RESEARCH ARTICLE

REVISED Assessing the economic impact of climate change in the small-scale aquaculture industry of Ghana, West Africa [version 2; peer review: 1 approved, 1 approved with reservations]

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Abstract

Background: Aquaculture in Ghana is very profitable, but faces sustainability challenges. This paper assessed the impact pathways by which climate change affects the production and profitability of small-scale aquaculture in Ghana. The study analyzed and compared the economic value of smallholder fish farms with and without the incidence of climatic parameters.

Methods: Simple random sampling and purposive sampling techniques were used to select the study area and farms. A total of 30 farmers were interviewed using a questionnaire-based interview. Additionally, using document analysis, observation, and data on farms' production input and output values, the economic impact of climate change on fish farms was assessed.

Results: Extreme temperatures, erratic rainfall, floods, drought, storm and erosion are prevalent in fish farms. Available data shows a decrease of 53.4% of small-scale revenue, a 6.9% reduction in small-scale aquaculture value from GH¢ 83,000 to GH¢ 120,000 reducing fish supply by 25%. The findings indicate that the profitability, economic value, and livelihoods of the small-scale aquaculture industry is greatly affected by changes in climate. The incidence of floods, drought, erratic rainfall, erosion, and extreme temperature synergistically induce poverty. The implication on the livelihoods of fish farming households is very alarming and poses a serious threat to food security in the country.

Conclusion: Based on the findings, this study concludes that; floods, rainfall temperature, and drought are the major climatic factors affecting the profitability and sustainability of the pond aquaculture industry. The preliminary recommendation is that there is an urgent need to map out flood-free zones close to perennial water bodies to overcome floods and droughts. Planting trees around ponds to create a micro-ecologies ideal for fish culture and also the construction of water storage facilities and proper dyke design would overcome drought and erosion issues. The adaptive capacity of fish-farmers must be built.

Open Peer Review

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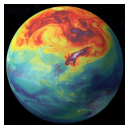
Keywords
aquaculture, climate change, impact, fish, profitability, and small-scale



This article is included in the Climate collection.

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REVISED **Amendments from Version 1**

The article has been revised based on reviewers comments:

The following changes have been made:

1. Introduction: update has been made with an additional reference (Sarker *et al.*, 2017)
2. Figure 2, Figure 3, and Figure 4 have been updated (X-axis labelled as Respondents)
3. "Severely" changed to "severity"
4. "lives people" changed to "lives of people"
5. References: full citation of Sarker *et al.* 2017

Any further responses from the reviewers can be found at the end of the article

Introduction

Food fish plays an important role in the livelihoods, nutrition, and security of millions of the people in Ghana and other parts of Africa. The small-scale aquaculture (SSA) sector, is recognized as making an important contribution to food and nutritional security, poverty alleviation, and socioeconomic development at the global level (Bondad-Reantaso & Subasinghe, 2013; Sarker *et al*., 2017), especially in the developing countries. The global wild fish industry is failing, falling over the past decades from 85 million tonnes in 1995 to 80 million tonnes in 2014 (FAO, 2016). Within the same period, the global per capita fish consumption has increased from 14 kg to 22 kg, which is credited to the growth in the aquaculture sector. The population of Africa is rising, with a corresponding increase in the demand for food, nutrition and livelihood support. While scientists and resource managers continue to battle with overfishing, pollution, and a decline in fish stocks, the impact of climate change is also attracting major attention. Variability in climate is modifying the productivity of aquatic ecosystems and thus affecting biological processes and food webs (Yazdi & Shakouri, 2010). These impacts will be widely felt by fish farmers, fishers and the coastal poor through unstable livelihoods, fish availability and quality, and compromised health, safety, and homes (De Silva & Soto, 2009; IPCC, 2007; and OECD, 2010). Many small-scale fish farmers live poorly due to low income level, low productivity, small pond size, low technology, and inadequate knowledge in aquaculture operations coupled with climate change. Climate change impacts like frequent floods, droughts, erosions, extreme temperature could worsen the situation of small-holder fish farming households through total stock loss, increased mortality, reduced fish yield, damage to ponds/tanks, increase operating cost, and affect their livelihoods (Allison *et al*., 2005; De Silva & Soto, 2009; Yazdi & Shakouri, 2010).

Aquaculture development in Ghana is on the increase. Aquaculture currently contributes about 11% (52,470 mt) to annual fish production (465,357 mt) (MoFAD, 2017). Pond-based aquaculture systems form about 35% of the production system, which is spread throughout all the regions in Ghana. However, many small pond-holder farmers have abandoned ponds due to floods, water scarcity and high mortality rate (Asiedu *et al*., 2017; Hiheglo, 2008; Ragasa *et al*., 2018). But how the variability in climate affects the socio-economic status and livelihood of this already stressed and vulnerable group is not given the required attention. However, the population is growing (around 2.3% per annum and is projected to reach 37 million by 2030, GSS, 2014; GSS, 2017), poverty and hunger persist, unemployment is high, and fish demand is increasing.

Climate variability remains a threat to human settlement, and food production and supply systems for several decades. In recent years, the intensity of climate change and related impacts on the livelihoods of the poor and most vulnerable population has attracted the attention of scientists, researchers, governments, organizations, and other stakeholders. The incidence of floods, droughts, erratic rainfall, extreme temperature, and storm have become more prominent in most fish farming communities in Ghana (Anane-Taabeah *et al*., 2010; Asiedu *et al*., 2017; Rurangwa *et al*., 2015). Ghana has recorded a 1°C rise in temperature over the past 6 decades (Agyeman-Bonsu *et al*., 2008). The implication of this variation for food security and fish farmers' livelihood is alarming. The consequential impacts could be direct or indirect on the socio-economic and livelihood of small-scale fish farming households. Smallholder farmers may have to incur extra costs to fight climate change shocks. In cases where farmers cannot cope with climatic losses, incidence such as flooding can carry their fish stocks away and, or damage their production systems, thereby becoming jobless and increasing their level of poverty. Accessing the cost of production, net revenue and cost farmers' incurred to fight climate variability, promote aquaculture development and improve livelihood is therefore important.

In Ghana, the total national fish production remains below 50% of quantity demand forcing the Government to spend about US$ 131 million to import fish in 2016 (MoFAD, 2017). The aquaculture subsector in country is underdeveloped, with the majority of farmers operating at the small-scale (Asiedu *et al*., 2017; Kassam, 2014). Several studies have been carried out on aquaculture development in Ghana. The majority of emphasis has been on the cost of inputs, market systems, and infrastructure (Kassam, 2014; Mboge, 2010; Rurangwa *et al*., 2015). The impacts of climate change on aquaculture is an area that is greatly underexploited. Available literature on climate change and aquaculture focus more on projections and predictions, not articulating properly the impacts of climate change at the farm level. This study goes beyond the art and science of predicting the potential implication of climate variability on aquaculture, but rather accessing and analyzing available data at the farm level to establish how climate change affects farmers' livelihoods.

Methods

Study area

The study was carried out in six fisheries zones in the Ashanti and Brong-Ahafo regions of Ghana (Figure 1). The majority of small-scale aquaculture (ponds) in Ghana are concentrated in Brong-Ahafo and Ashanti regions. The two regions are the core of small-scale aquaculture practices, characterized by climatically favourable conditions, good market system, and a good environment. FSCBP (1997) indicated that the Ashanti region forms the highest potential area for aquaculture in Ghana. The Food and Agricultural Organization of the United Nations (FAO) (1991) mapped the region to be rich in the availability of

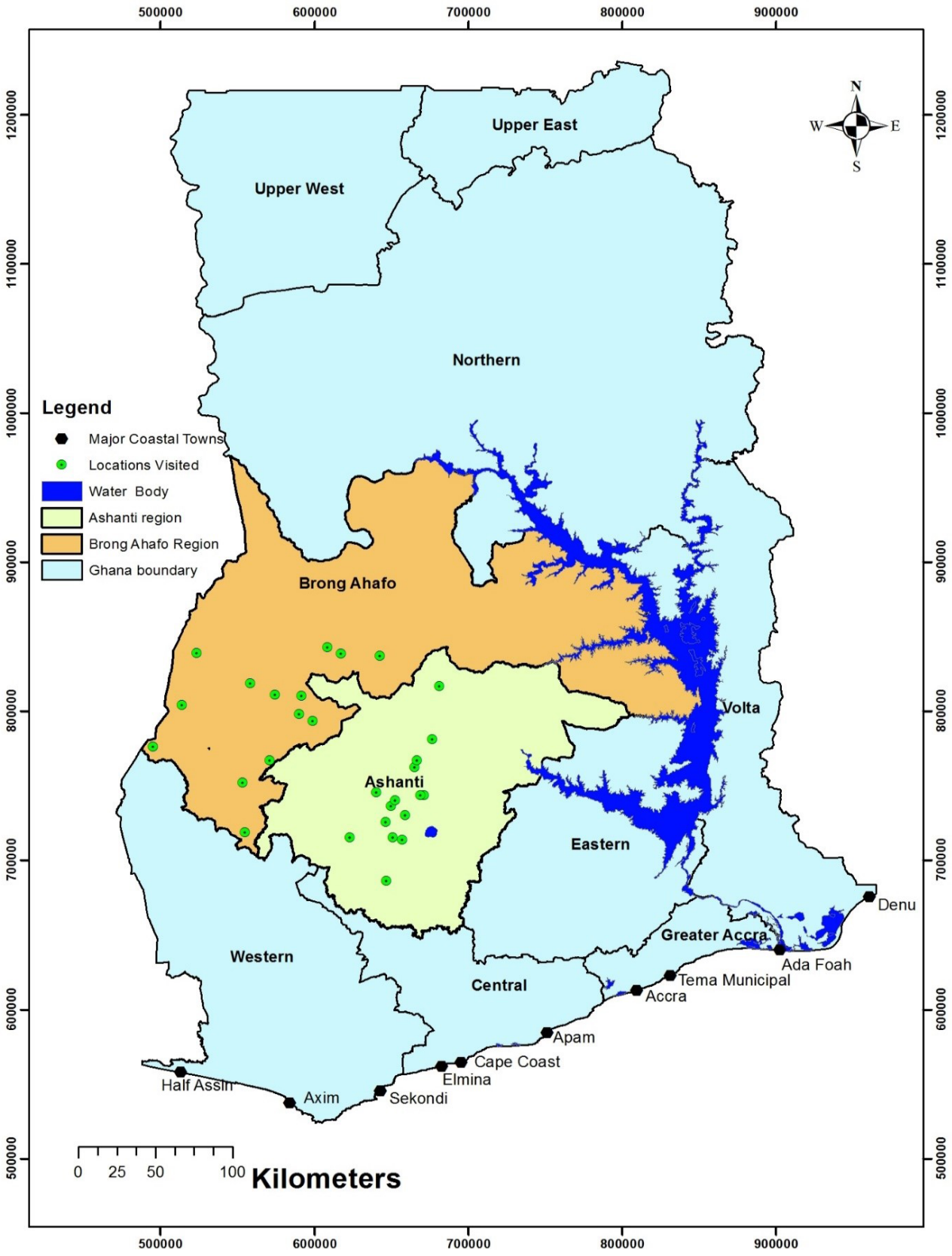

Figure 1. Map of Ghana showing locations visited for data collection.

land, water, rice bran and organic manure, thus suitable place for the viability of fish farming development. Generally, the whole area is inundated by rivers and streams which serve as a water source for fish farming (Dankwa *et al*., 1999). The Ashanti region has about 1,200 fish ponds (Gyebi, personal communication).

The Brong-Ahafo region is endowed with good climate, rainfall system, and temperature (MoFA, 2010). The region is a home to about 1,400 fish ponds, and 85% of its soil falls into the ochrosols groups, which generally have good water retention and are largely fertile (MoFA, 2010). The topography is fairly flat, thus suitable for large scale pond construction. The region experiences a bimodal rainfall system which most farmers depend on to fill their ponds for their operations. The major rainy season is between March and September with the minor rainy season between October and December. This rainfall pattern offers two farming seasons in a year. These provide optimal conditions for farm fish production (See Figure 1).

Sampling

The study employed a two-face sampling technique in site selection and data collection. A purposive sampling technique was first used to select two regions (Ashanti and Brong-Ahafo) out of ten regions in Ghana. The main target group was small-scale fish farmers, who are concentrated in the two regions. Fisheries zones were listed, and three randomly selected from each region. A list of registered farms with the Fisheries Commission was obtained, and simple random sampling used to select five farms from each fisheries zone for the farm survey. The random number feature of Microsoft Excel 2013 was used to randomly select fisheries zones and farms.

Data collection

Farmer interviews. A paper-based questionnaire guided interview was employed from June to December 2016. Key respondents for the farm level interview were either farmers or farm hand. The questionnaires (see Supplementary File 1 and Supplementary File 2) were structured to achieve the predetermined objectives of the study. Two sets of questionnaires were designed to target farm profitability and farm losses due to climatic effects. Farm profitability parameters included; cost of fingerling, cost of feed, cost of transportation, labour cost, quantity of fish harvested, and estimated value of harvest. Climatic factors herein refer to temperature, rainfall, floods, erosion, drought, and storms. These were modified from relevant studies (Asiedu *et al*., 2017; De Silva & Soto 2009; Hiheglo, 2008; Mboge, 2010) of climatic change impacts on fisheries, aquaculture, agriculture, and livelihoods. The climatic factors were used to develop both quantitative and qualitative questions of open- and close-ended types. A total of 30 farm workers were interviewed, 15 in each region (Ashanti and Brong-Ahafo), each comprising 10 farmers and 5 farm hands. The interviews were conducted in an interactive manner, allowing farmers to ask questions and elaborate their points. This was to enable farmers to understand the significance of the study and to provide information relevant to the research.

Desktop study. A desktop study was conducted. Notable reports, articles, and write-ups on climate change and related impacts on fisheries, aquaculture, agriculture and forestry were consulted. These included projected potential impacts of climate change on wild fisheries resources, cultured fisheries resources and on aquatic ecosystems. Keywords used included: food security, climate change, climate controls, climate change and food systems, climate change and aquaculture in the developing world, climate change implications for fisheries and aquaculture. Climatic factors identified impacting fisheries and aquaculture greatly through direct and indirect impact pathways were used to modify qualitative and quantitative questions for the field data collection. The following online resources were utilized: FAO GeoNetwork; FAO Climpag, FAO GIEWS, WorldFish Center, CGIAR Research Program on Climate Change, Agriculture and Food Security, The Technical Centre for Agricultural Research (CTA), Organisation for Economic Co-operation and Development (OECD) and the World Farmers' Organisation (WFO). The results of the desktop study are presented in the Introduction and Discussion sections.

Validation workshop. A one-day validation workshop was organised for farmers, fisheries administration officials, NGOs, regional organizations, academia/researchers to validate the findings collected during field data collection.

Ethics and consent. The study received ethical approval from the University of Energy and Natural Resources Research, Conferences and Scholarships Committee, and ensured informed consent was received for data collection and analysis. Three key ethical issues considered were: voluntary participation; anonymity and confidentiality with respect to data analysis in collective manner were ensured. Furthermore during the validation workshop, the participants were openly told of the purpose of the workshop and consent was sought verbally. Verbal consent was sought as the farmers were unable to read or write.

Data analysis

Quantitative and qualitative data collected during the field study included: a) operating cost: feed, fingerling, transport, harvest, and labour, b) outputs: total fish weight and value, and c) the incidence of floods, storms, temperature, droughts, rainfall, and erosion and their impacts on farm revenue and maintenance. All completed data collected was manually entered into Microsoft Excel 2013 and SPSS version 22 to await analysis (Asiedu, 2018). The results from the analyzed data is presented in the form of tables, and charts/graphs. Observation data was used as a guide to validate farmer's description of climatic factors. These include: topography, water source, pond size, evidence of erosion, local strategies put in place to mitigate impacts.

Estimations and assumptions

- Total production cost (*tpc*): the sum total of variable inputs example feed, fingerlings, labour, water, weed control, transport, and others as stated by the farmer. This is given by; $tpc = \sum(x_1,\ x_2 \cdots \cdots \cdots \cdots x_n), x =$ variable cost.
- Total wet weight (TWW): is the product of average weight (*aw*) of fish at the time of sales and the total number of fish harvested (*nfh*). This is estimated using; *tww* = *aw*nfh*

- Estimated value of harvest (*evh*): is the product of the unit market price of fish ($cost^{-kg}$) and the total units harvested (tww). Thus: $evh = cost^{-kg} * tww$
- Non-climate/net revenue: defined as the estimated value minus total production cost. It is given by the relation:

$$nonclimate\ revenue = (cost^{-kg} * tww) - \sum (x_1 \cdots x_n)$$

Results and discussion

Impact of climate change on aquaculture revenue

Farm revenue is a key profitability indicator of a project. Figure 2 compares non-climate revenues and climate revenues. In this study, non-climate revenue is the difference between the value of fish harvested (total cash inflows) and total production cost (total cash outflows). Whilst climate revenue is the difference between non-climate revenue and total cost climatic impact. Non-climate revenue is also referred to as actual revenue in the study.

Climate change poses an alarming threat to the economic development of the small-scale aquaculture industry in Ghana. This is evident in the gap between non-climate revenue and climate revenue as presented in Figure 2. The highest non-climate revenue stands at GH¢ 144,130 with a production cost of GH¢ 95,870 at point 1. This is about 50.3% of the amount invested. Hiheglo (2008) and Mboge (2010) predicted that small-scale aquaculture could generate a profit of 77% and 72%, respectively. This is a confirmation of the suggestion of Kassam (2014) that there may be an asset threshold over which fish farming allows higher income and asset accumulation than non-fish farming households. The climate revenue recorded at point 1 is GH¢ 67,130. This represents 53.4% loss of the farmer's non-climate revenue, over half of the farmers' economic returns. OECD (2010) noted that the socio-economic effects of climate change on fisheries and aquaculture are hard to determine but could amount to many billions of dollars. Comparatively, the climate total revenue is 40.2% of the non-climate revenue. The severity of climate change impact on aquaculture will depend on farm location, cultured fish species, and water used (Asiedu *et al.*, 2017; Hiheglo, 2008; Poff *et al.*, 2002).

The incidence of floods, extreme temperature, erratic rainfalls, droughts, and erosion are causing significant economic loss to small-scale fish farmers. Direct effects may be through stock loss, damage of infrastructure, high rate of mortality, and growth altering, water scarcity, and reproductive capacity (De Silva & Soto, 2009; Handisyde *et al.*, 2006; Yazdi & Shakouri, 2010), and thus affecting farming production and profit. Asiedu *et al.* (2017) indicated that changes in weather patterns and related disasters have led to serious economic losses in fish farms, loss of fish stock to floods, droughts, and damage of pond dike by erosion. But the study did not quantify the economic losses due to climate impacts.

Small-scale aquaculture non-climate value and climate value

The value of fish of an aquaculture establishment gives a telling detail of its ability to improve the socio-economic and livelihood of fish farming households. Value estimation is an important economic parameter informing the decision of investment. The non-climate value of small-scale aquaculture and climate value are compared in Figure 3 below. The total value in this study stands at over GH¢ 1.2 million for an estimated wet weight of 84.4 metric tonnes (Supplementary Table 1). This proves why small-scale

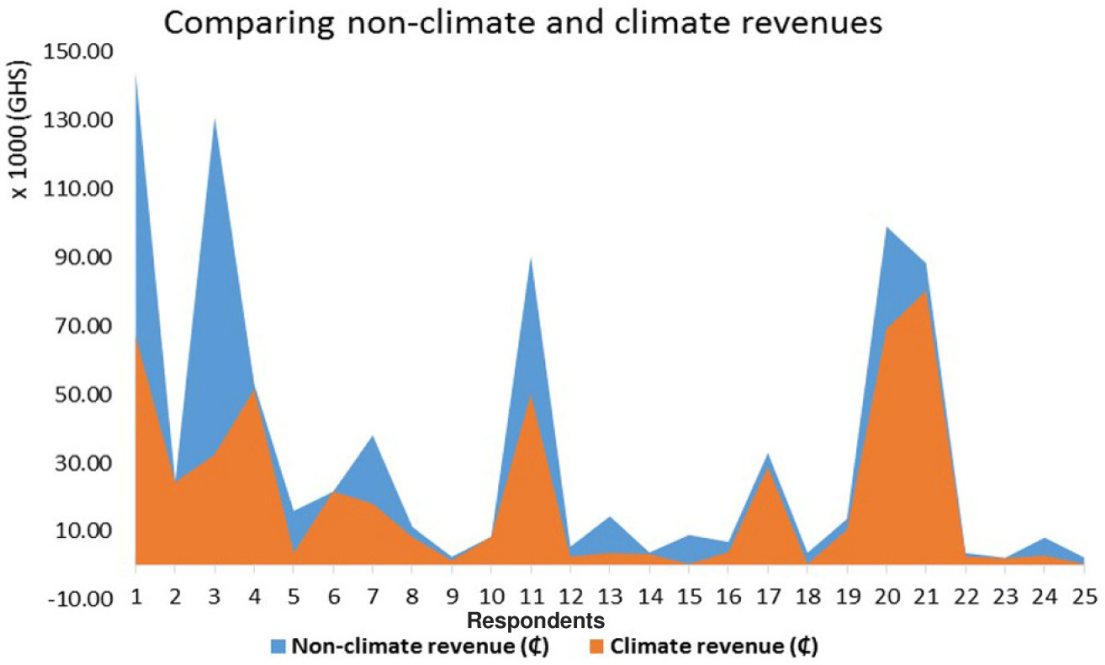

Figure 2. Impact of climate change on small-scale aquaculture revenue.

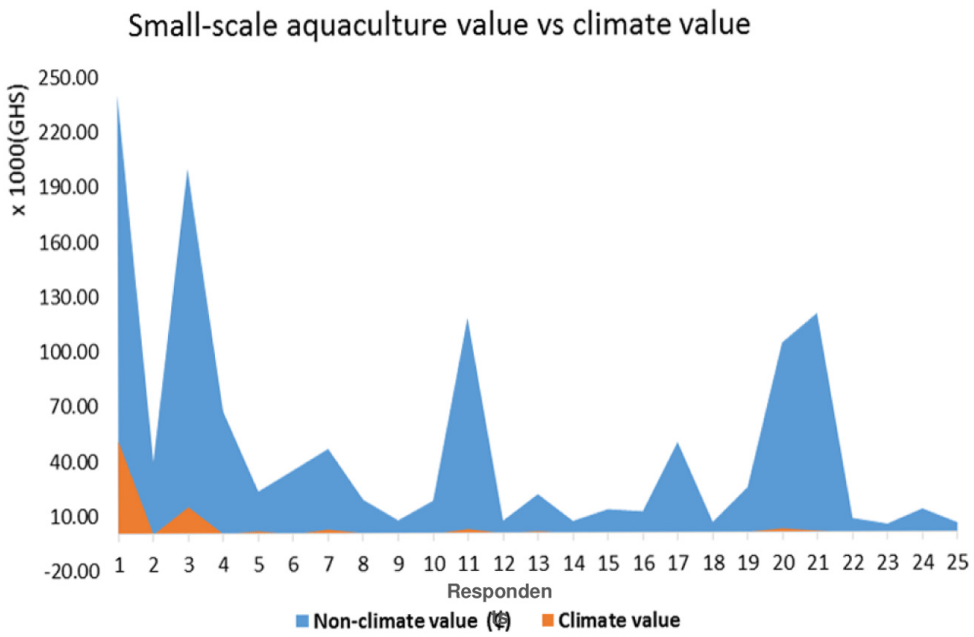

Figure 3. Impact of climate change on small-scale aquaculture yield.

aquaculture is widely considered as economically viable venture worth million tons and billions of dollars, and improving the lives of people (Bondad-Reantaso & Subasinghe, 2013; FAO, 2015; Worldfish, 2010). This is sustainable in the case of climate change effects and resultant impact pathways. Climate change impacts the economic value of small-scale aquaculture drastically, by reducing non-climate value of GH₵1.2 million to GH₵ 83,191.98 (Supplementary Table 1). This represents 6.9% reduction in small-scale aquaculture value. De Silva & Soto (2009) noted that changes in water availability, extreme weather events, vertical stratification, and nutrient supply may have negative effects on freshwater aquaculture production, relative to local conditions. This is observable in Figure 3 below, where climate value is nearly invisible and farmers do not incur many losses to climatic effects.

Climate change, food and nutrition security

The small-scale fish farming industry contributes significantly to food and nutrition security in Ghana, thus promoting the "blue revolution" concept and ensuring sustainable development. A single pond is capable of producing 24.0 mt/cycle (Figure 4). The total estimated small-scale production of sampled farms was 84.4 metric tonnes (mt) (Supplementary Table 1). Considering the estimated per capita fish consumption of 26 kg (national average), these sampled ponds have the potential to providing food to over 3,000 people, thereby providing more balanced diets and better nutrition (Golden *et al.*, 2017; Toufique & Belton, 2014; Troell *et al.*, 2014). Worldfish (2011) stated that millions of poor people in the developing countries of Africa and Asia rely on a combination of fishing and farming to earn their livelihoods and feed their families. But variation in climatic conditions is changing the trend. Analyzed data indicate about 25% reduction in small-scale aquaculture production from 84.4 mt (Supplementary Table 1) to 63.6 mt (Supplementary Table 2) due to incidence of floods, extreme temperatures, droughts, and erosion. Comparatively, the climate wet weight remains lower than the non-climate wet weight throughout the farms assessed (see Figure 4). This threatens the nutrition security and livelihoods of the rural poor fish farmers. Yazdi & Shakouri (2010) noted that the impact of environmental variability could affect the food and water scarcity of many people in the world by affecting fish production and the socioeconomic livelihood of already stressed small-scale fisheries communities.

Incidence of climatic disasters and costs

The occurrence of climate related disasters at fish farms is presented in Figure 5. Climate related disasters in this context refer to climatic factors; flood, temperature, rainfall, drought, and erosion. Extreme temperature and erratic rainfall are the climatic factors mostly experienced by smallholder fish farmers at the same level, 70% (21, n=30) for each. The incidence of flooding and pond erosion were also relatively high, contributing 63.3% and 60%, respectively. Whilst some 46.7% of farms experienced droughts and 30% also experienced storms (Figure 5). Mboge (2010) noted that flooding and erosion were the most prevalent natural disasters affecting pond aquaculture sustainability. This can be attributed to variability in environmental patterns resulting in changing disaster incidences. De Silva & Soto (2009) noted that temperature and salinity may impact aquaculture positively or negatively. Changes in temperature patterns affect the formation of clouds and rainfall pattern. This could result in either extremely low rains (inadequate water supply and droughts) or torrential rains that may result in serious floods and erosion of ponds. Changes in rain pattern will affect water availability ranging from droughts and shortages to floods

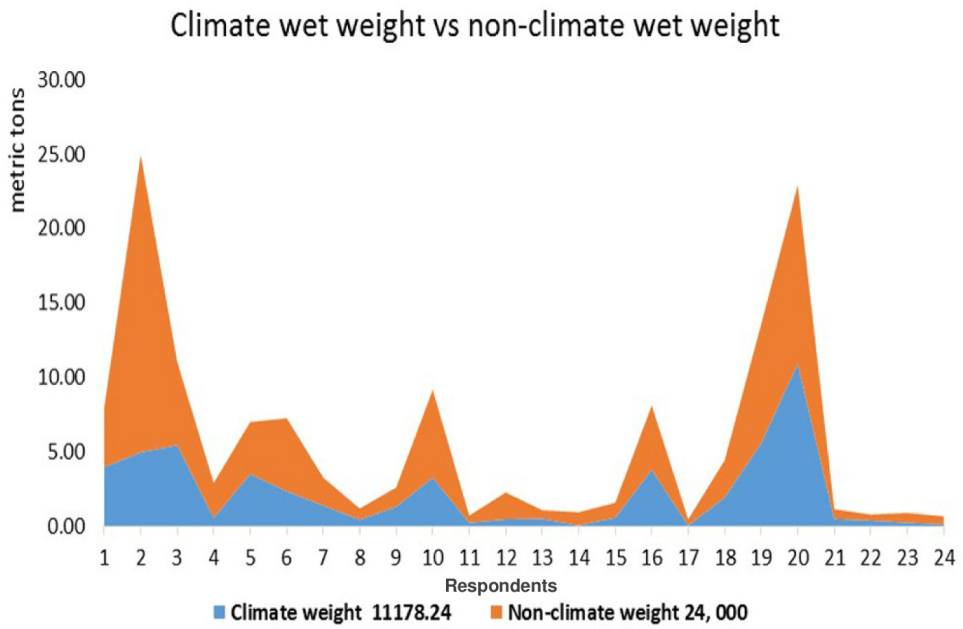

Figure 4. Impact of climate change on aquaculture production.

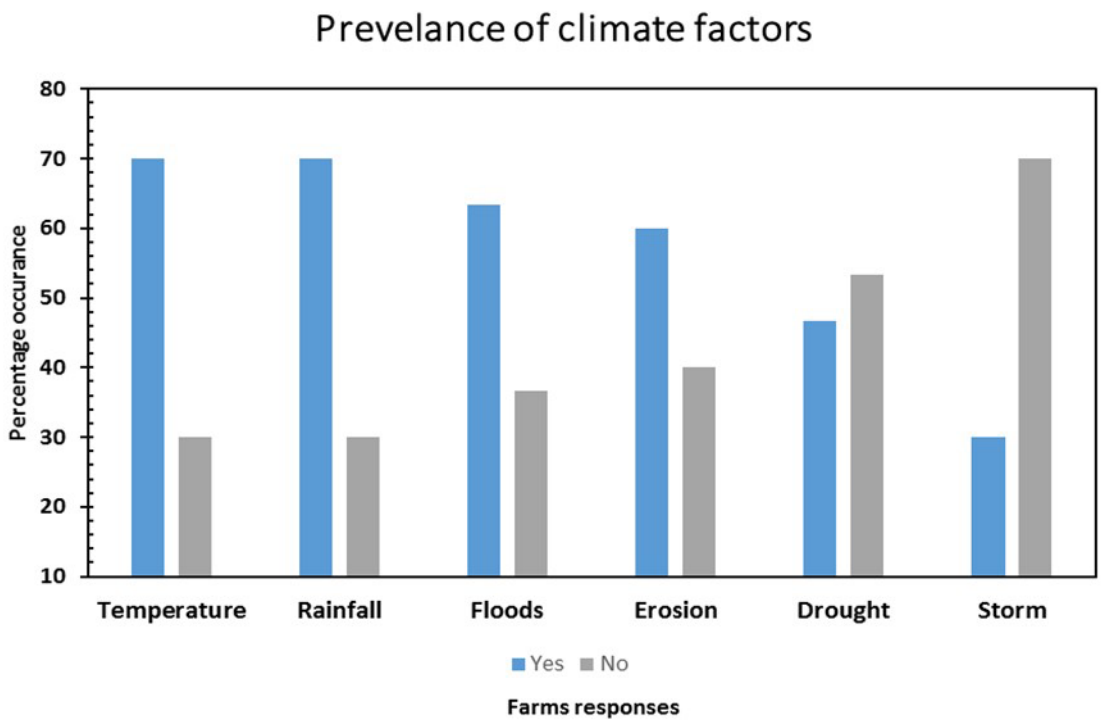

Figure 5. Incidence of climate change variable at fish farms.

and will reduce water quality, and threaten inland freshwater aquaculture (IPCC, 2007). Similarly increasing temperature affects dissolved oxygen and increase fish metabolism, heightens fish deaths, drops in production or increases in feed requirements while also increasing the risk and spread of disease (Allison *et al*., 2005; FAO, 2008; IPCC, 2007). This may probably account for the recognition of rainfall, temperature, floods, and erosion as the most prevalent climatic factors causing significant economic losses on pond fish farms (see Figure 5).

Although extreme temperature and erratic rainfall are the most prevalent climate disasters, flood is the most dominant climatic factor of significant economic impact on small-scale aquaculture (Figure 6). Flood stimulates poverty by reducing farmers'

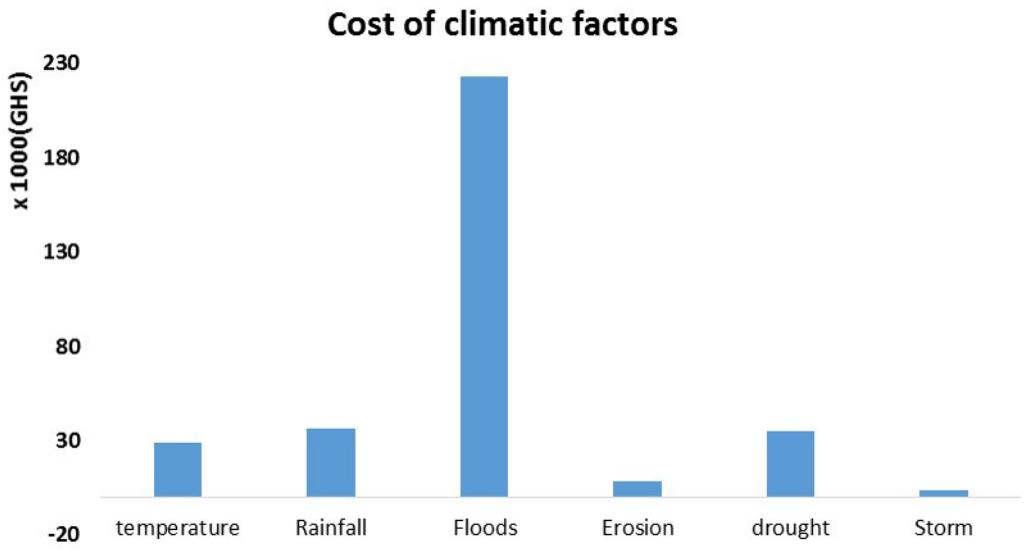

Figure 6. Climate related disasters and cost on farm value.

profitability significantly. This will hinder the effort of using aquaculture to sustainably reduce levels of poverty and improve economic performance in the country. Evidently, the total cost of flood impact in this study is estimated stands at GH¢ 223,435. This makes up 26.7% of the total non-climate revenue. The climatic factors with minimal economic impact in this study are storms (GH¢ 3,650) and erosion (GH¢ 8,210). OECD (2010) noted that typhoon-induced floods have had major impacts on the aquaculture industry through facilities damage and escapes of cultured fish. Floods are particularly disastrous for the world's poor, causing estimated agriculture losses of USD 5.1 billion (FAO, 2018). The most prevalent climatic factors, rainfall and temperature, also cause significant impact worth GH¢ 36,450 and GH¢ 29,195, respectively. The total cost of climate impact is estimated at GH¢ 336,230, which is 40.2% of non-climate revenue.

Conclusion

This study was carried out with an emphasis on aquaculture sustainability. The problem of food and nutrition insecurity still persists. Undoubtedly, the population of Ghana is growing rapidly. At the same time, there is increasing pressure on food production and supply systems due to the growing demand for food and increasing purchasing power. The major focus now is not only feeding the population but also on environmental safety and health. It is evident from the study that the changing climate has caused a serious reduction in small-scale aquaculture profitability. The aspect of climate change that will be detrimental to aquaculture growth is torrential rains-induced floods. The research showed that climate change will compromise the profitability and sustainability of pond aquaculture through affecting the physical structure (ponds and tanks) of farms and the loss of fish stocks. The likely and most obvious outcome will be increasing poverty, food insecurity, and malnutrition. Farmers will be compelled to abandon ponds, stop production and become jobless if this trend continues, or adapt to the changes. This will not only decrease food and protein availability, but hinders the global goal to "end poverty, in all forms, everywhere" (UN, 2018). Based on the findings, this study concludes that floods, rainfall temperature, and drought are the major climatic factors affecting the profitability and sustainability of the pond aquaculture industry. The preliminary recommendation is that there is an urgent need to map out flood-free zones close to perennial water bodies to overcome floods and droughts. Planting trees around ponds to create a micro-ecologies ideal for fish culture; additionally, the construction of water storage facilities and proper dyke design would overcome drought and erosion issues. Furthermore, the Ministry of Fisheries and Aquaculture Development should urgently develop a national policy on climate change and aquaculture, as well as establish climate change and fisheries/aquaculture unit to monitor and document all climate change issues.

Data availability

The raw data associated with this study are available on OSF. DOI: https://dx.doi.org/10.17605/OSF.IO/B2KP4 (Asiedu, 2018). Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

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Supplementary material

Supplementary File 1. Questionnaire concerning the economics and profitability of aquaculture in Ghana.

Click here to access the data

Supplementary File 2. Questionnaire concerning the impact of climate change at farm and community levels.

Click here to access the data

Supplementary Table 1. Production and profitability of pond aquaculture.

Click here to access the data

Supplementary Table 2. Incidence of climatic disasters and attributed costs.

Click here to access the data

Supplementary Table 3. Analyzed climate impact areas.

Click here to access the data

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Open Peer Review

Current Peer Review Status: ? ✓

Version 2

Reviewer Report 26 November 2019

https://doi.org/10.21956/aasopenres.14095.r27223

✓ **Anu Heikkilä**
Finnish Meteorological Institute (FMI) , Helsinki, Finland

The response of the authors to the reviewer's report is mainly satisfactory, but I would like to repeat the request on including a brief discussion on the non-separability of the effects of natural climate variability and climate change in this study. I could not identify a point in the manuscript where the authors would have done this. Furthermore, their response did not indicate that they had taken this request of the reviewer into account.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 03 April 2019

https://doi.org/10.21956/aasopenres.13981.r26816

? **Anu Heikkilä**
Finnish Meteorological Institute (FMI) , Helsinki, Finland

General statement:

Asiedu *et al.* report on a study focusing on assessing the multi-faceted effects of climate change on the

fish farming industry in Ghana. The metrics they use is the occurrence of events of extreme temperatures, rainfalls, floods, erosion, drought, and storms, and the connection of these occurrences to the decline in the revenues of the farmers.

The study is important as it brings the problem close to those whose livelihood is directly connected to pond aquaculture and who therefore are in a vulnerable position as the climate change proceeds. The study incorporates questionnaires to the farmers themselves. This has given the voice to a group of people that are already being affected by climate change. The events of flooding, drought, erratic rainfalls and extreme temperatures experienced by the farmers are of course caused by both natural climate variability and climate change. However, separation of these would be a challenging task and would require an independent source of historical climate data.

Specific comment:

It is not quite clear from the beginning of the article how the authors conclude the events of flooding, drought, etc. being caused by climate change. In the questionnaire based approach adopted by the authors the decision on that appears to remain with the farmers. It is rather questionable how they are able to distinguish which events are caused by climate change and which are just natural climatic variability. Would it be possible to normalize the data in any way to separate the actual impact of climate change, using independent historical climate data? The reader would appreciate if the authors could discuss this with a few sentences. The effect experienced by the farmers in their livelihood is all the same, despite the origin of the event causing a decline in their revenue, but the methods and metrics adopted in the study does not allow attributing the effects solely to the climate change.

Minor remarks:

1. “The severely of climate change” should be changed to “The severity of climate change”.

2. What is on the x-axis (ranging from 1 to 25) on the graph of Figure 2? Please include a label.

3. “lives people” should be changed to “lives of people”.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: atmospheric sciences, atmospheric radiative transfer, interactive effects of ozone depletion, solar UV radiation and climate change

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 15 Sep 2019

Berchie Asiedu, University of Energy and Natural Resources, Sunyani, Ghana

The main objective was to analyze the impact of climate change using farmers' perception and farm economics data. The authors agree that the parameters used in the study could be caused by natural climate variability or could be the result of climate change. The present study did not take historical climate data that permit the separation of climate change and natural climate variability. The authors wish to state that it could still be arguable whether the parameters used are the attributable climate change or natural variability of climate even if historical climate data is obtained. Because we did not put much emphasis on time scale and rate of variation of these events. It is on this background that, the study did not put much emphasis on separating natural variability of climate and climate change. We, however, consider the parameters as climate disasters.

Minor errors:

1. "severely of climate change" changed to "severity of climate change". *Correction done.*
2. The x-axis will be labelled appropriately. *Correction done.*
3. "lives people" changed to "lives of people". *Correction done.*

Competing Interests: None

Reviewer Report 27 December 2018

https://doi.org/10.21956/aasopenres.13981.r26670

?

Benjamin Apraku Gyampoh
Department of Fisheries and Watershed Management, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

General Comments

1. This is a good paper in a field that is relatively less-researched in Ghana. It is well written. The findings

are important baseline to trigger further studies in Ghana on the impacts of climate change on aquaculture production.

2. There are some inherent assumptions mostly in the area of cost of climate change impact which is not clear. It is generally acknowledged that climatic changes would have impacts on climate-dependent activities, both positive and negative. This work focuses on one side – the negative economic impacts. That notwithstanding, the relationships between climatic change and the cost elements of production are not clearly established.

3. The authors use three main nodes in their assessment of the economic impact of climate change on small-scale aquaculture industry of Ghana. These are a) operating cost: feed, fingerling, transport, harvest, and labour, b) outputs: total fish weight and value, and c) the incidence of floods, storms, temperature, droughts, rainfall, and erosion and their impacts on farm revenue and maintenance. I think the work would have benefitted from either a Life Cycle Assessment (LCA) or full Value Chain Analysis (VCA) of the selected small-scale fish farms and then subject the LCA or VCA to a climate change vulnerability assessment. This would be a more holistic approach.

Introduction

1. Is it climate change that this work focuses on or is it natural climate variability needs to be set clearly in the introduction. The title clearly states it is the impact of climate change in the small-scale aquaculture industry in Ghana which is the focus. This is not clear in the introduction. Climatic variables can fluctuate without causing the long-term average to change and that refers to the natural variability of climate. When there is entrenched long-term change in the climatic conditions then that brings in climate change. So, “Variability” and “Change” as used in this paper could create confusion as to where the actual focus lies.

2. Sieving out certain phenomena or impacts and attributing to climate change or climate variability has become blurred as a result of deliberate or unconscious interchanging use of the terms.

Methodology

1. The authors explain that a purposive sampling technique was used to select two regions (Ashanti and Brong-Ahafo) out of ten regions in Ghana. They justify selection of the two regions with the statements that majority of small-scale aquaculture (ponds) in Ghana are concentrated in Brong-Ahafo and Ashanti regions and the regions are the core of small-scale aquaculture practices. Quantitative justification would be better. For example, what does ‘majority’ specifically mean? The two regions are from 10 regions in Ghana so good quantitative justification in terms of production percentage would put the justification in proper perspective.

2. The Literature used to justify the selection of the Ashanti and Brong Ahafo regions for the study are quite old and will benefit from some newer sources.

3. Why a total of 30 farmers were interviewed will need to be explained to establish that number is representative of the aquaculture industry in Ghana. Authors make known that there are about 2600 fish farms in the region. How many of these 2600 farms are owned by the 30 farmers? Or what percentage of total fish production from ponds in the two regions are from these 30 farmers that make them a representative sample?

Results and Discussion
1. The explanation of climate revenue as the difference between actual revenue (non-climate revenue) and total cost of climatic impact has some inherent assumptions that is difficult to stand. How were the estimation of costs of production accurately attributed to climate change? The issue of correlation, causation and attribution are critical in this situation.

2. In figure 5, the authors present climate related disasters at fish farms and the main 'disasters' used are flood, temperature, rainfall, drought, and erosion. Flooding of farms, lack of water in ponds and erosion could be as a result of many other watershed factors. Human activities leading to various forms of environmental degradation could lead to 'droughts', flooding and erosion and not solely an effect of climate change. Noting from the paper that flood is the most dominant climatic factor of significant economic impact on small-scale aquaculture (Figure 6) throws the debate wide open because the factors that could lead to flooding can be both man-made and natural. In the context of Ghana, some possible causes of flooding include lack of vegetation, land use and land cover changes, development of infrastructure blocking water ways, topography and drainage of the land, poor location of the fish ponds and many more which are more human-induced than climatic.

3. The levels of attribution of issues to climate change are quite high in this paper. Should there have been recorded climate data (rainfall, temperature) to support some of the linkages, there would have been good explanation to some extent.

Conclusion
Conclusions are general. Good for planning and future studies.

References
They are OK.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate Change Vulnerability Analysis; Watershed Management; Water Resources Management; Climate Change Adaptation and Mitigation Strategies; Fisheries Management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 31 Jan 2019

Berchie Asiedu, University of Energy and Natural Resources, Sunyani, Ghana

Introduction

1. Yes, the focus is on climate change. Climate change is the result of natural climate variation and anthropogenic climate effects. Natural climate variability is used here as an aspect of climate change, not a substitute. Climatic variables could fluctuate and cause significant variation climate. So, using climate variability in the context of climate change should not be strange.

Methodology

1. Suggestion: The area has about 2,600 fish ponds making up about 55 percent of the total ponds in Ghana (MoFAD, 2014). Pond aquaculture abundance was the criteria used in site selection. In terms of national pond production, the two regions account for 40 percent of the pond production (MoFAD, 2012).
2. The authors agreed that the literature used for the selection of the Ashanti region is quite old. However, the documents provide important description of the selected site.
3. Not 2,600 fish farms, but 2,600 fish ponds. Registered farm list was obtained from the Fisheries Commission. There were 70 and 50 farms in Ashanti region and Brong-Ahafo region, respectively. This makes up a total of 120 farms. Authors sampled 25 percent (i.e. 30 farms) of the total farm list obtained for the farm level interview.

Results and Discussion

1. Kindly see sample questionnaire and supplementary Table 2 for further clarity. Firstly, incidence of climate disasters at farms was obtained. And when farms experienced these disasters what is the cost? These include fish mortalities (value loss), stock loss under severe floods (value), cost of fighting erosion and maintaining pond dikes, cost of pumping water in drought conditions, and cost destroyed farm structures by climate disasters.

2. Used climate disasters are weather events. Arguably, these could be the result of many watershed factors or human activities. Human activities impact both climate variation and watershed factors. Whilst changes in climate impacts watershed, which could result in floods, droughts, etc. Yes, flooding maybe both man-made or natural. That is why climate change looks at both internal processes (natural climate variability) or external forces (persistent anthropogenic changes in land use, vegetation cover, etc).

3. The climate disasters defined by this study are projected to impact ways by which climate change will affect the fisheries and aquaculture inustry ((Allison et al., 2005; WordFish, 2007; De Silva & Soto, 2009; Yazdi & Shakouri, 2010) by many studies. The author assessed the impacts of such disasters in small-scale aquaculture industry of Ghana.

Competing Interests: Authors have no competing interest to disclose.