	42	10%
Other (specify)	35	9%
Total	**408**	

Table 61 Type of employment of the respondents to the survey

HIGHEST LEVEL OF EDUCATION	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
None	30	7%
Primary school	42	10%
Secondary/middle school	211	51%
Vocational/technical training	46	11%
University/Bachelor's degree	47	11%
University/Master's degree or other	6	1%
Decline to answer	11	3%
Other (specify)	17	4%
Total	**410**	

Table 62 Highest level of education of the survey respondents

NEIGHBOURHOOD OF RESIDENCE	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
For Dansoman and immediate surrounding areas	49	12%
Bortianor and immediate surrounding areas	26	6%
Mallam and immediate surrounding areas	79	19%
Kasoa and immediate surrounding areas	30	7%
Achimota and immediate surrounding areas	71	17%
Ofankor and immediate surrounding areas	26	6%
Others (Specify)	136	33%
Total	**417**	

Table 63 Neighbourhood of residence of the survey respondents

Water source, use and expenditure

The following results describe the use of water from the Ghana Water Company (GWC) by the surveyed population.

PIPE CONNECTION WITH THE GWC FOR WATER SUPPLY	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
Yes	235	56%
Neighbourhood standing pipe	21	5%
No	159	38%
Total	**416**	

Table 64 Respondents with pipe connection to the GWC

SOURCE OF DRINKING WATER	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL SAMPLE
Drinks water from the GWC:	113	27%
Yes, drinks water from the GWC	92	22%
Yes, but boil/ filter it first	21	5%
Does not drink water from the GWC:	146	35%
Drinks water from other sources:	368	88%

Table 65 Source of drinking water for the surveyed population

SOURCE OF WATER FOR GWC	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL SAMPLE
Rainwater	6	1%
Volta Lake	26	6%
Densu &Weija	296	71%
Seawater	6	1%
Well/Groundwater	6	1%
Others	13	3%
I don’t know	92	22%

Table 66 Perception of the water source for the GWC. Answers to the questions: Where do you think that the Ghana Water Company gets the water it is distributing to your household?*

* The answers to this question were not exclusive, and hence, the percentages of respondents with respect to the total sample do not add up 100%.

Water quality and quantity issues

This section describes the main issues around water provision faced by the respondents to the survey. Furthermore, it presents the water supply in the period with worst supply.

WATER QUALITY PROBLEMS	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL SAMPLE*
Dirty water	247	59%
Diseases	6	1%
Others	40	10%

Table 67 Water supply problems faced by respondents to the survey

* The answers to this question were not exclusive. Therefore, the percentages do not total 100%.

NO. OF DAYS WITH WATER SUPPLY IN A MONTH	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
1-5 days	56	14%
6-15 days	64	16%
16-25 days	101	26%
25-all days	83	21%
Never	84	22%
Total	**388**	

Table 68 Number of days with water supply in the month with worst water supply

Awareness of the Forest Reserve and the Atewa Range

The tables below provide insights into the awareness the Atewa Range and the Forest Reserve regarding the familiarity of respondents with the area, and their perception of the area as a source of benefits and on possible threats

FAMILIAR WITH FOREST RESERVE?	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
Yes	49	12%
Somewhat familiar	61	15%
No	305	73%
Total	**415**	

Table 69 Familiarity with the Forest Reserve. Answers to the question: Are you familiar with the Atewa Range Forest Reserve?

THE ATEWA RANGE IS A…	NO. OF RESPONDENTS	PERCENTAGE OF TOTAL SAMPLE*
Source of bush meat	11	3%
Source of timber	21	5%
Gold mining area	11	3%
Potential bauxite area	7	2%
Wildlife area	8	2%
Microclimate	1	0%
Tourist attraction	9	2%
Water source for important rivers	13	3%
Forest reserve	26	6%
I don't know	71	17%
Others	1	0%

Table 70 Perception of the Atewa Range as a source of benefits. Answers to the question: The Atewa Range is a …

* The answers to this question were not exclusive. Therefore, the percentages do not necessarily add up to 100%.

THREATS	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
Farming activities	6	5%
Gold and bauxite mining	42	38%
Waste/pollution	18	16%
Industrial activities	1	1%
Sewerage	5	5%
Chainsaw logging	9	8%
Hunting	1	1%
Others (specify)	28	25%
Total	**110**	

Table 71 Threats on the Atewa Forest, Densu River and Weija Lake according to respondents to the survey

Opinion on Atewa Range Forest Reserve and water resource management

The answers presented in the tables in this section reflect the opinions of the survey respondents on water management and on giving the National Park status to the Forest Reserve.

DEGREE OF AGREEMENT	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
Disagree	130	31%
Neutral	65	16%
Agree	115	28%
Don't know	103	25%
Total	**413**	

Table 72 Degree of agreement with the statement: 'The Densu River and the Weija Lake are well managed'

DEGREE OF AGREEMENT	NO. OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
Completely agree	17	4%
Neutral	24	6%
Completely disagree	272	67%
Don't know	96	23%
Total	**409**	

Table 73 Degree of agreement with the statement: 'The Atewa Range Forest Reserve should become a National park'

RESULTS OF THE CHOICE EXPERIMENT IN GREATER ACCRA

Choice behaviour and choice consistency

A substantial share of 65 respondents (15.6%) did not complete the choice experiment and could therefore not be included in the analysis presented here. Only those respondents were kept in the analysis who answered at least 3 of the 7 choice cards. A majority of 91 percent of the remaining respondents answered all 7 choice cards, 5 percent six choice cards and the remaining 4 percent 3, 4 or 5 cards. Only 4 respondents consistently chose the opt-out for protest reasons, most importantly due to a lack of trust that the money would be spent appropriately for the purpose at hand. The distribution of the choices across the 7 choice cards is shown in Figure 44. Overall, the first option is chosen slightly more often (48.9%) than the second option (44.9%), especially in the first two choice cards. The share of opt-out choices is more or less constant across the seven choice cards, on average across all 7 choice cards 6.2 percent and at most 7.6 percent in choice card 2.

The fact that the seventh choice card offered to respondents is identical to the first one, choice consistency can be tested. In this study, 80.2 percent of the respondents who answered both the first and seventh choice card chose exactly the same alternative in both choice occasions. This is somewhat higher than the 73 percent reported in Brouwer *et al.* (2010) and means that one in every fifth respondent was not consistent in his or her choice behaviour. This may have various underlying reasons, including preference learning. Regressing whether or not a respondent consistently chose the same choice alternative at the start and the end of the choice experiment in a binary logistic or probit model on various demographic (e.g. sex, age, household size) and socio-economic (e.g. income) respondent characteristics yields no significant results, implying that these characteristics play no role in explaining choice consistency. The same applies to self-reported choice certainty (measured between 1 and 5) between respondents who consistently chose the same alternative in choice cards 1 and 7 and those who did not (standardized Mann-Whitney test statistic is -0.409, *p*=0.682).

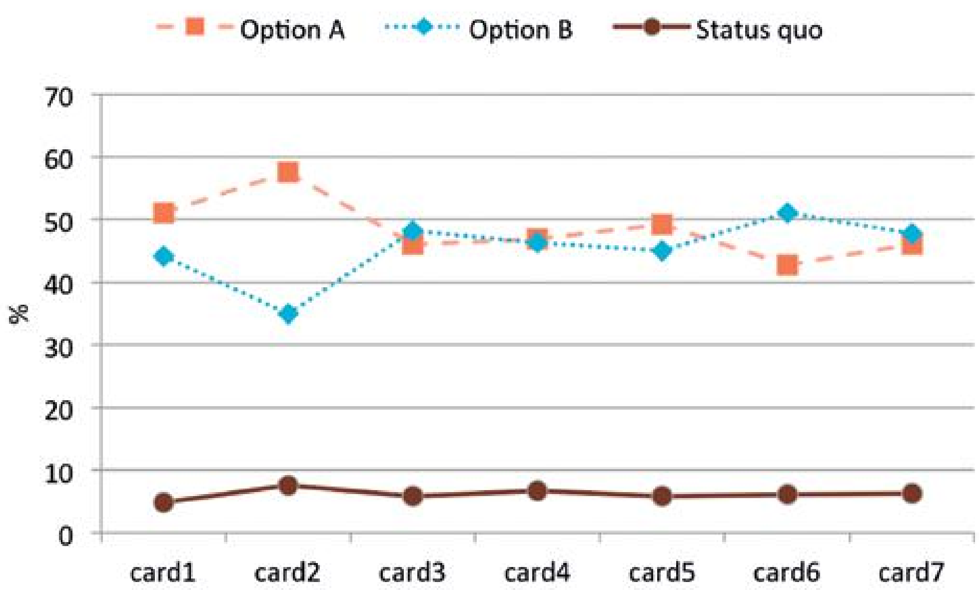


Figure 44 Choice share across choice options and choice tasks

Estimated choice models

Respondent choices were regressed on the choice attributes and various other explanatory factors in a random parameters logit (RPL) model in NLOGIT version 5.0. No significant correlation could be detected between the choice alternatives when adding an error component to the RPL model. In order to increase their statistical efficiency, the models were estimated using 500 Halton draws (Bhat, 2001). The estimated models accounts for the panel structure of the data, including 6 choices per respondent since the first and seventh card are identical, and preference heterogeneity in the estimated parameters of the choice attributes. Following the recommendation in Hensher *et al.* (2005), dummy variables have a uniform distribution. Based on the log-likelihood function, the estimated models perform best when using a normal distribution for the parameters related to the continuous variables for water availability and environmental tax. Two models are presented in Table 74: the basic RPL model including the choice attributes only (Model 1) and an extended RPL model including covariates (Model 2). Numerous combinations of possible additional explanatory factors were tested for their statistical significance in the estimated choice models. The variables presented here are based on theoretical expectations and existing empirical evidence in the literature. The estimated models are highly significant as can be seen from the Likelihood Ratio chi-square test and also the McFadden pseudo R-square is very high for this type of cross-section analysis. The number of observations is lower in Model 2 than in Model 1 due to missing values for some of the covariates.

As expected based on extensive pre-testing of the experimental design, the coefficient estimates of the choice attributes are all highly significant at the one percent level in both Model 1 and 2, including the distribution of their random parameters. The latter indicates that there exist significant differences between individual respondents in their valuation of the choice attributes (preference heterogeneity). The distributions around the mean coefficient estimates are wide in view of the fact that the standard deviations of the random parameters are consistently bigger than their means for all choice attributes in absolute terms. The mean coefficient estimates also all have the correct signs: respondents are more likely to choose one of the hypothetical water supply options the more reliable water supply measured in number of days per month is, if water quality is such that no treatment is required before drinking, and the Atewa forest becomes a National Park to increase the level of protection of this water source for urban residents in Accra. As expected, the higher the environmental tax over and above a household's monthly water bill, the lower the likelihood that the water supply options are chosen over and above the status quo. The alternative specific constants (ASC's) are also significant at the one percent. The positive coefficients indicate that all else being equal, respondents prefer some change (as specified through the hypothetical water supply options) than no change and stay with the status quo.

The effect of various socio-demographic respondent characteristics on choice behaviour was tested. Only a significant effect could be detected for female household members. As can be seen from Table 74, female respondents are significantly more likely to agree than male respondents to the proposed increase in their water bill for more reliable water supply. This is probably due to the fact that women are most directly affected by reliable water supply since they are usually most involved in household activities that require reliable water supply, such as cooking and food preparation.

No significant effect was found for other socio-demographic variables such as a respondent's age, the number of household members, how many children there are in every household, a respondent's education level or a household's income. The latter variable is an important predictor of willingness to pay but is highly correlated with the residential area where respondents live. Given the fact that a large share of the respondents was unwilling to share information with the interviewers about their household income (26.7%), dummy variables were therefore included for the residential areas and household income was omitted from the analysis to avoid a substantial reduction in the number of observations and multicolinearity. Compared to the baseline category of respondents living in any of the other 44 residential areas in Accra (n=111) than the ones listed in Table 74, respondents living in Bortianor, Mallam and Ofankor are significantly more likely to choose one of the two water supply options. Especially in Ofankor, mean household income was significantly higher than in the other residential areas. However, no significant differences exist between the coefficient estimates for these three residential areas when applying the Wald test[17].

	Model 1
Explanatory variables	**Coeff. est.**
ASC	16.052***
CHOICE ATTRIBUTES	
Water quality (1=no treatment required)	1.720***
Water supply (days/month)	0.035***
Atewa forest (1=national park)	1.484***
Environmental tax (Cedis/month)	-0.004***
COVARIATES	
Respondent sex (1=female)	
Respondent age (years)	
Choice attribute interaction terms	
Water quality x Children in household[1]	
Atewa forest x Familiar with Atewa[1]	
CURRENT WATER SUPPLY CONDITIONS	
Own water connection1	
Current water supply (days/month)	
Residential areas1	
Place of residence is Dansoman	
Place of residence is Bortianor	
Place of residence is Mallam	
Place of residence is Kasoa	
Place of residence is Achimota	
Place of residence is Ofankor	
SUMMARY STATISTICS	
Log likelihood	-1154.460
McFadden pseudo R^2	0.490
Chi-square (p<)	2217.362
Number of observations	2112
Number of respondents	352

NOTE

17 The outcome of the Wald test statistic is 2.05977 (p=0.357), -0.34271 (p=0.9246) and -2.40248 (p=0.4659) when comparing the coefficient estimates for Bortianor and Mallam, Bortianor and Ofankor, and Mallam and Ofankor respectively

Model 1			Model 2			
St. err.	St.dev. rp's	St. err.	Coeff. est.	St. err.	St.dev. rp's	St. err.
3.330	11.991***	2.188	7.536***	2.746	8.224***	1.763
0.151	2.125***	0.254	1.989***	0.334	2.166***	0.284
0.006	0.051***	0.009	0.033***	0.006	0.054***	0.010
0.148	2.312***	0.256	1.456***	0.164	2.257***	0.282
0.001	0.008***	0.001	-0.004***	0.001	0.008***	0.001
			2.370**	1.119		
			0.011	0.045		
			-0.232	0.335		
			0.083	0.362		
			2.583*	1.595		
			-0.099**	0.051		
			4.455	4.539		
			5.223**	2.287		
			3.164**	1.433		
			-2.501	2.551		
			2.871	2.035		
			5.566*	3.363		
			-997.802			
			0.493			
(0.001)			1939.625	(0.001)		
			1791			
			299			

Table 73 Estimated random parameters logit models

Explanatory notes: rp's are random parameters; ASC is the alternative specific constant; [1]dummy variable where 1=yes; * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Whether a household includes children was interacted with the choice attribute ‘improvement in water quality’. The expectation here was that households with children are more vulnerable to diseases like diarrhea due to poor drinking water quality (e.g. US EPA, 2003; Cameron *et al.*, 2010; Brouwer *et al.*, 2015) and therefore more interested in and hence willing to pay for improved water quality than households with no children. However, no such effect was picked up in the estimated choice models, also not when including the number of children. A possible explanation is that of those respondents who indicated that they experienced water quality problems over the last 2 years, only 5 respondents (1.4%) mention diseases like diarrhea.

Respondents who have their own (i.e. not shared) piped water connection are significantly (at the 10% level) more interested in the improved water supply options than respondents who do not. Here too a significant income effect plays a role (also at the 10% level): households who have their own piped water connection earn significantly higher incomes (standardized Mann-Whitney test statistic is 1.829, p=0.067). As expected, having currently already more reliable water supply significantly reduces demand for the improved water supply options. Other variables related to current water supply such as household water consumption, drinking water storage facilities and having access to other drinking water sources (substitution effects) do not play a significant role in explaining choice behaviour. The same applies to the current costs of household drinking water supply. Insufficient information was available from the survey about current drinking water treatment methods to also test their effect on the value respondents attach to the improvement of drinking water supply (Tarfasa and Brouwer, 2013)[18].

Finally, also the influence of respondent familiarity with the Atewa forest as an important drinking water source for Accra on household preferences for the forest to become a National Park and hence improve its protection level was tested. However, interacting this variable with the relevant choice attribute does not yield a significant effect.

Household willingness to pay for improved drinking water supply

Mean willingness to pay (WTP) values are derived from the estimated choice model including the attributes only (Model 1) and presented for 5 different policy options in Table 75. Standard errors are estimated using the Krinsky and Robb (1986) bootstrap procedure. The first row in Table 75 shows current average household spending on drinking water (US$24.5/month).

NOTE

18 Only 14 respondents indicated to boil their water before drinking (4%). Unfortunately due to the loop included in the questionnaire where respondents skipped questions if they indicated not to receive water from the Ghana Water Company this information was missing for 40 percent of the sample.

NO.	POLICY OPTION	WTP (CEDI/MONTH)	ST. ERROR (CEDI/MONTH)	95% CONFIDENCE INTERVAL (CEDI/MONTH)
0	Average current household water expenditures	90.9	8.8	73.5 - 108.2
1	No water treatment required	469.7	124.0	226.8 - 712.7
2	15 days per month tap water supply security	130.6	39.0	54.2 - 207.0
3	30 days per month tap water security	261.2	77.9	108.5 - 413.9
4	Atewa designated National Park	411.1	108.0	199.5 - 622.8
5	Scenario 1, 3 and 4 combined: 30 days per month tap water security, no treatment required, Atewa designated National Park	1,055.0	274.4	517.2 - 1,592.7

Table 75 Estimated mean WTP values for different water supply policy options

Note: 1 Ghanaian New Cedi (GHS) equalled on average US$0.27 in the month July 2015 (source: Oanda).

Total water expenditures are very high compared to the average household income. On average, a household in Accra spends 26 percent of its monthly income on drinking water. However, this share varies significantly across the residential areas (the outcome of the Kruskal-Wallis test statistic is 18.825, p=0.004). Although for half of the whole sample this share is 12 percent (median value), this is still a substantial amount of money.

Most of the estimated mean WTP values are several orders of magnitudes higher than what an average household currently spends on drinking water. The estimated WTP values reveal that households have a much higher preference for clean and safe drinking water than for improved supply reliability. Mean WTP is almost a factor 2 higher if respondents can drink water safely from the tap without prior treatment (US$126.8/month) than for having water available every day (US$70.5/month). Household WTP for tripling supply reliability from currently 5 days per month to 15 days per month is US$35. This hence doubles when offering respondents 100 percent supply reliability every month. Non-linear relationships were also tested in the estimated choice models presented in Table 74, but these non-linear relationships did not have a significant effect. Remarkable is also the relatively high WTP for increasing the protection status of Atewa as a National Park (US$111.0). This value is almost just as high as for the improvement in drinking water quality to a level where treatment is not necessary anymore.

Finally, the WTP values are relatively high given the maximum price of 200 Cedi per month in the choice experiment design. This is partly due to a fat tail problem: only in 6 percent of the choice occasions was the opt-out chosen, in all the other cases respondents chose one of the two hypothetical policy scenarios and were hence willing to pay the extra environmental tax on their water price. An important question that unfortunately cannot be answered here is the reason why 15 percent of the original sample refused to make the trade-offs presented in the choice experiment. If we assume that this was because they were unable to pay extra for the drinking water supply options that were offered to them, this would have lowered WTP substantially.

ANNEX G RESULTS OF MULTI-CRITERIA ANALYSIS ON TOURISM POTENTIAL OF NATURAL AREAS IN GHANA

Options	Overall score	No. of visitors	Entrance fee	Distance accra	Road accessibility	Highway 500	Agriculture suitability	Mineral deposits
Max. Rank	1.00	1	1	1	1	1	1	1
Kakum	0.79	1.00	0.91	0.80	0.99	0.00	0.98	1.00
Digya	0.73	0.00	1.00	0.18	0.00	1.00	0.57	0.79
Mole	0.69	0.70	0.85	0.00	0.72	1.00	0.57	0.28
Atewa	0.65	1.00	0.91	0.94	0.99	1.00	0.92	0.10
Kyabobo	0.64	0.02	0.97	0.23	0.93	1.00	0.57	1.00
Bui	0.62	0.02	0.97	0.04	0.99	0.00	0.57	0.00
Nini-Suhien	0.61	0.08	0.97	0.24	0.83	1.00	0.98	0.62
Shai-Hills	0.60	0.46	0.95	0.98	0.99	0.00	0.86	0.62
Bia	0.52	0.00	0.97	0.07	0.31	1.00	0.98	1.00
Min. Rank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weights		0.018	0.011	0.071	0.057	0.028	0.040	0.121

Settlements	Mammals	Birds	Big 5	Park size	POI	MGMT	Budget
1	1	1	1	1	1	1	1
0.77	0.51	0.80	0.60	0.53	0.96	0.91	0.51
0.98	1.00	0.69	0.80	1.00	0.98	0.72	0.10
0.98	0.44	0.49	1.00	1.00	0.50	0.99	0.64
0.40	0.95	1.00	0.40	0.39	1.00	0.91	0.26
0.88	0.63	0.35	0.80	0.54	0.00	0.52	1.00
0.95	0.90	0.52	0.80	0.98	0.65	0.99	0.10
0.90	0.61	0.38	0.60	0.67	0.29	0.72	0.16
0.05	0.56	0.86	0.40	0.10	0.89	0.91	0.94
0.67	0.80	0.42	0.60	0.48	0.00	0.31	0.15
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.153	0.034	0.062	0.178	0.015	0.11	0.083	0.017

ANNEX H ANNUAL VALUES OF COSTS AND BENEFITS IN DIFFERENT SCENARIOS

	Provisioning services				
	Non-timber products	Timber products	Atewa Range cocoa production	Water for agriculture	Water for consumption
2016	$12,390,228	$40,631,023	$9,335,528	$3,100,349	$25,058,711
2017	$12,328,448	$38,943,025	$9,275,575	$3,029,413	$24,425,558
2018	$12,266,668	$37,255,027	$9,215,621	$2,958,477	$23,792,404
2019	$12,204,888	$35,567,030	$9,155,668	$2,887,541	23,159,251
2020	$12,143,108	$33,879,032	$9,095,714	$2,816,605	$22,526,097
2021	$12,081,328	$32,191,034	$9,035,761	$2,745,669	$21,892,943
2022	$12,019,549	$30,503,036	$8,975,807	$2,674,733	$21,259,790
2023	$11,957,769	$28,815,039	$8,915,853	$2,603,797	$20,626,636
2024	$11,895,989	$27,127,041	$8,855,900	$2,532,860	$19,993,483
2025	$11,834,209	$25,439,043	$8,795,946	$2,461,924	$19,360,329
2026	$11,772,429	$23,751,045	$8,735,993	$2,390,988	$18,727,176
2027	$11,710,649	$22,063,048	$8,676,039	$2,320,052	$18,094,022
2028	$11,648,869	$20,375,050	$8,616,086	$2,249,116	$17,460,868
2029	$11,587,089	$18,687,052	$8,556,132	$2,178,180	$16,827,715
2030	$11,525,309	$16,999,054	$8,496,179	$2,107,244	$16,194,561
2031	$11,463,529	$15,311,057	$8,436,225	$2,036,308	$15,561,408
2032	$11,401,749	$13,623,059	$8,376,272	$1,965,371	$14,928,254
2033	$11,339,970	$11,935,061	$8,316,318	$1,894,435	$14,295,101
2034	$11,278,190	$10,247,063	$8,256,365	$1,823,499	$13,661,947
2035	$11,216,410	$8,559,066	$8,196,411	$1,752,563	$13,028,793
2036	$11,157,855	$7,991,132	$8,140,544	$1,702,066	$12,602,704
2037	$11,099,300	$7,423,199	$8,084,677	$1,651,569	$12,176,615
2038	$11,040,746	$6,855,265	$8,028,810	$1,601,072	$11,750,526
2039	$10,982,191	$6,287,332	$7,972,943	$1,550,575	$11,324,437
2040	$10,923,636	$5,719,398	$7,917,076	$1,500,077	$10,898,347
2041	$10,865,081	$5,151,465	$7,861,209	$1,449,580	$10,472,258
2042	$10,806,527	$4,583,531	$7,805,342	$1,399,083	$10,046,169
2043	$10,747,972	$4,015,598	$7,749,474	$1,348,586	$9,620,080
2044	$10,689,417	$3,447,665	$7,693,607	$1,298,089	$9,193,991
2045	$10,630,862	$2,879,731	$7,637,740	$1,247,592	$8,767,901

The following tables present the net annual values of the ecosystem services provided by the Atewa Range in the different scenarios over the 30-year period. Additional management costs of the National Park and the buffer zone are also included. The values presented below have not been discounted.

Scenario 1. Business as usual: annual net value (no discount applied)

Regulating services	Cultural services	Mining benefits		Management costs
Carbon sequestration (annual change)	Tourism (potential)	Bauxite alumina	Gold (average annual revenue)	Park management costs
$-243,140	$-	$-	$4,138,340	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-
$-243,140	$-	$-	$4,461,318	$-

Scenario 2. National Park: annual net value (no discount applied)

	Provisioning services				
	Non-timber products	Timber products	Atewa Range cocoa production	Water for agriculture	Water for consumption
2016	$12,390,228	$40,631,023	$9,335,528	$3,100,349	$25,058,711
2017	$12,328,448	$38,943,025	$9,275,575	$3,029,413	$24,425,558
2018	$12,266,668	$37,255,027	$9,215,621	$2,958,477	$23,792,404
2019	$5,288,791	$9,567,938	$9,155,668	$2,891,482	$23,159,251
2020	$5,238,154	$9,068,630	$9,095,714	$2,824,487	$22,526,097
2021	$5,187,517	$8,569,321	$9,035,761	$2,757,491	$21,892,943
2022	$5,136,880	$8,070,013	$8,975,807	$2,690,496	$21,259,790
2023	$5,086,242	$7,570,704	$8,915,853	$2,623,501	$20,626,636
2024	$5,035,605	$7,071,396	$8,855,900	$2,556,506	$19,993,483
2025	$4,984,968	$6,572,087	$8,795,946	$2,489,511	$19,360,329
2026	$4,934,331	$6,072,779	$8,735,993	$2,422,515	$18,727,176
2027	$4,883,694	$5,573,470	$8,676,039	$2,355,520	$18,094,022
2028	$4,833,056	$5,074,162	$8,616,086	$2,288,525	$17,460,868
2029	$4,782,419	$4,574,853	$8,556,132	$2,221,530	$16,827,715
2030	$4,731,782	$4,075,545	$8,496,179	$2,154,534	$16,194,561
2031	$4,681,145	$3,576,236	$8,436,225	$2,087,539	$15,561,408
2032	$4,630,508	$3,076,928	$8,376,272	$2,020,544	$14,928,254
2033	$4,579,870	$2,577,619	$8,316,318	$1,953,549	$14,295,101
2034	$4,529,233	$2,078,310	$8,256,365	$1,886,553	$13,661,947
2035	$4,478,596	$1,579,002	$8,196,411	$1,752,563	$13,028,793
2036	$4,433,102	$1,459,039	$8,140,544	$1,700,683	$12,602,704
2037	$4,387,609	$1,339,075	$8,084,677	$1,648,804	$12,176,615
2038	$4,342,116	$1,219,112	$8,028,810	$1,596,924	$11,750,526
2039	$4,296,622	$1,099,149	$7,972,943	$1,545,045	$11,324,437
2040	$4,251,129	$979,186	$7,917,076	$1,493,165	$10,898,347
2041	$4,205,635	$859,222	$7,861,209	$1,441,286	$10,472,258
2042	$4,160,142	$739,259	$7,805,342	$1,389,406	$10,046,169
2043	$4,114,648	$619,296	$7,749,474	$1,337,527	$9,620,080
2044	$4,069,155	$499,332	$7,693,607	$1,285,647	$9,193,991
2045	$4,023,661	$379,369	$7,637,740	$1,233,767	$8,767,901

Regulating services	Cultural services	Mining benefits		Management costs
Carbon sequestration (annual change)	Tourism potential (entrance fees	Bauxite alumina	Gold (average annual revenue)	Park management costs
$-243,140	$-	$-	$4,138,340	$91,382
$-243,140	$-	$-	$4,461,318	$91,382
$-243,140	$-	$-	$4,461,318	$91,382
$-209,026	$-	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382
$-209,026	$221,875	$-	$4,118,139	$91,382

Scenario 3. National Park and supporting buffer zone: annual net value (no discount applied)

	Provisioning services				
	Non-timber products	Timber products	Atewa Range cocoa production	Water for agriculture	Water for consumption
2016	$12,390,228	$40,631,023	$9,335,528	$3,100,349	$25,058,711
2017	$12,328,448	$40,294,456	$9,275,575	$3,029,413	$24,425,558
2018	$12,266,668	$39,957,890	$9,215,621	$2,958,477	$23,792,404
2019	$5,288,791	$9,567,938	$9,155,668	$3,029,413	$23,159,251
2020	$5,303,647	$9,051,848	$9,217,340	$3,100,349	$24,600,698
2021	$5,318,503	$8,535,758	$9,279,012	$3,100,349	$26,042,146
2022	$5,333,359	$8,019,667	$9,340,684	$3,100,349	$27,483,593
2023	$5,348,216	$7,503,577	$9,402,357	$3,100,349	$28,925,041
2024	$5,363,072	$6,987,487	$9,464,029	$3,100,349	$30,366,488
2025	$5,377,928	$6,471,396	$9,525,701	$3,100,349	$31,807,936
2026	$5,392,784	$5,955,306	$9,587,374	$3,100,349	$33,249,383
2027	$5,407,640	$5,439,216	$9,649,046	$3,100,349	$34,690,831
2028	$5,422,496	$4,923,126	$9,710,718	$3,100,349	$36,132,278
2029	$5,437,352	$4,407,035	$9,772,390	$3,100,349	$37,573,726
2030	$5,452,208	$3,890,945	$9,834,063	$3,100,349	$39,015,173
2031	$5,467,064	$3,374,855	$9,895,735	$3,100,349	$40,456,621
2032	$5,481,921	$2,858,764	$9,957,407	$3,100,349	$41,898,068
2033	$5,496,777	$2,342,674	$10,019,080	$3,100,349	$43,339,516
2034	$5,511,633	$1,826,584	$10,080,752	$3,100,349	$44,780,963
2035	$5,526,489	$1,310,493	$10,142,424	$3,100,349	$46,222,411
2036	$5,541,755	$1,205,982	$10,208,089	$3,100,349	$48,317,082
2037	$5,557,022	$1,101,471	$10,273,754	$3,100,349	$50,411,754
2038	$5,572,288	$996,960	$10,339,420	$3,100,349	$52,506,426
2039	$5,587,555	$892,449	$10,405,085	$3,100,349	$54,601,097
2040	$5,602,821	$787,938	$10,470,750	$3,100,349	$56,695,769
2041	$5,618,088	$683,427	$10,536,415	$3,100,349	$58,790,440
2042	$5,633,354	$578,915	$10,602,080	$3,100,349	$60,885,112
2043	$5,648,621	$474,404	$10,667,745	$3,100,349	$62,979,783
2044	$5,663,887	$369,893	$10,733,410	$3,100,349	$65,074,455
2045	$5,679,154	$265,382	$10,799,075	$3,100,349	$67,169,127

Regulating services	Cultural services		Mining benefits		Management costs
Carbon sequestration (annual change)	Tourism (entrance fees	Tourism expenditures	Bauxite alumina	Gold (average annual revenue)	Park management costs
$-243,140	$-	$-	$-	$4,138,340	$182.527
$-243,140	$-	$-	$-	$4,461,318	$182.527
$-243,140	$-	$-	$-	$4,461,318	$182.527
$43,129	$332,813	$4,050,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527
$43,129	$443,750	$5,400,000	$-	$-	$182.527

Scenario 4. Complete degradation: annual net value (no discount applied)

	Provisioning services				
	Non-timber products	Timber products	Atewa Range cocoa production	Water for agriculture	Water for consumption
2016	$12,390,228	$40,631,023	$9,335,528	$3,100,349	$25,058,711
2017	$11,844,514	$38,492,548	$8,844,185	$2,958,477	$38,542,701
2018	$11,298,801	$36,354,073	$8,352,841	$2,816,605	$34,497,517
2019	$10,753,087	$34,215,598	$7,861,497	$2,674,733	$30,452,334
2020	$10,207,373	$32,077,123	$7,370,154	$2,532,860	$26,407,150
2021	$9,661,660	$29,938,648	$6,878,810	$2,390,988	$22,361,966
2022	$9,115,946	$27,800,173	$6,387,467	$2,249,116	$18,316,783
2023	$8,570,232	$25,661,699	$5,896,123	$2,107,244	$14,271,599
2024	$8,024,519	$23,523,224	$5,404,779	$1,965,371	$10,226,415
2025	$7,478,805	$21,384,749	$4,913,436	$1,823,499	$6,181,232
2026	$6,933,092	$19,246,274	$4,422,092	$1,681,627	$2,136,048
2027	$6,387,378	$17,107,799	$3,930,749	$1,539,755	$-
2028	$5,841,664	$14,969,324	$3,439,405	$1,397,882	$-
2029	$5,295,951	$12,830,849	$2,948,062	$1,256,010	$-
2030	$4,750,237	$10,692,374	$2,456,718	$1,114,138	$-
2031	$4,204,523	$8,553,900	$1,965,374	$972,266	$-
2032	$3,658,810	$6,415,425	$1,474,031	$830,393	$-
2033	$3,113,096	$4,276,950	$982,687	$688,521	$-
2034	$2,567,382	$2,138,475	$491,344	$546,649	$-
2035	$2,021,669	$-	$-	$404,777	$-
2036	$2,021,669	$-	$-	$404,777	$-
2037	$2,021,669	$-	$-	$404,777	$-
2038	$2,021,669	$-	$-	$404,777	$-
2039	$2,021,669	$-	$-	$404,777	$-
2040	$2,021,669	$-	$-	$404,777	$-
2041	$2,021,669	$-	$-	$404,777	$-
2042	$2,021,669	$-	$-	$404,777	$-
2043	$2,021,669	$-	$-	$404,777	$-
2044	$2,021,669	$-	$-	$404,777	$-
2045	$2,021,669	$-	$-	$404,777	$-

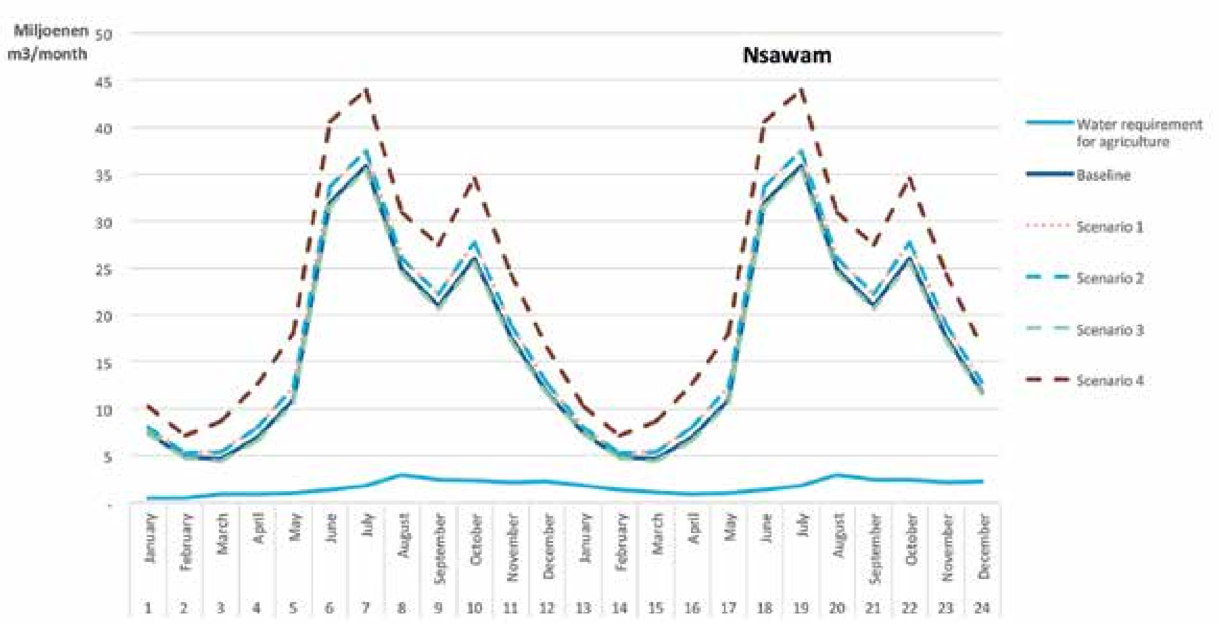
Regulating services	Cultural services	Mining benefits		Management costs
Carbon sequestration (annual change)	Tourism potential	Bauxite alumina	Gold (average annual revenue)	Park management costs
$-243,140	$-	$-	$4,138,340	$-
$-1,517,443	$-	$-144,240,000	$25,681,584	$-
$-1,517,443	$-	$-144,240,000	$21,396,481	$-
$-1,517,443	$-	$-144,240,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$21,396,481	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-
$-1,517,443	$-	$36,300,000	$-	$-

ANNEX I ALLOCATION OF NET BENEFITS AMONG STAKEHOLDERS IN THE DENSU BASIN

	Percentage of benefits					
	Local communities Atewa Range	**Farmers downstream**	**Residents Accra**	**Mining companies**	**International community**	**Forestry Commission**
PROVISIONING SERVICES						
Non-timber products	100%	0%	0%	0%	0%	0%
Timber products	100%	0%	0%	0%	0%	0%
Cocoa farming	100%	0%	0%	0%	0%	0%
Water for agriculture	0%	100%	0%	0%	0%	0%
Water for consumption	0%	0%	100%	0%	0%	0%
REGULATING SERVICES						
Carbon sequestration	0%	0%	0%	0%	100%	0%
Cultural services						
Tourism entry tickets	0%	0%	0%	0%	0%	100%
Tourism expenditures	100%	0%	0%	0%	0%	0%
MINING BENEFITS						
Bauxite alumina	0%	0%	0%	100%	0%	0%
Gold (average annual revenue)	35%	0%	0%	65%	0%	0%
MANAGEMENT COSTS						
Park management costs	0%	0%	0%	0%	0%	100%

ANNEX J WATER SUPPLY AND DEMAND FOR AGRICULTURE IN THE DENSU BASIN

The following graph shows the monthly water discharge in Nsawam in the different land use scenarios and the water requirement estimated for agriculture in the floodplains of the Densu River over a two-year period. Nsawam is representative of the midstream area of the basin, where the majority of the agriculture occurs in floodplain areas. As seen in the figure, the water discharge in the worse months (January to February) is at least three times as large as the water requirement for agriculture in the floodplains. It is important to notice that surface water is unlikely to be the only water source for this type of agriculture. The large majority of the agricultural area of the Densu Basin is occupied by rain-fed crops, and part of the water requirement is also covered by other water sources, such as boreholes. Therefore, it is likely that part of the agriculture in the floodplains also uses these alternatives water sources.



For details about the estimation of the water discharge, please see Chapter 4. For details on the estimation of the water requirement, please see the section about water for agriculture in Chapter 5. Based on the estimations presented in these chapters, it is thus safe to assume that water quantity is not a constraint for the current levels of agricultural production depending on surface water.

ANNEX K VALIDATION WORKSHOP

Workshop schedule

On the 25th of August 2015, a one-day workshop was organized in Accra for the validation of the results of the TEEB study. The workshop commenced with opening remarks from key actors in the study. Fallouts from all remarks presented a justification on the need to seek long term sustainable solutions in managing the Atewa forest reserve. Seth Appiah Kubi, National Director-A Rocha Ghana, explained the context of the TEEB study as part of efforts to improve the knowledge base of the Atewa forest through economic valuation of its ecosystem services.

Mathew Parr, Senior Advisor-Natural Capital from the IUCN Netherlands Committee, underscored the relevance of the TEEB study as a tool in shaping policy decisions within the natural resource sector, particularly, in achieving long term sustainable goals. Fred Smiet from the Royal Netherlands Embassy reiterated the embassy's support for the living water from the mountain project and called for increased inter-sector collaboration and synergies in realizing the ultimate objective of securing the Atewa forest for long term benefits especially, in the area of water provision for communities, households and business.

The workshop proceeded with a presentation on the preliminary findings of the Atewa TEEB Study by Dr. Pieter Van Beukering, lead consultant of the TEEB study from the Institute of Environmental Studies-Netherlands. Round table discussion sessions were also held to review concluding statements made in the preliminary report.

Statements on Atewa and stakeholder views

During the workshop, participants expressed their degree of agreement or disagreement on the concluding statements of the study, provided supporting arguments to the report's conclusions, made suggestions to achieve the necessary conditions for successful management of the Atewa Range and identified key actors within the context of the concluding statements presented below.

STATEMENT 1: In economic, conservation and sustainability terms, only the conditions provided by creation of a National Park with a supporting buffer zone (Scenario 3) achieves a long term increasing trend in value. A process to establish the Atewa National park with buffer zone should be put in place as soon as possible
On this statement, all participants within their groups agreed 100% with the statement. Reasons for supporting this statement include:

- Protection will be enhanced
- Jobs will be created
- Through tourism the public will be educated
- Land economy will be improved
- Traditional livelihoods will be maintained eg. Farming
- Creating of the national park will bring multiple benefits

Key actors participants considered essential for achieving this statement include: Environmental Protection Agency, Forestry Commission, FORIG, Ministry of Local Government, Ministry of Lands and Natural Resources, Traditional Authority, Minerals Commission, District Assemblies and RD

Participants also made some suggestion on how to achieve the statement. These include:

- The conversion and attainment of the status National Park should be accelerated
- There should be collaboration between land owners and farmers to create and manage the buffer
- Practical issues with the concept of buffer including ownership issues etc. to incorporate the concept of CREMA
- Compensation, Human Enclaves, etc
- The affected people/activity must be duly compensated and relocated
- The state must acquire the forest and buffer zone compulsorily
- Adequate measures be put in place to pay realistic compensations
- Adding the farmers and commuters must be compensated and relocated

STATEMENT 2: Water quality is much more an argument to protect the Atewa Forest Reserve plus Buffer than water quantity. **Raising awareness** of the Accra population and related businesses about their dependence on Atewa for quality water is crucial.

- Participants within their groups also agreed on the above statement, reasons given for supporting the statement include
- Increased water quality will reduce health cost. Eg. Epidemics etc
- Provision of potable water
- Reduced burden on cost of purchasing potable water (sachet)

KEY ACTORS were identified as; EPA, MOFA, FC, MINISTRY, NGO, DAs, Traditional Authority, Farmers, Government.

Participants were of the view that with the scenario of total degradation, water quantity will not be an issue because the will be the possibility of flooding. Water quality should therefore be the focus to protect the Atewa forest plus the buffer. Efforts should also be focused on getting the support of the water users downstream in addition to the stream levels of water use – both upstream and midstream as well. They agreed that quality and quantity of water is important, thus raising awareness of population along the entire water basin and businesses is crucial.

Some suggestions were made as contributions to the statement. These include

- Conclusion to be revised to include the awareness of the people in the midstream and upstream
- Mining permits within the buffer zone are to be revoked
- Awareness raising be aimed more at the industries than the households so that the revenue goes to the management of the National Park
- Advocacy to cover schoolchildren too

STATEMENT 3: Alternative and supplementary livelihoods for fringe communities are essential to maintain the quality of downstream ecosystem services. **A payment for ecosystem services** scheme is a suitable mechanism to catalyze this transition. All participants also agreed with this statement. Reasons for supporting the statement include

- Provision of funds/income during lean season
- It reduces illegal activities
- It will prevent poaching
- Payment of Ecosystem services will ensure sustainability of the Atewa Forest

Some participants were concerned about how the PES scheme will be implemented given that water management is centralized in Ghana. They thus suggested that a premium be added to the common fund of the relevant MMDAs on top of what they are getting to be used for the protection of the forest and water catchment. This premium will be put into a fund that will be managed and use for the PES venture. Other suggestions also included;

- PES in addition to other incentives should be put in place to catalyze the transition.
- Alternative livelihoods must be tailored to suit their desires
- The funding must be sustainably managed
- Beneficiaries must be made to pay to ensure sustainability
- There should be a survey of livelihood options that will benefit the community
- Care must be taken not to raise community expectations on what they stand to benefit
- Dwell more on the non-tangible benefits of reserving the forest than money
- Identifiable stake holders (chiefs, farmers, families, developers) must be compensated to procure that forest reserve and the buffer zone.

STATEMENT 4: Internal collaboration between departments while allowing for involvement of local communities to develop an inclusive management plan in which all stakeholders are considered is essential for long term management of Atewa. An **integrated management approach** will be needed to achieve the transition towards more sustainable livelihoods and use of the Atewa Range. Participants agreed with the statement and reasons for the support include;

- It ensures sustainability of the forest management
- It reduces waste of resources and supplies
- It creates trust and a sense of belongingness
- It would provide an avenue for capacity building of stakeholders

Though participants agreed with the statement, they were concerned about scenarios where industrial sector policies conflicted with potentials of naturally impinging on this process of achieving integrated management approach. Participants were also of the view that it was important to know that current arrangements might have been with multi-stakeholders in their approach as much as possible. This should be continued to increase buy-in, and support for success. There is also the need to develop a model that will work for especially Atewa because many similar attempts have failed elsewhere. They suggested Atewa can be created as a special park that accounts for how conflicting interests are handled. They also suggested that an integrated management framework must be established to ensure sustainable management of the forest Reserve and buffer zone.

STATEMENT 5: Enforcement of existing regulation is currently insufficient in the Atewa Forest Reserve. Effective land use management can only be achieved if the **enforcement** of the regulation in place.

Majority of the participants agreed with the statement stating the following as reasons for their support.

- Ensure enforcement of existing laws
- Build capacity of judiciary and prosecutors
- Sensitize local people on the laws

Those who disagreed with the statement indicated that the Forestry Services Division has enough existing regulations for the protection of the reserve. The main challenge is the enforceability giving that the division has challenges in the areas of;

- Inadequate staff strength
- Perception of corruption
- Logistical and funding continuity
- These therefore makes it imperative for a change in the regime and the upgrading the reserve to that of NP

They thus made the following suggestions

- Education and awareness creation is important and needed for effective enforcement
- Enough presence (personnel) on the ground for the protection/enforcement effort (policies and programs)
- Vulnerability of mining in the buffer zone area
- Provision of alternate livelihoods fit will here
- Ensure adequate logistical support
- Adequate staff to effectively police/maintain activities within the forest and buffer zone

The identified key actors that could support the process include District Assembly, Police, Judiciary, Traditional Authority, NGOs, and Forestry Commission.

Overall ranking of statements

STATEMENT	IMPORTANCE (1 HIGHEST - 5 LEAST)					
Create National Park with buffer zone	1	1	1	1	2	1
Awareness in Accra of importance Atewa for water	5	2	2	5	3	5
Payments for ecosystem service scheme	3	2	5	3	5	2
Integrated management approach	2	4	4	4	4	3
Enforcement	4	3	3	2	1	4

Community project for alternative sources of income, Photo Jan Willem den Besten

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