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ECOSYSTEM SERVICES VALUATION FOR IMPROVED WATER RESOURCE MANAGEMENT UNDER CLIMATE CHANGE IN AFRICA

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Scientific publications, reports and blog posts linked to this thesis

- **Scientific publication**

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- **Project reports**

Pettinotti, L., 2017. Baseline valuation report of the Pwalugu communities' reliance on ecosystem services, northern Ghana (WISE UP Project report). Basque Centre for Climate Change, Bilbao, Spain.

Pettinotti, L., 2014. Methodological framework for valuation of ecosystem services in water resources management (WISE UP project). Basque Centre for Climate Change, Bilbao, Spain.

- **Blog posts**

Photo story on the Water Future website – a global platform by Future Earth "How can communities adapt to climate change and manage water?" by Pettinotti, L. and Mosello, B., 2017. Available at https://water-future.org/blog/ghana-story/ and republished by Climatelinks, a global knowledge portal for climate and development practitioners, at https://www.climatelinks.org/blog/community-spotlights-water-security-and-climate-change-resources

Blog post on the IUCN website "Measuring livelihood dependency on river flow - an interdisciplinary approach" by Pettinotti, L., 2017. Available at https://www.iucn.org/news/water/201702/blog-measuring-livelihood-dependency-river-flow-interdisciplinary-approach

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Blog post on the IUCN website "Life with grandmother crocodile" by Mul, M., Pettinotti, L., Amonoo, N. A., Bekoe-Obeng, E., Obuobie, E., 2018. Available at http://www.waterandnature.org/blog/life-grandmother-crocodile

List of chapters and statement of contribution

Chapter 1

Title: Benefits from water related ecosystem services in Africa and climate change.

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Accepted and presented at the Spanish-Portuguese Association of natural Resources and Environmental Economics (AERNA) conference by Dr Amaia de Ayala in September 2018.

Chapter 2

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Contribution to chapter 2: Data collection design in Ghana (including preparing and leading focus group discussions and testing of survey); enumerators' training for the survey; data analysis; write up; policy framing. The co-authors provided hydrological data and its analysis as well as guidance for the policy framing.

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Chapter 3

Title: Realities of decision-making for built and natural water infrastructure in the Volta Basin.

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Chapter 4

Title: Households coping responses to ecosystems driven shocks: no flood and extreme flood event, northern Ghana.

Authors: Laetitia Pettinotti [a]

This draft paper is a work in progress and presents preliminary findings. The full regression analysis and final article will be developed in collaboration with Sébastien Foudi (BC^3) and Anil Markandya (BC^3).

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Contribution to chapter 4: Data collection design in Ghana (including preparing and leading focus group discussions and testing of survey); enumerators' training for the survey; data analysis; write up; policy framing.

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Thesis Summary

The present thesis is entitled "Ecosystem services valuation for improved water resource management in Africa". Through four chapters, ecosystem services valuation is used as a tool to inform water resource management. After a first chapter at continent-level, the geographic focus of the remainder chapters shifts to Ghana and its northern region.

Chapter 1 synthetizes available evidence on ecosystem services monetary values in Africa. The study collects original monetary estimates for water related ecosystem service benefits on the African continent from 36 valuation studies. A database of 178 monetary estimates is constructed to conduct a meta-analysis that, for the first time, digs into what factors drive water related ecosystem service values in Africa.

The service type, biome and other socioeconomic variables are significant in explaining values from water related services. In order to understand the importance that water related ecosystem services have for climate change, we explore the relationship between these benefits and the countries' vulnerability and readiness to adapt to climate change.

Countries face synergies and trade-offs in terms of how valuable their water related ecosystem services are and their potential vulnerability and adaptation capacity. While more vulnerable countries are associated with lower benefits from ecosystem services, countries with a higher readiness to adapt are also associated with lower ecosystem service values. These results are then discussed in light of natural capital accounting and ecosystem-based adaptation.

In chapter 2, the research focuses on local communities in northern Ghana that rely on ecosystem service based activities for their livelihoods. The ecosystem services are delivered by a natural water

infrastructure constituted of a river, ponds and floodplain system. Using valuation methods, the role of the natural infrastructure in supporting livelihoods for different socio economic household groups within local communities is quantified as well as the impacts of a proposed multipurpose Pwalugu dam upstream.

On average, households are dependent on the natural water infrastructure for 54% (2015 USD 1,365) of their livelihood. Better off households have the highest dependence (59% of total revenue USD 2,180). Middle and poor households derive 47% (but representing USD 1,220 and USD 615 mean revenue, respectively).

Linking the values to past, current and estimated future hydrological flow regime, the current situation (t) is compared to past benefit estimates (t-1) before the upstream Bagré dam construction in Burkina Faso and to potential future estimates (t+1), after the proposed Pwalugu dam is constructed.

With a dam operated for constant flow regime as hypothesised in t+1, the households potentially incur a 20% loss of income and experience a widening of inequalities within and across household groups, with the poor households losing out the most. Alternative dam operations are discussed in light of the expected benefits that could be produced by the dam at regional and national levels.

The third chapter centres on the water resource management decision to prioritise one planning goal, for example energy production, over others, such as food production and ecosystems maintenance when planning and operating the Pwalugu dam, northern Ghana. This is to understand national and sectoral dynamics surrounding policy-making and implementation of dam building and choice of operational rules.

A decision support approach is proposed. It combines water resource system simulation modelling, economic valuation and political economy analysis to quantify the benefits yielded by different water resource system planning and management decisions, and their impacts on different actors and interests.

Results show that decisions over the dam's design ultimately depends on the political-economy context within which the project is framed. The research also gives substance to the concept of natural infrastructure in terms of bio-physical and economic assessment, highlighting its trade off with built infrastructure, as well as its potential political value.

The final chapter investigates the potential risk coping strategies adopted by the local Pwalugu communities if the upstream Pwalugu dam is operated to maximise hydropower or irrigation production (cf. chapter 3). As no compensation is planned for the communities who stand to lose part of their livelihoods (cf. chapter 2), coping responses will be put in place over others. The analysis shows access and immediacy of proposed coping response shape adoption, giving pointers for poverty alleviation programmes that could be put in place by the government of Ghana to specifically address this livelihoods loss.

Resumen de la tesis

La presente tesis se titula "Valoración de los servicios de los ecosistemas para una mejor gestión de los recursos hídricos afectados por el cambio climático en África". A través de cuatro capítulos, la valoración de los servicios ecosistémicos se utiliza como una herramienta que se incorpora en el análisis de la gestión de los recursos hídricos. Después de un primer capítulo que presenta un análisis a nivel de todo el continente africano, el enfoque geográfico de los capítulos restantes se traslada a Ghana y, en concreto, a su región norte.

El cambio climático es una de las principales causas de la alteración y deterioro de los ecosistemas y la biodiversidad. El Quinto Informe de Evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático de las Naciones Unidas afirma que los ecosistemas africanos están viéndose afectados notablemente por el cambio climático y se espera que los impactos futuros sean aún más considerables.

De la misma manera, la Evaluación de los Ecosistemas del Milenio declara que los ecosistemas se están degradando a causa de la sobreexplotación y otras tensiones antropogénicas directas. En este contexto, resulta necesario entender cómo la gestión y la mejora de los servicios de los ecosistemas, entendidos como los múltiples beneficios que la naturaleza aporta a la sociedad, pueden fomentar la capacidad de una sociedad para desarrollarse sosteniblemente.

El estudio se centra en África por tres razones principales: los recursos hídricos son esenciales para proveer servicios ecosistémicos necesarios para millones de medios de vida en el continente; África presenta una alta vulnerabilidad al cambio climático lo que conlleva la necesidad del diseño de políticas adecuadas; y la investigación sobre la relación entre los servicios de los ecosistemas y el cambio climático es escasa.

El Capítulo 1 resume la evidencia disponible sobre los valores monetarios de los servicios de los ecosistemas en África. El estudio recoge las estimaciones monetarias originales de los beneficios del servicio de los ecosistemas relacionados con el agua en el continente africano a partir de 36 estudios de evaluación. Una base de datos de 178 estimaciones monetarias es construida para llevar a cabo un meta-análisis que, por primera vez, explora los factores que determinan los valores de los servicios ecosistémicos relacionados con el agua en África.

El trabajo realizado muestra que el tipo de servicio, el bioma y otras variables socioeconómicas (como el PIB per cápita o la tasa de pobreza rural) son estadísticamente significativos para explicar los beneficios de los servicios derivados de los recursos hídricos. Para comprender la importancia que los beneficios de los servicios de los ecosistemas relacionados con el agua tienen para el cambio climático, se estudia la relación entre estos beneficios, la vulnerabilidad de los países ante el cambio climático y la disposición de los países para adaptarse al cambio climático.

Se obtiene que existen sinergias y *trade-offs* para los países entre el valor de los servicios de los ecosistemas relacionados con los recursos hídricos, su potencial vulnerabilidad y su capacidad de adaptación. Mientras que los países más vulnerables obtienen menores beneficios de los servicios de los ecosistemas, los países más preparados para adaptarse al cambio climático asocian menores valores a los servicios de los ecosistemas. Estos resultados se discuten, posteriormente, a la luz de la contabilidad del capital natural y de las acciones de adaptación basadas en los ecosistemas.

En el capítulo 2, la investigación se centra en las comunidades locales del norte de Ghana que dependen para su sustento de las actividades basadas en los servicios de los ecosistemas. Estos servicios son facilitados por una infraestructura de agua natural constituida por un río, estanques y un sistema de terrenos inundables.

Utilizando métodos de valoración, se cuantifica el papel de la infraestructura natural en el apoyo a los medios de subsistencia para diferentes grupos socioeconómicos dentro de las comunidades locales, así como los impactos que tendrá la construcción aguas arriba de la presa multi-propósito de Pwalugu.

En promedio, los hogares dependen de la infraestructura de agua natural para el 54% (2015 USD 1.365) de sus medios de subsistencia. Los hogares más prósperos tienen mayor dependencia (59% de sus ingresos, USD 2,180) que los hogares medios y pobres (47% de sus ingresos, USD 120 y USD 615, respectivamente).

A continuación, se relacionan estos valores con el régimen de flujo hidrológico pasado, actual y estimado. La situación actual (t) se compara con las estimaciones de beneficios (t-1) antes de la construcción de la presa río arriba en Bagré (Burkina Faso), y con las estimaciones futuras (t + 1) después que se construya la presa propuesta en Pwalugu.

Si suponemos que la presa opera con un régimen de flujo constante en t + 1, los hogares incurrirían en una pérdida de ingresos del 20% y experimentarían una ampliación de la desigualdad dentro y entre los grupos de hogares, con una mayor pérdida para los hogares pobres. Se analizan los beneficios esperados que la presa podría generar, a nivel regional y nacional, para otros posibles regímenes de funcionamiento distintos a los de flujo constante.

El tercer capítulo se centra en la gestión de los recursos hídricos al planificar y operar la presa de Pwalugu (norte de Ghana) en función de que se priorice un objetivo de planificación como, por ejemplo, la producción de energía, sobre otros, como la producción de alimentos o el mantenimiento de los ecosistemas. Este análisis ayuda a comprender las dinámicas que, tanto a nivel nacional como en términos de sectores económicos, afectan al diseño de políticas, el tipo de presa que se construye y la elección de las reglas operativas de la presa.

Esta investigación propone un marco de apoyo a la toma de decisiones que combina un modelo de simulación de sistemas de recursos hídricos, la valoración económica y el análisis de economía política para cuantificar los beneficios generados por diferentes decisiones de planificación y gestión de sistemas de recursos hídricos, y sus impactos en diferentes actores e intereses.

Los resultados muestran que las decisiones sobre el diseño de la presa dependen, en última instancia, del contexto político-económico dentro del cual se enmarca el proyecto. La investigación también da sustento al concepto de infraestructura natural en términos de valoración biofísica y económica, destacando su relación con la infraestructura construida, así como su potencial importancia política.

El último capítulo investiga las posibles estrategias para hacer frente a los riesgos que podrían adoptar las comunidades locales en caso de que la presa de Pwalugu se dedique a maximizar la producción de energía hidroeléctrica o riego (véase el capítulo 3). Como no se planifica ninguna compensación para las comunidades que perderían parte de sus medios de subsistencia (véase el capítulo 2), se trata de analizar las posibles estrategias que se podrían adoptar.

El análisis muestra la disponibilidad y la eficiencia de la respuesta de afrontamiento propuesta, proporcionando indicadores para el programa de alivio de la pobreza que el gobierno de Ghana podría implementar para abordar esta pérdida de medios de subsistencia.

List of acronyms and abbreviations

BI: Built Infrastructure

CCLM: [COSMO-CLM] Consortium for Small Scale Modelling Climate Limited-area Modelling

CICES: Common International Classification of Ecosystem Services

CFA: West African CFA Franc

CORDEX: Coordinated Regional Climate Downscaling Experiment

ES(s): Ecosystem Service(s)

FE: Fixed Effects

FRA: Flood Recession Agriculture

GCM: Global Climate Models

GDP: Gross Domestic Product

GEF: Global Environmental Facility

GHc: Ghanaian Cedis

GIDA: Ghana Irrigation Development Authority

GIS: Geographic Information System

GLS: Generalised Least Squares

GoG: Government of Ghana

ICHEC: Irish Centre for High-End Computing

INDCs: Intended Nationally Determined Contributions

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC: International Panel on Climate Change

IRAS: Interactive River-Aquifer Simulation

IWRM: Integrated Water Resource Management

MA: Millennium Ecosystem Assessment

MNDWI: Modified Normalised Differential Water Index

MoFA: Ministry of Agriculture

MOHC: Met Office Hadley Centre

MPI: coupled Models Inter-comparison Project

NAPA: National Adaptation Plan of Action

NDWI: Normalised Differential Water Index

NEDCo: Northern Electricity Distribution Company

NI: Natural Infrastructure

NTFPs: Non Timber Forest Products

OLS: Ordinary Least Squares

PMD: Pwalugu Multi-purpose Dam

PPP: Purchasing Power Parity

RACM: Regional Arctic Climate Model

RCM: Regional Climate models

RCP: Representative Concentration Pathways

RE: Random Effect

SDGs: Sustainable Development Goals

SE: Standard Errors

SWAT: Soil and Water Assessment Tool

TEEB: The Economics of Ecosystems and Biodiversity

TLU: Tropical Livestock Unit

UNEP: United Nations Environment Program

UNFCCC: United Nations Framework Convention on Climate Change

USD: United States Dollars

VRA: Volta River Authority

WB: World Bank

WLS: Weighted Least Squares

WUAs: Water Users Associations

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Introduction

1.1 Ecosystem services

1.1.1 Concept and mainstreaming initiatives

Ecosystems underpin human livelihoods as they deliver services which contribute actively or passively, currently or in the future, to aspects of human well-being (Fisher et al., 2009; MA, 2005; TEEB, 2010). Ecosystems are defined as “ecological system consisting of all the organisms in an area and the physical environment with which they interact” (Chapin et al., 2011).

Ecosystem disservices also exist, as an ecosystem can provide a negative contribution to human welfare – a disservice. For example, ecosystems can be breeding grounds for vectors of human diseases e.g. areas with malaria-infected mosquitos; or habitat for wildlife that can cause crop damage e.g. elephants or baboon monkeys (Sandbrook and Burgess, 2015; Shapiro and Báldi, 2014).

Mainstreamed in the early 2000s by the United Nations led Millennium Ecosystem Assessment (MA) (MA, 2005), the concept of ecosystem service (ES) has since increasingly been used in research. Searching for “ecosystem services” on Web of Science returned more than 1,900 results in 2014, compared to a 100 results in 2005 – date of the MA’s final publication (West, 2015).

Indeed, several large scale initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) (de Groot et al., 2012; TEEB, 2010); the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013); and the ongoing Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2018, 2015) have kept the concept evolving and maintained research attention, especially regarding ESs classification.

1.1.2 Classification

The different classification iterations led over the years (MA, TEEB, CICES, IPBES) are part of an effort to better apprehend, measure and quantify how biophysical processes occurring in a range of ecosystems translate into services that contribute to human well-being.

The most recent assessments (CICES and IPBES) have retained the provisioning, regulating and cultural ES categories, while the MA and the TEEB used to make a distinction for supporting services – now integrated in regulating services to limit double counting issues that arose in practice (Haines-Young and Potschin, 2013). Table 1 details the breakdown of ESs where provisioning services correspond to raw biomass, water or energy; regulation and maintenance services mediate the biotic system and; cultural services are all physical, intellectual, spiritual and symbolic interactions with ecosystems.

Table 1: ESs classification

Section	Division	Group	Class
Provisioning	Nutrition	Biomass	Cultivated crops
			Reared animals and their outputs
			Wild plants, algae and their outputs
			Wild animals and their outputs
			Plants and algae from in-situ aquaculture
			Animals from in-situ aquaculture
		Water	Surface water for drinking
			Ground water for drinking
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing
			Materials from plants, algae and animals for agricultural use
			Genetic materials from all biota
		Water	Surface water for non-drinking purposes
			Ground water for non-drinking purposes
	Energy	Biomass-based energy sources	Plant-based resources
			Animal-based resources
		Mechanical energy	Animal-based energy
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems
			Dilution by atmosphere, freshwater and marine ecosystems
			Mediation of smell/noise/visual impacts
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates
			Buffering and attenuation of mass flows
		Liquid flows	Hydrological cycle and water flow maintenance
			Flood protection
		Gaseous / air flows	Storm protection
			Ventilation and transpiration
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal
			Maintaining nursery populations and habitats
		Pest and disease control	Pest control
			Disease control
		Soil formation and composition	Weathering processes
			Decomposition and fixing processes
		Water conditions	Chemical condition of freshwaters
			Chemical condition of salt waters
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations
			Micro and regional climate regulation
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings
			Physical use of land-/seascapes in different environmental settings
		Intellectual and representative interactions	Scientific
			Educational
			Heritage, cultural
			Entertainment
			Aesthetic
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes	Spiritual and/or emblematic	Symbolic
			Sacred and/or religious
		Other cultural outputs	Existence
			Bequest

Source: CICESv4.3 in Haines-Young and Potschin (2013)

These major research efforts to standardise ESs into well-identified, measurable elements help integrate ecosystems in decision making in view of better managing declining ecosystems.

1.2 The economic valuation of ecosystem services

1.2.1 Rationale for valuing ESs

At the core of the ES concept is the idea that ecosystems' degradation is due to the lack of recognition given to ecosystems' contribution to human welfare (Laurans et al., 2013; MA, 2005; TEEB, 2010). Indeed, despite their crucial role for livelihoods, ecosystems are negatively impacted by global and local, direct and indirect anthropogenic degradation. Species´ population and diversity that underpin ecosystems functioning are reduced due to over-harvesting, land use change, nutrient pollution, high CO_2 levels or ultraviolet radiation (Butchart et al., 2010; Cardinale et al., 2012; Hooper et al., 2012). As a result, more than 60% of ecosystems are degraded globally and these degradation trends are worsening (MA, 2005; Tittensor et al., 2014).

Degradation of the state of ecosystems impacts the quality and/or quantity of the services´ provision (Díaz et al., 2006). Ultimately, sustained degradation can trigger the loss of the entire ecosystem once it reaches its tipping point, passed which there is no recovery of the ecosystem (Scheffer et al., 2001). Hence, ecosystem degradation has been identified as a central challenge to sustaining livelihoods globally (Guerry et al., 2015).

In this context, ES economic valuation is based on the recognition of ecosystems as valuable, exhaustible resources, which support human livelihoods and need to be mainstreamed into policy (CBD, 2011; UNEP, 2010). The expectation is for ES valuation to be a tool, among others, that can foster ecosystem protection and enhancement by considering the ES values - gain or loss - associated with different policy options (Barbier et al., 1990; Markandya, 2016; OECD, 2018).

Economic valuation elicits the monetary value derived from one or several ESs in a given area, at a given time and for a specific group of beneficiaries. The idea is that by eliciting ES values, ESs can be integrated in policy appraisal frameworks and thus become represented in public policy decisions. Ecosystems are considered as potential investment options just as human-made capital. Valuation is a tool to internalise policies' environmental externalities into the policies own appraisal framework. As stated by the IPBES (2018a) "failure to reflect [ES] values in decision-making often results in unsustainable use and depletion of biodiversity and ecosystem services".

This narrative on the use of economic valuation implicitly postulates the rationality of decision-making to seek a collective optimum. Decision-making is defined as an optimising choice by a policy maker entity (individual or collective) that occurs in a social, political and technical context of constraints and enablers (Laurans and Mermet, 2014).

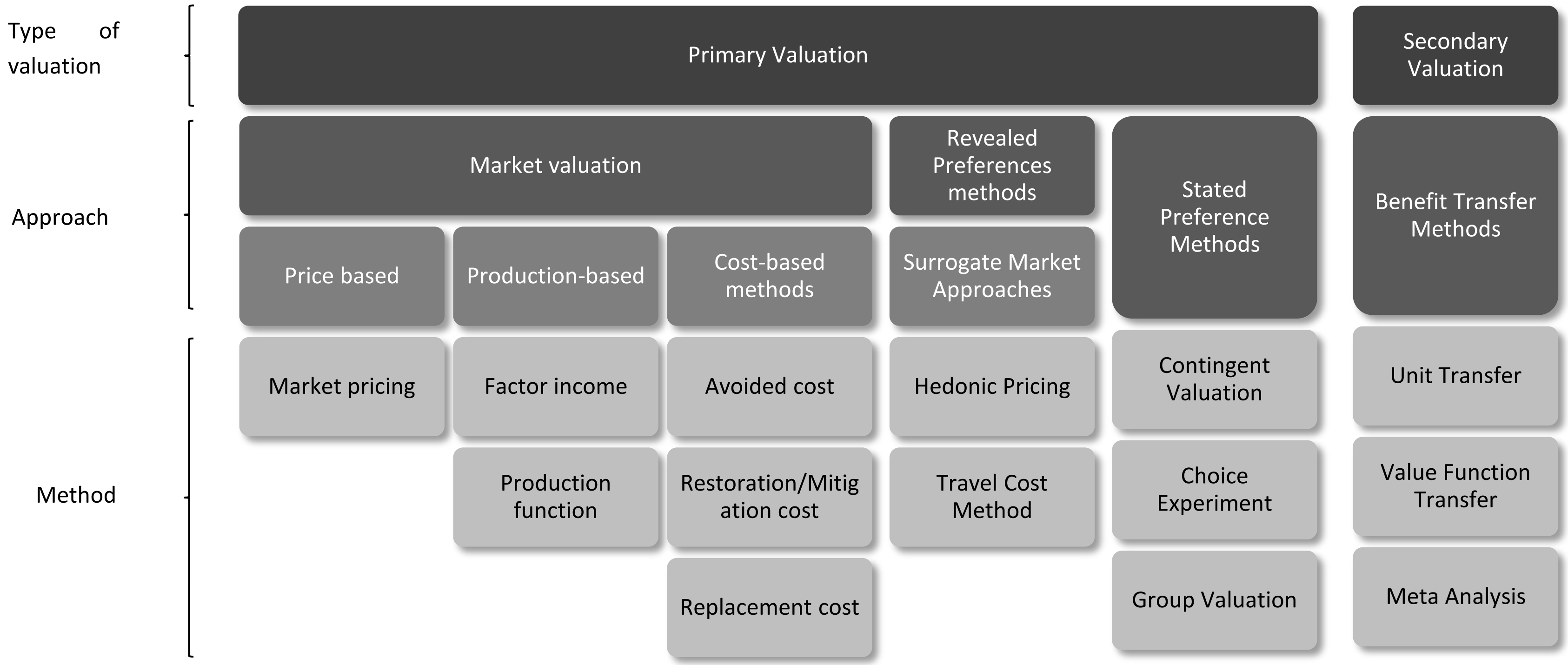
However, more economic evidence may not readily translate into uptake and use in decision-making (Berghöfer et al., 2016; Laurans et al., 2013; Laurans and Mermet, 2014). Already in OECD (2001), this difficulty was highlighted, and 17 years later, Saarikoski et al. (2018) makes the same observation. The reasons for this potential implementation gap are still debated and range from under reporting of ES value use in decisions due to the lack of post ES valuation monitoring; to limited ES value use due to imperfect methodologies and; reluctance from decision-makers to use such tool (Laurans and Mermet, 2014).

Nevertheless, the ES concept has been increasingly integrated in the policy discourses of developed countries' cities and of the European Union, even though this remains a moderate development, and even more so in African countries (Bouwma et al., 2018; Hansen et al., 2015; Inkoom et al., 2017).

1.2.2 Methodologies for valuing ESs

Since most ESs are either not exchanged on a market or are but at a highly distorted price, their values are estimated with a range of valuation techniques (Figure 1). Several institutional reports have focused on ES valuation techniques over the years such as OECD (2006); OECD (2018); Pascual et al. (2010) in TEEB.

Figure 1: ES valuation methods



Source: Based on Pascual et al. (2010)

The techniques can be categorised into primary and secondary valuation methods. Primary valuation techniques produce primary estimates, as values are calculated from raw, original data. They can broadly be divided in two categories (Figure 1): i. Revealed Preferences Methods that draw on individuals´ observed preferences and; ii. Stated Preference Methods that directly ask individuals to state the value of their preferences. Secondary valuation techniques transfer and adjust values from primary studies. Each technique carries their own technical uncertainty, for a detailed discussion see Pascual et al. (2010) and OECD (2018).

Critics of the use of valuation for ESs raise the ethical issue of considering nature as a commensurable commodity. Intrinsic value and irreplaceability of nature along with the responsibility to conserve for future generations are concepts difficult to capture within the traditional liberal economic framework (Kosoy and Corbera, 2010; McCauley, 2006). In this sense, Spash (2008) refers to the “diamond water paradox”: diamonds are traded at higher prices than water because their relative value of exchange is greater than that of water even though the marginal value of water exceeds the one of diamonds in scarcity conditions.

Costanza et al. (2014) argue that valuation of ESs is different from commoditisation as valuation does not postulate substitutability with other capital but highlights relative change in ES values due to policy changes. Nonetheless, this criticism has been taken into account by the research community and the IPBES has been working on the development of inclusive and multidimensional valuation in an attempt to answer this concern (Díaz et al., 2015; Pascual et al., 2017).

1.3 ESs in Africa

1.3.1 Role of ESs for livelihoods

ESs’ provision on the African continent varies by climatic and ecological zone and similarly, the dependence on ESs differs per socio-economic context and groups across Africa.

ES valuation research on the continent has predominantly focused on East and Southern Africa. Provisioning services are the most frequently valued ES, this is due to the relative ease of valuing this service and the large contribution of this service to livelihoods (Pettinotti et al., 2018).

While ESs are important for livelihoods in both developed and developing countries, it is recognised that ES reliance is especially high in Africa where poverty is predominant with 43% of the population living below the poverty line at USD 1.90/cap/day in 2012 (Beegle et al., 2016; Egoh et al., 2012). ESs contribute to poverty alleviation as about 62% of the continent's rural population depends directly on ESs to secure their subsistence – the highest percentage across all continents (IPBES, 2018a). Ecosystem degradation could hence increase poverty if no poverty alleviation measure is put in place.

In particular, ESs provide a crucial safety net during the hunger season (end of the dry season) since state funded social protection is often inadequate or non-existent (Egoh et al., 2012). Importantly, this reliance is conditioned by access, that itself is shaped by gender, socio-economic status and management regime of the ecosystems (Daw et al., 2011).

This large reliance on ESs for livelihoods entails a vulnerability to changes in the services' provision. But the current pressures on ecosystems are expected to be amplified by potential impacts of climate change and likely socio-economic changes such as population and economic growth (Niang et al., 2014). In addition, increase in temperatures coupled with heightened variability of inter and intra annual precipitations is expected to particularly impact rainfed agriculture, with up to 30% estimated yield decrease (Parry et al., 2004). This would further increase livelihoods reliance on ESs.

At the same time, the possibility of ecosystems to contribute to climate change adaptation has been highlighted as a potential successful strategy. Ecosystem-based adaptation consists in ecosystems capacity to reduce communities' vulnerability to climate change impacts through ES delivery (Andrade Pérez et al., 2010; Munang et al., 2013a). Ultimately, this strategy suggests that maintaining ecosystems delivers climate change adaptation, and possibly mitigation for ecosystems that are carbon sinks, as well as contributing to sustainable economic development (Munang et al., 2013b).

1.3.2 ESs to inform decision-making on water resource management

Greater integration of ecosystems in water resource management was called for when the framework of Integrated Water Resource Management (IWRM) was coined by the Global Water Partnership (Agarwal et al., 2000). Since then, ecosystems have been integrated in the water resource management discourse under the angle of water security (Sadoff et al., 2015) and a few studies such as Korsgaard, (2006); Loth, (2004) have highlighted ESs' economic contributions for water resource management.

Water resource – as a crucial and finite resource - entails complex management due to trade-offs in its allocation to different planning goals (Loucks et al., 2005). Irrigated agriculture, energy production and maintenance of environmental flows to support ecosystems are the different competing objectives dealt with in water resource management, framed as the "water, food and energy nexus" (Hoff, 2011).

While irrigated agriculture and energy production are goals represented in decision-making as benefits with figures and expected returns, allocation of water to ecosystems is represented as a regulatory constraint within the system rather than an objective delivering benefits that support livelihoods (e.g. the constraint can be a threshold number of days when water cannot flow below a certain level in $m^3 s^{-1}$).

Using ES values allows representing river flow - per se - as a water use that provides services to human beneficiaries who depend on them for their livelihoods. Water related ESs – i.e. ESs provided by ecosystems that impact or depend on river flow – can be valued to be considered in decision-making. This is a way of representing livelihoods in decision-making over water allocation.

Water allocation is a politically sensitive as well as a technical issue (Loucks et al., 2005). Especially as water policies can durably affect livelihoods and development paths of river basins and countries (Hall et al., 2014; Sadoff et al., 2015). Hence, representing ecosystems and their - often rural - beneficiaries is crucial to integrating them in decision-making over water resource management for long term sustainability.

This is even more important in Africa where high freshwater variability is combined with low investment level in built water infrastructure, resulting in water stress currently and potentially in the future under climate change (Faramarzi et al., 2013; Grey and Sadoff, 2007; Sadoff et al., 2015). This means water management is set to become increasingly politically sensitive and evidence for public policy making will be necessary.

1.4 Objectives and outline of thesis

The present thesis uses ES valuation in the context of water resource management in Africa and particularly in Ghana, West Africa. The research draws links to the existing literature on ecosystem based adaptation, smallholder farmers' livelihoods strategies and risk coping, poverty alleviation, nature based-solutions, climate change adaptation and the political economy of water resource management.

Given the pressures water related ecosystem are under, ES valuation can play a role in providing economic evidence to policy-makers. The main objective of the present work is to apply ES valuation and use its results to produce tailored evidence that is of value in specific policy contexts.

The work inscribes itself to what Laurans et al. (2013) call “the use of ES economic values for a specific decision”. In other words, ES valuation is used to inform a specific policy decision by providing evidence on the economic consequences of the proposed decision on ESs and their beneficiaries. This is an *ex-ante* instrument that supports decision-making and considers ecosystems as productive components dependent on investment.

Hence, the valuations reviewed and undertaken in the present thesis do not claim to elicit the total worth of entire ecosystems but to value the income retrieved at a given time, for given beneficiaries, relative to different policies. This thesis attempts to demonstrate how ES value can inform policy making for improved water resources management under climate change in Africa through four chapters summarised below.

The first chapter reviews the water related ES value literature in Africa and how they relate to reduced vulnerability to climate change as well as adaptation. In Chapter 2, water related benefits are then valued for livelihoods among different population groups within local communities downstream of a proposed dam in Ghana. Since ES values depend on the biophysical, social, institutional and policy processes where they occur, ES valuation is one of the steps in the generation of decision-support information as is investigated in Chapter 3 for the case of this proposed dam in Ghana. Last, Chapter 4 examines risk coping strategies adopted by small-holder farmers in face of a change in water related ES delivery.

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Chapter 1

Benefits from water related ecosystem services in Africa and climate change

Keywords: Adaptation; Africa; Ecosystem Services; Meta-analysis; Natural Capital; ND-GAIN; Readiness; Valuation; Vulnerability; Water.

JEL classification: N57: Africa • Oceania. O13: Agriculture • Natural Resources • Energy • Environment • Other Primary Products. Q57: Ecological Economics: Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology. Q54: Climate • Natural Disasters • Global Warming.

1 Introduction

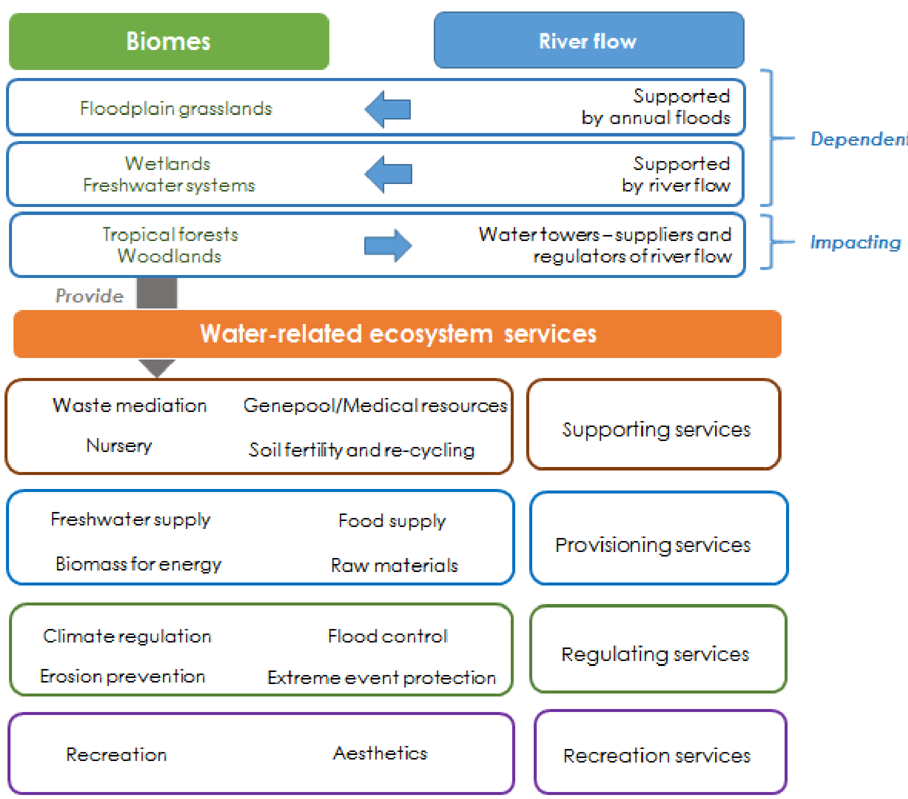
The concept of ecosystem services (ESs), understood as the contribution of the benefits derived passively or actively from ecosystems towards current and future human well-being (Fisher et al., 2009), has gained increasing recognition in the last decade. Mainstreamed by the Millennium Ecosystem Assessment (MA) Program (2005), ESs were at the focus of the United Nations Environment Programme (UNEP) led study on The Economics of Ecosystems and Biodiversity (TEEB, see de Groot et al., 2012), and are still evolving under the currently developing Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) initiative (Díaz et al., 2015). The conservation and improvement of ecosystems has been identified as a central challenge to sustaining livelihoods for the XXIst century (Gleick, 2003; Guerry et al., 2015), and research programs as well as conservation initiatives have been launched at local, national and international levels (Díaz et al., 2015). In this context, research to synthetize available evidence on ES monetary values is of prime importance, and understanding what drives these values and how they relate to countries' climate vulnerability can provide policy guidance regarding the potential of ESs for climate change adaptation.

The present paper focuses on water related ESs in Africa and their links to climate change vulnerability and adaptation. Water-related ESs are understood as the services provided by biomes that are river flow impacting or river flow dependent (see the concept of natural infrastructure in Mul et al., 2017)[a]. In other words, biomes that impact or are predominantly dependent on river flow, as opposed to being predominantly rain fed, deliver water related ESs. This landscape approach considers biomes as the entry point to identify the set of ESs produced. The water related ES category draws on the MA and TEEB classifications (MA, 2005; de Groot et al., 2012) and encompasses more ESs than hydrological services (Grizzetti et al., 2016). Figure 1 presents the biomes included in the present study which interact with surface river flow and provide water related ESs.

[a] For more on this distinction, please see the WISE UP project http://www.waterandnature.org/initiatives/wise-climate

Previous research has paid a lot of attention to water related ESs in other regions mainly due to the development of Payment for Ecosystem Services (Lele, 2009), but no previous studies have analysed the values of water related ESs in relation to climate vulnerability and adaptation. In this paper, the focus is on the African continent, for three main reasons: 1) River flows are pivotal to the delivery of ESs crucial to millions of livelihoods (WWAP, 2016); 2) the African continent presents in general a high climate change vulnerability exacerbating the need for immediate policy solutions (World Bank, 2007), and; 3) water related ESs in Africa continue to be inadequately investigated with very poor coverage (Lele, 2009).

Figure 1: Water related services from biomes linked to river flows.



Source: adapted from TEEB, 2010 and Mul et al., 2017.

Water related ESs are affected by a very high variability of all climate and water resources characteristics - in turn exacerbated by climate change (Faramarzi et al., 2013; IPCC, 2014). Understanding the benefits of water related services delivery through economic valuation and the factors that affect these economic benefits can provide guidance for water resource management and climate change adaptation.

Africa is not the continent with the largest ES valuation literature (for details on ES valuation methods see de Groot et al., 2012; Pascual et al., 2010). Only 19% of the valuation studies referenced in TEEB are located in Africa. Most studies are located in the Americas (33%) and Asia (26%) (based on Mc Vittie and Hussain, 2013). Moreover, the valuation literature in Africa is geographically disparate: Southern and Eastern Africa gather the highest number of studies while North, West and central sub-Saharan Africa go under-represented. Valuation studies on water related ESs in Africa represent 28% of all water related ES valuation studies globally. The most frequently valued water related ESs are raw materials and food provision, mainly due to two different reasons: 1) these services are relatively easy to value using the direct market pricing method (Van der Ploeg et al., 2010) and; 2) dependence on provisioning services is high and proportionally larger in African developing countries than in developed countries, hence an early focus on estimating values for this type of service (Egoh et al., 2012; Mc Vittie and Hussain, 2013). Indeed, ESs' consumptive outputs (e.g. crops and fish) contribute to subsistence livelihoods and constitute a very important share of households' income in African developing countries, thus participating in poverty alleviation and reducing vulnerability to negative shocks (Egoh et al., 2012; Suich et al., 2015).

The role of ESs in reducing vulnerability and in contributing to adaptation is particularly important in the face of climate change (Jones et al., 2012a; Munang et al., 2013b). Adaptation to climate change can be rooted in ES sustainability - known as 'ecosystem based adaptation' (Ojea, 2015). It is defined as an approach that "harness the capacity of nature to buffer human communities against the adverse impacts of climate change through the sustainable delivery of ES" and is expected to provide cost-effective adaptation resulting in resilient socio-ecological systems (Jones et al., 2012a). Such adaptation option is hailed as particularly beneficial as carbon sequestering ecosystems[b] such as forests, wetlands and peatlands can contribute to achieving mitigation targets set under the 2015 Paris agreement as well as the sustainable development goals of the United Nations while delivering on adaptation to climate change (Munang et al., 2013b). Early evidence on ecosystem based adaptation supports this is the case (Doswald et al., 2014). However, little is known yet on the linkages between adaptation and the value of ESs at a regional scale (Ojea et al., 2015). Indeed, ecosystem-based adaptation approaches have not been mainstreamed yet, with only little evidence in the literature (Jones et al., 2012). Indeed, ES valuations are mostly conducted in isolation of climate change and adaptation considerations. To fill this gap, one feasible approach is to explore to what extent water related ES values are related to higher (or lower) vulnerability and higher (or lower) leverage to adapt to climate change in countries. The present paper addresses these questions to explore the potential links between the value of water related ESs and countries vulnerability and potential to adapt to climate change.

To do this, the paper synthesises water related ES values elicited for Africa in the last three decades using a meta-analysis. Meta-analyses – the analysis of analyses as defined by Glass (1976) - have been increasingly used in the field of environmental valuation (Brander et al., 2006; Ghermandi et al., 2008) as it allows for a rigorous testing of a central tendency across a large number of studies while controlling for the effect of several parameters (Nelson and Kennedy, 2009). In this context, a meta-analysis for water related ES values is carried out to: 1) provide a quantitative answer to what factors drive water related ES values in Africa and; 2) understand the relationship between climate change vulnerability and readiness to adapt and the benefits obtained from ESs.

[b] Recent review highlights that much of the claimed climate regulation benefits of EbA, beyond carbon sequestering ecosystems, relate to local temperature regulation rather than mitigation (McVittie et al., 2017).

The next section introduces the methodology and outlines the data selection, standardization and coding carried out in order to perform the meta-regression. Section 3 presents the model specification and section 4 its associated results. Section 5 discusses the result implications before the concluding section.

2 Methodology

2.1 Existing meta-analyses of water-related ESs

Studies aimed at understanding the benefits from ESs have so far conducted meta-analyses focused on one ecosystem type, such as coral reefs (Brander et al., 2007; Ghermandi and Nunes, 2013), coastal and marine ecosystems (Liu and Stern, 2008), wetlands (Brander et al., 2006; Brouwer et al., 1999; Chaikumbung et al., 2016; Ghermandi et al., 2008; Woodward and Wui, 2001), forests (Barrio and Loureiro, 2010; Ojea et al., 2016), or mangroves (Brander et al., 2012). Other studies focus on one or a bundle of ESs for a specific ecosystem, such as recreational services from forests (Ojea et al., 2015; Zandersen and Tol, 2009); water ESs from forests (Ojea et al., 2015; Ojea and Martin-Ortega, 2015); regulating services from wetlands (Brander et al., 2013) and non-carbon services from forests (Ojea et al., 2016). The geographic coverage of these meta-analyses is slightly biased towards North America, especially if the study is focused on wetlands (Ghermandi et al., 2008). Most studies have adopted a global coverage while a few have specifically focused on developing or emerging economies (wetlands in developing countries in Chaikumbung et al., 2016; water and recreation services from forests in central America in Ojea et al., 2015; and water services from forests in central and south America in Ojea and Martin-Ortega, 2015).

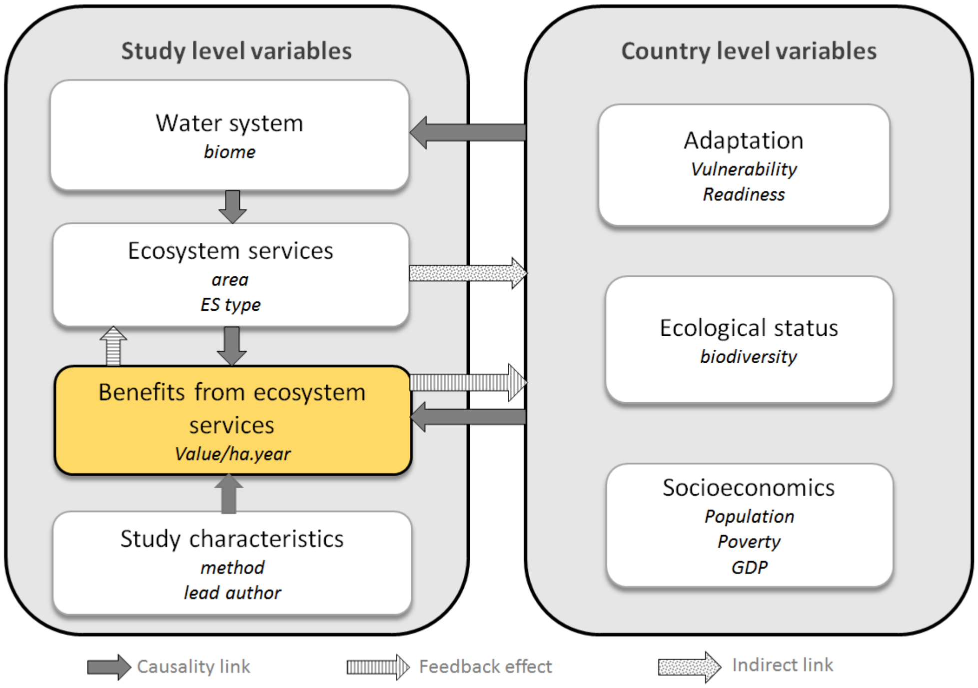
The present work is, to our knowledge, the first meta-analysis study on the economic valuation of water related ESs focussed on the African continent. For this, an original dataset is constructed based on secondary data from published literature, gathering information on the ES, its monetary value, and additional socioeconomic variables following our understanding of the context where the values occur (section 2.2). A meta analytical model is estimated (section 3.3) to explain the observed variations in water related ES economic values while controlling for a set of study and context characteristics (Stanley et al., 2013).

2.2 Context for variable selection

The selection of potential variables affecting ES values in the meta-analysis is guided by previous studies (e.g. Brander et al., 2012; Ghermandi et al., 2008; Ojea et al., 2010; Richardson and Loomis, 2009) and the understanding of the system and processes where the ESs occur (Figure 2). The water system (the biome) supports the delivery of ESs (categorized as surface area of production[c] and type of ESs), which yields a benefit to people that can be measured in monetary terms and could potentially depend on the valuation methodology used and the authors' familiarity with the case study area. This monetary or economic value is also dependent on the wider context where it occurs, and will be influenced by context variables on a larger scale, including socio economic and demographic factors (e.g. population, GDP, education level), biodiversity richness, and climate change adaptation readiness and vulnerability. At the same time, the ES economic value also impacts the water system. In turn, it can have a feedback effect on the delivery of ESs (depletion, for example) as well as on the context (e.g. reduced poverty).

[c] Standardization by production unit area is necessary to allow comparability across estimates.

Figure 2: Potential variables affecting ES values in the meta-analysis.



Previous meta-analytical approaches for ESs support this reasoning. These studies include variables related to the context, the study and the ecosystem, that are impacting the economic values of the ESs - the dependent variable (Brander et al., 2013; Chaikumbung et al., 2016; Ojea et al., 2010; Ojea and Martin-Ortega, 2015). The next sub-section details the selection process for the dependent variable. The full list of variables and their summary statistics are presented in Table 1. In addition, a more detailed definition of each variable is given in Appendix 1.

2.3 Database building

A peer reviewed literature search was conducted through electronic journal databases including EVRI[d], SCIENCEDIRECT and Google Scholar during the months of March to August 2014 using all different combinations of the keywords "Economic Valuation", "Africa", "Valuation", "Ecosystem" and "Ecosystem service" in the title, topic and keywords. Studies where collected from 1980 to 2014, as the

[d] Accessible at http://www.evri.ca/en

number of studies using the concept of ESs has increased steadily since the 1990s (Fisher et al., 2009). The grey literature was screened as well using web-based search engines with the same keywords. This was to avoid publication bias and reflect that some ES valuation studies are intended for policy makers and might not be published as journal papers but as reports or policy briefs (Ghermandi et al., 2008; Ojea and Martin-Ortega, 2015). Backward literature search was also performed. The global TEEB valuation database by Van der Ploeg et al. (2010) was screened as it gathers a comprehensive collection of valuation data updated to 2010. 36 data points drawn from 12 studies were extracted from this database.

The valuation of water related ESs in an African country constituted the main criterion for inclusion of a study in the dataset i.e. the study would provide a clear definition of an ES that falls under the definition of water related, (i.e. an ecosystem that impacts or is dependent on river flow[e], cf. Figure 1), with a stated valuation methodology and value unit. To ensure homogeneity of the dependent variable entries (the ES value), the goods and services valued in the studies had to comply with the MA or TEEB ES definition. Indeed, this ensures that the same shared concept is measured across studies, a key point for a meta-analysis (de Ayala et al., 2014). On a second screening, studies were selected if containing primary valuation data that was explicitly associated to a given service, for a given ecosystem type and elicited with a clearly laid out valuation method[f]. Third, a monetary value per hectare per year unit was adopted to ensure comparability between values, another crucial element when undertaking a meta-analysis (de Ayala et al., 2014). If the data was not readily available in this unit, only values which could be recalculated to the standard unit with information presented within the studies were included. When necessary, values given for a whole area were divided by the surface area under valuation, if the latter was available in the study. If studies were unclear on how the values were calculated, or the values

[e] To check for this, we relied on information given within the paper and complementary cross checks in the scientific literature when necessary.
[f] These information were added as dummy explanatory variables, see 3.1.

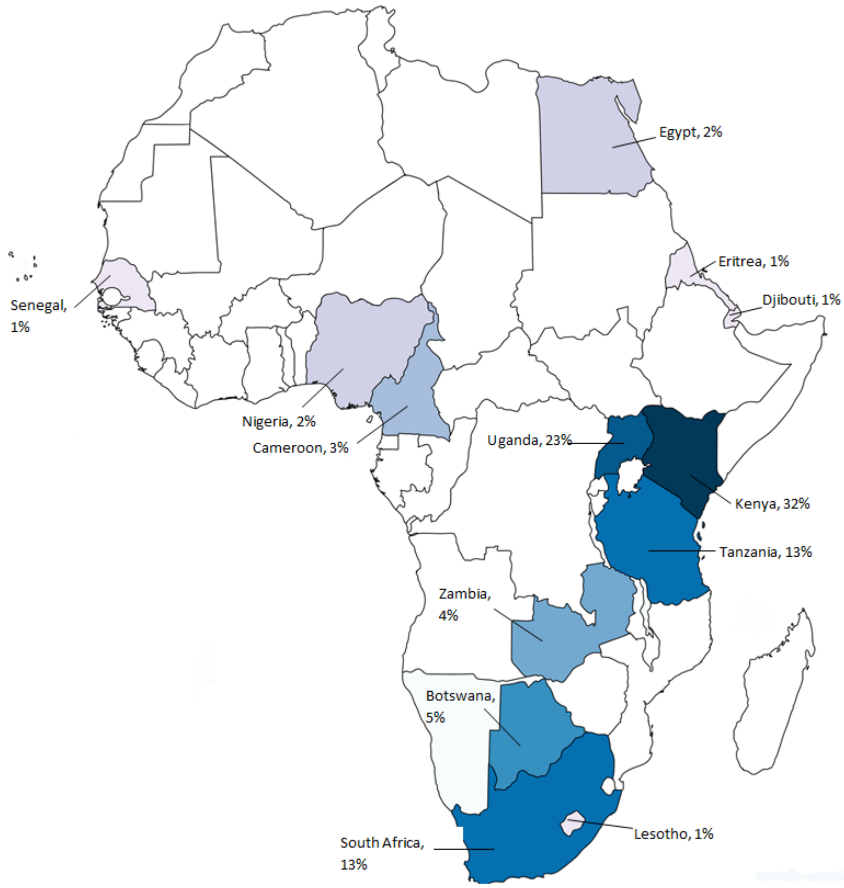
presented were secondary data or did not provide enough data for standardisation per ha, they were excluded from the dataset.

Care was taken to avoid double counting by only reporting disaggregated primary data. As a result, 36 studies out of the 72 derived from the search were not included due to qualitative or secondary valuations, data incompleteness or to the impossibility to convert the value to the standard unit.

All observations were deflated and standardised for comparability to 2014 international USD using the World Bank GDP deflator and purchasing power parity dataset (World Bank, 2015). This is standard procedure due to the various time period reported and to adjust for the different currencies, income and consumption levels among African countries (Brander et al., 2006; Ojea and Martin-Ortega, 2015; Woodward and Wui, 2001).

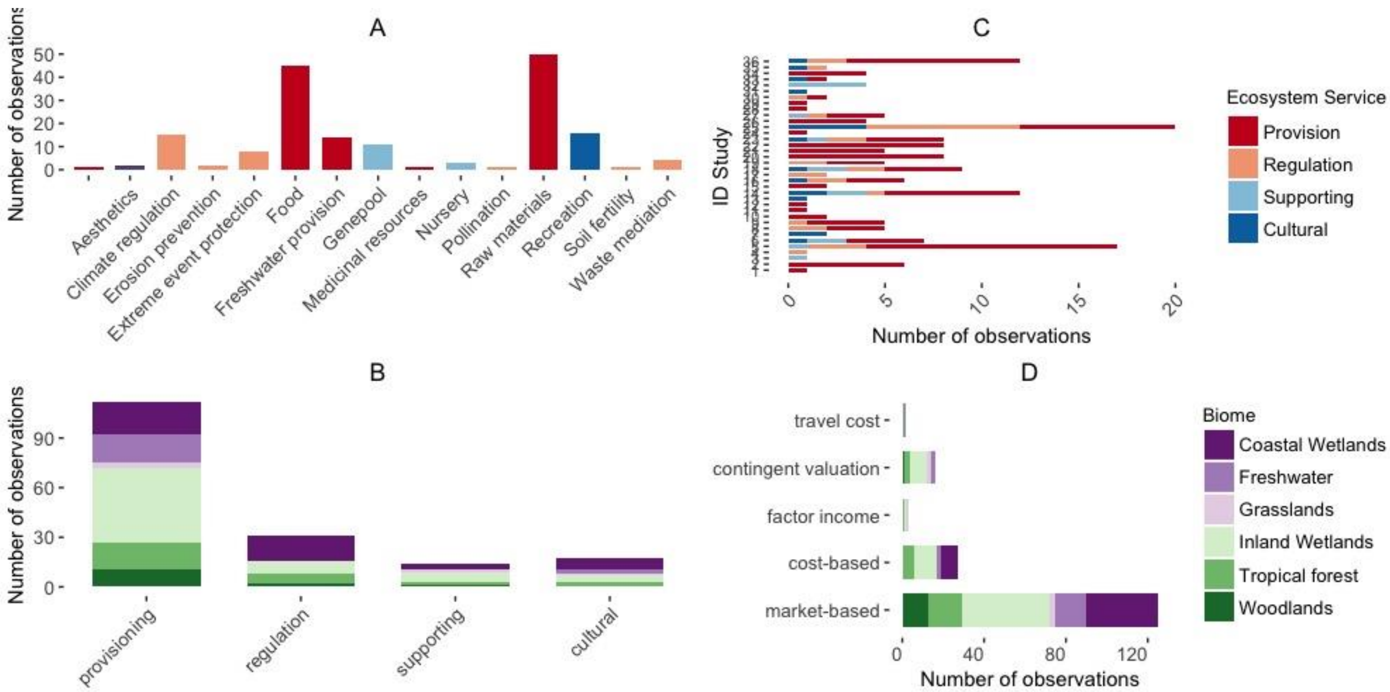
The semi-systematic search resulted in an original dataset of 178 ES value observations drawn from 36 studies dating from 1982 to 2014 and spanning 13 countries (see Figure 3). Data is distributed across Kenya, 32% of the observed values, representing 16% of the studies; Uganda, 23% of total data points representing 27% of included studies; and Tanzania and South Africa, 13% of the reported values, respectively representing 8% and 18% of all studies. East Africa makes up more than half the data points. Other countries provided 19% of data points representing 29% of the studies.

Figure 3: Geographic distribution of the ES value observations



A detailed description of the dataset is presented in Figure 4. Most observations are provisioning services, such as food, raw materials and freshwater provision (Figure 4-A). On average, each study provided 5 observations with one outlier study containing 20 observations (Emerton, 2014) and 10 studies providing a single one (e.g. Naidoo and Adamowicz, 2005; Turpie and Joubert, 2001) (see Figure 4-C). Biomes are represented across all ES categories as observed in Figure 4-B. Market based methods are the most used methods and are present in every biome (Figure 4-D). A list of studies included in the analysis is available in Appendix 2 as well as a cross tabulation of the water related ES values per biome in international dollars in Appendix 3.

Figure 4: Summary statistics of the water related ESs in Africa dataset



Number of observations per sub-type of ESs (A); Number of observations per ES type and biome (B); Number of observations per original study and ES type (C); and number of observations per methodology and biome (D).

Figure 5: Histogram of ES values (ln($/ha)) per biome and ES type.

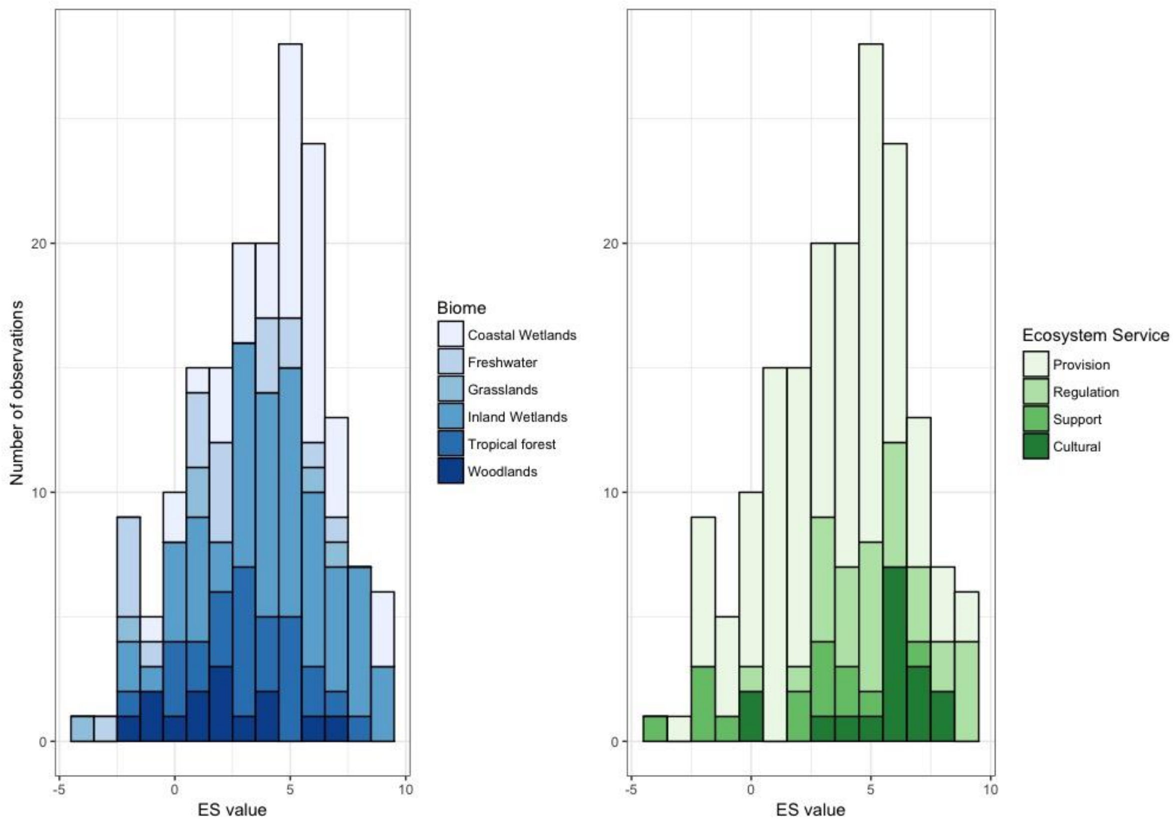


Figure 5 provides further descriptive statistics on the values of ESs in the original studies. Values per hectare per year are log-transformed to normalize the data, therefore ranging between negative and positive values in the histograms. Colours represent biome types on the left chart, and ES types on the right chart. The most commonly valued type of biome corresponds to inland wetlands, while the most commonly valued ES type is provisioning services.

3 Model and specification

3.1 Explanatory variables

We shall distinguish between study-specific variables that are obtained from the original studies and context variables that are excerpted from global development datasets and from natural indices databases. Description, sourcing and summary statistics of all variables used in the model are available in Table 1.

Table 1: Variable description and summary statistics

Variable	Type	Description	Variable name	Coding	Number of observations	Mean (Std. Dev.)	Range [Min; Max]
Dependent variable							
lnVAL	Numeral	Natural logarithm of the ES value in international $/ha.year (2014 value)			178	3.84 (3.00)	[-4.35; 11.35]
Explanatory variables							
Study variables							
BIO	Dummy	Type of biome where the service is provided	B_IWT	Inland wetlands (=1)	64	0.36 (0.48)	[0; 1]
			B_CWT	Coastal wetlands (=1)	45	0.25 (0.44)	[0; 1]
			B_FWT	Freshwater[g] (=1)	20	0.11 (0.32)	[0; 1]
			B_WDL	Woodlands (=1)	14	0.08 (0.23)	[0; 1]
			B_TRO	Tropical forest (=1)	27	0.15 (0.36)	[0; 1]
			B_GRAS	Grasslands (=1)	8	0.04 (0.21)	[0; 1]
SERV	Dummy	Type of ecosystem service as per the TEEB classification	PROV	Provisioning (=1)	113	0.63 (0.48)	[0; 1]
			REG	Regulating (=1)	35	0.18 (0.39)	[0; 1]
			SUPP	Supporting (=1)	15	0.08 (0.28)	[0; 1]
			CULT	Cultural (=1)	18	0.10 (0.30)	[0; 1]
logHA	Numeral	Log of the surface area of the ESs in hectares	logHA		178	10.35 (3.60)	[-.47[h]; 18.19]
METD	Dummy	Original valuation method used in the primary valuation	METD_M	Market –based methods: direct market price, cost-based, factor income (=1)	158	0.90 (0.31)	[0; 1]
			METD_NM	Non-market- based methods: Contingent valuation and travel cost (=1)	19	0.10 (0.31)	[0; 1]

[g] Freshwater biomes include rivers, lakes and floodplain in line with the categorisation of the TEEB (2010)

[h] The negative values are due to the <1ha figures for certain ESs

Variable	Type	Description	Variable name	Coding	Number of observations	Mean (Std. Dev.)	Range [Min; Max]
LEAD	Dummy	Whether the lead author of the study is based in a local or international institution located in Africa.	LEAD	First author based in Africa (=1) other (=0)	178	0.80 (0.40)	[0; 1]
Context variables							
Socio economic and demographic							
PMRY_ENROL	Numeral	Primary school enrolment rate, both sexes, in percentage (World Bank, 2015)			177	102.94 (17.13)	[30.61; 131.27]
GDP	Numeral	GDP per capita in thousands of 2014 PPP USD (World Bank, 2015)			178	3.30 (3.27)	[0.61; 12.3]
POP_R	Numeral	Percentage of rural population (World Bank, 2015)			178	74.86 (12.00)	[23.56; 88.17]
POVTY_R	Numeral	Rural poverty headcount ratio at national poverty line in percentage (World Bank, 2015)			175	50.17 (19.09)	[22.4; 92.2]
Biodiversity							
GEF	Numeral	Composite index by the Global Environmental Facility of relative biodiversity potential for each country. (Pandey et al., 2006)			178	9.37 (6.67)	[0.31; 23.52]
Climate change							
VUL	Numeral	Composite index scoring the vulnerability of each country to climate change. (Notre Dame Global Adaptation Initiative, 2015)			178	1.01 (0.024)	[0.98; 1.11]
READ	Numeral	Composite index scoring the readiness of a country to leverage investment in climate change adaptation policies. (Notre Dame Global Adaptation Initiative, 2015)			178	0.99 (0.06)	[0.88; 1.09]

Study-specific variables include the methodology applied in the original valuation exercise and other characteristics of the case studies. Biome (*BIO*) is based on what is defined in the original publication and can be an inland wetland (B_IWT), a coastal wetland (B_CWT), a freshwater system i.e. river, lake, floodplains (B_FWT), woodlands (B_WDL), tropical forest (B_TRO), or grassland (B_GRAS) (Table 1). The number of observations for terrestrial and aquatic ecosystems is 49 and 129, respectively. Both types of biomes present similar average values per hectare with 2014 PPP USD 1,457 for terrestrial and 1,469 for aquatic biomes. Ecosystem services (*SERV*) are classified following the MA and TEEB categorisation into provisioning (PROV), regulating (REG), habitat or supporting (SUPP) and cultural (CULT) services (Table 1). The valuation method (*METD*) can be market-based (METD_M), i.e. direct market pricing, cost based methods, factor income and production function; or non-market based (METD_NM) i.e. contingent valuation and travel cost. The surface area is included in log-transformed hectares (*logHA*) and refers to the area of the ES provision. Finally, information on the lead author is collected to identify any "authorship effect" (Brouwer et al., 1999), recording if the lead author has an affiliation to a research centre or an international organisation based in Africa (*LEAD*)[i]. The literature shows mixed evidence on authorship effects. On one side, one can expect that first authors affiliated to an institution located in Africa might be more likely to report higher ES values, as they may have better knowledge of the local context and of the communities where the market and non-market based valuation methods are implemented, therefore providing more accurate and comprehensive estimates. On the other side, in the case of market-based methods, these local authors may have access to finer scale market data that could lower the estimates (Brander et al., 2006), and have better knowledge of cultural and social norms that may help design unbiased non-market preference elicitation approaches.

Context variables related to socio-economic traits, biodiversity level, vulnerability and adaptation to climate change at the national level are also expected to influence the value of water related ESs (see

[i] It is assumed that affiliation between publication time and research time has not changed.

Figure 2) and were included in the dataset. Each data point for the context variables corresponds to the study's country and year[j]. First, socio-economic and demographic variables such as GDP per capita (*GDP*), education level as the percentage of the population of official primary education age enrolled in primary school (*PMRY_ENROL*), rural population share expressed as the percentage of population living in rural areas (*POP_R*) and rural poverty, the percentage of rural population living below the national poverty lines (*POVTY_R*). The last two variables above are at rural level to reflect that ES provision in the dataset mainly occurs in rural areas. All variables relate to a country's development levels and can potentially explain data heterogeneity. Indeed, it can be expected that more developed countries would tend to present higher ES values as highlighted in previous meta-analyses (Barrio and Loureiro, 2010; Brander et al., 2006; Ghermandi et al., 2008; Ojea et al., 2010).

Second, a variable reflecting the country's biodiversity status is also included with the biodiversity richness indicator elaborated by the Global Environmental Facility (*GEF*). Indeed, biodiversity fundamentally underpins ecosystems, supporting their capacity to provide services to humans (Cardinale et al., 2012; Ojea et al., 2010). Higher biodiversity levels are associated with water related ESs (Balvanera et al., 2014). However, given that a single service may result from multiple functions, positive and negative effects of biodiversity richness can counteract each other and the resulting net effect is still unknown (Balvanera et al., 2014). Less evidence is available regarding the effect of biodiversity on the economic value of those ecosystem services and the present study wants to contribute in this respect.

Third, climate change indices developed by the Notre Dame University[k] for vulnerability to climate change and readiness to adapt are also considered (*VUL* and *READ*). These indices are included to explore the extent to which ES values are related to climate change vulnerability and potential adaptation leverage in study countries. It is expected that higher ES values are associated with less

[j] As an example, for a 2012 study in Uganda, GDP per capita and all other context variables will correspond to year 2012 for Uganda.
[k] ND Gain country index http://index.gain.org/

vulnerable and more ready to adapt countries, as a high value ES can reflect the state of the ecosystems and the associated level of benefits society receives. Each index considers several dimensions of a country's vulnerability and readiness (see Appendix 1). The adjusted for GDP indices are used, they measure the actual performance of the country compared to its expected performance given its GDP. A detailed explanation on all context variables and their sources is available in Appendix 1. Care was taken when selecting the variables to minimize potential collinearity[l]. The tests for collinearity produced a diagnostic of no correlation problem as the Variance Inflation Factors (VIF) returned values lower than 6 for all variables[m] (Ojea et al., 2010). Correlation coefficients between each variable are available in Appendix 4.

3.2 Model specification

The dependent variable in the models ($\ln y_{in}$) is a vector of the water related ES monetary values converted to 2014 international US$ per hectare per year. It is expressed in logarithmic terms (see Table 1) based on the analysis of the histograms of the dependent variable in log and non-log form as well as on the result of the Box-Cox model test (Cameron and Trivedi, 2009, chapter 3)[n]. Semi-logarithmic regression is also the resulting functional form in previous meta-analyses of ES values (Barrio and Loureiro, 2010; Brander et al., 2007; Johnston et al., 2005; Lindhjem, 2007; Liu and Stern, 2008; Richardson and Loomis, 2009; Rolfe and Brouwer, 2012; Woodward and Wui, 2001). The explicit specification of the meta-regression model can be described as follows:

$$\ln y_{i,j} = \alpha + X_{s,i,j}\beta_s + X_{c,i,j}\beta_c + \varepsilon_i + u_j, \quad \text{Eq. (1)}$$

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[l] For example, the adjusted for GDP ND gain indices were chosen over the non-adjusted ones to limit collinearity.

[m] Mean VIF for model 1 is 2.36 ranging from 1.25 to 3.84 and 2.69 for model 2, ranging from 1.36 to 4.95.

[n] The Box-Cox test resulted in a value of – 1038 (χ^2 = 129.45) hence the null hypothesis of no difference between semi-log and linear model was rejected at a 1% significance level (i.e. models are significantly different at 99% confidence level in terms of goodness of fit). In addition, we obtain an estimate of $\hat{\theta} = 0.04$, which gives much greater support for a log-linear (or semi-log) model $(\theta = 0)$ than the linear model $(\theta = 1)$ (see Cameron and Trivedi, 2009, chapter 3).

where i denotes each specific study $(i = 1, 2, ..., N)$, j refers to the value estimate reported in the study $(j = 1, 2, ..., M_i)$, α is the usual constant term or intercept and the β vectors are the coefficients to be estimated in the meta-analysis. Each β coefficient is associated to a type of explanatory variable: either study specific (X_s) or context specific (X_c) (see Table 1). Where each study i provides a single estimate j, then $M_i = 1$ and ε_i collapses into u_j . However, where a study gives more than one value estimate, it is necessary to account for the common error across estimates (u_j) and the individual-specific effect or panel error within a study (ε_i).

3.3 Model estimation

There are several approaches to estimating this model depending on assumptions regarding the error variance-covariance matrix (Lindhjem, 2007). Table 2 presents the different estimators used in recent meta-analysis literature in environmental economics. These include Weighted Least Squares (WLS), Generalized Least Squares (GLS), explicit specifications of panel models with fixed or random effects, and Ordinary Least Squares (OLS) usually applied with Huber-White adjusted standard errors clustered by study. This last estimator has been most commonly used in the environmental economics literature (see Table 2). Meta-regression models dealing specifically with data heterogeneity, heteroscedasticity and correlated observations are described in Nelson and Kennedy (2009).

Table 2: Models estimated in meta-analysis studies

Estimation technique	Study
OLS	Brander et al., 2012; Ghermandi et al., 2008; Lindhjem, 2007; Liu and Stern, 2008; Loomis and White, 1996; Ojea et al., 2016, 2010; Richardson and Loomis, 2009; Shrestha and Loomis, 2001
OLS with Huber–White adjusted SE	Barrio and Loureiro, 2010; Brander et al., 2006; Ghermandi and Nunes, 2013; Johnston et al., 2003; Lindhjem, 2007; Woodward and Wui, 2001; Zandersen and Tol, 2009
Weighed OLS with Huber White	Ghermandi and Nunes, 2013
Multi-level OLS	Bateman and Jones, 2003; Brander et al., 2007; Brouwer et al., 1999; Ghermandi et al., 2008; Johnston et al., 2003
GLS	Ojea et al., 2015; Ojea and Loureiro, 2011
Fixed GLS	Ojea and Martin-Ortega, 2015
RE GLS	Chaikumbung et al., 2016; Ojea and Loureiro, 2011
GLS cluster SE	Chaikumbung et al., 2016
Weighed GLS with cluster SE	Chaikumbung et al., 2016; Johnston et al., 2003

Note: some studies estimate more than one model and hence are reported multiple times. Generalized Least Square (GLS), Ordinary Least Squares (OLS), Fixed Effects (FE), Random Effects (RE), Standard Errors (SE).

Since most studies in the database report more than one monetary value estimate - a panel of observations - estimates from the same study are likely to be correlated. Therefore the meta-regression specification defined in Eq. (1) can be estimated with data-panel structure (Nelson and Kennedy, 2009).

The appropriateness of including the study specific error term ε_i was tested by applying the Breusch Pagan Lagrange Multiplier test for random effects (Torres-Reyna, 2007; Zandersen and Tol, 2009)[o] . The null hypothesis of no panel effect was rejected at the 5% significance level (χ^2 value of 6.92 with Prob.> χ^2 = 0.0043). In addition, the Hausman test was used to determine whether the random effects model (as opposed to the fixed effects one) is the correct specification. This procedure tests whether a significant correlation between unobserved individual-specific random effects (ε_i) and the explanatory variables (X_i) exists (Cameron and Trivedi, 2009, chapter 8; Wooldridge, 2002, chapter 10). Under the

[o] This test helps choosing between a random effects regression and a simple OLS regression (Torres-Reyna, 2007)

null hypothesis, ε_i in (1) is purely random, implying that it is uncorrelated with regressors X_i in (1). The Hausman specification test resulted in a χ^2 value of 11.46 with Prob. > χ^2 = 0.32, yielding to not reject the null hypothesis of non-correlation at the 5% significance level, and therefore supporting the adoption of a random effects model. Cluster-robust standard errors were specified for the random effects panel data models estimated in section 4 (Cameron and Trivedi, 2009, chapter 8).

4 Results

To better explain the variations in the value observations and check for the robustness of the results obtained, Model 1 and extended Model 2 with a focus on climate change vulnerability and readiness to adapt are estimated. In addition, cross-products of variables are computed to further interpret the results (section 4.2).

4.1 Models 1 and 2

Both models are random effects panel data models with cluster-robust standard errors and are estimated in STATA (V.14.1)[p]. The two models perform well with reasonable R square for this type of study[q]. The estimated coefficients along with their standard errors and 95% confidence intervals are presented in Table 3:

[p] A GLS model corrected for heteroscedasticity and an OLS with cluster robust standard errors were also estimated for both models (model 1 and model 2) and similar results were obtained in terms of coefficients significance and behavior.

[q] The overall R-sq is in line with previous published work using the same model (Mattmann et al., 2016) as well as with other model results (Brander et al., 2012, 2006; Brouwer et al., 1999; Chaikumbung et al., 2016; Ghermandi et al., 2008; Ojea et al., 2010, 2015; Shrestha and Loomis, 2001; Woodward and Wui, 2001).

Table 3: Meta-analysis regression model 1 and 2 results.

	Model 1		Model 2	
Variable	**Coefficient (Std. Error)**	**95% CI**	**Coefficient (Std. Error)**	**95% CI**
B_FWT	-1.086** (0.376)	[-1.822 -0.349]	- 1.023** (0.337)	[-1.684 -0.363]
PROV	-1.481* (0.859)	[-3.165 0.204]	-1.461* (0.868)	[-3.163 0.241]
REG	-0.166 (0.713)	[-1.564 1.232]	-0.215 (0.727)	[-1.639 1.210]
SUPP	-1.668* (0.951)	[-3.531 0.196]	-1.810** (0.914)	[-3.603 -0.019]
logHA	-0.357*** (0.084)	[-.523 -0.192]	-0.295*** (0.083)	[-0.458 -0.133]
METD_M	-0.617 (0.852)	[-2.288 1.053]	-0.587 (0.859)	[-2.271 1.097]
LEAD	1.949** (0.817)	[0.349 3.550]	2.044** (0.749)	[0.575 3.512]
PMRY_ENROL	-0.035 (0.031)	[-0.096 0.027]	-0.0342 (0.026)	[-0.085 0.017]
GDP	0.311* (0.189)	[-0.060 0.681]	0.367** (0.143)	[0.087 0.648]
POP_R	0.039 (0.044)	[-0.048 0.126]	0.0482 (0.040)	[-0.029 0 .126]
POVTY_R	-0.040** (0.017)	[-0.074 -0.007]	-0.044*** (0.014)	[-0.071 -0.018]
GEF	-0.019 (0.075)	[-0.166 0.128]	-0.139* (0.074)	[-0.284 0.005]
VUL			-46.302*** (12.166)	[-70.147 -22.458]
READ			-12.971** (6.840)	[-26.377 0.435]
Constant	9.985** (3.930)	[2.282 17.688]	9.950** (4.165)	[1.785 18.114]
Observations	174		174	
Groups	34		34	
R-sq:	0.3917		0.4818	

Note:
***, **, *: Significance at the 1%, 5% and 10% levels, respectively.
CI: Confidence Interval
Other combinations of variables were tried but gave no significant result
If the regressions had included METD_NM instead of METD_M the coefficients for this variable would have been the reversed of the ones presented here i.e. 0.617 and 0.587 for Model 1 and 2, respectively.

The coefficients for the dummy variables can be interpreted as constant proportional changes given an absolute change in the variable.

For the study characteristics, freshwater ecosystems (*B_FWT*) resulted into a negative and significant coefficient indicating that freshwater ecosystems have in general, lower ES benefits than other types of biomes in the dataset (grasslands, wetlands, tropical forests and woodlands). Provisioning (*PROV*) and habitat or supporting services (*SUPP*) display significant negative coefficient estimates, with respect to cultural services as the omitted variable (*CULT*). This result indicates that provisioning and habitat services are, in general, related to a lower ES monetary value as compared to cultural services. One explanation could be that revenues from international tourism can be substantially larger than the economic value derived from generally low value provisioning goods (e.g. fish catch), as obtained in other analyses (UNEP, 2010). Indeed, international users may place higher values than local users on services such as tourism, but lower values on regulation services, while local users may do the opposite. Most original studies included in the database did not provide explicit information on end users. However, it can be expected that end users of cultural services are most often foreign visitors, who are wealthier than end users of provisioning and regulating services, who are mostly local communities. Another potential explanation lies in the common use of the market price valuation method for provisioning services valuation, which in the literature is recognized for providing slightly lower estimates than other methodologies (e.g. Brander et al., 2006).

Regarding the valuation method of the primary studies, market-based valuation methods (*METD_M*) seem not to be significantly different from non-market methodologies in our dataset. However, environmental valuation literature generally shows higher values with non-market valuation techniques than with market-based valuation methods (Brander et al., 2006).

The coefficient for the surface area is also negative and significant, showing that, on average, the larger the area where the ES is produced, the lower the marginal benefit per hectare. This tendency is in line with other studies on environmental valuation and is due to decreasing marginal returns with size (Brander et al., 2006; Chaikumbung et al., 2016; Ghermandi et al., 2008).

The African affiliation of the study lead author (*LEAD*) has a significant and positive impact on the values, which indicates that, on average, valuation studies led by a researcher based on the African continent tend to provide higher benefit estimates. One reason behind this could be that locally based researchers, being more aware of the country and community context, can design and implement questionnaires and focus groups that have greater success in estimating true preferences, which can translate into a higher ES estimate. Further analysis on this effect is needed to understand what particular factors drive this finding, specifically related to the methodologies involved.

ES values greatly differ depending on context characteristics such as GDP and rural poverty. *GDP* per capita is positively related with the ES values, albeit for a very low effect. The rural poverty measure (*POVTY_R*) has, on average, a significant negative effect on ES benefits. Potentially, rural poverty might have a negative impact on the observed values due to the lower market prices practiced in these areas – since the direct market pricing method dominates the dataset (see Figure 4-D), and the effect of this methodology could be felt in this relationship. Another possible explanation (not in opposition to the previous one) is that a higher poverty rate in a rural setting translates into a higher reliance on natural resources, which subjected to heightened human pressure degrade and provide services of lesser value (either due to lower quality or quantity). This is a two-way effect and the opposite argument could also be made, as having low ES values leads to greater poverty rates. Primary education enrolment (*PMRY_ENROL*) and percentage of rural population (*POP_R*) are on average not significant in either model. Our expectation was that education level might impact positively or negatively ES values but this is not shown in the analysis.

Model 2 results are very similar to model 1 with the exception of the biodiversity indicator (*GEF*) that becomes statistically significant. The negative coefficient for *GEF* suggests a trade-off between a country's biodiversity potential and its water related ES values. Such trade-off has been observed for ES provision (i.e. the service delivery not the value) and biodiversity. For regulating services, Phelps et al.

(2012) suggest that there may be important trade-offs between biodiversity level and the delivery of regulating services such as carbon uptake by forests. In the case of provisioning services, it could be expected that ecosystems with higher provisioning services extraction level (food, raw materials, etc.) would be more degraded sites and can be associated with lower biodiversity levels (Butchart et al., 2010; Rey-Benayas et al., 2009; Vitousek et al., 1997). However, when it comes to ES values, little evidence exists, and Ojea et al., (2010) show a positive link between biodiversity and provisioning service values. These issues are further investigated in section 4.2.

Model 2 also shows that the coefficient for vulnerability to climate change of a given country (*VUL*) has a significant negative effect. Higher vulnerability in a country is related to lower water related ES benefits, which may indicate the importance of highly valued ESs for adaptation, as less vulnerable countries have a comparatively smaller adaptation gap (UNEP, 2017). A feedback loop pattern could be at play: an increased vulnerability can in part be due to a degradation of ecosystems, potentially translating into lower values, and a heightened degradation could lead to a reinforced vulnerability. It is to be noted that in our database GDP and vulnerability levels are not correlated[r] (see Appendix 4), suggesting that in our case, GDP levels are not associated with higher or lower vulnerability to climate change. To understand the causal relationship between vulnerability to climate change and ES values, a case study-based analysis where vulnerability and adaptation levels are available at a finer spatial scale would need to be developed. This is not possible with the present dataset, which supports a more exploratory analysis. Our results on *VUL* are in line with the expectations and results from previous literature, showing for some cases (but not at country level) that promoting ESs can be a cost-effective adaptation measure by reducing vulnerability (Doswald et al., 2014; Jones et al., 2012a; Munang et al., 2013b).

The readiness to adapt to climate change index (READ) displays, on average, a negative relationship with ES values. This suggests that in countries where institutions are less ready and less able to leverage

[r] VUL and GDP correlation coefficient corresponds to 0.159 at the 5% level (see Appendix 4)

finance for climate change adaptation and implement adaptation policies, the values associated with ESs are higher. This result is somehow surprising and it may be pointing out to a larger issue a country may face. Indeed, the readiness to adapt index is a ranking in absolute that involves economic, institutional and social readiness (see Appendix 1) which mainly rely on non-natural capital. Since ES values mostly contribute to natural capital (Daily et al. 2009), countries may be facing a trade-off between their natural capital and non-natural capital, where the former is related to climate vulnerability and the latter is related to readiness to adapt. Further research is needed to confirm this hypothesis.

4.2 Interactions

Cross-effects between multiple variables allow further exploring the results of the meta-models and understand the interactions between variables (Ghermandi et al., 2008). A few interactions were investigated in model 2[s] (see Table 4). This was carried out to: 1) check the interplay between biodiversity levels and the different types of ESs (GEF*REG); 2) explore the authorship effect with the methodologies (LEAD*METD_M); 3) further investigate vulnerability to climate change and ES types (VUL*PROV and VUL*REG); and 4) examine effects of GDP on vulnerability to climate change (VUL*GDP). Results are available in Table 4.

[s] The cross products were included in model 2, one at a time, to analyse each interaction independently.

Table 4: Cross products

Name of cross product	Coefficient (Std. Error)
*GEF*REG*	0.131 ** (0.061)
*GEF*PROV*	-0.032 (0.083)
*LEAD*METD_M*	-4.475*** (0.976)
*VUL*PROV*	- 41.666 ** (16.835)
*VUL*REG*	- 73.602 *** (16.586)
*VUL*GDP*	-9.121 *** (3.588)

Note: ***, **, *: Significance at the 1%, 5% and 10% levels, respectively. Absence of sign means the interaction was not significant.

The interactions between *GEF* and the type of ESs (Table 4) further investigate the link between a country's biodiversity potential and its ES values. While biodiversity is affecting ES values in a negative direction in the general model, the cross products of biodiversity and ES values (*GEF*REG* and *GEF*PROV*) are yielding mixed results. There is a positive relation for regulating service values and no significant effect for provisioning. Given these results, a more detailed analysis with study site specific biodiversity levels would be necessary to disentangle the effects of biodiversity on ES values.

The cross-effect of the author's institution (*LEAD*) and the valuation method (*METD_M*) further explains the authorship effect. When the lead author is based in an institution located in Africa and uses market based valuation methods, the ES benefits obtained are lower (*LEAD*METD_M* in Table 4). One reason for this can be access to and understanding of more reliable market data, at a finer scale for a locally based researcher that may avoid over estimation bias. Of course, this interpretation comes with caution as it is unclear whether this explanation applies if the researcher is based in a country different from the one where they do the research. The inverse effect applies and if the lead author uses non-market based methods, the values of the ES benefits will be higher[t].

The interaction between the vulnerability index and the type of service further informs us about the importance of the different benefits from ESs on adaptation to climate change. Countries more vulnerable to climate change present lower values both for provisioning and regulating ESs (Table 4), while results for cultural and supporting services are not significant. This result reinforces the role of both provisioning and regulating ESs in reducing climate vulnerability. Finally, higher vulnerability to climate change in our sample is related to lower GDP, as the negative coefficient for the cross effect between the vulnerability index and the GDP shows (Table 4).

5 Discussion

Livelihoods and economies of African developing countries are especially vulnerable to climate change due to their climate sensitive economies that are largely underpinned by ESs and natural resource management (McCarthy, 2001). At a time when the 5th International Panel on Climate Change (IPCC) assessment states with high confidence that “African ecosystems are already being affected by climate change and future impacts are expected to be substantial” (Niang et al., 2014), understanding how managing and enhancing ES values can foster a society’s capacity to adapt to climate change is necessary (Doswald et al., 2014). In this context, the present work is novel for two main reasons: 1) to the best of our knowledge, this is the first meta-analysis on benefits from water related ES values in Africa and; 2) we find supporting evidence of a link between the value of water ESs and the vulnerability level of African countries at the national scale.

[t] LEAD*METD_NM= 4.475*** (Std. Error = 0.976).

This work synthesizes existing evidence and effect of factors driving water related ES values in Africa. Results suggest that water related ESs present different values depending on the type of service, biome, lead author's affiliation and socioeconomic factors such as GDP per capita, rural poverty ratio and biodiversity levels, as well as a country's vulnerability and readiness to adapt to climate change. More precisely, the analysis highlights that a country's poverty level and vulnerability to climate change are directly linked to low water related ES benefit values. These interlinks between ES values and - what are essentially - proxy indicators for development levels (poverty, GDP and vulnerability) make the case for ecosystem-based adaptation. Indeed, by bringing evidence of the existing synergy between development levels and the value of water related ESs, the analysis gives quantitative evidence that ecosystem-based adaptation could fulfil its "win-win" promise described in Munang et al. (2013b) and Seddon et al. (2016) of contributing to adaptation to climate change while delivering on the United Nations Sustainable Development Goals (SDGs) (see UN, 2015). However, we only find this link for vulnerability to climate change as the results also show a negative effect of water related ES values on readiness to adapt. More research will be needed to understand what drives this novel result by addressing the question of the extent to which natural capital and non-natural capital are facing inherent trade-offs that might limit the capacity of a country to leverage adaptation action.

This new evidence comes in the context of a recent shift in focus in the adaptation agenda of the international community towards ecosystem-based adaptation. Indeed, under the Paris agreement negotiated within the United Nations Framework convention on Climate Change (UNFCCC), every five years, countries submit Intended Nationally Determined Contributions (INDCs) that comprise a National Adaptation Plan of Action (NAPA) (see UNFCCC, 2016). The review of the first set of INDCs submitted in 2016 by Seddon et al. (2016) states that the INDCs of 25 African countries have developed detailed NAPAs with tangible ecosystem-based adaptation targets. Now, given how ES values can vary with biomes, type of service etc., research and policy should address who the end users are and how much they benefit from ESs. As ultimately, the end users are key to natural resource management enforcement, especially in rural Africa, and particular attention should be paid to ES end users so that ecosystem-based adaptation policies can affect targeted populations.

6 Conclusion

ESs are important for achieving sustainability and have been successfully used in management and policy around the world. Studies have also highlighted the importance of ESs in adaptation, where investing in recovering and maintaining ESs may be a climate proof policy. However, less has been shown on how the values from ESs interact with vulnerability and adaptation to climate change. In this study, we address this last question with a meta-analysis of water related ESs in Africa. We find that higher ES values are related to lower vulnerability to climate change reinforcing the case for ecosystem-based adaptation in Africa. However, we also find that high ES values are related to lower readiness to adapt and further research should look in this direction to explore trade-offs between natural capital and non-natural capital in adaptation.

Further research should address what drives ES values at the local scale by combining observed values with spatial information that can explain variation at a finer scale. This was not possible for exploring biodiversity, adaptation and vulnerability to climate change in the African case studies. But it may be a necessary approach to understand the specific dynamics of the service users and providers, the area of the ecosystems producing the services and potential seasonal variations in the service provision that may have an effect on their value.

Appendices

Appendix 1 – List of variables

ACRONYM	VARIABLE	DESCRIPTION	UNIT	TYPE
VAL	**VALUE**	ES value in 2014 purchasing power parity (PPP) $ per hectare (ha) and year	2014 PPP $ per ha and year	Quantitative
	ECOLOGICAL VARIABLES			
BIO	**BIOME**	Type of biome in which the service is provided	n.a.	Qualitative
SERV	**SERVICE**	Type of ecosystem service considered as per the TEEB classification in 4 categories: provisioning (PROV), regulating (REG), supporting (SUPP) and cultural (CULT). Source: http://www.teebweb.org/resources/ecosystem-services/	n.a.	Qualitative
	STUDY VARIABLES			
METD	**METHOD**	Original valuation method used for obtaining the value estimate of the ES. Note: Benefit transfer valuation method was replaced by the original valuation method of the original study for Seyam et al., (2001) and Turpie et al.,(2000).	n.a.	Qualitative
HA	**SURFACE AREA IN HA**	Surface area in hectares where the ES is delivered	Hectares	Quantitative
LEAD	**LEAD**	Whether the lead of the paper (first author) is affiliated to either an organisation located in Africa, either an international organisation with offices in Africa at the time of publication.	n.a.	Qualitative
	SOCIO ECONOMIC INDICATORS			
PMRY_ENROL	**GROSS ENROLMENT RATIO, PRIMARY BOTH SEXES, PERCENTAGE**	Total enrolment in primary education, regardless of age, expressed as a percentage of the population of official primary education age. The ratio can exceed 100% due to the inclusion of over-aged and under-aged students because of early or late school entrance and grade repetition. Note: Data is not always available for the study year. When this was the case the closest year with data available was entered. Source: World Bank indicator, can be accessed at http://data.worldbank.org/indicator/SE.SEC.ENRR/countries	Percentage	Quantitative
GDP	**GDP PER CAPITA IN THOUSANDS OF 2014 PPP $**	GDP per capita based on purchasing power parity (PPP). Data are in current international dollars based on the 2011 ICP round. Note: For year 1982 in Zambia, data was not available in 2014 PPP. The current 2014 USD data was taken from the World Bank. Current 2014 USD is equivalent to PPP 2014 USD. Source: World Bank indicator, can be accessed at http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD	2014 PPP USD	Quantitative
POP_R	**PERCENTAGE OF RURAL POPULATION**	Rural population refers to people living in rural areas as defined by national statistical offices. It is calculated as the difference between total population and urban population. Aggregation of urban and rural population may not add up to total population because of different country coverages. Source: World Bank indicator, can be accessed at http://data.worldbank.org/indicator/SP.RUR.TOTL.ZS	Percentage	Quantitative

ACRONYM	VARIABLE	DESCRIPTION	UNIT	TYPE
	VULNERABILITY/ ES RELIANCE INDICATORS			
	POVERTY INDICATOR			
POVTY_R	**RURAL POVERTY HEADCOUNT RATIO AT NATIONAL POVERTY LINE IN PERCENTAGE**	Rural poverty headcount ratio is the percentage of the rural population living below the national poverty lines. Source: World Bank indicator, can be accessed at http://data.worldbank.org/indicator/SI.POV.RUHC	Percentage	Quantitative
	ENVIRONMENTAL INDICATOR			
GEF	**GEF BENEFITS INDEX FOR BIODIVERSITY**	GEF benefits index for biodiversity is a composite index of relative biodiversity potential for each country based on the species represented in each country, their threat status, and the diversity of habitat types in each country. The index has been normalized so that values run from 0 (no biodiversity potential) to 100 (maximum biodiversity potential) Source: World Bank indicator, can be accessed at https://www.thegef.org/gef/sites/thegef.org/files/documents/GBI_Biodiversity_0.pdf	Index	Quantitative
	CLIMATE CHANGE INDICES			
VUL	**VULNERABILITY INDEX ADJUSTED FOR GDP**	The adjusted for GDP Notre Dame Global Adaptation Index (ND-GAIN) for vulnerability is an index assessing the vulnerability of a country by considering six life supporting sectors: food, water, health, ES, human habitat, infrastructure. Each sector is represented by six indicators that span the three cross cutting components of vulnerability: - exposure to climate related hazards; - sensitivity of that sector to climate related hazards; - adaptive capacity of the sector to cope with these impacts. Index ranges from - 0.989 to 0.222. Lower scores indicate lower vulnerability. We used the adjusted for GDP version of the index as there is a correlation between the ND-Gain scores and GDP per capita. The adjusted for GDP score is defined as "the distance of a country's measured ND-GAIN score and its expected value based on the regression of ND-GAIN and GDP". Source ND-GAIN website, can be accessed at http://index.gain.org/	Index	Quantitative
READ	**READINESS INDEX ADJUSTED FOR GDP**	The adjusted for GDP Notre Dame Global Adaptation Index (ND-GAIN) for adaptation is an index measuring readiness by considering a country's ability to apply economic investments to adaptation actions. It considers three components: - economic readiness; - governance readiness; - social readiness. Index ranges from -0.387 to 1.228. A lower score indicates a lower performance. We used the adjusted for GDP version of the index as there is a correlation between the ND-Gain scores and GDP per capita. The adjusted for GDP score is defined as "the distance of a country's measured ND-GAIN score and its expected value based on the regression of ND-GAIN and GDP". Source ND-GAIN website, can be accessed at http://index.gain.org/ Note: Education in the index is the enrolment rate at tertiary school level, not primary school like the variable we used in our model.	Index	Quantitative

n.a: not applicable

Appendix 2 – Studies in the database

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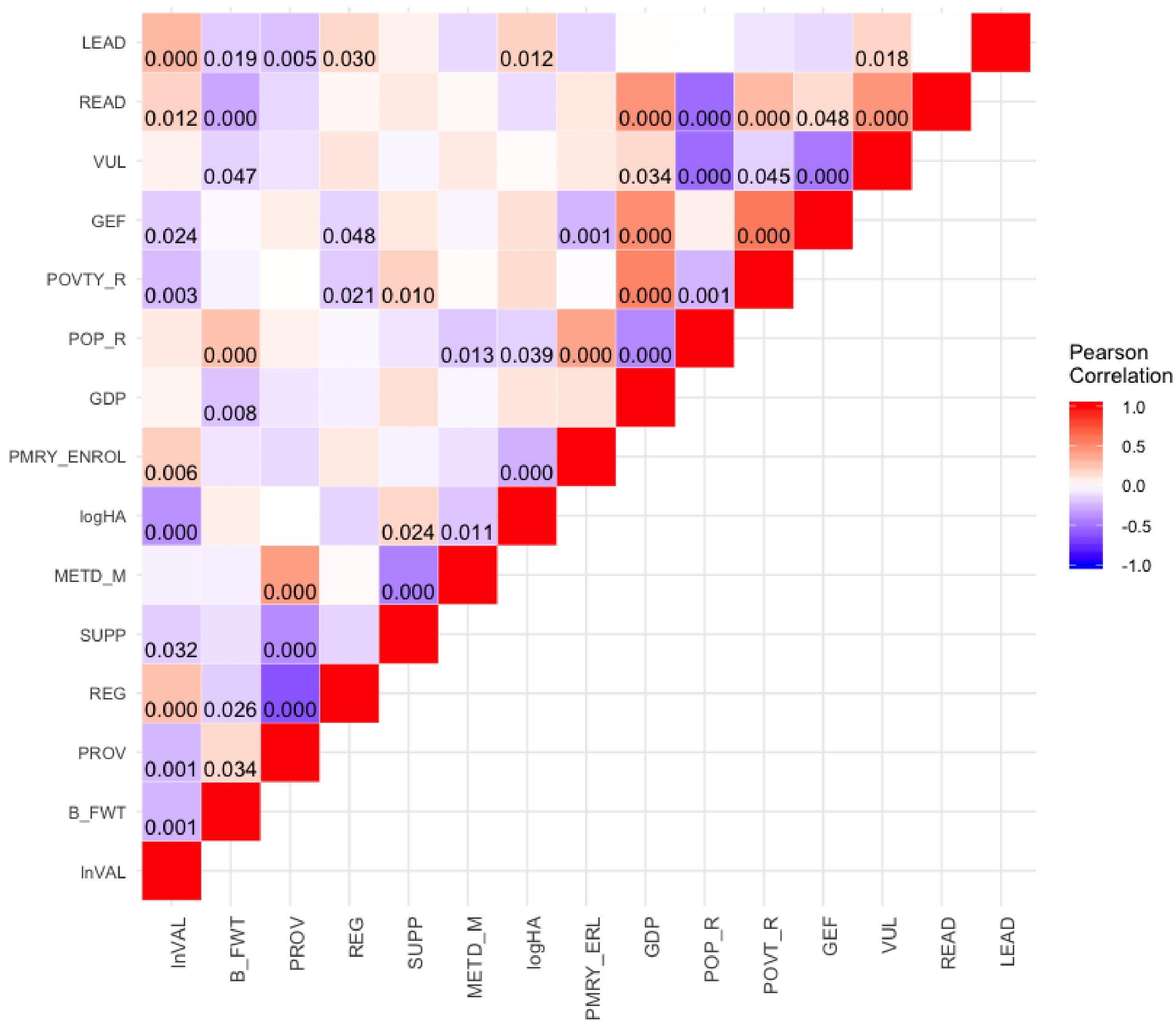
Appendix 3 – Cross tabulation of the value of water related ESs and biomes in 2014 PPP USD.

Biome\ES sub type Mean (standard deviation)	Climate regulation	Aesthetics	Erosion prevention	Extreme event protection	Food	Genepool	Medicinal resources	Nursery	Pollination	Raw materials	Recreation	Soil fertility	Waste mediation	Freshwater provision
Inland Wetlands	239 (375)	2,304 (3,058)		10,735 (10,785)	444 (908)	235 (491)	97	16		912 (2,112)	518 (648)		3,862	512 (1,111)
Coastal Wetlands	476 (270)		6,541	1,775 (2,865)	271 (247)	5		28,406 (49,043)		191 (451)	337 (203)			
Freshwater					52 (68)					2 (4)	622 (582)			43 (53)
Woodlands	43 (50)				2 (1)	1				254 (574)				
Tropical forest	42 (33)		287		9 (16)	20 (13)			39	69 (76)	1,260 (1,488)	150		233 (319)
Grasslands					3 (0.2)	0.1 (0.1)				1,012	5,552 (7,478)			51,552

Appendix 4 – Correlation matrix



The figures in the matrix correspond to the correlations significant at the 5% level.

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Chapter 2

Estimating the distributional impacts on local livelihoods of river flow change due to dam building, northern Ghana

Keywords: Distributional analysis; Ecosystem services valuation; Ghana; Hydrology; Livelihoods; Social equity.

JEL classification: Q57: Ecological Economics: Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology. Q12: Micro Analysis of Farm Firms • Farm Households • Farm Input Markets. Q250: Renewable Resources and Conservation • Water. O22: Project Analysis.

1 Introduction

1.1 Natural and built infrastructure to manage water resources

Ecosystems deliver services - defined as “the aspects of ecosystems utilised (actively or passively) to produce human well-being” – which underpin many livelihoods activities (Fisher et al., 2009; Millennium Ecosystem Assessment Program, 2005). The concept of ecosystem services (ESs) has been mainstreamed in research by the United Nations - led Millennium Ecosystem Assessment (MA), later by The Economic for Ecosystems and Biodiversity (TEEB) and reinforced with the work of the Intergovernmental Platform for Biodiversity and Ecosystem services (IPBES) (de Groot et al., 2012; Díaz et al., 2015; Millennium Ecosystem Assessment Program, 2005). These initiatives have promoted the role ecosystems can play in sustaining and improving human livelihoods, especially under climate change (Munang et al., 2013; Seddon et al., 2016).

Ecosystems and their services can be understood as performing “infrastructure like” functions (Ozment et al., 2015; Smith and Barchiesi, 2009; UNEP, 2014), albeit at a less targeted level than built infrastructure which is developed for a particular purpose and to deliver specified services (Mul et al., 2017). To consider ecosystems as natural infrastructure enables the services they provide to be better recognised, understood, and valued. This allows ESs to be considered as investment options, as part of a portfolio of ‘infrastructure assets’, instead of a purely environmental concern that requires protection, or management through regulation and safeguards. Such a framing of natural and built infrastructure highlights the need to combine natural and built assets to manage water resources, and to deliver - and possibly enhance - benefits for people at the local and national level.

This research focuses on natural water infrastructure, specifically the case of Pwalugu in northern Ghana. There, the natural water infrastructure corresponds to the interconnected system formed by the river, perennial ponds on the floodplain and the floodplain. The aim is to quantify in economic terms the role of natural water infrastructure in supporting local livelihoods for different socio-economic groups and their relationship with a proposed multipurpose dam on the White Volta River in northern Ghana.

1.2 Providing evidence for decision making

The study is set in what Laurans et al., (2013) call “Use of Ecosystem Services Valuation for trade-offs” where the valuation methodology is used to help reach a decision over investment and management of an asset, law or policy, by factoring in the impact of a given project on the natural environment. The research contributes to the wider literature on the environmental impacts of dams (World Commission on Dams, 2000) focusing on the downstream impacts on communities, which, as pointed out in Richter et al., (2010) are seldom taken into account. Finally, this work also links to the larger literature on downstream ecosystem restoration (see for example, Emerton and Bos, 2004; Hamerlynck et al., 2016; Hamerlynck and Duvail, 2003; Loth, 2004).

Integrating river flow change arising from built infrastructure construction and operation with ESs and their economic values has been undertaken in river basins in Nepal (Korsgaard et al., 2008), Kenya (Emerton, 1994), Cameroon (Loth, 2004) and Mozambique (Fanaian et al., 2015) but such research has always stopped short of quantifying the distributional consequences of a change in these services in terms of livelihoods. Specifically for Ghana, Owusu et al., (2017) provide a qualitative account of the impact of the Kpong dam (southern Ghana) on the downstream communities’ livelihoods.

We take this literature a step further by linking changes in the natural infrastructure and the immediate downstream ESs it provides to its direct beneficiaries i.e. the households reliant on it. Hence, we want to examine: i. What is the economic impact of a change in river flow due to dam construction and operation on the livelihoods of the communities immediately downstream? And ii. How are different socio-economic groups within communities affected by possible changes in the functioning of the natural infrastructure? The contribution of this paper is therefore to provide economic evidence tailored to a practical decision-making situation by analysing the distribution of ES benefits within local communities.

The analysis is structured as follows. First, the current economic reliance of Pwalugu households on river flow dependent ES based activities is quantified and compared to overall livelihoods activities (other ES and non ES based) using data collected via a household survey. Then, economic hydrographs, a novel visual approach to link the current ES values to annual river flow, are used in a second step. Three flow regimes are defined and used to provide an understanding of the benefits the communities - and different socio-economic household groups within them - obtain from a given river flow regime. Third, the current situation (t) is compared to an estimate of benefits retrieved in the past (t-1) before an upstream dam (named Bagré) was constructed in Burkina Faso. In addition, an estimate is made of the potential future situation (t+1), after the proposed Pwalugu Multipurpose Dam is constructed.

Section 2 provides case study background while the methodology is described in Section 3. The values elicited for ESs directly dependent on the White Volta River flow are examined in Section 4 and linked to ecological flow data. Section 5 discusses the results and their policy implications before concluding (Section 6).

2 The Pwalugu case study

To provide evidence of the combined benefits of managing a portfolio of natural and built infrastructure together, the case of the Pwalugu communities located immediately downstream of the planned Pwalugu dam was selected. The communities are located across the Talensi district, Upper East region and the West Mamprusi district, northern region of Ghana (see Figure 1).

2.1 Socio-economic background of the Talensi and West Mamprusi districts

According to the latest national population census[a], both the Talensi and the West Mamprusi districts, where the Pwalugu communities are located (Figure 1), have a low population compared to the rest of the region (Ghana Statistical Service, 2014a; 2014b). The population is predominantly under 25 year old (59% and 63% of the Talensi and the West Mamprusi population, respectively) and rural (84% and 63% of the Talensi and the West Mamprusi population, respectively) (GSS, 2014a; 2014b). Religious denomination is Christian and traditionalist/animist in Talensi, and Muslim in West Mamprusi (GSS, 2014a; 2014b).

Livelihoods for these rural populations essentially rely upon farming (crop production and livestock rearing) or on daily work as hired labour. About 50% of the two districts' population live below the poverty threshold defined as USD 1.8 per day and 20% live below the extreme poverty line of USD 1.10 per day (GSS, 2014c). Child poverty is a severe issue, with the Northern and Upper East regions being the poorest in terms of child poverty (Mba et al., 2009; Mba and Badasu, 2010). Seasonal migration to other regions in search of casual agricultural work, and in particular youth seasonal migration (20 to 24 year olds), is the highest in Ghana for both regions (GSS, 2014d).

Less than half the population is literate and illiteracy is disproportionately concentrated among women (GSS, 2014a, 2014b). Health services are limited and inadequate. Child mortality in the two regions is the highest in Ghana and malaria is prevalent (GSS, 2014e; 2011). Access to water and sanitation services is poor as waste treatment, water supply schemes and toilet facilities are limited to a few urban areas (GSS, 2014a, 2014b). The electrification rate is low and the primary source for lighting is kerosene lamps while the most used energy sources for cooking and heating are firewood and charcoal (GSS, 2014a, 2014b). For more details on socio-economic background see Mul et al., (2017).

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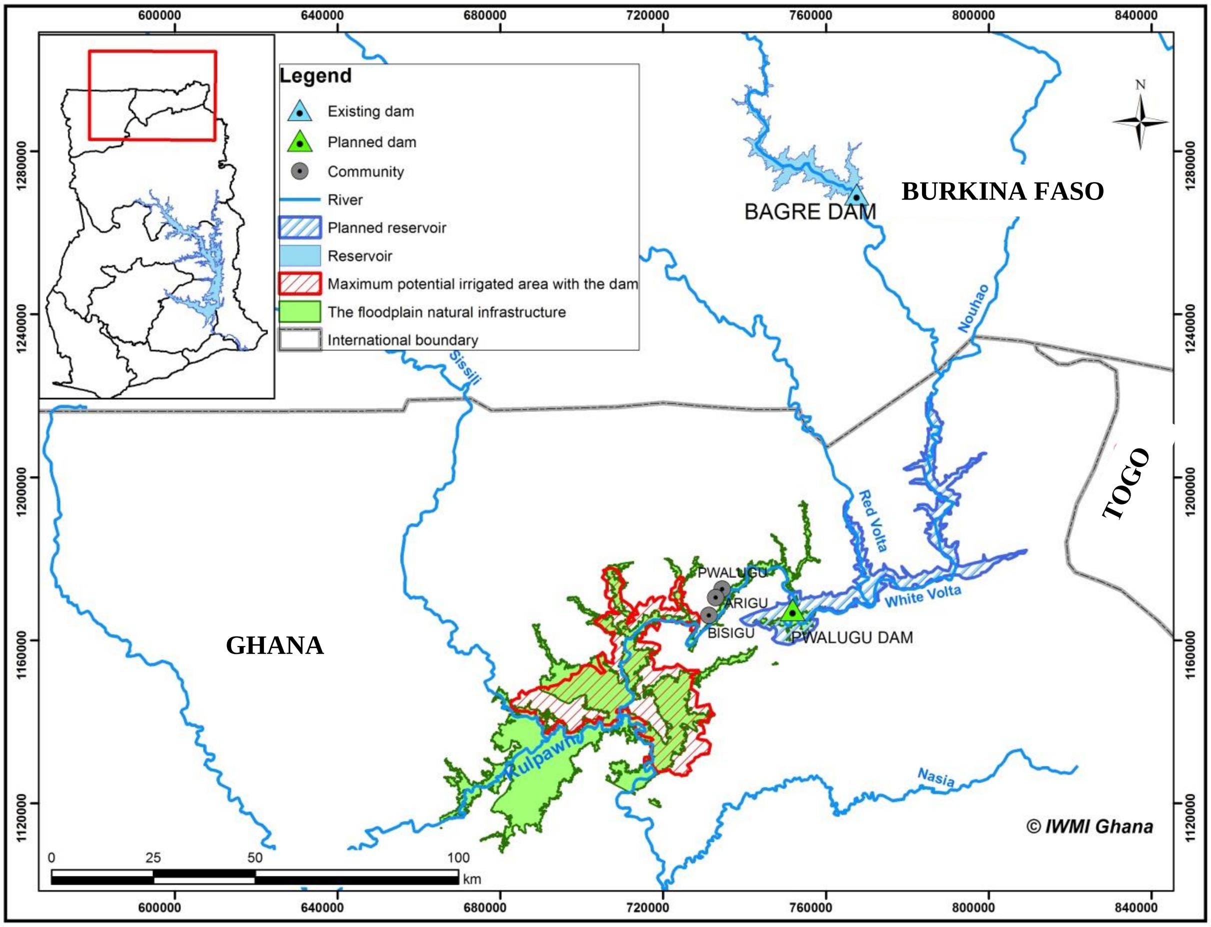
[a] Unless otherwise stated all figures in this subsection are for year 2010, corresponding to the last year of national census.

2.2 The Pwalugu infrastructures

2.2.1 Pwalugu built infrastructure

In Ghana, the proposed Pwalugu Multipurpose dam (PMD) on the White Volta River (Figure 1) is viewed favourably by different governmental agencies. Its feasibility is under appraisal by the government of Ghana at the time of writing (see the project's historic background in Mosello et al., 2017). The project has been branded successively as a development project to foster economic growth in the savannah region of the Upper East and subsequently as a flood control project to counter the damaging impact of the emergency flood releases from the Bagré dam in Burkina Faso at the end of the wet season, which often damage assets and sometimes cause loss of lives (Ghana Web, 2010).

Figure 1: Location of the Pwalugu communities in Ghana.



Source: IWMI Ghana office.

Funding for the PMD is yet to be secured, and the final design for the irrigation scheme and dam operation rules are still to be confirmed. According to the feasibility study, the 5,061 Mm^3 reservoir will have an installed capacity of 70MW (Volta River Authority, 2015), generating an additional 108 GWh yr^{-1}, corresponding to 0.9% of Ghana's energy production (based on USAID, 2015). In addition, a reservoir fed irrigation scheme covering a maximum command area of 24,500 ha with a mix of gravity and pumping systems is planned (Volta River Authority, 2015). This would increase the total irrigated land area in the country by about 80% (based on The World Bank, 2017). Moreover, the project would provide water for the public drinking water network serving the town of Walewale, the capital of the West Mamprusi in the Northern region.

The reservoir is expected to displace few people since it will flood a quarter of the largely uninhabited Gambaga protected forest where human settlements are illegal – although a very small number of farmers have established illegal plots there (Mul et al., 2015). However, it is foreseen that the irrigation component will require agreement over land tenure change since the scheme will cover fields currently cultivated by communities further along the river downstream of Pwalugu (based on GIS maps in Volta River Authority, 2015 and interviews with village chiefs, and see Figure 1). Once in operation, the dam is set to alter the downstream river flow, which currently underpins the functioning of the natural infrastructure and its associated livelihoods activities.

2.2.2 Pwalugu natural infrastructure

The river, perennial ponds on the floodplain and the floodplain constitute Pwalugu's natural infrastructure. Together, they support the livelihoods of the downstream riparian communities (Bisigu, Arigu and Pwalugu villages form the Pwalugu communities, see Figure 1) and enable them to undertake ES based activities on which they partly rely for their subsistence. The natural infrastructure functioning is enabled by the annual overtopping of the riverbank, thus relying on the hydrological variation of the White Volta river flow. Currently, this annual variation is triggered by the upstream Bagré dam spills in late August when the reservoir is close to full capacity. Hence, at present, the communities' livelihoods rely in part on the operation of this upstream dam, located in Burkina Faso (see Figure 1). The building and operation of the PMD would affect the natural infrastructure's service delivery and hence the current livelihoods of the Pwalugu communities. This type of impact is rarely taken into account when dam design and operation rule are decided (Loth, 2004; Richter et al., 2010) and to date, the issues have received limited attention for Pwalugu (Volta River Authority, 2015).

An added stressor on the natural infrastructure will be climate change, which is also likely to alter the flow dynamics of the White Volta River. Historical flows have shown considerable variations including a 13% decline in mean annual flows of the Volta (measured at Senshi Halcrow, southern Ghana) between 1931-1960 and 1961-1990 (Conway et al., 2009). Roudier et al., (2014) reviewed several studies investigating climate change impacts on the Volta River basin and found a large range of potential flow changes. However, the overall results of multiple studies show no clear increase or decrease in river flow under climate change due to the uncertainties associated with climate projections from different climate models (Roudier et al., 2014). Nonetheless, studies have identified intra-annual variability that could affect these riparian communities. For example, using one climate change emission scenario (A1B), McCartney et al., (2012) project that the magnitude of low return period floods (i.e. relatively frequent) would decrease between 2035 and 2085. For higher return period floods (i.e. less frequent), the results are inconclusive. Regarding changes in timing of flood regime, Jung et al., (2012) found a delay in the peak flows towards September. Hence, both direct and indirect anthropogenic activities will affect the natural infrastructure in the future.

2.3 Operational categorisation of activities underpinning livelihoods

Households engage in a set of livelihoods activities during the year that support their livelihoods, all of which (except some aspects of off-farm income) are to some degree dependent on the maintenance and functioning of ecosystems. To highlight how the proposed dam intervention would affect the communities, the ES based activities underpinning the communities' livelihoods are categorised based on their dependence on river flow (Table 1, column furthest left). The categorisation of ES based activities is operational i.e. "policy ready" for Pwalugu's decision making context. It frames and guides the analysis of the household survey.

Table 1 presents each livelihoods activity, related ecosystem and output drawing on the Common International Classification of Ecosystem Services (CICES) framework (Haines-Young and Potschin, 2013). All ES based activities valued are a provisioning service.

Table 1: Operational categorisation of Pwalugu ES based activities using the CICES classification

Grouping used for analysis	**Ecosystem**	**Activity undertaken by the communities**	**Ecosystem service**	
			Group	**Type**
Directly river flow dependent	Floodplain	Flood recession agriculture; Irrigated agriculture	Biomass for nutrition	Cultivated crop
		Livestock rearing	Biomass for nutrition	Livestock products: meat, milk and skin
	Floodplain and river	Fishing	Biomass for nutrition	Fish and other water animal (crocodile and turtles)
	River	Water collection	Surface water	Drinking water for humans and livestock
Indirectly river flow dependent	Forest	Charcoal making Fuelwood collection	Biomass for energy production	Energy for cooking and processing food
		Collection of construction material	Biomass for construction	Timber for construction pole, grass and reeds for fencing and roofing
		Wood products collection	Biomass for other construction	Handles for agricultural tools, fibres to make fish traps
		Non-timber forest products (NTFPs) collection	Biomass for nutrition	Wild food such as fruit, roots and vegetables, honey, bushmeat and shea nuts
Non river flow dependent	Dry land	Rainfed agriculture	Biomass for nutrition	Cultivated crop

Source: Authors

The floodplain, riparian habitat and river are directly dependent on the river flow that is expected to be altered by the PMD. Consequently, the delivery rate and quality of the outputs currently retrieved from the ES based activities reliant on these ecosystems will be affected by the proposed dam. These activities include irrigated and floodplain agriculture, fishing, water for domestic purposes and livestock rearing during the dry season i.e. the directly river flow dependent ES based activities. The forest ecosystem supports collection of firewood for direct use or for charcoal making, construction material, wood products and Non Timber Forest Products (NTFPs). Changes in river flow may have a limited impact on the forest as it is mostly rain-fed. However, during the dry season, it may be partly reliant on underground water which recharges with the flood. Only rain-fed farming is unsupported by the natural infrastructure since it is practiced in the upland areas.

3 Methodology

This section describes the different methods used in the paper. First, the household survey is laid out, second, the valuation methodology that monetarised the survey results is explained. Third, the overlay of the economic valuation with the hydrological data to create the economic hydrographs is detailed along with the possible future PMD operations and resulting built infrastructure benefits calculations.

3.1 Household survey

3.1.1 Sampling strategy

To calculate the baseline ES values, a household survey collected quantitative data on the outputs obtained through the year from ES and non ES based activities, i.e. off-farm income. Qualitative data were also gathered during focus group discussions and informed the design of the survey. The survey comprised about 200 questions covering the socio-economic background of the household, inputs used and resulting outputs produced by season and location for each livelihoods activity. To account for realities on the ground, an anthropological definition of household, not limited to the nuclear unit, but as “a group of individuals who produce in common and receive food out of a common food store” was used (Meillassoux, 1981).

The total sample size of 150 households was drawn from 1,006 households constituting the target population, following best practices recommended by Angelsen (2011). In total, about 15% of households in the three villages were surveyed in local dialect during May 2015 by a team of trained local enumerators. To accurately reflect how the communities are structured and increase representativeness of the sample[b], a stratified random sampling strategy was followed to select the interviewed households (Bataglia, 2008; Cochran, 1977).

3.1.2 Socio-economic status index

To assess the socio-economic status of each household relative to the sample group, and to analyse the dataset at a disaggregated level, a socio-economic status index was developed that combined proxy measures for wealth and income. This index grouped the households into poor, middle and rich socio-economic status groups, which helps assess to what extent differences and common traits exist between groups, and in particular whether dependence on ES based activities varies between groups.

Five indicators were used as proxies of socio-economic status for each household: i. Cultivated land area per capita per household (to measure land capital (wealth) and potential productive area relative to the number of individuals reliant on it); ii. Information on material assets owned such as information channels (TV, radio), transport vehicles (car, motorbike, bicycle), agricultural tools (plough, tractor); iii. Ownership of livestock (in Tropical Livestock Unit[c]), given the insurance value livestock has for small holders farmers (Binswanger and McIntire, 1987); iv. Off-farm revenues and; v. Total on farm production value which represents cash and non-cash flow of income.

All scores were equally weighted except for the off-farm income indicator that was assigned a weight two thirds[d] higher than other indicators. This was to reflect the fact that off-farm income generates cash that can be reinvested into farm inputs, school fees, clothes and food items. Thus, a household with higher cash availability may have more economic opportunities than one with less available cash (Frelat et al., 2016; Haggblade et al., 2010).

[b] Given time and budget constraints.
[c] Tropical Livestock Unit as per Chilonda and Otte, (2006).
[d] Arbitrary weight.

3.2 Valuation methods

All ESs listed in Table 1 were valued in monetary terms to assess the current contribution of river flow dependent ES based activities to overall livelihoods (ES and non ES based). Several methods are available for ESs valuation, details of which can be found in de Groot et al., (2012) and Pascual et al., (2010). Given the use value of the ESs' outputs under consideration, direct market pricing was applied to all ESs except for domestic water, which was valued using the opportunity cost of time method.

The direct market price method consists of applying the price of the output as exchanged at the local market to the overall output generated. The total ESs' output value was estimated i.e. not only the fraction of the output sold on the market but also the home consumed share of the output. Prices for each output were collected for each household in the survey and cross-checked at the Pwalugu and Bolgatanga local markets (good price correspondence was found).

The opportunity cost of time method values time spent by a household on an activity by using the monetary value the household could have gained by dedicating that time to the next best alternative. In other words, if a household had not been spending time fetching water, what would it have dedicated its time to doing and what could have been the value of that activity? Based on focus group discussions, it is assumed the next best alternative for a household in the Pwalugu area is to engage in casual or formal agricultural labour. The Ghanaian government official wage rate per hour for agricultural labour in rural areas was used to value the number of hours a household spends on water collection. The focus group discussions reported that women and children are responsible for this task, as widely noted in the literature (Parker et al., 2016; United Nations, 2015). However, women are paid five times less (0.33 GHc hr^{-1}) than their male counterparts (1.63 GHc hr^{-1}) for equivalent agricultural labour (Ghana Statistical Service, 2014d). Thus, an average of the official female and male agricultural wage in rural setting was used to smooth out the gender pay gap.

Both valuation methods rely on complementary data to enable standardization by weight (kg) of the different output measures given by the households (buckets, bundles, bunch, sacks, crates etc.). This information was obtained from the households and cross-checked at the market.

Note that all values are net annualised values for the year 2015 (i.e. cost of tools as well as any pesticides, fertiliser, fuel and pump costs, where applicable, were deducted). Labour cost was not subtracted from net income as disaggregation of labour time spent on each activity is difficult since two activities might be carried out simultaneously. For example, collecting NTFPs in the woodlands might take place during livestock keeping. This is a recognised difficulty in the literature on rural households' livelihoods in developing countries (Babulo et al., 2009; Kamanga et al., 2009; Nielsen et al., 2013).

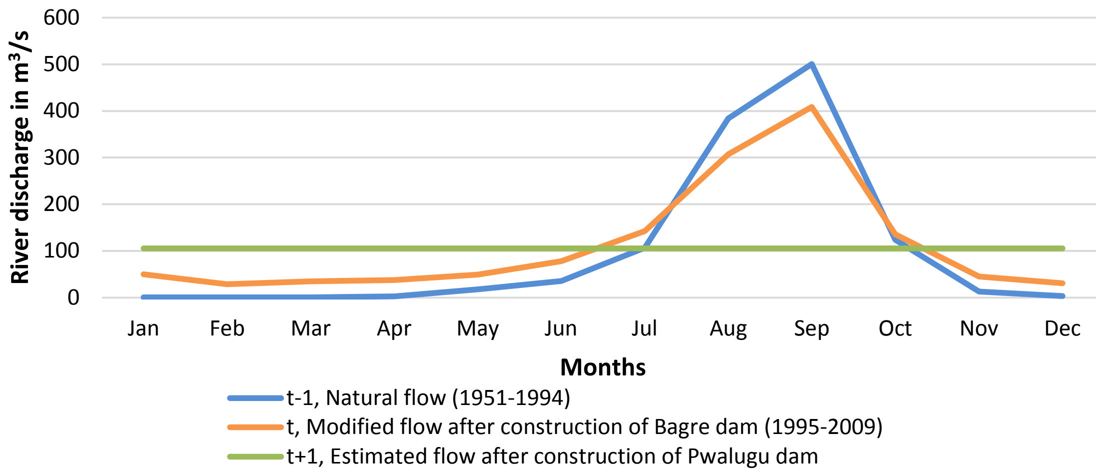
3.3 Linking economic valuation and hydrological data

3.3.1 Current and estimated flow regimes

Three river flow configurations are considered: historic (t - 1), current (t) and potential future (t + 1) flow regimes (see Figure 2). The t - 1 situation corresponds to the historic mean flow regime at Pwalugu based on observed flows between 1951 and 1994[e], before the Bagré dam's construction. Flow regime at t is the mean of current observed flows at Pwalugu between 1995 and 2009, which are mainly dominated by releases from the upstream Bagré dam in Burkina Faso. The t + 1 scenario - once the PMD is built - is an estimate of the mean river flow which depends on the dam operation. The estimate is based on the existing Akosombo dam operations in the Lower Volta River, which flattened a highly dynamic river flow regime to a steady flow regime to maximise energy production – a common operating rule for dams in the region (Mul and Gao, 2016). Given this, the proposed PMD is assumed to prioritise hydropower production and irrigation to maximise economic returns, which would result in a regular and constant downstream flow regime through the year.

[e] Data source: Hydrological Services Department, Ghana

Figure 2: Three flow scenarios at Pwalugu



Last, to enhance the analysis, we suggest an alternative dam operation in situation t+1, with flow releases similar to the ones in scenario t. Such flow releases would come at the cost of partly foregoing the intended dam benefits: hydropower generation, irrigated agriculture and reservoir fishing. For comparison purposes, these built infrastructure benefits were calculated with a simple water allocation model (Savenije, 1995). The hydropower generation is computed as:

$$P = \rho\ q\ g\ h \qquad (1)$$

Where P is power generation (MW); ρ is water density (1,000 kg m^{-3}); q is discharge through the turbines (m^3 s^{-1}); g is acceleration of gravity (9.81 m s^{-2}) and; h is the falling height (m). For this analysis, the power generation solely depends on the discharge released from the dam. The average height of the water in the PMD was used (VRA, 2015). The monetary value of hydropower generation was calculated using the Volta River Authority (VRA) tariffs of October 2015 at 0.058 USD kW h^{-1} (Balana et al., 2017).

The potential irrigated area from the PMD releases is based on minimum flow during the year and the irrigation water demand of 1 L s^{-1} ha^{-1} (Brouwer et al., 1992). It is assumed that maximum abstraction for irrigation is 50% of the minimum flows. Irrigated crop value is based on a crop mix of maize and rice

(25% and 75% of the total command area, respectively) for an average yield of 5 t ha^{-1} and using crop market prices of 884 and 1,565 USD per ton, respectively[f].

Finally, the reservoir can be used for fishing. The fish catch from the proposed reservoir was calculated based on a 60 kg yr^{-1} ha^{-1} coefficient estimated by Vanden Bossche and Bernacsek (1990) for large reservoirs in West Africa and applied to the average surface area of the PMD reservoir. A market price of 5,362 USD per ton was used to value the reservoir fish catch[g].

3.3.2 Seasonal calendar for timing of ESs' use

ES based activities that are directly flow dependent can be divided into two types, i. those dependent on the annual flood peak and ii. those reliant on dry season flows. i. The flood flow dependent outputs consist of flood recession farming, practiced immediately following the flood; pond fishing, which relies on the flood for the fish stock to be replenished and breed and; livestock that water and graze during the dry season around riparian ponds that re-fill each year during the floods. ii. Domestic water use and irrigated agriculture on the other hand are dependent on dry season flows.

To link the economic and hydrological data over a year, the total estimated annual ES based activities values directly reliant on river flow were distributed by month over a standard year. This was done using the seasonal calendar (Figure 3) elaborated during focus group discussions with the Pwalugu communities. The calendar shows at which time of the year the different outputs are retrieved and consumed or used by the households. There is a crucial time and seasonality dimension to the use of the ES based products. For example, fishing in ponds occurs during the lean season in March to April, helping households to bridge over to the next harvest in September (see Figure 3, where "++++" indicates intensity of the activity, here peaking in March). All activities, their timing during the year and reliance on the ecosystems in the Pwalugu area are discussed in more detail in Mul et al., (2017).

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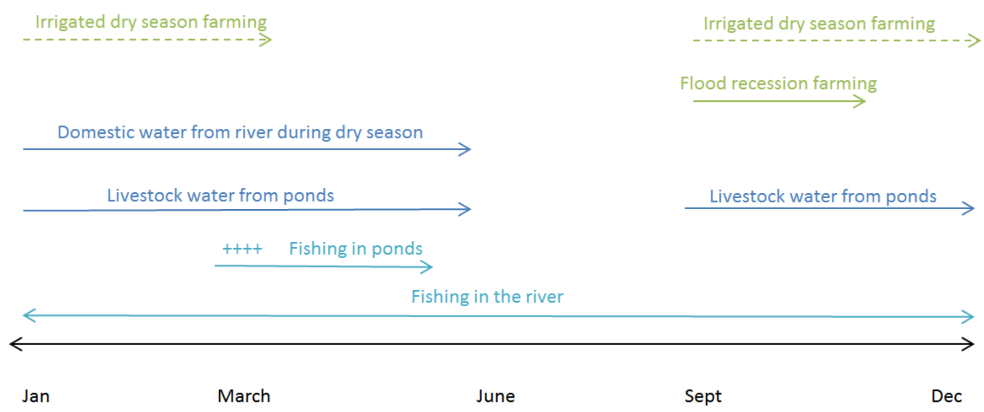
[f] As per the prices given by the Ministry of Agriculture during an interview.
[g] As per the prices given by the Ministry of Fisheries during an interview.

Figure 3: Seasonal calendar of the Pwalugu communities' livelihoods directly reliant on river flow



+++ indicates intensity of labour effort; - - - - - indicates less than 50% of households engage in this activity.

Livestock rearing and drinking water rely on river flow during dry season only[h], the total annual value of these benefits was inputted nonetheless, since it can be argued that without the support of the river and floodplain during the dry season the annual value would be zero. Given that livelihoods opportunities are limited, incomes are assumed to be constant through all three economic hydrographs, meaning that uptake or drop out of an activity is not accounted for. As a result, the economic hydrographs values are potential estimates for historic t – 1 and t + 1 scenario.

4 Results

4.1 Pwalugu livelihoods valuation

4.1.1 Sample description

The Pwalugu communities' household size can be large compared to the ones at regional level reported by the Ghana Statistical Service (2014b). A household can be composed of several nuclear units spanning succeeding generations i.e. vertically extended households; and siblings i.e. horizontally

[h] During wet season, livestock grazes in the uplands and near farms, while drinking water is collected in rain barrel or from the borehole.

extended households (Binswanger and McIntire, 1987). Moreover, polygamy is practised among the Muslim and traditionalist communities (source: key interviews and Ghana Statistical Service, 2014b). On average in the sample, a household comprises 20 individuals spending on average more than 6 months in the household (median is 14 persons).

Differences in house building materials and land ownership are apparent between socio-economic groups. Farmland size on average corresponds to 4.2 ha [min 0.8; max 10.5] with variation ranging from 2.8 ha on average for the poor households, 4.7 ha for the middle and 5.9 ha for the better off households.

The total mean value of actual and imputed income per capita and per day in 2015 corresponds to USD 2.51/cap/day across the sample. It ranges from USD 3.24/cap/day for better off households, to USD 2.33/cap/day for middle households and to USD 1.97/cap/day for poor households. Actual and imputed income is the cash value of what the households earn from selling labour and outputs from ES based activities, plus the imputed value of the ES based outputs consumed at home. From here on, this total is referred to as income or revenue.

Comparison with other indicators is difficult as they do not account for ES values (on environmental based income falling out of poverty assessment see Cavendish, 1999). For example, the poverty line in Ghana is calculated based on the minimum calorific intake necessary for basic subsistence (Ghana Statistical Service, 2014c). Nevertheless, results suggest that the villagers live above the Ghanaian poverty line of USD 1.8/capita/day thanks to the contribution of ESs.

4.1.2 Current breakdown of income contribution to overall livelihood

The ES based activities contribute in different proportions to a household's overall income depending on the household's socio-economic status (Table 2 and Appendix 1 for a disaggregated breakdown per activity). On average, a household is dependent on ES based activities that directly rely on river flow for

54% of its livelihoods income. The better off group has the highest dependence on outputs directly reliant on the river flow (59% of its revenue in 2015), while the middle and poor household groups derive 47% of their revenue from the same ES based activities.

Table 2: Annual contribution of each category of ES based activity to total revenue (%, in 2015)

Average annual contribution of each category of ES based activity per household group				
	All	Poor	Middle	Better off
Directly river flow dependent	54%	47%	47%	59%
Indirectly river flow dependent	27%	49%	31%	18%
Non river flow dependent	19%	4%	22%	23%

Even though reliance on direct river flow ES outputs varies between groups, on average and relative to other activities, these outputs contribute to more than a third of the households' revenue per year.

4.1.3 Access, opportunities and barriers to engage in directly river flow dependent ES based activities

In the sample, all households engage in water collection and a large majority engage in livestock rearing and fishing (see Appendix 2). Indeed, open access rights and low input requirement (i.e. a jerrican, buckets etc.) enable water collection and fishing in the river and ponds (Mul et al., 2017). Similarly, open access lands during the dry season ensure livestock rearing is not reserved to land owners with large holdings.

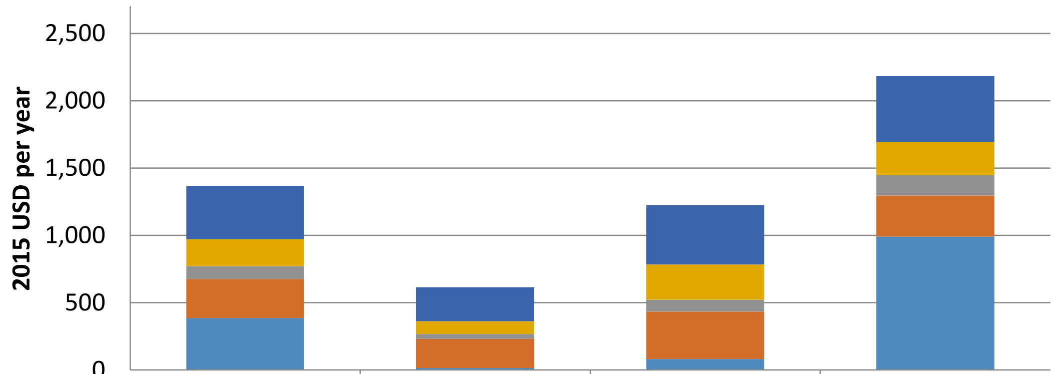
While all households engage in crop cultivation, the type of agricultural practice varies per household group. Engagement in flood recession and irrigated agriculture can be precluded by lack of access rights to a plot on the floodplain; or because of barrier to entry, such as the high cost of irrigated farming (i.e. renting a pump and purchasing diesel). This particularly concerns the poorest socioeconomic group where only 4% practice irrigated farming while 41% of the better off household group do (Appendix 2). Access to land on the floodplain is not an issue to the poor households since 84% of them engage in flood recession farming, so the obstacle is the cost of irrigation. Conversely, if rich households engage more in locally managed irrigated farming and less in flood recession farming it is because the former returns more value for the same land area. Labour availability and farmers' preferences can also be determinants of the choice of activities. For example, flood recession farming is less labour intensive, takes place on more fertile ground according to the farmers and is thus preferred to rainfed farming.

4.1.4 Monetary value of ES based activities directly reliant on river flow

In terms of economic value per year, a poor household retrieves on average half the value (USD 615) of what a middle household obtains (USD 1,223), while both types of households rely on directly river flow dependent ES based activities in the same proportion (47%, see Figure 4). Rich households retrieve on average per year the highest value (USD 2,181) while also displaying the greatest reliance on directly river flow dependent ES based activities (59%) due to their involvement in irrigated farming (USD 990).

Figure 4: Average value of each directly river flow dependent activity for different groups of the Pwalugu communities

Value of each ES based activity directly reliant on the White Volta river flow



	All	Poor	Medium	Better off
Total - Directly river flow dependent	1,365	615	1,223	2,181
Fishing	395	254	439	489
Domestic water	200	94	261	245
Livestock products	94	37	88	152
Flood recession farming	290	216	353	306
Irrigated agriculture	386	15	81	990
Directly river flow dependent income as a percent of total income	54%	47%	47%	59%

Irrigated farming is the river flow reliant activity that produces most value for middle and better off households, contributing to poverty alleviation. The better off households retrieve an average of USD 990 per year (Figure 4).

Flood recession farming contributes the most to poor households' livelihoods - 17% of overall livelihoods - equivalent to USD 216. Middle households rely up to 14% on this farming practice, retrieving the equivalent of USD 353 per year (Figure 4).

The percentage contribution of livestock products to livelihoods is low with little variation between groups but the monetary value can be quite different, ranging from USD 37 for poor households to USD 152 for better off ones – a difference explained by variations in livestock ownership. Livestock is a low productivity activity in this semi-arid area (Aboagye, 2002) and is more important for its insurance value than its production value. Indeed, in places with no crop insurance like northern Ghana, to insure themselves against crop failure risk, households buy livestock that can be sold to cope with unexpected economic shocks (Binswanger and McIntire, 1987). This risk coping pattern explains the small share of livestock products in overall livelihood.

Water for domestic purposes contributes to the same extent to livelihoods - between 7 and 10% - for all household groups. Fishing contributes on average about USD 400 per year to an average household (15% of total revenue). The seasonality of the contribution of these two activities is crucial in sustaining the communities. Water collection from the river during the dry season and fishing in ponds at the end of the dry season are of vital importance to the communities that otherwise would need to walk much further for water and would find themselves with limited alternatives for food sources.

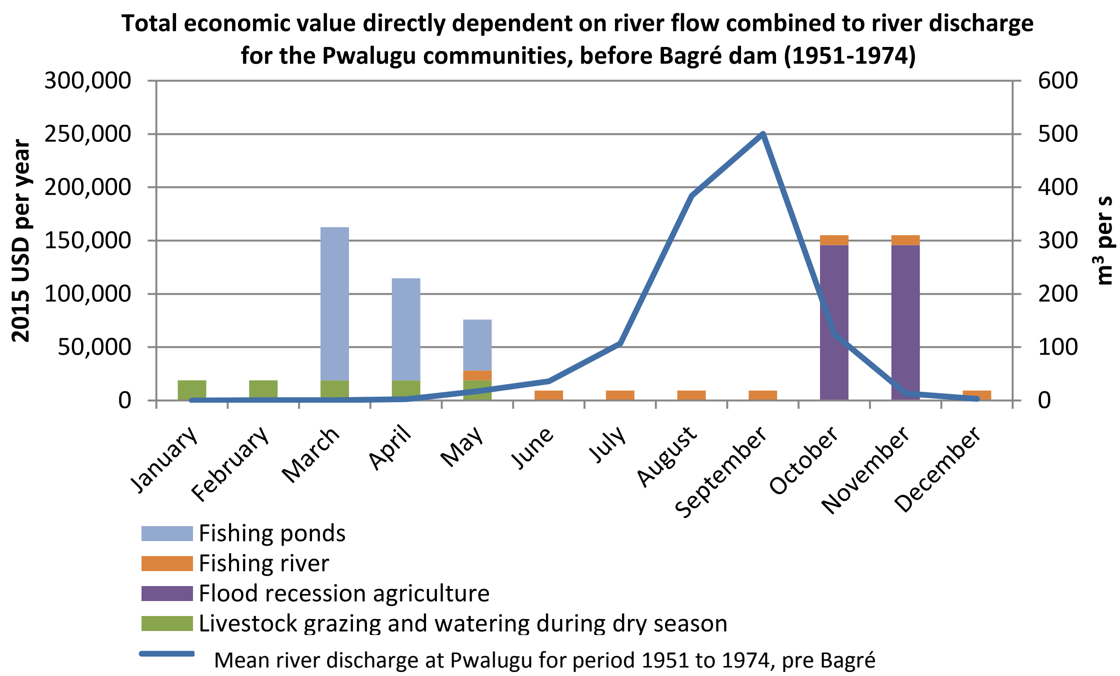
4.2 Economic hydrographs

To create the economic hydrograph and estimate the impact of the PMD on the communities' income, the average values per household were extrapolated to the total number of households (total n = 1,006). Based on that, Pwalugu communities retrieve on average a total value of USD 2,568,000 per year split between ES based (about USD 2,140,000 or 83% of total income) and off-farm (USD 428,000 or 17%) activities. Of this total annual value, USD 1,373,000 or 54% worth of outputs are directly river flow dependent, USD 695,000 (or 27%) are indirectly river flow dependent and USD 499,000 (or 19%) are not river flow dependent (see Table 1 for categories). The directly river flow dependent values were distributed over a year as explained in 3.3.2.

4.2.1 Natural flow regime at t – 1, before the Bagré dam

During the historical natural flow regime (t - 1), the highest ES values were derived from seasonal flooding, which supported flood recession agriculture and pond fishing (Figure 5). Limited income was generated from river fishing and livestock watering and grazing. Moreover, under this flow regime, during the dry season the river historically dried up for 2-3 months (based on Mul and Gao, 2016), thus limiting river fishing and irrigated agriculture. In total, this river flow contributed approximately USD 747,000 annually to the Pwalugu communities.

Figure 5: Estimated economic hydrograph at Pwalugu before the construction of the Bagré dam in Burkina Faso, scenario t - 1

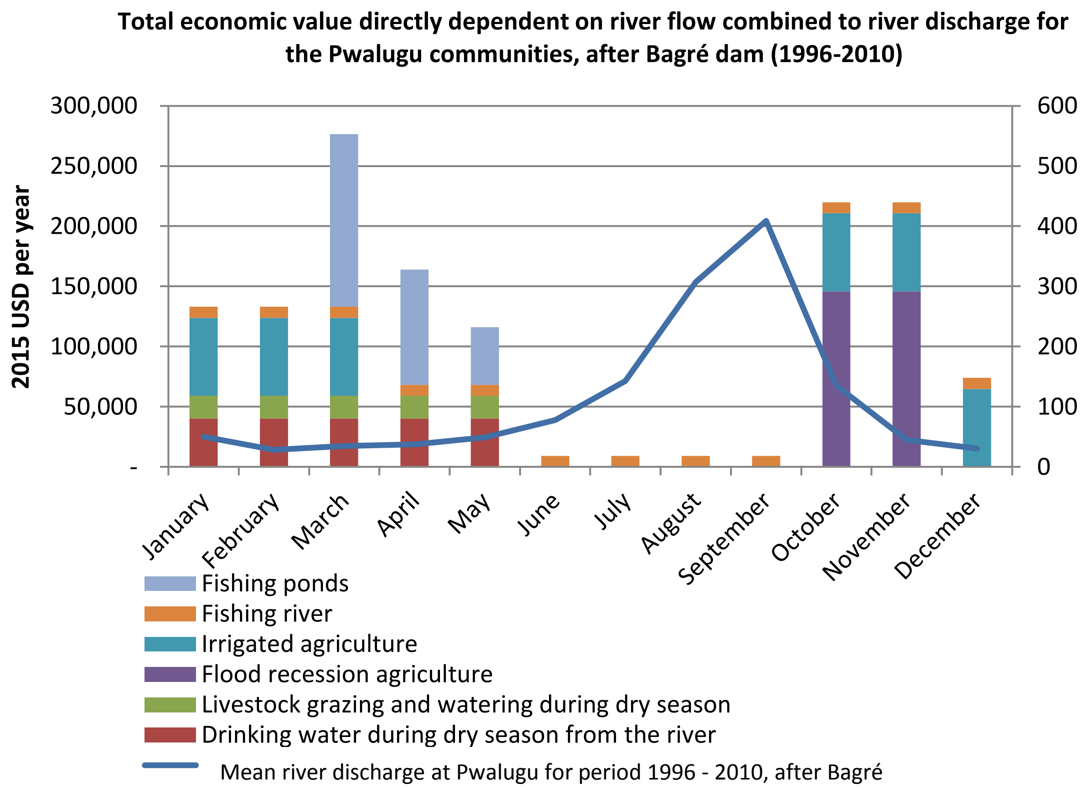


The better off households were unable to practice irrigated farming during the dry season, losing out a share of what is now their current revenue. Unavailability of water for domestic use from the river was affecting all household groups but particularly impacted women as they would have had to walk longer distances to fetch water (Mul et al., 2017; Perez et al., 2015).

4.2.2 State t, Current flow regime, after the Bagré dam

Cumulatively, over a year this flow regime contributes up to USD 1.37 million to the Pwalugu communities. The additional value of the dry season flow due to the upstream Bagré dam releases corresponds to the positive difference between t – 1 and t, valued at USD 626,000 in 2015.

Figure 6: Estimated economic hydrograph at Pwalugu after the construction of the Bagré dam in Burkina Faso, scenario t



The Bagré dam releases increase dry season flows and enable the communities to practice additional activities, such as year-round river fishing and locally managed irrigation. These two activities are, however, conditioned by ownership of, or access to, a boat or a water pump, and hence only a percentage of the communities (the better off households, predominantly) benefit from these opportunities. By contrast, dry season availability of water for domestic purposes from the river benefit all households with a reliable and constant water source of higher quality than water fetched from stagnant ponds subject to faecal matter contamination from livestock.

4.2.3 Scenario t + 1, Possible future flow regime - After the Bagré and Pwalugu dam

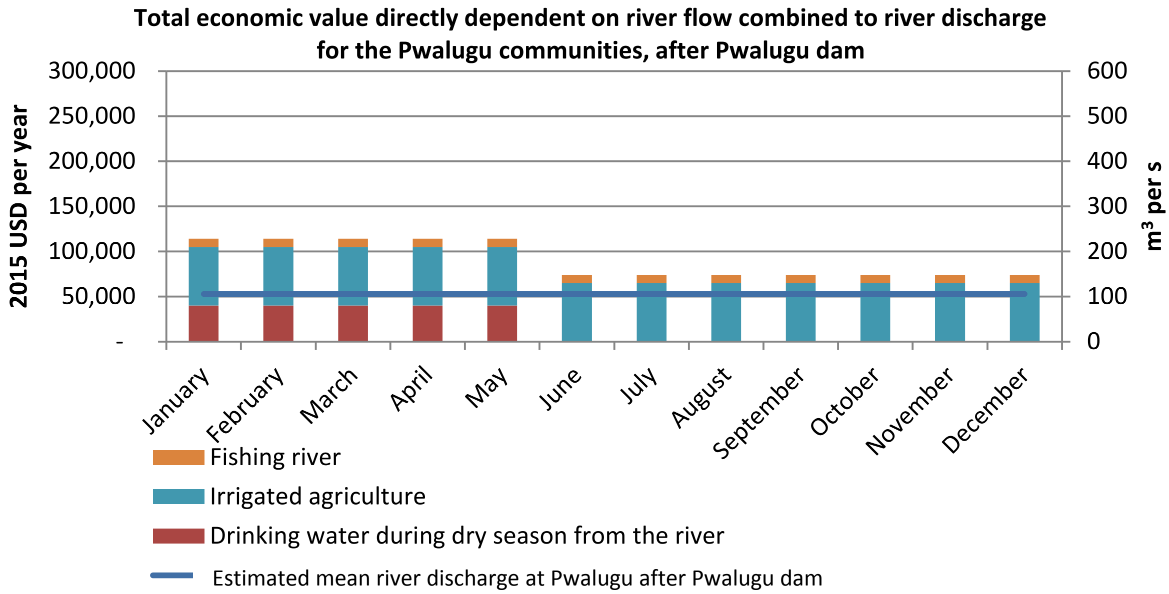
The t+1 scenario corresponds to one possible option for the design and operation of the PMD. We use it to estimate the possible impact of the dam on downstream livelihoods, if the dam is operated for maximised electricity generation and large-scale irrigation. Other possible dam operational rules are discussed in section 5.

Compared to t-1 and t, the economic values vary less across seasons and are relatively lower than the current values in t. The values mainly represent irrigated farming and drinking water from the river. The dry season values decrease by 41% per month compared to the current estimated values. During the wet season the values per month increase by 88% compared to the current flow regime as irrigated agriculture is assumed to be practiced since no flooding takes place. This is because the river flow is highly regulated across the year to maximise electricity generation and large scale irrigation. No flooding occurs, which would have brought benefits during the dry season (flood recession farming and pond fishing).

Over a year, this scenario contributes about USD 1 million to the Pwalugu communities. This represents a 20% decrease compared to the current flow regime. However, in this scenario, if flood related benefits are foregone, so too are the potential detrimental impacts of flooding[i]. Historically, once every 10 years, due to emergency releases from the Bagré dam, heavy floods have occurred in the White Volta basin in Ghana damaging crops and causing loss of human lives and livestock (UNDP, 2009).

[i] No historic damage estimates are available.

Figure 7: Estimated economic hydrograph at Pwalugu after construction of the PMD, scenario t +1

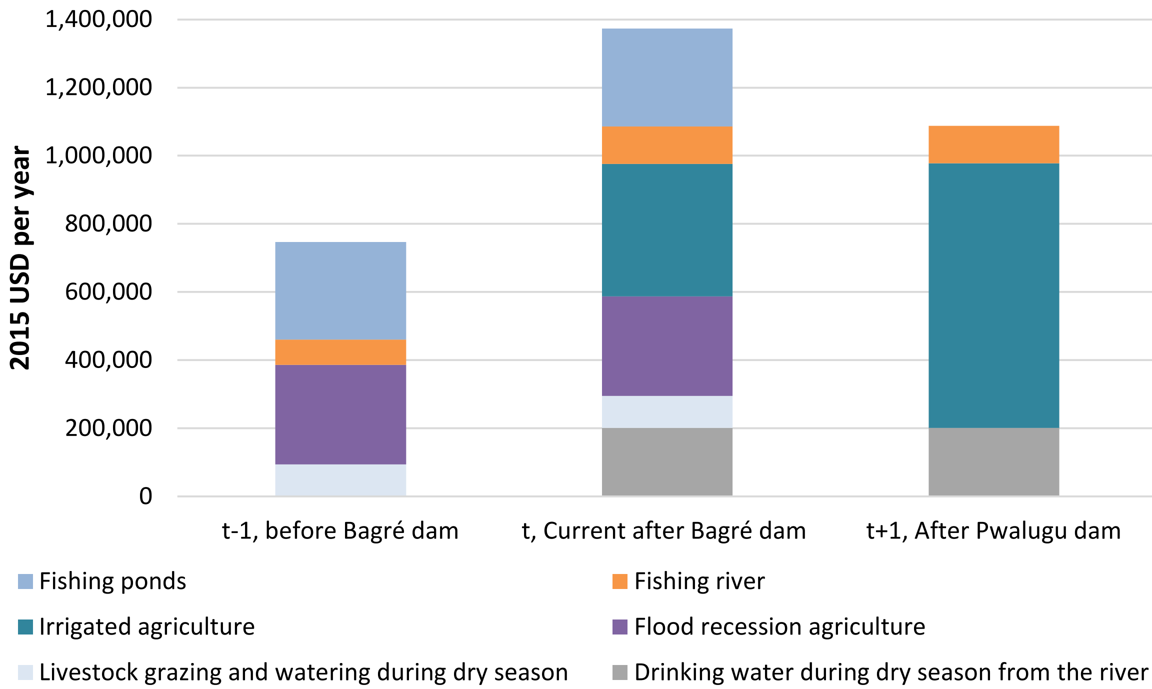


Under this possible future scenario, households would not be able to practice flood recession farming, translating into an average reduction in approximately 11% of their income. Similarly, ponds would not be replenished by flooding, rendering fishing there impossible. The communities and in particular the poorer households rely on fishing in ponds during the lean season for food security to help 'bridge' to the wet season. Results from this possible scenario suggest households would lose this safety net once the dam is built. The distributional issue of who benefits from the different flow regime is investigated in the next section.

4.2.4 Comparing the distributional impact of a change in river flow

In Figure 8, the natural flow regime (t - 1) yields the lowest total value and during the dry season water for domestic and locally managed irrigation use is in short supply. The highly modified flow regime (t + 1), although yielding higher values than the natural flow regime (t – 1), raises other challenges by reducing income activities associated with seasonal flooding. The current mixed flow regime due to the upstream Bagré dam provides dual benefits from seasonal flooding as well as dry season water supply (t), and generates the highest average income per year.

Figure 8: Directly river flow dependent income under three flow regimes



Depending on their socio-economic status, the households benefit differently from the three flow regimes (Table 3), even though the percentage contribution of directly river flow dependent ESs to livelihoods is on average, and relative to other income sources, important for all type of household groups (cf. Table 2). However, in absolute terms, poor households' income is lower than richer ones by a factor of 3.5 in the current situation t, and by a factor of 1.9 and 12 for t – 1 and t + 1, respectively (calculation based on Table 3). In other words, a t+1 scenario, when the dam is operated for constant flow release, results in a more unequal community as the income gap potentially widens by twelve times between the poorer and the richer households of the Pwalugu communities.

In contrast, between t-1 and current situation t, a household's average income from directly river dependent ES based activities increased by about 79% and income variation decreased (from 171% to 95%, Table 3), showing that enabling ESs' delivery from base flow and flood flow benefited the communities while lessening inequalities within the community, not just within socioeconomic groups.

Table 3: Distributional impact of different flow regimes on the Pwalugu households directly river flow dependent mean income and associated coefficient of variation within each group.

Scenario / Mean income	t-1, before Bagré dam	t, current, after Bagré dam	t+1, after Pwalugu dam
All (cv)	761 (171%)	1,365 (95%)	1,082 (120%)
Poor household (cv)	494 (115%)	615 (92%)	194 (291%)
Middle household (cv)	860 (68%)	1,223 (48%)	546 (108%)
Better off household (cv)	923 (185%)	2,181 (78%)	2,362 (72%)

In 2015 USD; cv stands for coefficient of variation i.e. $\frac{\sigma}{\mu}$*100

On average, scenario t+1 lowers households' income by 20%, as flood related benefits are not available (based on Table 3). Moreover, this scenario primarily benefits better off households (average income for this group increases by 8%) since this group is the one that can predominantly access dry season benefits. Indeed, richer households are more able to gather the cash necessary than middle or poor households for renting pumps, buying diesel and boats to practice irrigation farming and river fishing – all base flow benefits available in this scenario. In addition, income variance for better off households reduces slightly, meaning that inequalities within the better off group lessen.

Poor households do not depend as much on directly river flow dependent ES based activities as the middle and better off households, relative to other available income sources, which is in line with the literature (Angelsen et al., 2014). Free access and low input costs to engaging in forest products explain this. However, poor households rely the most on flood recession farming (17% livelihoods contribution, see Appendix 1). The activity is the third most important contributor to their livelihoods and will be impossible to practice under scenario t+1 (based on Table 3). This means that a constant flow release hurts the poorer households, reducing their income by 68% in t+1. Furthermore, in this scenario, income variance is also greater for the poor and middle (291 and 108%, respectively, Table 3) than the rich households (72%), indicating that even within a household group inequalities widen – not just between household groups.

5 Discussion: distributional impact and equity concerns

The analysis shows that directly river flow dependent ES based activities support 54% of Pwalugu households' livelihoods on average. With a dam operated for constant river flow regime as hypothesised in scenario t+1, the households would potentially incur a 20% loss of income and experience a widening of inequalities within and across household groups, with the poor households losing out the most from this change. About USD 1.3 million per annum of services stand to be modified by the possible change in river flow, impacting about 5,123 people immediately downstream of the planned infrastructure. Consequently, this loss would impact the communities' nutrition, food security and safety net strategies to bridge the lean season.

At the same time, the proposed dam is planned to provide significant economic benefits as it would generate irrigated crop production, electricity and additional extreme flood protection. A key issue revolves around whether the immediate downstream communities – those that will bear the impact of the change in flow regime due to the dam - will in fact share in the benefits from the built infrastructure that is aimed to benefit at a broader regional and national level.

According to the 2015 PMD feasibility report, no specific provisions for these downstream communities has been earmarked to ensure equitable and shared benefits between national and local level (Volta River Authority, 2015). Indeed, the energy component is not planned to supply the communities. Similarly, the conditions of access to the irrigation scheme, its affordability for the communities and the land tenure arrangements were not set out in the 2015 feasibility study. In addition, the impact of climate change on inter and intra-annual variability of future rainfall patterns and temperatures adds another layer of uncertainty as to the long term sustainability of the irrigation scheme (McCartney et al., 2012).

To be sure, protection against the high return period extreme flood is to benefit the downstream communities. Moreover, in the context of climate change, even if studies are inconclusive regarding the frequency of these floods in the future (McCartney et al., 2012), dam operations can be used to mitigate climate change impacts. However, it is to be noted that extreme flood protection improved after the last damaging flood in 2010, as cooperation between Burkina Faso and Ghana tightened to better manage the timing and extent of the Bagré dam releases (Mosello et al., 2017).

Table 4 sets the ES benefits to the downstream communities in the broader context of the national benefits of the PMD, which are derived from hydropower and irrigation. These benefits will vary according to the release regime. The constant flow reduces benefits to the downstream communities by USD 0.3 million, which is small in overall terms but a significant loss to the communities. Under the same regime, the PMD generates significant benefits at national level in terms of hydropower and irrigation, estimated to approximately USD 150 million (Table 4). Thus, in purely economic terms the case for the constant base flow regime would be very clear.

In distributional terms however, the choice of a constant flow regime as currently proposed in the feasibility study does not deliver equity (cf. Table 3). Operating a mixed flow regime similar to the one in t could deliver more social equity for the PMD project. It would prevent the economic loss to the communities if the releases occur after the harvest of the rainfed crops cultivated on the floodplain (Table 4).

Table 4: Possible options for the PMD operations

2015 USD	No dam, current situation	Dam with constant base flow regime	Dam with mixed flow regime (base flow and artificial flood flow)
Benefits to Pwalugu communities – total	**1,373,600**	**1,080,000**	**1,373,600**
Base flow benefits	699,100	1,080,000	699,100
Flood flow benefits	674,500	0	674,500
Benefits at the regional or national scale – total*	**0**	**150,090,000**	**108,720,000**
Hydropower	0	10,610,000	7,600,000
Irrigated crop production	0	139,480,000	101,120,000

*Note: The value of the benefits at the regional or national scale is based on the planned dam design and corresponding benefits given in the PMD feasibility study (VRA, 2015). Prices used are described in 3.3.3.

Indeed, a mixed flow regime would maintain the base flow and flood flow ES based activities to support downstream communities and maintain the natural biological and habitat function of the floodplain while still delivering the built infrastructure benefits, albeit at a reduced rate. Further analyses are required to establish threshold values and to estimate any corresponding potential losses in electricity generation and/ or irrigated area but the preliminary figures (Table 4) show that to preserve the current benefits to downstream beneficiaries would reduce the national benefits by 28%, and is unlikely to be politically acceptable.

Hence, it is highly likely a constant flow would be operated, forcing the communities to modify their livelihoods strategies. This may also trigger youth and predominantly male migration to urban centres in search of employment opportunities. The threat of causing deeper rural poverty is therefore real. What policy interventions could potentially mitigate this loss and prevent further poverty entrenchment?

One possibility would be to compensate the downstream households and particularly the poorer ones, with the ability to benefit from the changes in the flow regime. This could include subsidised inputs for agriculture or guaranteed prices for agricultural production, and support to improve agricultural practices and locally managed irrigation. These measures would need to be designed to ensure the most vulnerable household benefit from them but investigating the range and likelihood of success of these options is beyond the scope of this paper.

6 Conclusion

ES based activities constitute a large part of rural household income in northern Ghana and in particular directly river flow reliant ESs, as we have shown. Studies have highlighted the importance of ESs for livelihoods and poverty alleviation but they are very seldom taken into account when a project likely to impact them is proposed.

The approach adopted aims to be replicable and proposes a policy relevant categorisation of the livelihoods activities which would be impacted by the dam. It could also be useful to similar decision making contexts involving built water infrastructure and possible impacts on downstream communities. The economic evidence presented can enable better informed decisions to design more socially equitable and sustainable outcomes.

We presented a replicable way to combine economic and hydrologic data that provide evidence on the distributional impact of a project. The economic hydrographs can be used to assess when benefits from the natural infrastructure are delivered and who to, and that can inform decision making for improved water resource management.

The evidence reported here suggests that prioritising a mixed flow regime rather than a constant one for the Pwalugu dam to maintain livelihoods options for downstream communities would be a more socially equitable outcome, but the built infrastructure economic benefits that would be foregone by doing so are not politically acceptable. Nonetheless, it is important for decision-makers to take into consideration the economic cost of dam operations in terms of livelihoods loss. Preventing poverty entrenchment as a result of the PMD requires inclusive, medium to long term, livelihoods diversification support plan that will not fail the poorer households of the Pwalugu communities. Further research should examine what conditions and schemes would be best able to achieve an equitable outcome for the PMD and hence fulfil the “no one left behind” Sustainable Development Goals agenda of the United Nations.

Appendices

Appendix 1 - Percentage contribution of each activity to livelihood per household group

Average contribution of each revenue source to overall livelihood for different household groups in Pwalugu communities in 2015

	Overall	Poor	Medium	Better off
Total contribution of ES based activities	**83%**	**97%**	**82%**	**80%**
Directly river flow dependent ES based activities	53%	47%	47%	59%
Locally managed irrigated agriculture	15%	1%	3%	27%
Flood recession farming	11%	17%	14%	8%
Water for domestic use	8%	7%	10%	7%
Fishing	15%	20%	17%	13%
Livestock products	4%	3%	3%	4%
Indirectly river flow dependent ES based activities	27%	49%	31%	18%
Firewood	17%	42%	15%	10%
Charcoal	8%	3%	13%	7%
Construction materials	1%	1%	1%	0%
Wood products	0.1%	0.3%	0.2%	0.1%
NTFPs	1.3%	2.8%	1.2%	0.8%
Non river flow dependent ES based activities	3%	1%	4%	3%
Rain fed farming	3%	1%	4%	3%
Total contribution of non ES based activities (i.e. off farm income)	**17%**	**3%**	**18%**	**20%**
Casual labour	3%	1%	3%	3%
Formal employment	8%	0%	9%	10%
Home remittances	6%	2%	6%	7%

Appendix 2 – Rate of engagement in ES based activities

Percentage of households engaging in each activity for different socio-economic groups for year 2015

Household	Locally managed irrigated farming	Flood Recession farming	Livestock managing	Water for domestic use	Fishing (river and ponds)
All	23%	57%	87%	100%	92%
Poor	4%	84%	70%	100%	86%
Middle	24%	43%	93%	100%	96%
Better off	41%	43%	98%	100%	94%

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Chapter 3

Realities of decision-making for built and natural water infrastructure in the Volta Basin

Keywords: Institutions; Natural infrastructure; Volta River basin; Water resource Management.

JEL classification: Q57: Ecological Economics: Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology. Q250: Renewable Resources and Conservation • Water. O22: Project Analysis. Q54: Climate • Natural Disasters • Global Warming.

1 Introduction

1.1 Recognising natural infrastructure role for water resource management

Water is an essential input to a country's industry, energy production, agriculture, and human welfare. Societies invest in managing their water resources and services, to: i. satisfy basic needs; ii. support productive economies; iii. develop liveable cities and towns; iv. restore or maintain freshwater services including biodiversity and; v. build resilient communities that can adapt to change (Sadoff et al., 2015).

Conventional built infrastructure such as reservoirs, hydro-power dams, levees and canals is necessary to deliver on these objectives. Generation and delivery of electricity and clean water to households and businesses, to urban and industrial centres as well as water storage to buffer climate variability, all require built infrastructure (Green et al., 2015; Muller et al., 2015). While these infrastructures can have detrimental effects on ecosystems and livelihoods (WCD, 2000; Richter et al., 2010), they may prove particularly beneficial to developing nations where there is a development gap and an urgent need to improve food and energy security (Grey and Sadoff, 2007; Conway, 2013). Little work exists on combined management between ecosystems and built infrastructure to achieve these outcomes. Therefore, this paper focuses on integrating the value and management of natural infrastructure into decision-making for built infrastructure in the context of water resource management.

The concept of natural infrastructure stems from the recognition that ecosystems and their services play a central role in the functioning of water resource systems (Mul et al., 2017; Brauman et al., 2007). Some of these ecosystem services (ESs) provide "infrastructure-like" functions similar to built infrastructure (Dalton et al., 2013; Mul et al., 2017; Ozment et al., 2015; Smith and Barchiesi, 2009). Examples of natural infrastructure functions include wetlands purifying water, floodplains for food production (flood recession agriculture, fisheries, grazing grounds for livestock, as well as nutrient recycling and distribution), and forests that contribute to precipitation, soil stability and groundwater recharge. Harnessing the benefits and functions of natural infrastructure can contribute to sustain livelihoods as well as play a major role in adapting to water related risks and their detrimental effects, particularly in the face of future climate stresses that may exacerbate existing pressures (IPCC, 2014; Jones et al., 2012; Krchnak et al., 2011; Munang et al., 2013; NCE, 2015; Vörösmarty et al., 2005; WLE, 2017).

However, on its own, natural infrastructure may not generally deliver services at the same reliable rate as built-for-purpose infrastructure, but it can ensure, complement and potentially enhance the benefits built infrastructure provides (Dalton et al., 2013; Ozment et al., 2015; Green et al. 2015). Therefore, infrastructure portfolios combining built and natural infrastructure could provide sustainable water management solutions that help drive social and economic development, reduce ecosystems degradation and help adapt to climate change impacts. Considering both together can expose synergies and possible trade-offs between the various benefits generated by the two types of infrastructure. Improving the evidence considered in decision making, investing in natural infrastructure functions to support built options, and looking at this long term by integrating future river flows adjusted for climate change aims at better investment opportunity identification. Yet, this requires creating and combining information and analyses to support decision-making over water resource management.

1.2 Current representation of natural infrastructure in decision support approaches

Acknowledgement of the need to integrate natural infrastructure and the benefits it generates to different stakeholders, into water resource system planning and investment is relatively new, although it is gaining momentum as an option to support the water-energy-food nexus (Agarwal et al., 2000; Krchnak et al., 2011; Green et al. 2015; Overton et al., 2014). But natural infrastructure is seldom mainstreamed within water resource management context (Guerry et al., 2015). Separate decision support approaches have attempted to include the environment into decision-making.

Economic studies have used monetary valuation methods to assign a value to the biophysical outputs that ecosystems provide (for a comprehensive list, see Costanza et al., 1997; de Groot et al., 2012; van der Ploeg et al., 2010). However, these valuations rarely frame ecosystems as natural infrastructure or as part of a wider portfolio of investments, and often focus on current snapshot ecosystem values, i.e. values from a stock at a point in time. Few studies incorporate natural infrastructure as a benefit to be considered post construction in built infrastructure operation decisions (see Balana et al., 2017; Fanaian et al., 2015; for dam re-operation and Korsgaard et al., 2008 for irrigation scheme) or under various scenarios of change either driven by policy or by climate change (Huxham et al. 2015; Loth, 2004).

Water resource system planning approaches can be made to include ecosystems using a metric of environmental performance generally understood as an environmental flow target to be met. Indeed, water reuse simulation models can quantify multiple performance metrics of which environmental performance - if designed to. Matrosov et al., (2013) is such an example where environmental performance translates as a cost when a threshold flow target is not met. The study employs robust decision making to investigate the performance of different infrastructure portfolios to manage water supply and demand for the Thames Basin (United Kingdom) over a wide range of possible future scenarios. Multi-objective heuristics with system simulation studies can also include environmental metrics (Coello et al., 2007; Kollat and Reed, 2006) to identify strategies that maximise multiple planning objectives (Huskova et al., 2016; Kiptala, 2016; Matrosov et al., 2015; Hurford et al., 2014). While these studies have included the ecosystems using performance metrics, they did not explicitly consider the benefits that the ecosystems provide as natural infrastructure and as investment options but rather as a cost in the form of fine for not meeting environmental flow target.

In comparison, the costs and services provided by built infrastructure are well documented and integrated into decision-making. Indeed, many water resource system planning approaches have been used to determine the viability of built infrastructure investments and quantify their potential costs and benefits, such as cost-benefit analysis (Loucks et al., 2006) and least-cost optimisation (Harou et al., 2009; Lund et al., 2006; Matrosov et al., 2013). In these approaches, the effects of infrastructure investments on the upstream or downstream natural infrastructure, if accounted for, are typically monetised and aggregated as environmental costs – a loss, rather than an investment option.

1.3 Decision-making context for water resource management

In a context of increased anthropogenic pressure on limited water resources (Vorosmarty et al., 2000), water allocation entails choices resulting in trade-offs i.e. when choosing one type of benefit results in reducing one or more other benefits. Planning and management decisions that alter a river's flow regime, such as building new infrastructure or changing the operating rules of current built infrastructure (e.g. dams) can alter the downstream benefits provided by natural infrastructure functions and services dependent on the flow regime (Poff et al., 2016a & b). These changes, in turn, impact a range of beneficiaries – of which some will gain from the changes, while others may see a reduction of their benefits.

Importantly, these trade-offs between benefits result from specific decisions made by stakeholders at different institutional levels in terms of how much water is allocated, when, and to whom. Political and economic factors intrinsically influence decision-making processes and outcomes (Fritz et al., 2009; Hudson and Leftwich, 2014). This includes decision-making processes for water resources planning and management, which can be considered 'political processes, characterised by shifting political alignments and contestations' (Molle, 2009).

Disparities in power and access can also influence decision-making processes over resources allocation and use (Mason and Calow, 2012). Indeed, mechanisms for dispute resolution, differences in access to resources, and social or political structures shape power relations, interests and positions, and therefore decisions, stakes and claims to water resources (Cabral, 1998; Madison, 2007). This can result in imbalances between beneficiaries with differing interests and priorities within the same water resource system.

In the next section we introduce the steps followed in our case study to incorporate natural infrastructure into decision-making. Section 3 introduces the case study in Pwalugu, northern Ghana. Section 4 details the multidisciplinary method of our approach to the case study while section 5 presents and discusses the results through a political economy analysis lens and summarises the conclusions.

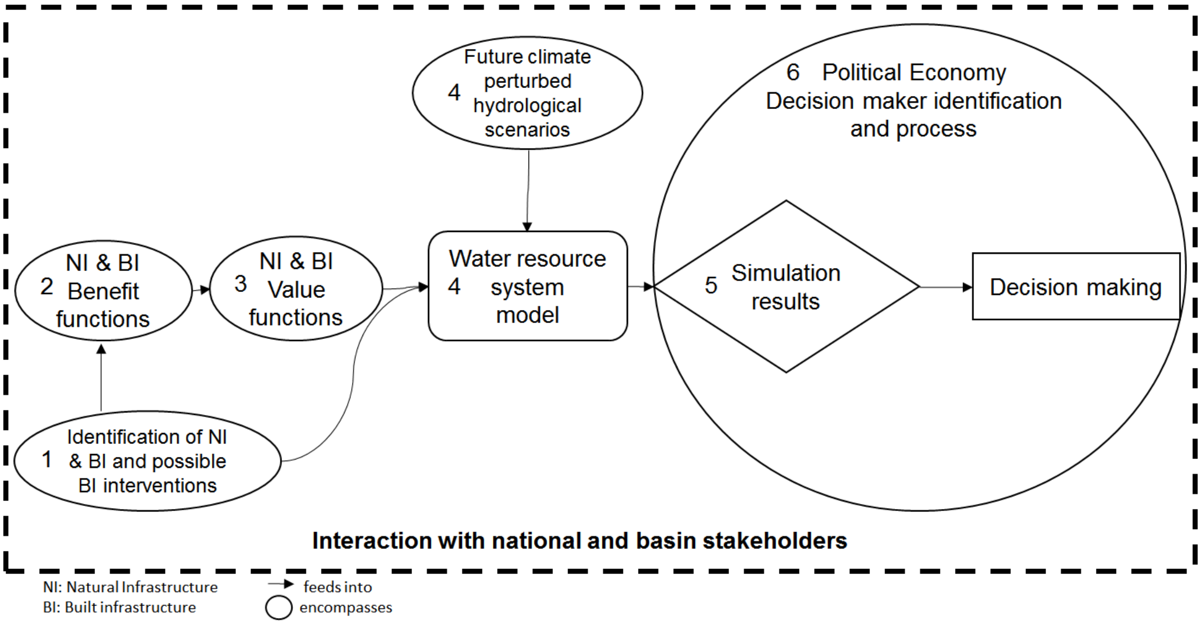
2 Incorporating natural and built infrastructure benefits into water resource system decision making

Multiple research disciplines are brought together to produce a coherent evidence-based approach to support decision-makers when planning water resource systems so as to promote equitable water management. The proposed interdisciplinary decision support approach combines eco-hydrological analysis, economic valuation and simulation modelling to estimate the possible impacts that water resource system planning and management decisions can have on the benefits generated from both built and natural infrastructure in a water resource system under future climate perturbed hydrological conditions. A political economy analysis explains qualitatively the quantitative evidence and identifies what other drivers may affect the decision making process and steer decision makers to choose one decision over another.

Natural infrastructure is incorporated directly into the identified decision making process by examining the benefits generated by mixed portfolios of natural and built infrastructure. Indeed, the approach (Figure 1) begins by identifying the natural and built infrastructure benefits that stakeholders receive from the water resource system and the potential planning and management interventions. These can be a new built infrastructure or a change in operating rules of existing infrastructure (Step 1 in Figure 1).

Some benefits may already exist and can potentially be impacted positively or negatively by the intervention or they can be created when the intervention is implemented. Examples of benefits include hydropower production, food production through irrigation, water supply and fishing from artificial reservoirs. Benefits from natural infrastructure include but are not limited to, flood recession agriculture and floodplain fishing, water treatment effects from wetlands and soil retention by forests.

Figure 1: Decision support approach: Incorporating natural and built infrastructure for river basin development under climate change.



In the second step of the approach, hydrological functions that quantify the physical natural and built infrastructure benefits are defined. These functions use the flow or storage of water through the system over time (e.g. months, seasons, years etc.) to determine the magnitude of benefits generated (e.g. annual amount of hydropower generated or yield from flood recession farming). If implemented, the new interventions may change the flow regime going through the system and therefore change the magnitude of benefits generated.

The third step consists of creating value functions to monetise the benefit functions by performing an economic analysis. Economic valuation allows decision makers to directly compare a range of different biophysical benefits. We inscribe our approach in what Laurans et al., (2013) call decisive valuation, where the valuation is meant to inform a specific decision and include nature in the evidence considered for decision making.

In the fourth step of the approach a simulation model of the water resource system is developed that includes the existing natural and built infrastructure as well as the future possible interventions. Water resource system simulation models are used to inform decision making (Loucks et al., 1981; Loucks and van Beek, 2006). They are applied to predict the effects of planning and management decisions under different scenarios of input conditions.

The benefit and value functions are incorporated into the system model which is then used to quantify the benefits under future scenarios – six in our case - using climate perturbed hydrological flows (4 in Figure 1). The system is then simulated under the different intervention decisions. The benefits and their values are quantified outputs of the model (5^{th} step). The different infrastructure and operating rules decisions are likely to produce a contrasting combinations of benefits resulting in possible trade-offs.

Step 6 is a political economy analysis, which examines the dynamics between the range of relevant stakeholders and attempts to determine the drivers of the decision-making process. The political economy analysis uses the 'issue-based' approach proposed by Booth and Golooba-Mutebi (2009) which identifies a decision-making process characterised by problems arising for political reasons, e.g. resulting from conflicting interests or institutional weaknesses. Bringing in this analysis enables a grounding of the simulation results within the wider decision-making context and a further understanding of potential trade-offs between decision-making outcomes. It helps expose the barriers to, and opportunities for, influencing these decisions, and to understand where change in policy and decision-making (e.g. such as including natural infrastructure in the policy for decision making) can be introduced at national, regional and local levels.

In the final step of the approach, decision makers use the knowledge obtained from the results analysis and the narrative from the political economy analysis. By doing so, they produce new political economy evidence that can feedback into that analysis – it is an iterative process that continues until a final decision is made (hence, the last box is not numbered). Consequently, the approach relies on interaction with national and basin-level stakeholder throughout the process, which is a strength but also a potential weakness as it requires effective stakeholder engagement. These stakeholders are technical experts, decision or policy makers.

The implementation of each step is guided and validated by stakeholders familiar with the water resources system. Stakeholders can help identify and value the benefits, and develop and validate results from the simulation model with their detailed knowledge of the system. The interaction also aids in validation of the technical results and capacity building, in that sense the approach can be iterative. This is what is called a co-design and co-production of evidence where information generated is co-owned by multiple stakeholders – and not driven by one dominant stakeholder group (Wills et al., 2016).

We demonstrate this approach through a case-study on the proposed Pwalugu dam in the White Volta basin in northern Ghana.

3 The Pwalugu Dam project in Ghana

3.1 Geographic and socio-economic context

The Pwalugu area is located in the Upper East region, one of the poorest in the country. High poverty levels have contributed to youth migration to southern Ghana or abroad in search of jobs (Ghana Statistical Service, 2014; Mul et al., 2017). Annual rainfall in northern Ghana varies between 785 and 1,100 mm/year, most of which falls during a single rainy season starting in April and ending in September or October. However, the rainfall is erratic both spatially and in duration making the region potentially vulnerable to inter-annual variability.

The White Volta River at Pwalugu has a highly dynamic flow regime with large areas flooding annually (Mul and Gao, 2016). The annual flood recharges local groundwater, fills riparian ponds, increases soil moisture and deposits fertile soils on floodplain farm plots (Mul et al., 2017). The river and floodplain system provide essential natural infrastructure functions distributing water and sediments and recharging groundwater. In turn, this provides essential services such as food (agriculture and fish), domestic water supply and grazing grounds for livestock during the dry season to riparian communities along the White Volta River (Mul et al., 2017).

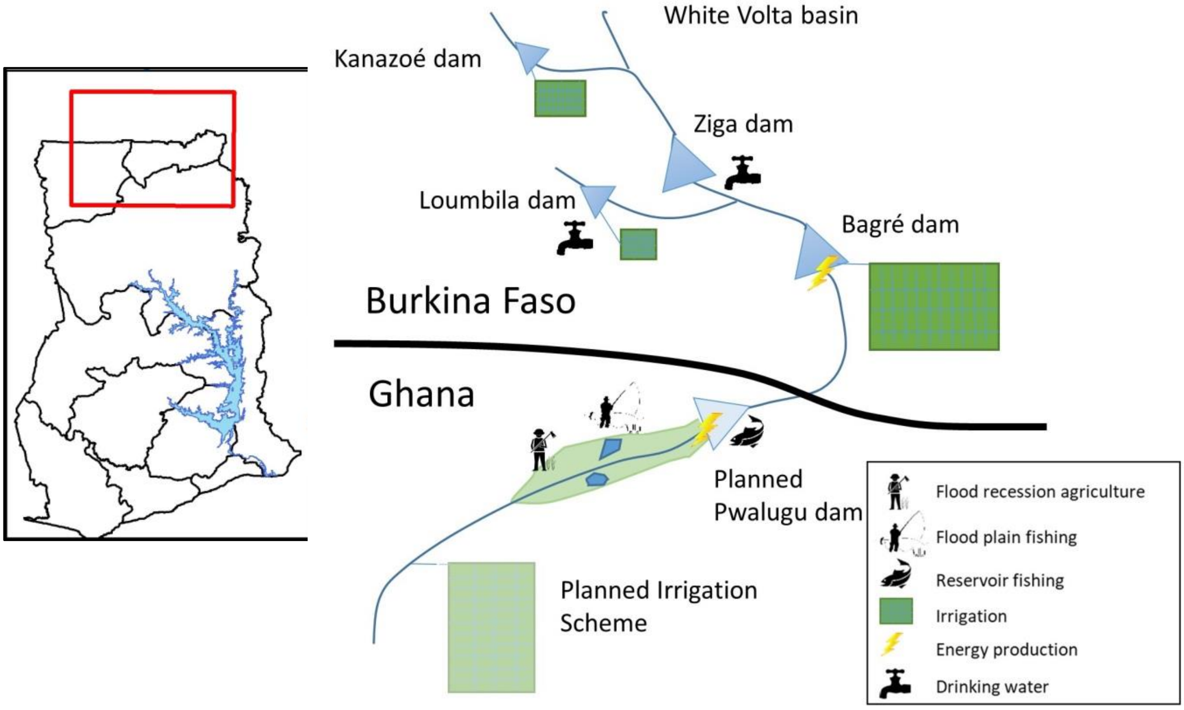
The White Volta River communities primarily identify themselves as farmers with livestock assets. They practice rainfed, flood recession and irrigated agriculture. They also engage in complementary seasonal activities such as fishing, off farm work, non-timber forest products and firewood collection and charcoal making (see for details Mul et al., 2017). It has been estimated that about 54% of the livelihood of three White Volta riparian villages in Pwalugu is dependent on the current river flow regime (cf. Chapter 2 of this thesis).

3.2 Policy context

In the 1960s the Government of Ghana (GoG) started considering the Pwalugu Dam project on the White Volta River, south of the Burkinabe border (Figure 2). In Ghana, the rules and responsibilities of water resource management and related investments are now regulated by the 2007 National Water Policy (MWRWH, 2007). In addition, and in part pushed by international initiatives such as the World Commission on Dam during the 2000s, the GoG has put in place environmental and social regulations for infrastructure projects such as the Pwalugu dam (Mosello et al., 2017).

Water infrastructure features prominently in the key strategies driving the country's economic growth and development, such as the Shared Growth and Development Agenda 2014-2017 (NDPC, 2015). The Pwalugu dam is therefore presented as a major investment that could trigger wider economic development in the region as well as benefits at the national level (SADA, 2016).

Figure 2: Schematic of the Transboundary White Volta River and map of Ghana with region boundaries locating the case study.



A 2014 feasibility study investigated the potential benefits of a multi-purpose dam which would produce an estimated 210 GWh/year of hydropower with an installed capacity of 70 MW and supply water for a 20,000 ha irrigation scheme (EEMC et al., 2014). In addition, it was foreseen that the reservoir could be used for fishing as is the case on the lake Volta in southern Ghana. In 2017, the Pwalugu Steering Committee[a] requested further studies on alternative design options following the World Bank's advice (Ghana News, 2017).

In terms of institutional set up, the Volta River Authority (VRA) would own the dam and hydropower plant and raise revenues from selling electricity to the Northern Electricity Distribution Company (NEDCo) (EEMC et al., 2014). The Ghana Irrigation Development Authority (GIDA) would own the irrigation weir and main canal but would delegate management of the irrigation scheme to a joint venture between a private company and Water Users Associations (WUAs).

[a] Constituted of representatives from the Volta River Authority (VRA), Water Resources Commission (WRC), Savannah Accelerated Development Authority (SADA), Environmental Protection Agency (EPA), Ghana Irrigation Development Authority (GIDA), Volta Basin Authority (VBA), and Ghana Dams Dialogue.

District and regional level government representatives and local communities' chiefs were marginally involved during the environmental and social impact assessment and feasibility studies (EEMC et al., 2014). Communities were presented with the project during information sessions (based on EEMC et al., 2014 and focus group discussions).

The construction and operation of the dam would have significant implications on the functioning of the downstream natural infrastructure, and therefore the continued delivery of its benefits to downstream riparian communities. However, the extent to which these benefits would be altered depends on the chosen dam design and its operation.

3.3 Pwalugu dam designs

In this study, we investigate and compare the benefits generated by the downstream Pwalugu natural infrastructure for three possible Pwalugu dam designs (A, B and C), in addition to the baseline system. The selected designs are taken from a Pareto-optimal trade-off surface produced by a many objective evolutionary optimisation formulation (see similar formulation explained in Matrosov et al., 2015 and Huskova et al., 2016). The designs are Pareto-optimal and will work on average for any future conditions within the boundaries of the six climate change scenarios used in this study. Design A maximises hydropower generation, design B corresponds to the maximum possible irrigation scheme as outlined in EEMC (2014), while design C is the design option investigated in the feasibility study. The analysis is carried out for six possible climate perturbed hydrological conditions to the 2050s.

The baseline system includes the existing upstream Burkinabe Bagré dam and natural infrastructure downstream of the PMD. Design A includes a single-purpose hydropower dam (70 MW) at Pwalugu with a reservoir capacity of 4,980 Mm3 - the dam is operated to maximise hydropower and has no irrigation scheme. Design B includes the same hydropower element but also adds a large 90,000 ha irrigation scheme. Design C corresponds to a smaller irrigation scheme (20,000 ha) in addition to the same hydropower component (70 MW). Design C corresponds to the design in the feasibility study (EEMC et al., 2014). Each dam design incurs different capital and operating costs (Table 1).

Table 1: Capital and operating costs of the three Pwalugu designs and the baseline system.

Pwalugu Dam Design	Capital costs (Million $)	Operating costs (Million $/year)
Baseline system	0	0
Design A: Hydropower only	383	2.3
Design B: Hydropower; 90,000 ha irrigation scheme	1,600	15.9
Design C: Hydropower; 20,000 ha irrigation scheme	740	6.3

Costs were based on those derived in the Pwalugu Feasibility Report (EEMC et al., 2014) and were linearly adjusted for sizes and capacities in this study.

While all designs have the same hydropower capacity installed (70MW), the energy generated differs between designs since operating rules are different to manage the irrigations scheme.

4 A multidisciplinary method to mainstream natural infrastructure in decision-making

4.1 Benefit and value functions

We quantified and then valued the existing and potential benefits generated by both Pwalugu infrastructures. The benefits to be considered were selected and prioritised during meetings by national and basin stakeholders from government agencies and NGOs since not all benefits could be integrated in the system (e.g. cultural value could not be integrated). The benefit functions are based on either river flow or storage (monthly or annual) at the points where the benefits are produced and change depending on which dam design is implemented.

For the proposed built infrastructure, we quantified the potential fish catch from the future reservoir, the crop output from the planned irrigation scheme, as well as the electricity generation from hydropower production (see Appendix for calculations). The benefits from natural infrastructure include yields from flood recession agriculture and floodplain fishing. Both benefits are dependent on the seasonal functioning of the floodplain that captures, moves and stores water. The functions recognise that ecosystems have declining benefit production beyond certain flow thresholds, but it was not possible to integrate tipping points due to uncertainty on ecological threshold (see Scheffer et al., 2001).

The magnitude of the natural infrastructure benefits depends on the flood peak which occurs in August or September. If the flood peak is too small no benefits are generated. But, similarly, if the flood peak is too high, flood recession agriculture yields reduce to zero while the fishing yields from floodplain ponds maximise after a certain threshold and do not increase further (see Appendix for pinpointing of threshold). This means that extreme floods are penalised in the system i.e. benefits reduce to zero under high flow conditions for flood recession agriculture and fishing yield is bounded.

All benefits were valued using the direct market pricing methodology (see Pascual et al., 2010 and Appendix). This method applies the price of a particular output as observed on the local market for a given year to the total quantity of output for the same year. Data collection and adjustment to international dollars (PPP USD) is explained in the Appendix.

Limitations to valuation as per Briggs (1999) include uncertainty in i. data requirement and ii. the process of evaluation i.e. extrapolation or generalisation. i. The values were collected via surveys as explained in Chapter 2, the value used being an average over a sample of 150 data points. ii. There is also uncertainty on value threshold as a constant price unit was hypothesised for the extrapolation (see Appendix for details).

4.2 Water resources system model

We used the Interactive River-Aquifer Simulation-2010 (IRAS-2010) software (Matrosov et al., 2011) to model the upper White Volta basin including Pwalugu. IRAS-2010 is an open-source generalised rule-based water resource system simulator that tracks flow and storage through a node-link network representing a water resource system over a specified time horizon (Loucks et al. 1995; Loucks 2002).

The upper White Volta model includes all major upstream built infrastructure in Burkina Faso including the Kanazoe, Loumbila, Ziga and Bagré dams (see Figure 2). The Bagré dam produces hydropower while Ziga and Loumbila reservoirs provide water to Ouagadougou. Bagré, Kanazoe and Loumbila dams have associated irrigation schemes. As with any simulation model, limitations are linked to data inputs and assumptions made to represent the real water system (Loucks and van Beek, 2017).

One point to note, the many objective optimisation linked to the water resource system simulator does not handle time continuity. Since the system looks at a snapshot in the future (i.e. the 2050s decade) corresponding to what infrastructure should be in place by a given decade, it cannot tell when the infrastructure should be built. This means the simulation system cannot handle economic discounting as it cannot represent sequences of cost and benefits i.e. when do capital costs start and end and similarly for operating costs and benefits, which means that net present values cannot be calculated.

4.3 Climate perturbed flow conditions

The Pwalugu model runs on a monthly time-step over a 30-year time horizon (years 2035 to 2064) and six climate change perturbed flow scenarios representing possible conditions in the 2050s. Hence, each performance metric is calculated over 12 months for 35 years and 6 scenarios.

We consider six climate change scenarios for the 2050s represented by an ensemble of flow time-series (from 2035 to 2065 to understand the 2050s within a trend) representing inflows into sub-basins in the upper White Volta. The six time-series of monthly flows were generated using a calibrated Soil and Water Assessment Tool (SWAT) hydrological model of the basin (Arnold et al., 1998) and are a combination of two Global Climate Models (CCLM and RACM) and three Regional Climate models (MPI, MOHC and ICHEC) from the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi et al., 2009). These models were selected as they contain full time series (1950-2100). The difference between projected and historical flow concerns the flood peak more than the base flow. One climate change perturbed flow regime is projected to be wetter than the historical regime, while two scenarios are close to the current flow conditions. The remaining three scenarios project a decrease in flood peak.

The data was bias corrected using the quartile-quartile approach for two Representative Concentration Pathways (RCP 4.5 and RCP 8.5), corresponding respectively to the medium emissions scenario where anthropogenic emissions continue to increase up until 2040 and thereafter decline (RCP 4.5) and to the high emissions scenario in which anthropogenic emissions increase indefinitely in this century (RCP 8.5) (van Vuuren et al., 2011; IPCC, 2014).

At the end of each 30-year time horizon the White Volta model produces a summary annual average value for each benefit. Following Huskova et al. (2016), we take the mean value of each of the benefits for each of the six climate scenarios into the analysis to look at the benefits' performance over the spread of futures. Hence, the average benefit or cost corresponds to the mean annual value or cost for any future condition within the six climate change scenarios for the decade of the 2050s.

4.4 Political economy analysis

The political economy analysis examines the factors guiding the decision-making process over dam design option selection and the processes used to assess the different trade-offs in benefits. In addition, we investigated what entry points exist in the Ghanaian context to mainstream natural infrastructure within built infrastructure investment[b].

To do so, we analysed the relations of power, influence and the interests of the various stakeholders in the water sector in Ghana based on their role in the initiation and development of the Pwalugu dam project. We used Eden and Ackermann (1998)'s model of 'power' and 'influence' relationships, modified to map the relative degrees of influence that actors have in the decision-making process over the Pwalugu dam project, as well as their interest in built infrastructure as opposed to natural infrastructure.

[b] For a more detailed discussion of the methodology and concepts used, refer to: Mosello et al. (2017).

The methodology for data collection consisted of a review of the literature on water resources management and basin development in Ghana and a survey of the current national policies and strategies in relation to the relevant sectors (water, energy, agriculture/food, environment and climate change). We then conducted four separate sets of key informant interviews with actors at the national level in Accra, the regional level in the cities of Tamale and Bolgatanga, and the local level in the Talensi and West Mamprusi districts in the Upper East and Northern regions, where the Pwalugu dam would be located (see Mosello et al., 2017 for details).

5 Results and discussion

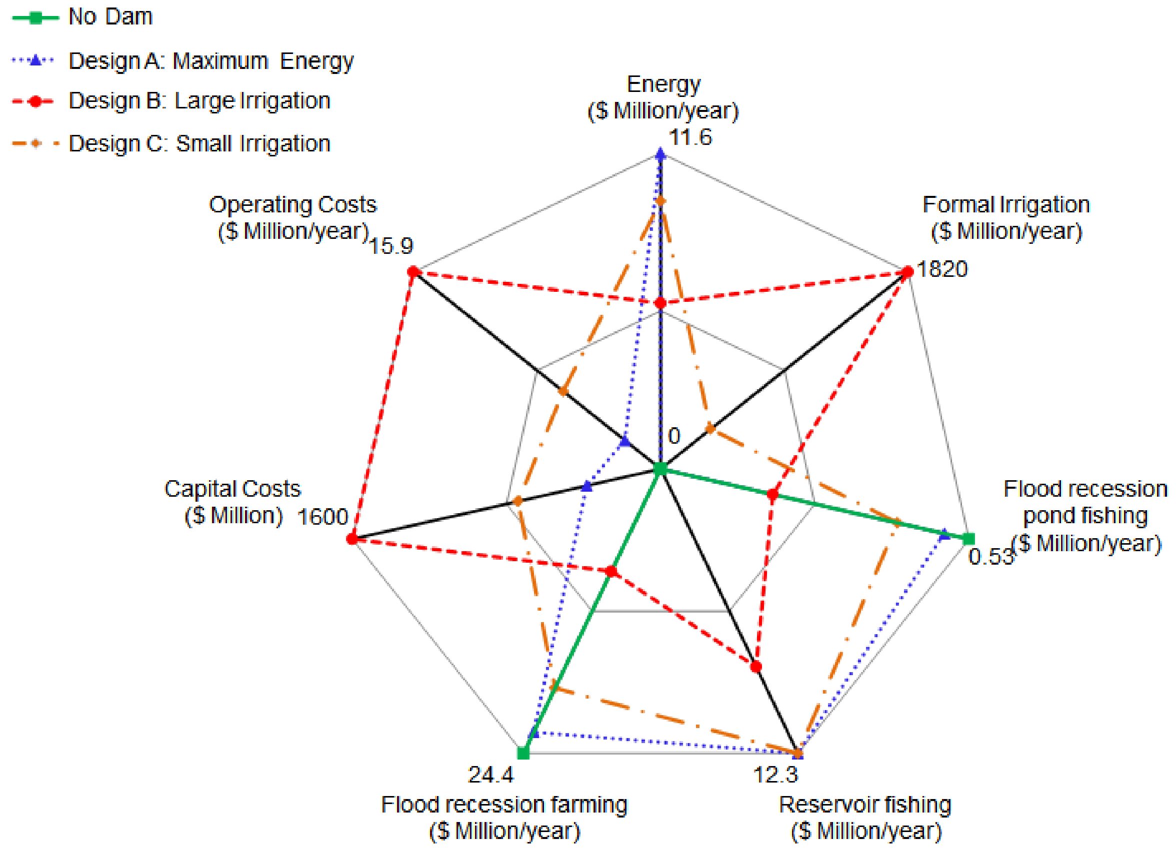
We first introduce the quantitative results regarding the benefits generated by the three Pwalugu dam designs and the baseline (no dam) system under future possible climate change induced hydrological conditions in the 2050s. We examine the results with the political economy analysis to further investigate what the different options mean at the local and national level and what negotiations they entail between different stakeholders.

5.1 Natural and built infrastructure portfolio options in Pwalugu

We simulated the three Pwalugu dam designs and the baseline system over six 30-year climate change flow scenarios representing the 2050s. Figure 3 shows the average annual economic benefits and costs from natural infrastructure associated to the different Pwalugu dam designs under climate change for the decade of the 2050s. The radar graph helps visualise trade-offs between benefits.

Services from natural infrastructure, without new built infrastructure, is projected to generate for the 2050s on average $24.9 million per year of economic value to the downstream rural communities due to the seasonal occurrence of floods at the end of the wet season. Maintaining the current flow regime (i.e. not building the dam, square marker green line in Figure 3) presents the highest potential value directly accruing to downstream communities by maximising flood recession agriculture and pond fishing. However, this investment in natural infrastructure alone does not allow for formal irrigation, reservoir fishing and hydropower benefits which can bring large economic multiplier gains (WCD, 2000). Introducing these built infrastructure benefits reduces the annual flood peak, resulting in a large reduction in flood recession benefits that directly contribute to the downstream communities' livelihood. The magnitude of the reduction depends on which dam design is built.

Figure 3: Average natural and built infrastructure benefits and costs generated per year under climate change by the 2050s for the Three Pwalugu Dam designs and the baseline system.



Note: Each axis on the radar plot is normalised, such that the maximum value of each benefit or cost is found at the point furthest from the centre.

Building the single-use hydropower dam (design A, triangle marker line) reduces the value generated by flood recession agriculture and pond fishing by 8% - total value for both benefits reduces from $24.9m to $23m/year, see Table 2. Installing a small irrigation scheme (design C, small dot marker line) reduces the flood recession agriculture value by 23% (to $18.8m/year) and pond fishing by 25% while the larger irrigation scheme (design B, large dot marker line) reduces the flood recession benefits (agriculture and fishing) by 64% each - to $8.8m/year and $0.19m/year, respectively.

However, these potentially forgone flood recession benefits can be compensated for - at a cost (see capital and operating costs in Table 1) - by the introduction of formal irrigation, hydropower and reservoir fishing. All combined, built infrastructure benefits would largely offset, natural infrastructure benefits (Table 2). Built infrastructure benefits are also traded off with each other. Hydropower value is reduced by the installation of the irrigation schemes. Implementing the small irrigation scheme (Design C) reduces hydropower production by 15% compared to design A, while installing the large scheme (design B) results in a 48% decrease.

Table 2: Mean economic value per year for the 2050s of different portfolio of natural and built infrastructure (see Appendix for methods and sources).

	Baseline: No Dam	Design A: Hydropower only	Design B: Hydropower & 90,000 ha irrigation	Design C: Hydropower & 20,000 ha irrigation
Value generated				
Natural infrastructure				
Flood Recession Pond Fishing (m$/year)	0.53	0.49	0.19	0.40
Flood Recession Farming (m$/year)	24.4	22.6	8.8	18.8
Built infrastructure				
Energy (m$/year)	0.0	11.6	6.1	9.9
Irrigation (m$/year)	0.0	0.0	1,820.8	367.2
Reservoir Fishing (m$/year)	0.0	12.3	8.6	12.3

Design C can be considered to be a compromise solution, with a relatively small loss - 15% - in energy production when compared to the maximum energy design A, no reduction in reservoir fishing benefits ($12.3m/year) as compared to design A, while still allowing $18.8m/year of flood recession benefits, which corresponds to the smallest flood recession benefits reduction, 17%, compared to the baseline system. However, this design reduces irrigation benefits to $367m/year, corresponding to an 80% loss compared to design B. This is a large difference but this option represents a possible compromise between delivering national development imperatives (energy production and increasing national food production through formal irrigation) and still preserving some existing local benefits (floodplain farming and fishing), while potentially introducing new benefits to local inhabitants (reservoir fishing).

Indeed, it is possible that local communities currently benefiting from flood recession agriculture and pond fishing may offset the losses in these benefits by taking advantage of the built benefits enabled by the irrigation scheme or reservoir fishing. However, for these built infrastructure benefits to accrue to local communities, specific provision to guarantee access are necessary. At the time of writing, it is uncertain who would have access to the irrigation scheme and whether there would be training and small loans to encourage downstream farmers to engage in irrigated farming. Furthermore, reservoir fishing requires equipment (boats and nets) and training to which local communities may not have easy access. Moreover, the irrigation scheme and reservoir would be located further away than the floodplain the communities currently use, making transport a potential hindrance to shifting away from natural to built infrastructure benefits. Hence, it is possible that benefits at the national level would be created at the cost of a decrease in local benefits.

5.2 Decision making over water resource infrastructure

5.2.1 Constraints to introducing natural infrastructure in decision-making

Lack of proper mechanisms to link local and national level governance structures tends to result in local communities' interests to be put aside. Indeed, decentralisation in Ghana has been 'crippled'; local governments lack the financial and human resources necessary to design and implement development plans in line with national objectives[c]. In the Pwalugu case study, based on their current livelihood strategies, local stakeholders would most benefit from design C, which is the option that best preserves their current flood recession benefits while still introducing the built infrastructure benefits. However, the top-down characteristics of the current decision-making process in Ghana implies that design A or B are more likely to be adopted over C, or over the option of leaving the system as it is. A mechanism for the redistribution of benefits to specifically address

[c] According to a District Assembly representative, "*organising community meetings is costly, you need vehicles to reach the communities, you need to buy water and food for people, they even expect a small payment for participating; our office [at the district level] simply does not have the resources for this*". Interview conducted in Bolgatanga in April 2017.

the loss incurred in designs A and B does not exist in the current governance system, as explained below.

Indeed, decision-making on water infrastructure investments in Ghana is skewed to meet the interests of stakeholders with more power and resources. This is because the decision-making process tends to occur outside pre-established and agreed rules. In fact, while Ghana has a strong policy and institutional framework for water resources management and infrastructure development, it is rarely implemented (Mosello et al., 2017). The stakeholders with the power resources to shift the decision-making process sit in key national Ministries with a mandate over energy and irrigation – both key priority areas of Ghana's development and economic agenda. Clear policies and processes are in place, which have substantially improved in recent years in an attempt to give local communities the opportunity to have their say[d]. However, it is felt that the environmental and social guidelines are still weak and do not demand enough of project developers and investors (source: key informant interviews). Moreover, interviews with government representatives pointed to a number of challenges in relation to their actual implementation, including the failure to monitor compliance, poor coordination and data sharing between agencies and ministries, and the lack of financial and human resources especially at district level[e].

5.2.2 Hindrances to long term and consistent water development planning

In addition to weakly implemented rules and regulations, decision-making processes for water infrastructure are heavily influenced by a number of political and institutional factors. Infrastructure investments tend to be decided upon on a case-by-case basis, rather than being inscribed within an overall strategy for water resources development and utilisation.

First, competition between ministries is strong and hampers coordination that could deliver on an overall strategy. This is because controlling a project such as Pwalugu is a power booster for the

[d] "At least environmental and social impact assessments are conducted now, respecting international standards, and informed by some form of consultation with communities". Interview with representative of government conducted in Accra in March 2015.
[e] Interviews with representatives of government and donors conducted in Accra and Bolgatanga in April 2017.

ministry in charge of it, as these sort of projects attracts loans and generate economic returns that can be capitalised on to secure a bigger share of the government's annual budget, which in turn translates into a better ability to secure new projects.

Second, this is reinforced by poor coordination mechanisms which are often project-specific and are not designed in view of a long term strategy. In the case of the Pwalugu project, dialogue between different stakeholders has been limited to the forum of the Steering Committee, which deals with technical aspects. It has not extended to more general considerations of how the project fits in broader mid-term development plans at national and district level, and ultimately with Ghana's long-term shared growth and development agenda. Coordination within the same government agencies is also limited, particularly between the national and local level. Hence, because resources tend to sit with government agencies in Accra, interests at the national level prevail (that would correspond to design B being built), leaving local level stakeholders at a disadvantage.

Third, incentives are skewed by political motivations. The search for political support is often the primary factor motivating investment decisions at both local and national levels. This is especially true for large infrastructure projects such as the Pwalugu dam used as 'vote winners' by politicians in key positions to obtain the favour of the electorate. Typically, in Ghana, politics plays an important role in determining one's position and appointment, and setting the political and planning agenda – what some commentators have defined as 'Ghanaian party politics' (see, e.g. Booth et al. 2005; Gyima-Boadi, 2007; Lindberg and Zhou, 2009). This shifts the focus of the decision-making process away from mid- and long-term local and national development objectives. Fundamentally, party politics conditions the decision-making process: issues will be included or excluded from the political agenda depending on priorities and interests of the party in power. Given the priority of the current government to tackle environmental pollution and address climate change adaptation and mitigation, this can be a positive element. However, it means that policies' and regulations' implementation is contingent upon who is in power, to the detriment of long-term and consistent development planning.

5.2.3 Recommendations for entry points in the decision process to mainstream natural infrastructure

Based on these considerations, we identified two entry points for mainstreaming natural infrastructure in decision-making over dam options. The objective is to identify where information and evidence on natural infrastructure can be included and by whom.

First, the case for natural infrastructure solutions within water resource planning and management strategies should be made with national level actors that are mandated with implementing long-term development plans and goals. It is essential that “champions” i.e. motivated individuals and organisations push these issues through the political process, for example by calling for their inclusion in development plans, and for a monitoring system with sanctions and rewards for implementation at national and local levels. Nonetheless, our results highlighted the importance of working with local governments and traditional authorities as they are generally in closer contact with communities, and are hence better positioned to understand their needs and demands.

Second, more funding for basin-level cooperation could help the transboundary basin to engage in dialogue to agree on mutually beneficial infrastructure investments and go beyond the limited role it plays at the moment due to limited staff and no overseeing authority. Engaging development partners in discussions over natural infrastructure solutions is also important, as it opens opportunities to access international knowledge, technology, and funding, including climate finance.

6 Conclusion

In this study, we proposed a decision support approach that explicitly takes into account the benefits from both natural and built infrastructure in the decision making process under possible future conditions. The Pwalugu Dam case study demonstrated that an inter-disciplinary research approach can capture the biophysical and economic value of natural infrastructure, as well as its political value. Since dam designs deliver different levels of benefits to different stakeholders at the local and regional and national scale, the design choice is a highly political decision. The information generated can serve two purposes: it can inform the design choice of the built infrastructure during the feasibility stage and, depending on the chosen design, it can then help determine complementary policies in case benefits from natural infrastructure to local communities are partly or completely lost. Through the political economy analysis, we identified opportunities to support positive change in water governance, with a view to leveraging greater recognition and inclusion of natural infrastructure in investment planning and policy-making.

Together with built infrastructure, natural infrastructure can offer solutions to deliver economic development to communities at river basin and national levels. But for this, natural infrastructure needs to be an essential part of decision-making over water resource system planning and management. As Ghana increasingly experiences the impacts of climate change and environmental degradation, the concept of natural infrastructure and the approach presented can help provide evidence to support the delivery of inclusive social and economic development.

Appendix – Benefit and value functions parametrization

This appendix describes the parameterizing of the benefit and value functions for the water beneficiaries in the Pwalugu water resources system simulation model.

Monetary values were standardised for comparability and aggregation. In case of data not for year 2015, data in local currency (West African CFA franc (CFA), or Ghanaian cedis (GHc)) was adjusted for the country's inflation for year 2015. For all data, figures were converted from local currency to international dollars to express the parity of the two countries Purchasing Power's (and referred to in the text as PPP $ or PPP USD). International dollars give a measure of how many dollars are needed to buy a dollar's worth of goods in the country. This is more representative of the value of the goods to the people using them and better reflects the purchasing power of cedis or FCFA related to the same good. At the time of this work, inflation and PPP factors for year 2016 had not been released yet by the World Bank, hence all economic values are presented for year 2015. Local currency to international USD rates as well as inflation percentages were taken from the World Bank database (World Bank, 2015).

It should be noted that the benefit functions for natural infrastructure are not definitive for two reasons: a) modelling environmental thresholds and tipping points (Scheffer et al., 2001) was not possible for this paper due to lack of long-term data and uncertainty – although this represents the reality of development decision making for large infrastructure; and b) the figures presented are potential benefits, as the actual harvest rates and responses at the local level are difficult to model. Despite these limitations, the trade-offs can serve as useful entry points for decision-makers to engage in discussion over the benefits and costs of the various investment portfolios that are available.

Flood recession agriculture

Flood recession agriculture (FRA) in the White Volta basin is dependent on the seasonal flooding of the floodplain during the months of July, August and September. The annual FRA area utilized by local communities is a function of the annual flood peak – which occurs in August or September (Balana et al., 2015). During normal years, the flood covers large portions of the river banks surroundings. Some of these areas are suitable for FRA (Balana et al., 2016). If the flood peak is too low, the river banks do not overflow and no flooding occurs. This prevents FRA activities from taking place, resulting in zero benefits. If the flooding threshold is reached, the flooded area increases, where the flood extent using the Height Above Nearest Drainage approach by Balana et al. (2015) is linked to the mean August flow (Nobre et al., 2011; 2016). To determine the flooding threshold, river flow monitoring instruments recorded the water flow while local observers monitored when the river banks overflowed. FRA area initially expands with increasing peak flow. However, extreme floods can negatively affect the FRA benefits by removing the fertile topsoil. Therefore, the area suitable for FRA reduces to zero for extreme flows defined as 95% exceedance probability.

If the flood flow is comprised between the minimum threshold and extreme flow thresholds, then the total FRA yield ($Y_{T,FRA}$) (tons/year) is a function of the flood area (A_f), a suitability factor of 50% (f_{FRA}) (Balana et al., 2016) and of the crop yield of 1.5 ton/ha (Sidibe et al., 2016) assuming a typical FRA crop mix of maize, beans, bambara beans, soya, millet and groundnuts reported in the region (Chapter 2):

$$Y_{T,FRA} = (A_f * f_{FRA}) * Y_{FRA} \quad (1)$$

Total monetary value from FRA (I_{FRA}) is calculated as the total crop production from FRA multiplied by the average regional market price of the crops at 1,222 PPP USD/ton. Data is sourced from the household questionnaires and analysis detailed in Chapter 2.

FRA is dependent on fertile sediment deposit by the annual floods. In general, dams retain sediment affecting the downstream sediment loads (e.g. Ligon et al., 1995; Wang et al., 2016). The expected sediment retention as a result of building the Pwalugu dam could reduce the deposition of fertile soils on the floodplains. However, Ogden et al. (2007) indicated that sediment retention due to water resources development did not affect soil fertility. The effect of a sediment poor river downstream (e.g. change in the river cross section) of the Pwalugu dam is expected to have localized effects, only directly downstream of the dam (Kondolf, 1997) and is therefore not incorporated in the analysis.

Flood recession pond fishing

Like FRA, pond fishing is dependent on the seasonal flood. When the river overflows its banks during the flood, natural topographic depressions fill with flood water and fish. These ponds remain when the river retreats back to its bed. The fish are caught at the end of the dry season during a community event (Mul et al., 2017).

The absence of flooding therefore prevents pond fishing. As the flood peak increases, more depressions fill resulting in an increase in pond fishing benefits. However, because a limited number of depressions exists no additional benefit is generated after a certain threshold.

When the flood flow goes above the flooding threshold, the total fish catch, C_f, (tons) was estimated using the fish catch per surface unit area (u_f) (tons/ha) and multiplied by the total surface area of the ponds ($A_{t,\,p}$) to obtain the total fish catch:

$$C_f = A_{t,\,p} * u_f \qquad (2)$$

The fish catch per unit area was estimated by dividing the fish catch reported by the Pwalugu villages in the year 2015 (Chapter 2) by the surface area of the ponds in that year. Pond surface area was estimated using remote sensing to identify water bodies within the floodplain (using the Normalized Differential Water Index (NDWI) and Modified Normalised Differential Water Index (MNDWI) (Xu, 2006). The total fish catch attains a maximum value of PPP USD 0.5m/year at Q_{95} flow above which no more fish catch is generated.

The monetary value of the fish catch was estimated to be 4,390 (PPP USD/ton) and was based on market price information for capture fish from ponds reported at the first local market downstream of the Pwalugu site as per the survey administered in Chapter 2.

Reservoir fishing

The reservoir fishing benefits were estimated using an approach described in FAO (1990) to estimate the fish catch in the Bagré reservoir, upstream of the Pwalugu area:

$$C_{fish}(t) = 60 * A_y \qquad (3)$$

where C_{fish} is the annual fish catch (kg/year) and A_y (ha) is the average area of the reservoir over each year and is calculated within the IRAS-2010 model using the Pwalugu reservoir rating table that defines reservoir's surface area based on its real time volume. The reservoir will have a much higher surface area than the floodplain ponds and for this reason the reservoir produces significantly more fish.

Southern Burkina Faso has a similar climate and ecosystem (dry savannah) typology to Northern Ghana and therefore we assume that the fish catch value at the proposed Pwalugu dam is the same as at the Bagré dam (5,362 PPP USD/ton) as estimated by the Burkinabe Fishery Commission (2015)[f]. Note, different prices were used to value capture fish from ponds and from reservoir to recognize the difference in value between the two types of fishing (cost, size of fish, value chain is different between ponds fisheries and reservoir fisheries).

Formal irrigation

The formal irrigation scheme is assumed to be composed of 50% rice and 50% horticulture (tomatoes, onions, sweet peppers and watermelon split equally). The annual yield of each crop is evaluated using a custom module (Hurford and Harou, 2014) within the IRAS-2010 which uses a simplified version of the crop yield response to water relationship developed by Doorenbos and Kassam (1979):

$$\left(1-\frac{\mathrm{Y}_a}{\mathrm{Y}_x}\right)=k_y\left(1-\frac{\mathrm{ET}_a}{\mathrm{ET}_x}\right) \qquad (4)$$

where Y_x and Y_a are the maximum and actual yields, ET_a and ET_x are the maximum and actual evapotranspiration and K_y is a yield response factor. As a simplification, IRAS-2010 uses the ratio of irrigation supply to irrigation demand as a proxy for the ratio of actual to potential evapotranspiration. Maximum crop yields, water requirements were obtained from EEMC et al. (2014). Crop prices were sourced from EEMC et al. (2014) and from interviews with the Talensi District Office for the Ministry of Food and Agriculture (MoFA) (see Table 1).

Table 3 : Summary table of prices in PPP USD per ton

Irrigated crop	2015 PPP USD/ton
Rice	1,257
Tomato	1,565
Sweet Pepper	1,217
Onion	2,369
Watermelon	1,622

Hydropower

The hydropower generation benefits, *P* (kW) are calculated using the equation for hydropower generation:

[f] Personal communication of the Burkinabe Fishery Commission

$$P = \rho \, g \, h \, q \, \eta \qquad (5)$$

where ρ is the density of water (1,000 kg m^{-3}), g is the acceleration of gravity (9.81 m s^{-2}), h is the water level above the turbine (m), q is the discharge through the turbines (m^3 s^{-1}) and η is the turbine efficiency (90%). The hydropower benefits were monetarized using the Volta River Authority (VRA) rates for 2015 of 0.058 USD/ kWh (Balana et al., 2017).

Investment costs

The costs for the construction of the Pwalugu dam and irrigation scheme were included in the analyses based on the information from the Environmental Impact assessment report (EEMC, 2014).

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Chapter 4 – Preliminary findings

Households coping responses to ecosystems driven shocks: no flood and extreme flood event, northern Ghana.

Keywords: Coping strategies; Livelihoods; Shock; Ecosystems.

JEL classification: Q57: Ecological Economics • Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology. Q54: Climate • Natural Disasters • Global Warming. O13: Agriculture • Natural Resources • Energy • Environment • Other Primary Products. Q12: Micro Analysis of Farm Firms • Farm Households • Farms Input Markets.

1 Introduction

1.1 Coping strategies and livelihoods in rural communities

Livelihoods of rural communities in Sub-Saharan Africa depend partly on environment based income - defined as the natural rent captured within the first market chain link (Sjaastad et al., 2005). Analysis by Angelsen et al. (2014) for Africa establishes that environmental income constitutes 30% of household mean total income. This reliance implies community wide vulnerability to shocks that would negatively impact the ecosystems supporting the households' environmentally based income.

To mitigate such negative impacts to their livelihoods, households adopt coping strategies defined as per the Intergovernmental Panel on Climate Change Glossary (2012) to be "the use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term". Long recognised in the anthropological field and originally studied in the context of severe famine, coping strategies can be categorised into social, economic, ecological and political sets (Campbell, 1990). They are enabled by economic, social, political and institutional conditions and characteristics - and can hence evolve over time (Smit and Wandel, 2006).

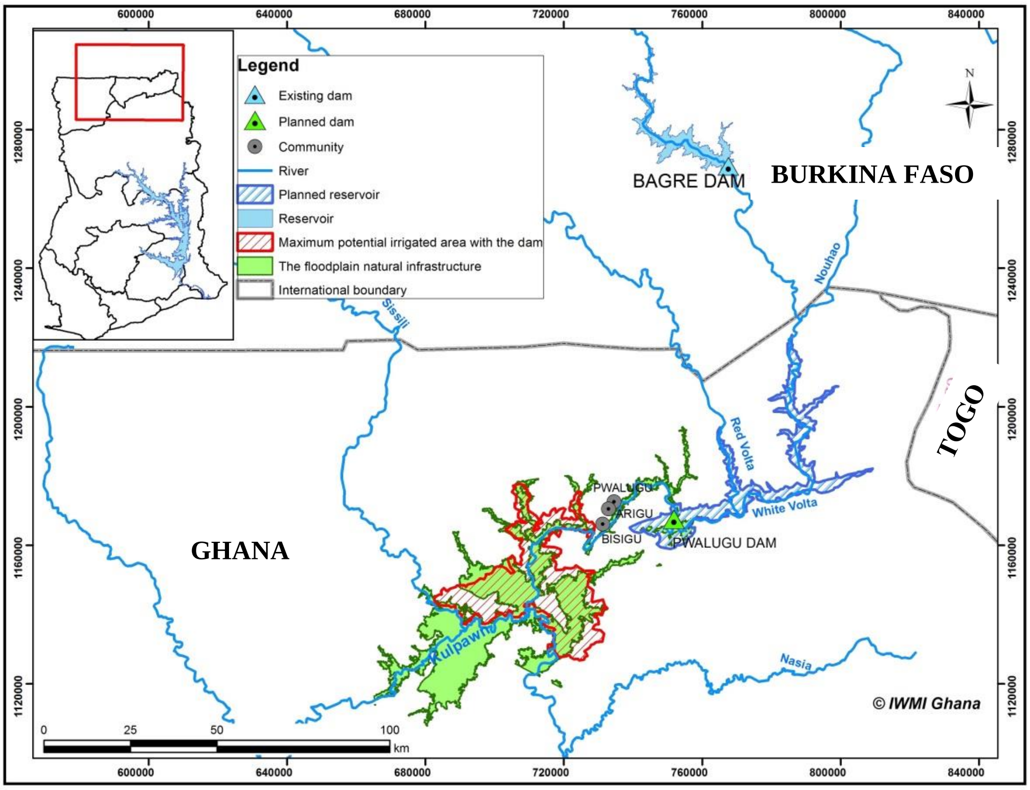
Coping strategies at household level can be definitive, like selling of livestock or other household assets, or reversible such as reducing food consumption, harvesting more of a natural resource to sell on the market – what de Waal (1989) calls erosive and non-erosive strategies as they erode or not the capacity of the household to sustain more shocks and/or rebound back.

1.2 Case study: the planned Pwalugu dam and downstream local communities

The case study analysed in this paper is located in the Pwalugu communities of northern Ghana (Figure 1), in a rural farm-based economy with limited economic opportunities, where a dam with hydropower and irrigation components is planned[a] - called the Pwalugu Multi-purpose Dam (PMD) (Mosello et al., 2017; Mul et al., 2017). We investigate the households' coping responses to potential future negative shocks due to: i. an absence of regular annual floods under non-drought conditions and ii. extreme floods. Both shocks have been experienced by the communities in the past.

Both events would mainly result from the planned upstream PMD. Indeed, the absence of a regular annual flood would be caused by the dam operation releasing a constant flow regime to prioritise hydropower and irrigated crop production, as is the case for dams' operating rules in the west African region (see Chapters 2 and 3). During the commissioning of the Bagré dam in the early 1990s, no regular floods occurred during two years (source: Focus group discussions). A high return extreme flood would be triggered by the dam emergency releases at the end of the wet season (end of August/early September) as has occurred in the past with the Burkinabe Bagré dam located upstream of the proposed PMD (Lolig et al., 2014 and Figure 1).

Figure 1: Location of the Pwalugu communities in Ghana.



Source: IWMI Ghana office.

[a] Funding still to be secured at the time of writing, see Mosello et al. (2017).

Both events would have a negative impact on the communities. Under current conditions, the Pwalugu households rely on average for about 54% of their livelihood on ecosystems dependent on a dynamic river flow (see Chapter 2). Indeed, the high flows at the end of the wet season regenerate the river flow dependent ecosystems – the floodplain and riverine ponds (Mul et al., 2017). A constant flow regime, i.e. no flood, would affect the capacity of these ecosystems to deliver some of the services that support the communities' livelihoods. Three ES based livelihood activities would be hindered by the absence of flood: flood recession farming, grazing of livestock on the floodplain and fishing in the ponds. Currently, residual soil moisture and the sediments deposited on the floodplain by the flood enable short growth cycle crops' cultivation immediately after the water recedes. Furthermore, during the dry season, the rewetted ponds and floodplain provide grazing grounds for livestock. In addition, the ponds are fished by the communities at the end of the dry season - a safety net activity as it helps them secure food until the next wet season (for details see Chapter 2 and Mul et al., 2017). Hence, a large share of the communities' livelihood would be hindered by the constant flow release.

As to the extreme floods, these can damage crops grown on the floodplain and can sometimes cause loss of human and animal lives. Moreover, the high water speed scourges the floodplain, removing more fertile top soils and hence lowering the next season's crop output (Mul et al., 2017). Extreme floods are also associated with an increased risk of water borne diseases when drinking water facilities are contaminated (e.g. typhoid fever and cholera) as well as an increased risk in vector borne diseases due to the expansion of vector habitats (e.g. malaria and dengue fever) (WHO, 2018).

As per the planned dam feasibility study, no provision has been made to compensate or offer livelihoods alternatives or complements to the downstream communities in case of no or extreme flood (Volta River Authority, 2015 and see Chapters 2 and 3).

We want to know: i. how households respond to negative shocks to the river flow related ecosystems the households rely on, and what drives their preferences for a strategy relative to another and; ii. whether the choice of coping strategy can be explained by the households' livelihoods choices, assets and gender of the household head. Statistical regression will be used to investigate these research questions in the fully developed paper. This work presents preliminary findings on which the full analysis will build.

1.3 Previous research

The study is set in the context of previous analyses of negative shocks and responses in rural African communities. In Mali, livelihood diversification by non-poor households and gift exchange by poor households in response to negative income shocks has been found by Harrower and Hoddinott (2005), as well as small stock sale response in Burkina Faso in the face of drought (Fafchamps et al., 1998). Increase in child labour has been related to crop loss in Tanzania (Beegle et al., 2006), while intra household risk sharing behaviours as a response to income fluctuation in Ethiopia, such as re allocation of nutrition between household members along the gender line, have been demonstrated (Dercon and Krishnan, 2000).

The present research draws links to an infrastructure planning issue to inform what are the coping strategies adopted and understand the factors driving these choices in case of a change in livelihood options for communities downstream of a planned dam. As highlighted by Richter et al., (2010), downstream dam impacts on communities are seldom investigated and not under the angle of risk coping mechanisms. The evidence provided can feed into the design of poverty alleviation and community support programmes that the government of Ghana could put in place to mitigate the impact of the dam on the downstream communities' livelihoods.

The next section describes the data collection methodology used for the study. Section 3 presents descriptive statistics and outlines preliminary findings before the discussion and final remarks in section 4.

2 Methodology

2.1 Data collection: focus group discussion and household survey

The data collection included mixed methods and was two staged. First, six gender segregated focus group discussions were held to identify the coping strategies the households have adopted in the past and could adopt in the future when faced with the no flood and extreme flood events. Following participatory rural appraisal methods, iterative pairwise ranking was carried out to understand which were the preferred and actually chosen strategies and why (Chambers, 1992; FAO, 2001). Six follow up one-on-one qualitative interviews with household heads of differing economic status[b] and gender were carried out.

Second, this qualitative data informed the design of the household survey which was pre-tested before being rolled out to the total sample (n=150) given a target population of 1,006 households - following best practices as outlined by Angelsen (2011). The survey was conducted in local dialect by a team of five trained local enumerators during the months of April and May 2017. Stratified random sampling was adopted to reflect the communities' structure and increase representativeness of the sample (Bataglia, 2008; Cochran, 1977).

The definition of household as a group "who produce in common and receive food out of a common food store" was used for the survey (Meillassoux, 1981). The household definition used is not limited to the nuclear unit as the household can be extended vertically (ascendant and descendants family members) and/or horizontally (same generation family members) (Binswanger and McIntire, 1987).

The survey was made up of 12 sections, 9 of which designed to gain an understanding of the households' livelihoods in terms of income flow and assets over the last year as well as their access to financial and agricultural extension services. Each livelihood activity's total output – i.e. sold on and consumed at home - was valued using market prices collected at the Pwalugu or Bolgatanga

[b] Livestock numbers and ownership of motorised vehicle were taken as approximate proxies to select the households.

markets – the local market for fruit, vegetable and poultry and the regional animal market (for details on the direct market pricing valuation method, see Pascual et al., 2010). The statistical software called STATA v.14 was used for the valuation as well as for all descriptive statistics.

The survey's other three sections focused on the coping strategies that the households prioritise in case of no flood and extreme flood events and their perceived efficiency in resorbing the loss incurred by the shock. In case of no flood the households were asked to report for each activity they could not practice what coping response they did first, second and third. In case of the extreme flood event, the households were asked their coping responses ranking for a 10 to 50% crop loss[c] and for a 50 to 100% crop loss. The ranking of strategies reveals which strategy is put in place first immediately after the shock and which ones are put in place in a second and third time if the first and then second strategy delivers limited results (i.e. fall back strategies). The full list of strategies cited during focus group discussions and then suggested in the survey is available in the Appendix.

3 Preliminary findings

3.1 Statistical description of the households

The average household in the sample is constituted of 7 individuals [2; 15]. This is within the averages reported by the 2010 national census for the rural areas of the Talensi and West Mamprusi districts across which the communities are located (5.1 and 8.8, respectively as per Ghana Statistical Service, 2014a, 2014b).

Approximately 7% of the surveyed households are female headed. Data from the FAO (2012) reports 12% of female headed households in 2005 in the rural areas of north Ghana. It is possible that certain women did not perceive themselves as the head of the household - while being one in effect

[c] Given the lay of the land, extreme floods do not have the same impact on all farm plots. The same flood might affect less than 50% of rain fed crop production for one household and more than 50% for another.

- due to tradition and social constructs. Indeed, according to key informants[d] many households are led by women due to male migration and spouse deaths.

When it comes to education, 40% of the household heads have never completed at least one year of schooling, with female headed households relatively more represented (64% of all female headed households) compared to male headed households (37% of all male headed households).

In terms of assets, most households (>70%) in the sample own all of the following: cell phone, radio, bicycle and sprayer and; in addition, about one third of the sample owns a TV as well as a motorcycle. Less than 20% own a motorised water pump for irrigation. On average, households own 2.6 Tropical Livestock Unit (TLU), with 98% of households owning at least one poultry and sheep or goat. Managing livestock on behalf of an owner is not widespread – only 13% of households do it. Loss of crop production and animals in the last 5 years is common for over a third of the households.

Migration to find work in Kumasi or smaller urban centres is reported by a third of the households. Migration is seasonal and concentrated during the dry season months with 50% of households having migrating household member(s) for 4 to 6 months.

Recourse to loans for investment from formal institutions is very limited (5% of households) and – unsurprisingly - even totally absent in case of emergency loans (0%). The primary lender is first, the family, and then, the network of friends and neighbours, both for investment (31% and 25%, respectively) and emergency loans (60% and 28%). Informal lenders and micro-saving money groups are also used in case of investment loans (19% and 21%, respectively). More than a third of households report borrowing money every year during the wet season to buy inputs or hire labour. Another third reports borrowing only during a bad cropping year, 21% every year during the hunger season, and only 3% report borrowing year round.

[d] Key informants were the Queen Mother who is the mother of the chief and the leader of the women see Mul et al., (2017) and the Arigu village's "Assembly man" but no figure could be obtained.

About 20% of the sample has received agricultural extension services from the Ministry of Agriculture or other farmers, while 60% of households have received training from both these formal and informal sources. Training ranges from crop management, composting techniques and the introduction of new seed variety. When it comes to social protection, 17% of households report having received government or NGO aid over the last 5 years.

3.2 Households' livelihoods strategy

The households engage in a diverse set of activities through the year that form their livelihood strategy. Table 1 presents the breakdown of each activity's contribution to livelihood in terms of percentage and mean monetary value as well as the percent of households engaging in each activity to show the relative importance of each activity at community level.

Agricultural production represents on average the largest livelihood activity in terms of economic value in 2017 (67% of total value of livelihood activities, on average per household, see Table 1). For an average household, total mean crop production in terms of quantity is split between rain fed agriculture during the wet season (29% of total mean crop production in kg), flood recession agriculture at the end of the wet season (16%) and pumped or manually irrigated agriculture over the dry season (32 and 23%, respectively). Main cultivated crops are maize, peanuts, millet and soya for rain fed agriculture, beans and maize for flood recession cultivation and tomato and onion for irrigated farming. The majority (55%) of households declared their crop output for the year of the survey (season of 2016/2017) to be less than in a usual year. On the opposite, a third of the households stated to have had a better than usual crop output.

Overwhelmingly, the households report a negative change in the climate that has affected crop production conditions over the last decade. The households have observed a delay in the wet season that used to start in April/May, and now starts a month later, effectively shortening the wet season duration, and hence the cropping season. In addition, the communities report more erratic rainfall patterns. As a result, crop growth is time constrained and does not benefit from reliable water input – impacting the crop production.

Table 1: Pwalugu communities' livelihood activities

Livelihood activity	Mean output value per household (2017 USD)	Value of output as a percent of total livelihood	Percentage of household engaging in activity
Rain fed agriculture	394	11%	98%
Flood recession agriculture	492	13%	71%
Irrigated agriculture with pumps	716	20%	18%
Irrigated agriculture with buckets	855	23%	21%
Firewood collection	225	6%	98%
Charcoal production	223	6%	50%
Fish from ponds	162	4%	87%
Fish from river	108	3%	32%
Bush meat hunting	20	1%	22%
Shea nuts collection	215	6%	73%
Wild vegetable/fruit collection	47	1%	62%
Casual labour	32	1%	65%
Trade and business	121	3%	28%
Formal employment	13	0.3%	6%
Home remittances	45	1%	21%
Total	3,667	100%	n.r.

Pond fishing is a critical source of food – despite its relatively lower contribution to total livelihood (4%) - as the catch helps bridge over the households' food supplies at the end of the dry season (Chapter 2 and Mul et al., 2017). Timber felling and non-timber forest products collection (i.e. wild fruit and vegetables, roots, nuts etc.) correspond to 12 and 8% of average total livelihood value, respectively. In total, off farm income, which includes home remittances, casual labour and petty trading, contributes to 6% of the households' livelihoods.

3.3 Households risk coping strategy ranking

3.3.1 No flood event

No flood event - when flood recession agriculture, pond fishing and livestock grazing on the floodplain are limited - has been experienced by the communities in the past by 94% of the households and is rated as possible to happen again by a third of the sample. Such an event is perceived as negative, with half of the households rating its consequences as "bad" and a third as "very bad". However, 10% of households think no flood is "not bad". As 94% practice flood recession farming and fish in the ponds while 84% graze their livestock around the ponds, an overwhelming majority of households would be affected by a no flood event.

Limited flood recession agriculture

The most common first choice to cope with limited possibility to practice flood recession agriculture is to sell or barter their animals (36%), followed by reducing food consumption (22%), collecting more firewood (21%) and spending savings (7%) (Table 2). The second and third priority coping response chosen by the households are similar except for producing charcoal, an option that was not chosen as a first coping strategy (Table 2, the two columns furthest to the right).

Limited livestock grazing

Coping responses to substitute pond and floodplain grazing are specific to the livestock grazing activity. Feeding the animals with crop residues is chosen first (40%) before cutting leaves from trees in the non-protected forest (35%) and leading the animals to graze there (16%). Selling or bartering the animals is only chosen as a strategy by 10% of households. The same strategies are cited again as a second and third priority choice.

Limited fishing in ponds

To cope with limited fishing in the ponds, the households first prioritise the selling or bartering of animals to obtain cash (26%), then collecting more firewood than usual to sell the surplus (25%) and last, reducing food consumption (18%). Producing more charcoal for sale is cited as a lower ranked second and third priority choice.

Table 2: Coping strategy ranking

Issue	Coping strategy	Percent of households		
		First priority	Second priority	Third priority
No flood event				
Limited flood recession agriculture				
n=138	Spend savings	**7**	7	8
	Sell/barter animals	**36**	**19**	**21**
	Reduce food consumption	**22**	**23**	**14**
	Collect more firewood	**21**	**16**	**16**
	Produce more charcoal	6	**14**	**12**
Limited livestock grazing				
n=129	Feed them with crop residue	**40**	**24**	**18**
	Bring them to graze in the open forest	**16**	**40**	**32**
	Cut leaves from the open forest for fodder	**35**	**28**	**25**
	Sell/barter animals	**10**	3	**10**
	Get cash by doing small work in nearby villages	1	**4**	7
Limited fishing in ponds				
n=139	Spend savings	**13**	7	11
	Sell/barter animals	**26**	**24**	**13**
	Reduce food consumption	**18**	**21**	**18**
	Collect more firewood	**25**	**18**	**14**
	Produce more charcoal	4	**14**	**14**
Extreme flood event				
up to 50% crop loss				
n=150	Spend savings	**13**	**14**	7
	Sell/barter animals	**24**	**19**	10
	Reduce food consumption	**23**	**21**	**17**
	Collect more firewood	**12**	**23**	7
	Produce more charcoal	3	4	**13**
	Plant after the water has receded	11	2	**11**
	Borrow money from friends/relatives in Kumasi	4	6	**11**
50 to 100% crop loss				
n=146	Sell/barter animals	**21**	**20**	**12**
	Reduce food consumption	**13**	**11**	**9**
	Collect more firewood	**16**	**13**	6
	Produce more charcoal	**13**	6	6
	Plant after the water has receded	**25**	**21**	**15**
	Reduce expenses	3	9	**12**

3.3.2 Extreme flood event

Most households have experienced an extreme flood (99%) in the span of 2007 to 2016 with the highest proportion of households affected by the 2014 flood (43% of households). A small proportion (5%) of households report having lost the totality of their crop output to the flood. However, 27% and 40% of households report having lost 80% and 60% of their crop to the flood, respectively. On average, a household has lost around 2 sheep due to a flood. Households (43%) also noticed an increase in water vector borne diseases such as malaria, river blindness and sleeping sickness in the aftermath of a flood. Unsurprisingly, the occurrence of a flood is perceived as a negative event, which 76% of households think is likely to happen again and 21% think is very likely to happen again in the next 5 years.

Up to 50% crop loss

Similarly to when households cannot practice flood recession farming, the first coping strategy put in place in case of a 50% crop loss is to sell or barter livestock (Table 2). Livestock is tied up for grazing in the uplands during the wet season to prevent them from damaging rainfed crops, as a result, loss of livestock is limited in case of flood (cf. paragraph above). This reported sale of livestock assets echoes Binswanger and McIntire (1987) who first highlighted the accumulation of livestock as an insurance policy against livelihood shocks, and in particular for small holder farmers in case of agricultural loss. Collecting more firewood to obtain cash is reported as a second priority option by 23% of households. Reducing food consumption is cited as a third priority coping response (17%).

50 to 100% crop loss

In case of a 50% to 100% crop loss, planting after the flood is the top chosen strategy across all prioritised responses. However, this strategy entails a time lag corresponding to the crop growth cycle. Farmers plant short growth cycle crops such as beans and groundnut, but there is still a delay between setting up the response and its output. In this sense, reducing expenses and selling livestock, the next cited strategies, can be understood as complementary strategies to cope in the meantime.

4 Discussion and conclusion

The coping responses selected by the communities are well-acknowledged in the literature on risk coping strategies in developing countries (Dercon, 2002). They are part of the livelihood system already in place i.e. no strategy is a new livelihood activity or resource that is usually not deployed.

Moreover, the strategies deployed – although some are specific to the activity they are designed to maintain e.g. livestock grazing – are not specific to the shock as the same set of responses are recorded regardless of the nature of the shock (cf. Table 2). Furthermore, the responses are common to other communities irrespective of their location (Antwi-Agyei et al., 2018; Boafo et al., 2016; Dercon, 2002; Paumgarten and Shackleton, 2011).

The sequence of adopted coping strategies does not follow a pattern for any shock, meaning that no specific order of responses is found repeatedly. This may indicate no group response that would suddenly put one system under extreme pressure but rather a slower increased pressure as the households shift from one strategy to another.

There can be a discrepancy between preferred coping strategy and its efficiency. For example firewood collection is not a preferred strategy as it is a very strenuous activity: the forest is far, chopping the tree requires strength and same to carry back the fuelwood in several bundles to the village and then the market[e]. But once the fuelwood is ready and collected - according to the focus groups, it sells easily – the cash is immediate and can be spent on buying food. The strategy is not preferred but is efficient according to the households, hence it tends to be a fall back strategy (Table 2) since the result is guaranteed. The same is true for charcoal making which requires even more time and efforts due to the charcoal making process. These are strategies that may be difficult and time consuming in their realisation which precludes immediate result.

[e] The poorest households are too weak (lack of food) to carry the fuelwood back and ask the buyer to come pick up the fuelwood.

Some strategies may be difficult to access due to barriers to entry. Charcoal making requires knowledge (which grass to use and how to construct the mound) that constitutes a barrier. Another barrier to entry, which mainly affects the poorer households, can be the cost of inputs (seeds, pesticides and fertiliser) to plant after the flood recedes (see Table 2, source: interview in the field).

Reducing food consumption is cited as a coping strategy with immediate results in the short term but is not a preferred strategy (for obvious reasons). Beyond the pain of going hungry, focus group discussion highlighted how in the long term this is not a viable strategy, as once weakened by hunger if other responses are needed, certain coping strategies like firewood collection and charcoal making become even more strenuous and in worst case scenario, impossible.

Selling animals guarantees quick access to cash. To counter-act the loss of this asset, the household would try as much as possible to use part of the cash obtained to buy a smaller animal such as poultry, showing that the household tries addressing the issue of diminished capacity to manage future shock. Similarly, spending savings is a typical erosive coping strategy (de Waal, 1989) whereby the adaptive capacity to the next shock of the households decreases, especially if the next shock happens in short succession.

Some coping strategies can result in negative outcomes, they are called maladaptive strategies (Antwi-Agyei et al., 2018). These are negative responses as they rebound the vulnerability to the households implementing them; or shift the vulnerability to other households or groups; or actually result in further environmental degradation (Juhola et al., 2016).

As per the Juhola et al. (2016) categorisation, reducing food consumption rebounds vulnerability to the households managing their diet this way. In particular, malnutrition can have a very serious effect on the health of younger children, pregnant women, the sick and the elderly (WHO, 2017). Similarly, selling livestock deplete the animal stock and can keep the household in poverty (Haggblade et al., 2010).

Coping strategies that rely on the forest (fuelwood collection, charcoal making and livestock feed management based on forest products) can be qualified as maladaptive strategies as they result in further environmental degradation in an already degraded ecosystem (source: focus group discussion). Indeed, the villagers report having had to walk further and further and/or reduce the amounts they can collect due to the increasing distance to the forest which has progressively retreated. Moreover, the households have observed a reduction in the number of tree species as well as dying of trees due to overexploitation and intra annual rainfall variability. Given that the north of Ghana is projected to be the most vulnerable to climate change (Stanturf et al., 2011), the forest ecosystem is likely to further degrade.

It would be desirable to root coping strategies in sustainability as the shocks return and the households rely on some strategies that are maladaptive. This can be linked to the definition of a sustainable livelihood i.e. “when [livelihood] can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base” (Serrat, 2017). To achieve this, understanding the use of ecosystems in times of shocks and stresses at a disaggregated community level is important to design appropriate policy responses to reconcile long-term development and ecosystem’s sustainability.

Further research with this dataset will include the development of a multi-nomial regression analysis to explain what households’ characteristics drive the adoption of the coping strategies. Knowing which coping strategies are adopted and by whom would help understand these strategies and see how they can be strengthened where appropriate, so as to deliver development benefits and improve the coping capacity of households to respond to future shocks.

The information in this paper can help define the target ecosystems and populations for poverty alleviation and livelihoods development programmes. Such programmes should be grounded in equity and sustainability to support the households without creating dependence.

Appendix - List of coping strategies

The following list of coping strategies were identified during the six focus group discussions in the villages and used in the survey:

- spend savings;
- sell/barter animals;
- reduce food consumption;
- collect more firewood;
- produce more charcoal;
- migrate;
- borrow money from friends/ relatives in the village;
- borrow money from friends/relatives in Kumasi;
- borrow from wife/husband;
- hunt more;
- not pay school fees;
- reduce expenses (funerals etc.);
- pick more stone;
- fish more in the river;
- fish more in the ponds;
- find work (casual labour);

Specifically for no livestock grazing:

- spend savings to buy fodder;
- sell/barter animals;
- feed them with crop residue;
- bring them to graze in the open forest;

- cut leaves from the open forest for fodder;
- get cash from selling water/finding work in nearby villages to buy fodder.

Specifically in case of extreme flood:

- plant after the water has gone down.

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Conclusion

In a context of increased direct and indirect anthropogenic pressures on ecosystems, the inclusion of ES values in policies that could impact ecosystems is necessary. Recognising and mainstreaming the value of ESs for livelihoods and development in policy making was at the centre of this thesis. More specifically, the work centred on water related ecosystems, which impact or are dependent on river flow. After a first literature stock taking exercise at the continent level, the geographic focus was on a case study in Ghana.

The thesis has contributed to the literature in the field and attempted to generate evidence that can inform a specific policy situation. Climate change has been treated in the thesis as a stressor for hydrology (chapter 3), as a parameter that could contribute to explain ES values (chapter 1) and as a looming pressure for livelihoods in chapters 2 and 4. The chapters and their respective contribution to the literature are outlined before future research is discussed for the present thesis and more broadly.

1.1 Synthesis of research

The first chapter synthesizes available evidence on water related ES monetary values in Africa. The meta-regression aims at understanding what drives these values and how they relate to countries' climate vulnerability and readiness to adapt. The service type, biome and other socioeconomic variables are significant in explaining benefits from water related services.

The work is novel as it is the first meta-analysis on benefits from water related ES values in Africa. The study finds evidence of a link between the low value of water ESs and the climate change vulnerability and poverty level of African countries at the national scale. This points at a potential synergy between development levels and the value of water related ESs, which highlights that ecosystem-based adaptation could fulfil its “win-win” promise of contributing to adaptation to climate change while delivering on the United Nations Sustainable Development Goals (SDGs) (UN, 2015b).

In the second chapter the role ecosystems play in sustaining livelihoods relative to non-ecosystem based livelihood activities was quantified. A striking 83% of the local communities' livelihoods rely on ESs. This is an average and the contribution of ES based activities to livelihoods increases for poorer socio-economic groups – highlighting the crucial role ESs play in keeping communities out of dire poverty and hence the need to consider the impact of policy choices on ecosystems through the lens of poverty alleviation and social policy development.

This paper contributes to the literature in two regards. First, it disaggregates the distribution of ES values for different socio-economic groups, attributing at what time of the year, and for whom ecosystems deliver services, as called upon by Daw et al. (2011). Second, this valuation was tailored to a policy situation (dam building and operation upstream of the communities) to understand how much of the communities livelihoods would stand to be affected by this policy choice. The contribution and value of ESs delivered by the ecosystems that would be impacted by the policy were specifically highlighted - on average 54% of livelihoods income relies on river dependent ESs - fulfilling the primary aim of ES valuation (cf. the narratives developed in the MA (2005) and TEEB (2010)).

In the third chapter, a multi-disciplinary approach to mainstream ecosystems into decision-making was outlined and applied. The proposed multi-disciplinary decision support approach combined eco-hydrological analysis, economic valuation and simulation modelling to estimate the possible impacts that water resource system planning and management decisions can have on the benefits generated from both built and natural infrastructure in a water resource system under possible future climate perturbed hydrological conditions.

The results specifically highlighted the finite characteristics of water resources by showing trade-offs between different water allocation choices. The trade-offs entail benefiting certain interests over others. This kind of information is politically sensitive and resulting decisions are not technical but political choices as the design and operationalisation of the dam could redistribute benefits from local to regional or national level.

Hence, the contribution of this paper to the literature: it showcases an attempt to a more comprehensive approach to the issue of mainstreaming ecosystems into policy-making by combining four different research disciplines. This mixed method take on the issue aims at not only generating quantitative trade-offs on the water resource system but highlighting the entry points for such information in decision-making.

The fourth, and last chapter, investigates risk coping strategies adopted if livelihoods dependent on water related ecosystems are lost due to extreme flood or constant flow regime – both shocks triggered by the upstream dam. This work generated information on the potential response strategies that should be adopted if no social policy or poverty alleviation programme is set up by the government.

1.2 Further research avenues

1.21 Specifically for this thesis

Specifically for this thesis, a few research points could be further investigated in subsequent research papers.

The next step for the meta-analysis on ES values could be to use it for a meta-analytic equation for benefit transfer. This would help generate information on ecosystem values thus bridging the data gap where information cannot be generated with a primary data collection due to cost and time constraints. Another avenue could be to address what drives ES values at the local scale, refining the spatial scaling of the variables to explain value variation at a finer scale.

Chapter 2 to 4 would be interesting to investigate with a post ES valuation study that would monitor and track: i. whether the elicited information and values have been used in policy-making; ii. if so, by whom? At what decision level?; iii. how was this evidence used? Was it used for arbitration on the overall project? Was it used to advocate for project's impacts mitigation strategies? And; iv. more generally, have policy narratives in Ghana started using the concept of ESs or natural infrastructure? This monitoring could then – in addition with feedback from users – help further tailor the way evidence is generated to bring it closer to policymakers needs.

1.2.2 For the research topic

The ES valuation research field is in expansion, calls for mainstreaming ESs in public policies and corporate strategies will further gain in visibility with the upcoming releases of the IPBES reports (IPBES, 2018b) – qualified as the Intergovernmental Panel on Climate Change (IPCC) equivalent for biodiversity.

This drive to recognise the central role of ecological systems for human livelihoods entails an increase in ESs information. Given the direct and indirect underpinning of ESs for livelihoods, and especially in developing countries, ESs are a cross-cutting theme to be considered across public policies – not only water resource management, natural resource management and climate change adaptation policies but also for livelihoods security, social and economic development policies.

For this, generation of distributional and disaggregated ES values to accurately pinpoint who exactly benefits from what ESs, at what scale and at what time of the year is increasingly necessary to ensure implemented policies address target populations and/or mitigate appropriate impacts.

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