Investigating Gender Aspects of the Health Impacts of Climate Change in the Lake Chilwa Basin, Malawi.

by

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Abstract

Climate change affects human health and well-being directly through physical effects and indirectly through a myriad of interconnected pathways. Although global in nature, local impacts of climate change differ immensely based on a multitude of social, economic, and environmental factors, and often the poor and the vulnerable suffer incomprehensively without assistance. The Chilwa Basin in southern Malawi is one such region where climate change is playing a significant role in intensifying the already burgeoning pressures of population growth and acute poverty with severe consequences on human health and well-being. Women are impacted by climate change and variability at a disproportionately higher rate than men because of complex social contexts and adaptive capacities. Physical constraints due to reproductive demands, socio-economic inequalities and cultural norms limit women's choices and enhance their vulnerabilities. This is further exacerbated in rural areas by poor healthcare services and lack of access to family planning. Women are particularly vulnerable to environmental factors related to climate change, such as natural disasters and droughts, as they are not just directly impacted by diseases but also burdened with looking after sick family members. The objective of this qualitative study is to identify gender-specific variables, their relationships and resulting health impacts in the Lake Chilwa basin in the climate change scenario using systems dynamic. The results will be used to develop systems diagrams (Rich pictures and Influence diagrams) that will act as visual tools to better facilitate inclusion and diversity during future validation stages with local communities.

Keywords:

Gender-related health impacts, Climate change, Natural resources, Sustainable Development Goals, Complex-adaptive systems theory, Lake Chilwa, Malawi.

Foreword

This MES major paper is a product of knowledge and skills gained over the last 2.5 years of my academic journey at the Faculty of Environmental and Urban change in York University. Prior to joining the MES programme, I worked in the mining industry for 6 years where I observed extreme health inequities which were being blatantly ignored, not just due to indifference but also due to the unawareness of the complexities between human health and environment. The potential risk that this critical gap posed on the health and well-being of local communities in developing countries, who are already victims of extreme health inequities, is frightening. While this observation led me to return to academia, I did not come with a well-designed strategy. As I am writing this foreword, I can proudly state that this is not the case anymore, and for this I am very thankful to Dr. Martin Bunch, who has really opened doors for me through his teachings, mentorship, and network.

I designed my Plan of Study with the strategy to gain a broad understanding of topics related to natural resource management, human health, and climate change. To integrate the three, I chose Ecohealth, which is an emerging field pioneered in the 1990s by the International Development Research Centre (IDRC) to study the dynamic interplay among multiple determinants (natural and anthropogenic) and their effect on community health and well-being. The broad and versatile nature of the three components and the flexibility of the MES program allowed me to explore different topics through courses and internships and really get a robust and interdisciplinary understanding of the issues related to my field of study. Above all, the knowledge gained through this interdisciplinary approach really pushed me to become a holistic thinker, which helped me immensely to write this paper.

This major paper is inspired by my own experiences while living in Tanzania and India, and working in Burkina Faso, where I have seen the health inequities suffered by women with my own eyes. In my last year of the program, Dr. Bunch introduced me to Dr. James Orbinski from Dahdaleh Institute for Global Health Research, which has been pivotal in the selection of my final research topic. One of my objectives to return to academia was to do research that could be actionable. Dr. Orbinski trusted me to align my final research to one of his ongoing projects in Malawi, which I am deeply grateful for. My research on gender and health impacts of climate change, as presented in this paper, will be an original contribution to the field with a potential to become a useful resource to conduct future participatory community-based research. The paper has been written to maximize knowledge dissemination within and outside the academic field, and to inspire other researchers to appreciate the complexities in the nexus between gender, health, and climate change.

I take this opportunity to express my gratitude to Dr. Peter Mulvihill and Dr. Lewis Molot, whose guidance and encouragement throughout the program has been pivotal to my successful completion of this program. I would also like to thank Dr. Byomkesh Talukder from Dahdaleh Institute for Global Health who has mentored me patiently and has been key in shaping my research skills in climate change and health.

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Chapter 1: Introduction & Background

A global injustice of the climate crisis is that most of the burden is borne by the poorest in the Global South who have contributed the least to the crisis. Climate change can exacerbate existing health inequities by affecting the determinants of health. “Health equity resonates with the SDGs’ [Social Determinants of Health] overarching principle of leaving no one behind and the implicit moral imperative of social justice” (Marmot, 2018).

Gender is an important factor; and is critical for assessing the economic and social costs of environmental degradation in accelerating natural resource depletion and climate change. Health impacts of climate change on women vary from impacts on men owing to complex social contexts and adaptive capacities. Physical constraints due to reproductive demands, socio-economic inequalities and cultural norms limit women’s choices and enhance their vulnerabilities (Preet et al., 2010). This is further exacerbated in rural areas by poor healthcare services and lack of access to family planning. Women are particularly vulnerable to environmental factors related to climate change, such as natural disasters and droughts, as they are not only directly impacted by diseases but also burdened with looking after sick family members. In the World Social Science Report (2013), Agarwal links the differential impact of environmental degradation on men versus women to the latter’s reliance on common property resources due to two major reasons–(i) pre-existing gender division of labour, and (ii) gender inequality in access to private property resources (Agarwal, 2013). With a decline of commons, the cost in terms of time, income, nutrition, and health costs affect women more than men who have more occupation options (Agarwal, 2010). The nature of their tasks makes women more prone to health impacts from indoor air pollution, deterioration of water quality, and agricultural tasks (Ahmed et al., 2000, Goldemberg, 2012, WHO, 2002). Moreover, their role as caregivers exposes them further to diseases and chemical-induced ailments (Agarwal, 2013). Gender differences are important in recognizing, estimating, and monitoring in risk reduction strategies (Ostlin et al. 2006). Gender Analysis studies require rigorous empirical research strategies in addition to qualitative assessments (Agarwal, 2013) to cover the gap caused by failure to apply a gender lens to exposure risk (Coyle et al., 2020).

Malawi is a landlocked country in Southern Africa, and shares its borders with Mozambique, Zambia, and Tanzania. According to the World Population Review, the country’s current population of 19.13 million (HDR, 2020) is expected to surpass 50 million by 2058, and triple by 2099. From 2019 to 2020, the population grew by 2.69%. Malawi ranks 172 out of the 189 countries listed on the 2019 Human Development Index (HDI) Ranking with an Infant Mortality Rate of 35 per thousand deaths making it one of the least developed countries in the world. The rapid population growth will immensely pressure the country's health, education, economic and agricultural sectors. It will also lead to an increase in environmental degradation and depletion of natural resources, such as clean water, which will further add to the poverty levels in the country. A bigger rural, natural-resource dependent population and an agriculture-centred economy makes Malawi one of the most vulnerable countries to climate change. Malawi's development challenges are multi-pronged, including vulnerability to external shocks like weather and health, rapid population growth and environmental degradation. Energy shortages persist (11.4% of the population has access to electricity), adoption of new technology and infrastructure development is low and corruption levels are high (Transparency International ranking Malawi at 123/180 economies in 2019) (World Bank, 2020).

Chilwa background

Lake Chilwa - a Ramsar site, and a Man and Biosphere reserve is a large tropical, shallow, and closed (i.e., no outlet) lake in the south of Malawi and close to the eastern border with Mozambique. Due to its heavy dependence on seasonal variations, the water level in the lake can fluctuate up to one metre between dry (May-October) and wet seasons (November-April). Historically, the lake has dried and filled up to 8 times in the last century. In 1995, the lake and its wetlands dried up completely, causing severe starvation (UNESCO, 2015). Salinity is also a problem in parts of the lake due to its closed nature and local geology (Missi & Atekwana, 2020). The Chilwa Basin is one of the most climate-change affected regions of the world, and a victim of acute poverty where livelihoods primarily depend on natural resources, mainly agriculture and fishery. Rural people with natural resource-based livelihoods living in fragile ecosystems are most often both victims and unwilling architects of ecosystem degradation (Chiotha et al., 2017), especially when populations are large. Communities that are more vulnerable to climate change are often the ones that lack power, resources, and opportunities to anticipate, adapt or mitigate climate-change induced damage. Vulnerability affects individuals and social groups according to their rights and opportunities which vary with gender, ethnicity, religion, class, and age conditions (Perez et al., 2015).

The 916,447 people in the entire Lake Chilwa basin constantly live under the threat of highly variable weather and a dwindling source of natural resource base (Chiotha et al., 2017). Rice farming, fishing, bird hunting and livestock rearing are the principle economic activities within the transition zone[1], whereas those inhabiting the core and the buffer zones are restricted to fishing due to transportation limitations (UNESCO, 2015). The four regions of the basin - the Lake, Wetland, Flood Plain and the Upper Catchment have their own livelihood, disease and nutrition dynamics, and ecological characteristics (Chiotha et al., 2017).

[1] North of lake shore where the alkaline soils dry out during the dry season and get wet during the wet season.

Deficits in natural-resource governance, lack of income alternatives, food insecurity and rapid population growth expose the basin population to high levels of climate vulnerability. Extreme weather events (floods and droughts) and human-induced shocks (deforestation and secondary ecological changes like eutrophication) synergistically interact to cause significant social, economic, and environmental impacts which affects individual and population health through complex pathways (Chiotha et al., 2017). Some of these impacts are increases in infectious diseases like malaria, schistosomiasis, cholera and diarrhoeal illnesses, population displacement, poor sanitation and hygiene practice, lack of potable water, disruption of health services and food insecurity (Grandesso et al., 2018; Makaula et al., 2014; Pullanikkatil et al., 2013).

To strengthen health systems, "we need to know not only what works but works for whom and under what circumstances. Every intervention, from the simplest to the most complex, influences the overall system, and the overall system influences every intervention" (de Savigny & Adam, 2009). Systems science has much potential in deciphering the complexities of the dynamic and interrelated forces in an entire health system, and then applying the knowledge to design solutions that improve health and health equity. Plsek and Greenhalgh defined the concept of complex adaptive systems, "Complex Adaptive Systems Theory", as taking a holistic approach to studying a system instead of seeking a more reductive explanation (Dooley, 1997). Complex adaptive systems theory visualizes "a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions change the context for other agents" (Holden, 2005).

To gain a complete understanding of the entire system, it is important to identify and visualize the interrelationships within the subsystems. This can be achieved using systems diagrams which can also facilitate stakeholder engagement by visualization of a 'mind map' as an early stage in the modelling process (Lane 2016) and may allow a smoother transition to the final stock-and-flow diagrams (Abdelbari & Shafi, 2007). Agent Based and Systems Modelling that is informed by community, can make significant contributions to understanding and identifying trends that may otherwise be difficult to detect. These can help understand the present and predict the future and planning accordingly (Frerichs et al., 2016). Previous research studies in the Chilwa basin have illustrated that women are impacted by climate change and variability at a disproportionately higher rate than men (Pullanikkatil et al., 2013). However, these studies have been done in silos and lack integration. Therefore, this research attempts to build on existing studies and explicitly map out interrelationships that have been missed in the individual studies. Additionally, using a series of systems diagrams, the study will generate visualizations that will act as tools to conduct participatory community-based research in the future.

Chapter 2: Methodology

2.1. Introduction

This chapter will lay out a detailed description of the research methodology to meet the objectives set for the three components.

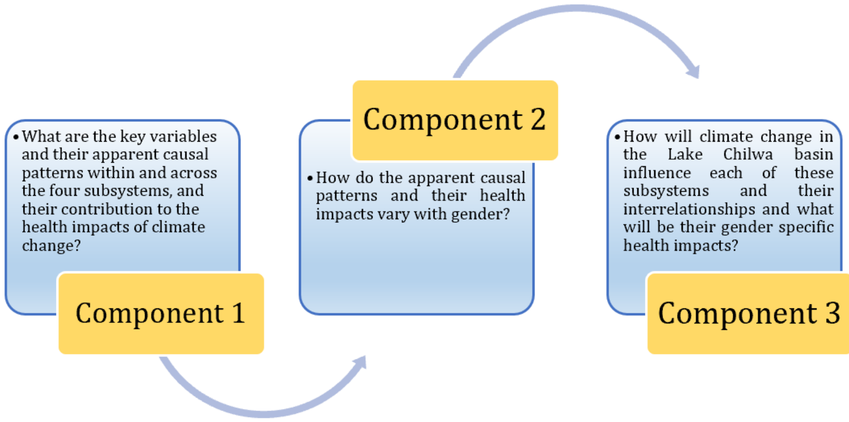


Figure 1: Overview - Three components of Climate change, Gender & Health impact research

The chapter is comprised of three main sections–(i) Generating the database, (ii) Analysis and (iii) Application to the Chilwa basin. The first section - "generating the database" details a systematic literature review guided by "The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)" checklist. The "Analysis" section introduces the aim to identify variables for the first two components (see Figure 1) and develop systems diagrams to visualize the complex relationships between four subsystems–food security, ecological services, communicable and non-communicable diseases, and extreme weather. In the last section, I apply the analysis from the first two components to the Lake Chilwa basin to identify the apparent causal links between stressors and their health impacts.

2.2. Generating the database

This review was done in accordance with "The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)" checklist which is a 27-item checklist used to add robustness and transparency to systematic review studies (Moher et al., 2009). Guided by the four steps of PRISMA - identification, screening, eligibility, and included (see Figure. 2 below), a pre-defined research protocol was developed with clearly defined inclusion and exclusion criteria. The steps are discussed in sections below.

2.2.1. Database creation:

In this step, several pilot searches were conducted on several databases–Scopus, Web of Science, PubMed, York University Library OMNI, and Google Search to test the search strategy and the keywords (Refer to Figure 2). Finally, 4 out of 5 of the tested databases were selected to create the database of choice for each component based on saturation in results and user-friendly interface of the database for sorting and exporting articles to the reference manager tool.

Database	**Keywords** ***(Search string and Boolean operators adjusted as required per database)***	**# Of hits**
Web of Science	TITLE: (“climate change” OR “global warming” OR “climate variability”) AND TITLE: (health* OR “human health” OR “well-being” OR “mental health” OR “illness” OR “ailment” OR “noncommunicable” OR “communicable” OR infectio* OR pollution OR contamination* OR food* OR nutrition* OR water OR vector OR disease* OR deficiency OR malaria OR dengue OR schistosomiasis OR stunting OR sanitation OR hygiene) *Refined by: DOCUMENT TYPES: (EXCLUDE (Review Articles or Proceedings Papers or Book Chapters or Editorial Materials) | LANGUAGES: (ENGLISH) | PUBLICATION YEARS: (2015-2021)*	2764
Scopus		2693
PubMed		1226
Omni		7145
Web of Science	TITLE: (“ climate change” OR “global warming” OR “climate variability”) AND TITLE: (Gender OR wom*n OR m*n OR girl* OR boy*) AND TOPIC: (health* OR “human health” OR “well-being” OR “mental health” OR “illness” OR “ailment” OR “noncommunicable” OR “communicable” OR infectio* OR pollution OR contamination* OR food* OR nutrition* OR water OR vector OR disease* OR deficiency OR malaria OR dengue OR schistosomiasis OR stunting OR sanitation OR hygiene) *Refined by: DOCUMENT TYPES: (EXCLUDE (Review Articles or Proceedings Papers or Book Chapters or Editorial Materials) | LANGUAGES: (ENGLISH) | PUBLICATION YEARS: (2015-2021)*	328
Scopus		44
PubMed		137
Omni		225
Web of Science	TOPIC: (Chilwa) Refined by: DOCUMENT TYPES: (ARTICLE OR PROCEEDINGS PAPER OR DISCUSSION) Timespan: All years.	88
Scopus		136
PubMed		56
Omni		638

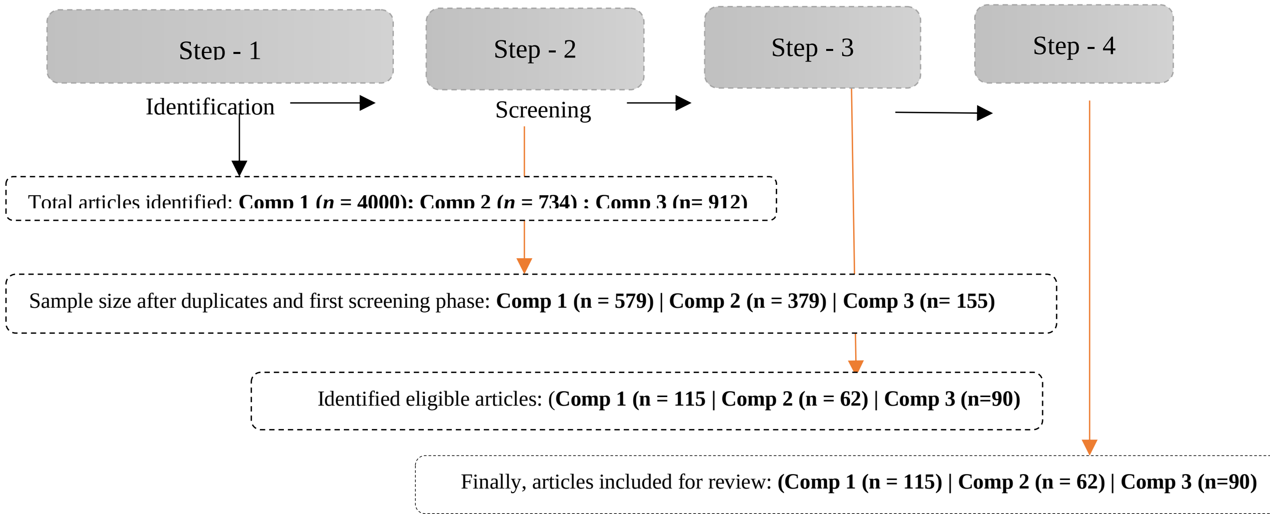
2.2.2. Screening:

A protocol for the inclusion and exclusion criteria was developed for the three components. The common inclusion criteria for the first two components were empirical research (including empirical research based on secondary data) only, written in English, peer-reviewed journal articles, and timeframe (2015 to 2021). Due to the limited number of studies on Chilwa, only the first three criteria (language, peer-reviewed criteria, and empirical study) were applied to Component 3.

Inclusion criteria tailored to each component were:

(i) **Component 1**: studies must include human health impacts specifically driven or exacerbated by climate change and at least one of the four subsystems (food insecurity, communicable & non-communicable diseases, ecological services, and extreme weather), and based in rural Global South.

(ii) **Component 2**: one of the study’s objectives must explicitly be focussed on gender specific health impacts of climate change, and at least one of the four subsystems, and based in the Global South.



(iii) **Component 3:** the location of study must be in the Lake Chilwa basin and objective of the study must be related to at least one of the three: climate change, human health, and gender.

The search resulted in **13,828** hits for *Component 1*, **734** hits for *Component 2* and **912** hits for *Component 3*. To make the sample size manageable, only the **1000** latest a)ase wei *Component 1*. Therefore, **4000** articles for *Component 1*, **734** hits for *Component 2* and **912** hits for *Component 3* were exported to Endnote Online. After eliminating **2819, 155** and **396** duplicates from *Component 1, 2 and 3* respectively, the sample size for screening was **1181** for *Component 1*, **579** for *Component 2* and **516** articles for *Component 3.*

The first stage of screening was done by title, abstract and methods to eliminate review articles, articles lacking the component specific nexus and non-empirical studies. Following the first stage of screening:

(i) Component 1 had a sample size of 1181 articles and 602 articles were excluded.
(ii) Component 2 had a sample size of 579, and 200 articles were excluded.
(iii) Component 3 had a sample size of 516 and 361 articles were excluded.

The second stage of screening was done by the results, discussion, and conclusion sections of the article. Following the second and final stage of screening:

(i) Component 1 had a sample size of 579 articles and 464 articles were excluded based on saturation of information
(ii) Component 2 had a sample size of 379 and 317 articles were excluded
(iii) Component 3 had a sample size of 155 and 65 articles were excluded

2.2.2. Eligibility & Included

Finally, **115**, **62** and **90** studies for Components 1, 2, and 3 were selected for analysis.

2.3. Analysis

Identifying variables and their inter-linkages for the components

Analysis of the papers will be recorded in two separates excel worksheets with sections to collect:

i. Bibliographic and overall article information: authors' name, locations and genders, year of publication, study location, study objectives (any gender specifications), and research methods (empirical/empirical based on secondary data).

ii. Variables (as per subsystem and if gender specific), exposure pathways (if applicable), their health impacts and their inter-linkages (positive or negative if available). For example, in the climate change-health interaction, temperature is a *variable,* farming an occupational exposure pathway and kidney failure, a health-related *impact*. Another example for social systems–health interaction, variable = income; exposure = inadequate food and impact = malnutrition.

A bibliometric analysis was conducted with the bibliographic and overall article information from Component 2 using Microsoft Excel's "Analyze Data" function with the aim to understand the status of academic research in gender and climate change, global participation (disaggregated by global south and north) and gender representation in authorship. The results will be presented using infographics created using Excel's "Chart" function. The results will be used to give recommendations (if any) on improvements to make academic research on this topic fairer.

The variables will be grouped into the four subsystems as stated below, guided by their respective definitions:

(i) **Food security**:

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO,2006).

(ii) **Ecosystem services:**

"Ecosystem services are the benefits people obtain from ecosystems" (MEA, 2005: V).

(iii) **Extreme weather:**

"An extreme (weather or climate) event is generally defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable. Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of weather or climate events that are, individually, not extreme themselves (though their accumulation is extreme). As well, weather or climate events, even if not extreme in a statistical sense, can still lead to extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system, or by occurring simultaneously with other events. A weather system such as a tropical cyclone can have an extreme impact, depending on where and when it approaches landfall, even if the specific cyclone is not extreme relative to other tropical cyclones" (IPCC, 2012: 111).

(iv) **Communicable (CDS) and Non-communicable diseases (NCDs)**:

"Communicable, or infectious diseases, are caused by microorganisms such as bacteria, viruses, parasites and fungi that can be spread, directly or indirectly, from one person to another. Some are transmitted through bites from insects while others are caused by ingesting contaminated food or water" (WHO, n.d.).

"Noncommunicable diseases, also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental, and behavioural factors" (WHO, 2021).

2.4. Application to the Chilwa Basin

90 articles were identified as included to meet the objectives set for Component 3. The analysis was guided by the research question: How will climate change in the Lake Chilwa basin influence each of these subsystems and their interrelationships and what will be their gender specific health impacts?

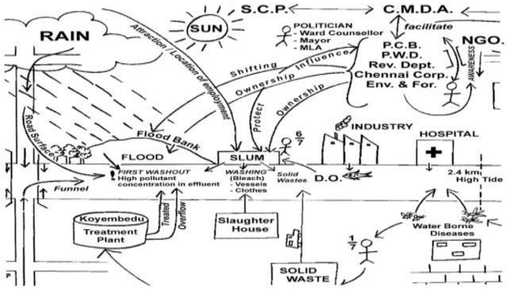
Component 3 would ideally have been the field portion of the project, but this was not feasible due to COVID-19 travel restrictions. As an alternative, using secondary literature identified through a systematic literature review and findings from *Component 1 and 2* to guide and fill gaps, the apparent causal links between stressors and their health impacts for each subsystem were identified. Additionally, each subsystem will be also discussed from the gender perspective to identify the gender specific health impacts.

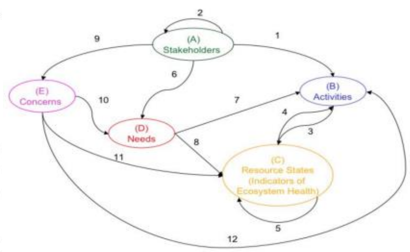
Complex Systems Diagrams

Rich picture–a technique from soft systems methodology is defined as "*a compilation of drawings, pictures, symbols and text representing a particular situation or issue from the viewpoint(s) of the person or people who drew them" (Open Learn, 2014).* They were used to first illustrate the stressors, exposure pathways and their resulting health impacts diagrammatically. They stimulate a holistic process of thinking and portray the key actors (stakeholders), actions, relationships, and the exposure pathways for the targeted health impacts within and across the five subsystems (Bunch, 2003). Guidelines from a free online course by The Open University called "Diagramming for development 1 - Bounding realities" were used to develop the diagrams. The rich picture was drawn by the author using Microsoft PowerPoint. The drawing tool was used to draw the layers of the lake–(i) open lake (ii) swamp and (iii) Typha, as well as the irrigation canals. Next, using Microsoft PowerPoint icons, the distinct elements of the rich picture were placed in their respective positions and "↑" or "↓" were added to denote an increase or decrease in the distinct elements triggered by climate change. Using the "Shapes" function of PowerPoint, connections between the elements were made with precautions taken to not compromise the aesthetics of the rich picture. Any connections that were not shown using arrows in the rich picture have been discussed in the summary section. A detailed situation summary has been provided following the rich picture to give readers a better understanding of the diagram.

An influence diagram specific to the Lake Chilwa basin climate change scenario was developed based on the rich picture. The Influence Diagrams (ID) and rich picture will be used as visual tools to better facilitate inclusion and diversity in future validation stages with local communities from the Chilwa basin. Influence Diagrams (ID) capture the cause-and-effect relationships within variables and help answer the question "Why things change over time?" (Proust & Newell, 2020). They also "map connections among a set of variables, where the interactions are complex and therefore not immediately obvious" (Neudoerffer et al., 2005). The Influence diagrams (ID) were constructed with words and phrases (like water quality, soil erosion, malaria,) representing measurable key variables (indicators) within each sub-system and arrows that represent processes or mechanisms whereby a change in one variable affected the levels of another variable (Proust & Newell, 2020). The focus indicators (F) (which play key roles in the system-of-interest) were first drawn, followed by the driver indicators (D) which affect the level of F, and finally the affected indicators (these are impacted by the levels of F). They were linked by arrows to form the diagrams. Positive and negative feedbacks between the variables and their health impacts will be determined based on one variable's effect on another with positive feedback showing an increase in change or output and negative feedback showing a decrease in change or output. For example: an increase in "average *temperature*" might lead to an increase in *"water temperature"* which will decrease the "*fish population*" and result in the decrease in "protein intake" and increase the risk of "*child stunting*". In this example, "average *temperature*" and "*water temperature*" are positively co-related as an increase in one lead to the increase in the other. On the other hand, "*water temperature*" and "*fish population*" are negatively co-related as a change in one variable leads to the decrease in the other. Some variables might be bi-directional, as with "*income*" and "*HIV/STD*". where lack of "*income*" can increase the chances of "*HIV/STD*" infections through sex-trade and an increase in "HIV/STD" infections can lead to a decrease in "*income*" through high health expenditure and low labour availability. The information on positive and negative feedbacks were added using arrows with "+" and "-" signs to describe possible feedback loops. The software Vensim PLE (free system dynamics software) was used to create the IDs.

Two influence diagrams (IF) will be produced for Chilwa–general and gender-specific scenarios (only the direct interactions) and differences explicitly noted within the diagrams. Please note that, only the gender specific IF will show the positive and negative links. Only the direct interactions are considered for the diagram to ensure visual aesthetics and to highlight the most relevant links from this study's context. The general IF will include all the variables (indirect and direct). A list with the details on the interactions between the variables and their respective health impacts will be provided for reference purposes.





Example of a Rich Picture (Bunch, 2003) **Example of an Influence Diagram (Neudoerffer et al., 2005)**

Summary: In the next chapter the results from the analysis of the data identified through the systematic literature review, will be presented in two sections – (a) Bibliometric Analysis and (b) Variables. Both sections will only present the results from *Component 1 and 2*. *Component 3 – "Application to Chilwa Basin"* will be discussed in a separate chapter.

Chapter 3: Results

3.1. Introduction:

The results section covers the first two components and represents the 115 and 62 articles identified through the systematic literature review for *Component 1 and 2*, respectively. This section is divided into (a) a bibliometric analysis with infographics based on the articles identified for the two components; and (b) a summary of the variables identified per subsystem in a table format.

3.2. Bibliometric Analysis

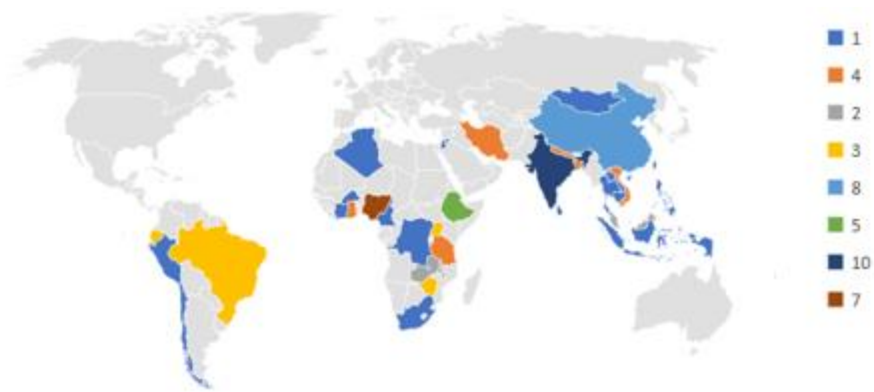


Figure 3: Global Article Distribution by study locations in Component 1

The scope of *Component 1* was limited to the latest empirical studies using primary or secondary data conducted in rural locations in the Global South since 2015. The studies in *Component 1* covered 38 Global South countries, with most of the studies conducted in Africa and Asia, and a few in South America and the Middle east (Fig 3). Out of the 115 studies, 25 studies were based on global data or generalized to the African continent and discussed issues specific to two of the subsystems–communicable diseases and food security.

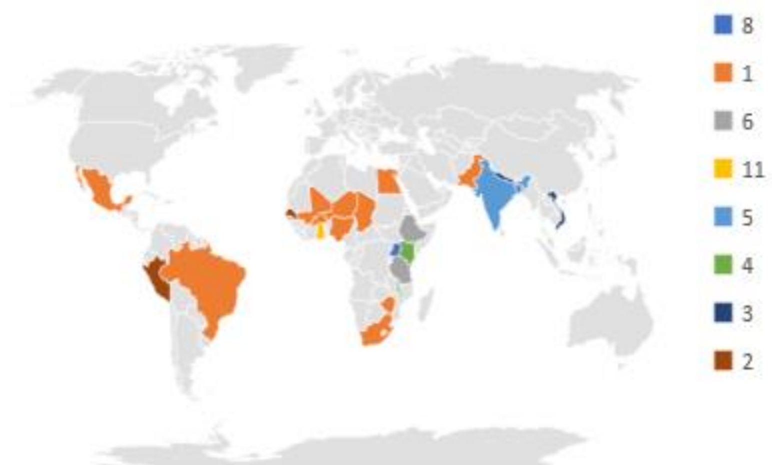
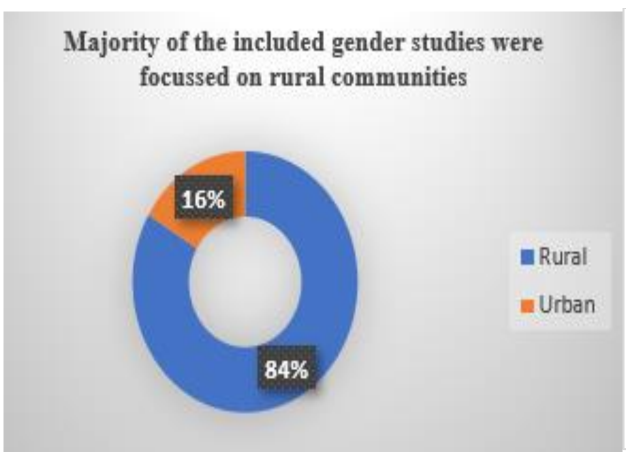


Figure 4: Article Distribution by study location in Component 2

The scope of *Component 2* was slightly larger and included both urban and rural studies based in the Global South. The reason for including urban was to identify and rule out the health issues that may be specific to the urban context at the application stage *(Component 3)*. The studies in *Component 2* covered 25 countries in the Global South, with the majority conducted in Africa (16 out of 25) (Fig 4). From Asia, only four study locations/countries-Bangladesh, India, Nepal, and Pakistan were identified.



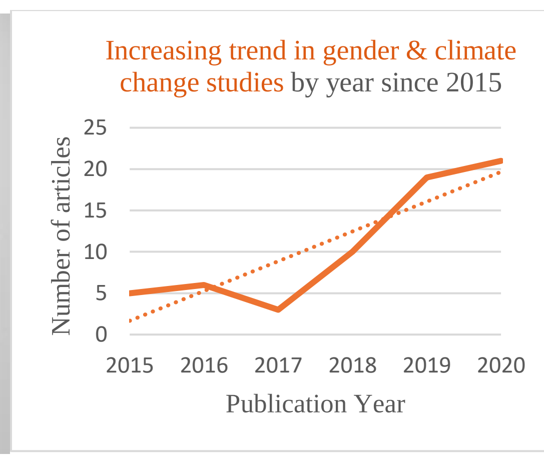
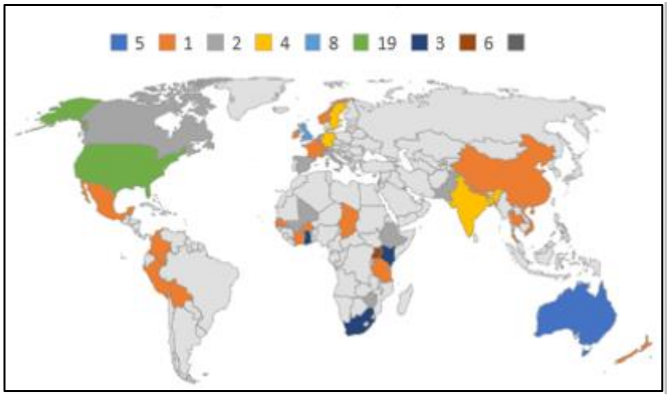


Fig 5: Distribution of study locations in Component 2 (urban vs. rural)

Figure 6: Trend in gender & climate studies since 2015

In terms of urban vs. rural study locations for *Component 2*, most of the gender studies were based in rural locations (Figure 5). An upward trend in studies focussed on gender and climate change was observed since 2015. In terms of authors' locations, the ratio between Global North and Global South in *Component 2* was highly noticeable, with only 27% of the articles with authors from the Global South versus 44% from the Global North. Only 29% of the articles were a product of a collaboration between the two.



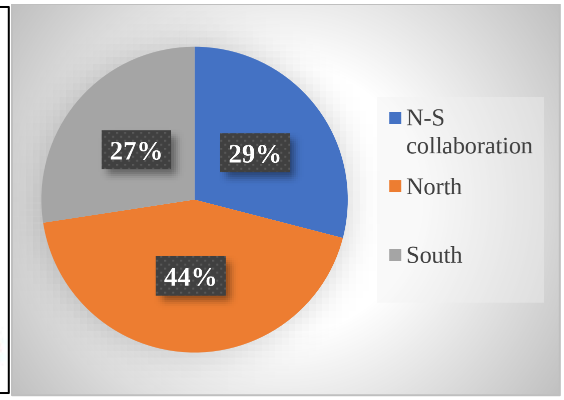


Fig 7: Distribution of articles in Component 2 by author's location.

Fig 8. Comparison between authors from Global South vs. Global North Component 2 by author

In terms of gender diversity in authorship, 53% of the articles were a collaboration between male and female authors. However, when gender diversity was analysed in the geographical context, articles with all female authorship showed a significant difference between Global North and Global South with a much higher participation in the former category than the latter. The difference was much less when the same comparison was done for articles written by all male authors (Figure 9).

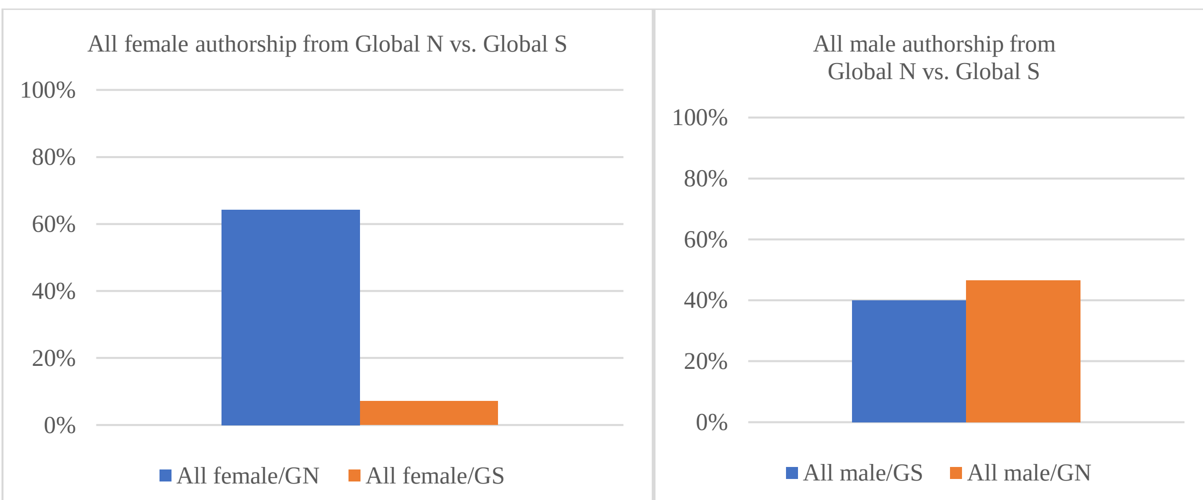


Figure 9: Comparison between all female and all male authorship from Global South and the North

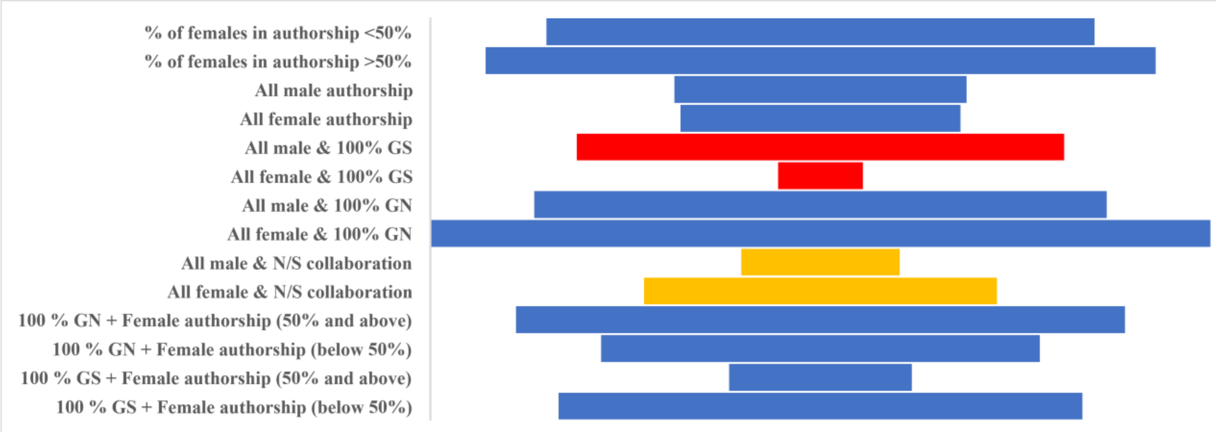


Figure 10: Distribution of female vs. male authors

3.3: Variables

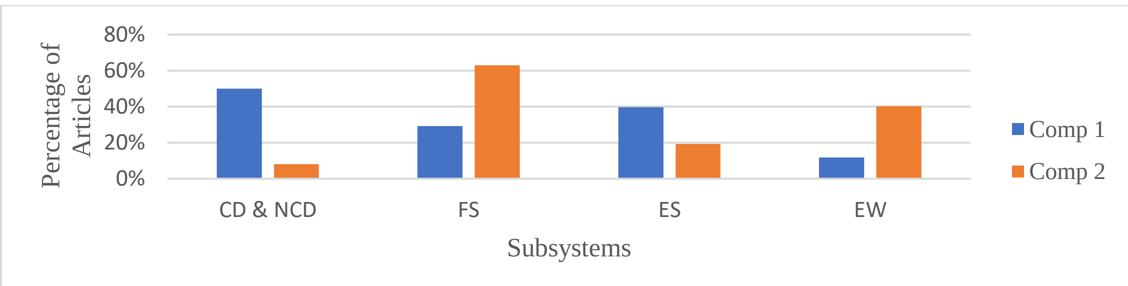


Figure 11: Number of articles per subsystem in Component 1 & 2

In terms of article distribution per subsystem, while the highest number of articles in *Component 1* were focussed on communicable and non-communicable diseases, food security was the dominant topic of interest in *Component 2*. Figure 10 shows a comparison between the two components for all articles per subsystem. The variables for the two components are listed in two separate tables. 112 and 52 variables were identified for *Component 1 and 2*, respectively. In terms of comparison between types of variables, socio-economic variables were found to play a more dominant role than environmental in *Component 2*. As per our findings, in the climate change context, gender has been extensively studied in relation to food security and least in relation to communicable and non-communicable diseases. It is important to note that although females are more vulnerable to climate change because of their low access to resources and poor decision-making power, in certain situations, men have shown higher vulnerability to climate change than women, and therefore generalization of women to be the highest at-risk category in all climate change related situations should be consciously avoided. For both components, the highest number of variables was found in the food security subsystem, illustrating high complexity and academic interest in this global issue.

Table 3: Variables for Component 1 & 2

	Variables	Gender specific	FS	ES	EW	CD &N CD	Exposure	Health impacts
1	Access to health services	Yes	X		X	X	Delayed or inadequate medical attention (*also affects labour efficiency, increases susceptibility and severity of diseases)*	Malnutrition, infectious Diseases
2	Frequency of aflatoxin contamination		X				Inadequate food intake *(due to contamination and loss of income)*	Malnutrition
3	Age	Yes				X	Recreational activities, occupation (outdoors)	Malaria, schistosomiasis
			X				Inadequate food intake *(older people are physically less productive = low income = low purchasing power)*	Malnutrition
					X		Not able to evacuate during disasters,	General health, mortality
4	Arable land supply		X				Lower food intake (due to lower crop yield)	Malnutrition
5	Access to extensional services	Yes	X				Inadequate food intake and lack of healthcare	Malnutrition, general health
6	Access to wild-harvested food plants (WFPs) and medicinal plants	Yes	X	X		X	Food intake, dietary diversity, lack of cure	Malnutrition, general health
7	Access to irrigation facilities	Yes	X	X			Inadequate food intake and lack of healthcare	Malnutrition, general health
8	Altitude		X			X	Exposure to vectors, lack of food (due to low crop yield, soil fertility)	Malaria, dengue, schistosomiasis, malnutrition
9	Bromide concentration in drinking water			X			Increased bromine consumption through food and water	Cancer, reproductive illness
10	Caste	Yes	X				Lack of access to agricultural inputs and water resources	Malnutrition, mental anxiety,
11	Crop yield		X				Lower food intake (will affect income and food availability)	Malnutrition
12	Crop quality		X				Lower food intake (will affect income)	Malnutrition
13	Crop value		X				Lower food intake (will affect income)	Malnutrition
14	Culture	Yes		X			Increased salt intake (eating salts as condiments despite high salt content in food and water)	Hypertension
15	Climate change awareness	Yes	X		X	X	Food intake *(through adaptive capacity and recovery rates)*, lack of prevention (due to lack of awareness), lack of precautionary measures/ prioritization of pregnant women during floods	Malnutrition, hypertension, malaria, dengue, mortality
16	Crop pest attacks and livestock diseases		X				Inadequate food intake *(affected through income and food availability)*	Malnutrition
17	Decision-making power	Yes	X				Inadequate food intake (mainly due to lack of income & access to resources), workload	Malnutrition, poor mental health, fatigue
18	*de jure/ de facto*	Yes	X				Inadequate food intake (mainly due to lack of income & access to resources)	Malnutrition
19	Dietary Diversity	Yes	X				Inadequate vitamins and protein low diet	Malnutrition
20	Daily hours of sunshine		X			X	Food intake *(affects crop yield)*, increased transmission rates, occupational exposure	Malnutrition, dengue, heat related stress
21	Disability	Yes	X		X	X	Inadequate food intake and lack of healthcare (due to low income caused by lack of labour) Disability also limits movement and ability to escape climate disasters	Malnutrition, poor health (general), infectious diseases, mortality
22	Disease carrier density					X	Rodent urine *(more rodents = more rodent urine)*	Plague
23	Distance to water source and fuelwood	Yes	X	X			Time poverty, increased physical labour, inadequate nutrition *(due to income caused by time poverty)*	Fatigue, mental health, malnutrition,
24	Drought-flood abrupt alternation (DFAA)		X	X			Intake of contaminated water *(DFAA increases soil erosion = contaminants in water)*	Potable water, water-borne diseases, malnutrition
25	Disease Transmission intensity (human transmission index)					X		Communicable diseases (general), schistosomiasis, malaria, dengue, plague
26	Education	Yes	X		X	X	Inadequate food intake *(affects livelihood diversification, low purchasing power; number of dependants (more money, more kids = higher consumption risk)*	Malnutrition, communicable diseases

					X	X	Lack of preventative measures *(due to lack of awareness)*	Malaria, dengue
27	Ethnicity	Yes	X	X	X		Inadequate food (due to low income, low access to resources, language barriers not understanding weather forecasts, poor access to potable water)	Malnutrition, mental stress and anxiety, general poor health
28	Evapotranspiration rates		X	X			Lower food intake (lower crop yield), lower water availability (through lower groundwater recharge rates and surface water availability)	Malnutrition, dehydration, WASH-related health issues
29	Food price		X		X		Lower food intake *(lower affordability)* and performance anxiety	Malnutrition, mental health
30	Farming style (subsistence or agroecology)		X				Lower food intake (due to lower crop yield)	Malnutrition
31	Frequency of disasters		X			X	Inadequate food intake *(crop damage)*, exposure to vectors *(through increase/ decrease in vector mortality caused by increase/decrease in breeding habitats)*	Malnutrition, dengue, malaria
32	Flood intensity & frequency					X	More exposure to mosquitoes *(increased breeding habitats caused by an inundation of upstream areas)*	Malaria, Dengue, other vector-borne diseases
33	Fishing productivity		X				Food intake *(fish for consumption and for selling)*	Malnutrition
34	First union & child-bearing age	Yes	X			X	Early pregnancies *(girls are married off early to lessen financial burdens)* Low literacy levels = low income	Fistulas, still births
35	Gender		X		X	X	Inadequate food, low dietary diversity, low protein intake, performance anxiety (not able to provide for household members), increased workload	Mental health., malnutrition, fatigue
				X	X		Poor WASH facilities *(due to lack of clean water and bathroom facilities)*	Urinogenital disease
					X		During evacuations on boats, on the way to see doctors, not evacuating due to gender roles, not able to swim. Stress for lack of livelihood)	Mortality (pregnant women), mental anxiety,
						X	Domestic chores, farming, taking part in transactional sex	Malaria, schistosomiasis, HIV
36	Geographical location		X	X	X	X	Inadequate food intake (due to low agricultural productivity)	Malnutrition
37	Growing season		X				Food intake (through crop yield)	Malnutrition
38	Groundwater recharge rate			X			Lack of water for sanitation and drinking	Dehydration, WASH-related health issues
39	Government support (through policies)	Yes	X	X			Inadequate food and healthcare (caused by lack of income as women are not involved in the decision-making process like agroforestry management).	Malnutrition, poor health (general)
40	Household type (male or female)	Yes	X				Inadequate food and healthcare *(female households have lower income and access to resources)*	Malnutrition, poor health (general)
41	Frequency of household and communal conflicts	Yes	X	X			Inadequate food intake, poor access to potable water *(diminished labour efficiency due to domestic violence, conjugal fights due to food insecurity can lead to mental illness and anxiety in men, higher competition due to lower sense of community, intra-household conflicts over water can further diminish women's rights in water management as they are portrayed as incapable to hold diplomatic relations*	Malnutrition, mental health
42	Health expenditure		X	X	X	X	Low food intake, performance anxiety (due to lowered affordability/higher expenses, fear of not able to provide for household, expenses might go up post disaster)	General health, malnutrition, anxiety
43	Healthcare capacity to deal with infectious diseases					X	Lack of treatment	General increase & severity in infectious diseases
44	Human footprint (or human disturbance)					X	Exposure to vector	Schistosomiasis
45	Households with physical assets loss		X		X	X	Scale of damage, time for recovery, resources for recovery, labour availability & efficiency, health expenditure	Malnutrition, general physical and mental health
46	Households with injury or death		X		X			
47	Income	Yes	X	X	X	X	Inadequate food intake, lack of dietary diversity, poor protein intake, financial inability to access potable water and healthcare services, inadequate preventative measures due to low buying power (mosquito nets), low recovery rate post disaster	Malnutrition, malaria, dehydration, WASH related health impacts
48	Livelihood diversification/ share	Yes	X	X	X	X	Inadequate food intake, financial inability to purchase or transport water, lack of monetary	Malnutrition, mental health, dehydration,

	of agricultural income in total household income						resources for quick recovery post disaster, inability to pay for healthcare services	WASH related health impacts
50	Labour availability	Yes	X		X		Lower food intake *(due to lower purchasing power/income/poor crop yields, adaptive capacity)*	Malnutrition
51	Land ownership	Yes	X		X		Lower food intake *(due to lower purchasing power/income/poor crop yields, adaptive capacity)*	Malnutrition
52	Level of household sanitation & hygiene					X	More exposure to mosquitoes *(increased breeding habitats due to garbage, stagnant water = increase in vector population)*	Dengue, malaria
53	Length of exposure to heat					X	Occupational risk	Kidney disease, dehydration, pregnancy complications
54	Lag time					X	Mosquito bites *(vector density increases following a lag period after floods)*	Malaria
55	Mobility	Yes	X		X	X	Inadequate food intake (due to lack of access to extensional services, training, climate smart agricultural technology); exposure to infectious diseases, inability to relocate during climate disasters	Malnutrition, poor health (general), mortality, infectious diseases
56	Media exposure	Yes				X	Watching news on disasters	Mental anxiety
57	Number of dependants (including elderly persons)	Yes	X		X		Inadequate food intake *(a greater number of dependants = less labour availability; higher financial burden); performance anxiety; increased female workload)*	Malnutrition, mental health, fatigue
58	Number of meals per day	Yes	X				Inadequate food intake	Malnutrition, loss of immunity
59	NGO support	Yes	X				Inadequate food and healthcare due to unaffordability	Malnutrition, poor health (general)
60	Occupation		X	X		X	Inadequate food intake; prolonged heat exposure, fear of crop damage	Malnutrition, kidney diseases, mental health
61	Outmigration	Yes	X		X	X	Labour availability, workload, prevalence of transactional sex, income, sense of security and safety, face extreme weather alone	Fatigue, mental anxiety, mortality, infectious diseases
62	Purpose for farming (self consumption/income generation)	Yes	X				Lack of healthcare due to unaffordability	Poor health (general)
63	Primary or secondary employment activity (High or low value chain)	Yes	X				Lack of food and healthcare	Malnutrition, poor health (due to unaffordability)
64	Precipitation (intensity & Volume)		X	X		X	Water quality and quantity, exposure to disease vectors (through breeding habitats for vectors, dilution capacity/ concentration of fecal coliforms in surface water)	Dehydration, diarrhoea, cholera, tick-borne diseases, trypanosomiasis, and epidemics of infectious diseases such as anthrax and blackleg, dengue, meningitis, yellow fever, malaria, schistosomiasis,
65	Pre-existing medical conditions	Yes				X	Inhaling polluted air, occupation *(pregnant female farm workers are more susceptible to heat related stress)*	Lung diseases, heat related stress
66	Protein intake (quantity)		X				Inadequate food intake *(due to low crop yield)*	Child stunting, low immunity
67	Proximity to river				X		More exposure to vectors *(vector population closer to river due to more breeding habitats)*	Malaria, schistosomiasis
68	Proximity to forests		X			X	Inadequate food intake (wild animals raid farms), high risk of zoonotic diseases if domestic animals come into contact with wild animals	Malnutrition, zoonotic diseases
69	Proximity to healthcare services					X	Lack of cure (too far from residence)	Poor health (general)
70	Relative Humidity		X			X	Food intake (through crop yield), exposure to vectors (affects mortality rates)	Malnutrition, dengue & malaria
71	Religion	Yes	X		X	X	Inadequate food intake (due to unaffordability), inability to relocate during climate disasters,	
72	Relative number of aerosols in air					X	Respiration	Meningitis
73	Rodent behaviour					X	Exposure to rodents *(rodent population will vary as per their preferred habitat)*	Plague

74	Reliance on rain for irrigation		X				Lack of food intake *(due to reduced crop yield)*	Malnutrition
75	Reliance on surface water	Yes		X			Water shortages and consumption of contaminated water	Water-borne diseases, dehydration, WASH-related health issues
76	Reliance on store-bought goods	Yes	X				Anxiety from low food quality	Poor mental health
77	Reliance on traditional sources of livelihood i.e., natural resources	Yes	X				Lack of nutritious food	Malnutrition
78	Sanitation facilities	Yes		X	X	X	Drinking contaminated water (caused by open defecation); Reduced feeling of safety & security while using bathroom facilities; adequate sanitation & hygiene OR with contaminated water P	Cholera, diarrhoea, mental health, HIV/STD, physical trauma, urinogenital health
79	Size of land	Yes	X		X		Lower food intake *(crop yield, income, recovery rate)*	Malnutrition
80	Social & traditional norms	Yes	X	X	X	X	Lower food intake (due to lack of income or reduced crop yield), mental	
81	Social network	Yes	X		X		Inadequate food intake (through access to knowledge, agricultural inputs, and extensional services)	Malnutrition
82	Soil erosion rate		X	X		X	Food intake (crop yield), contaminated water intake (sediments, ions, feal coliforms, *Vibrio Cholerae)*	Malnutrition, drinking water shortages, water-borne diseases
83	Soil fertility		X				*Food intake (through crop yield)*	Malnutrition
84	Stream flow rate			X		X	Intake of contaminated drinking water or by chance while doing domestic chores	Water-borne diseases
85	Salinity in ground water			X			Increased salt intake through food and water	Hypertension
86	Sediment load			X			Drinking water, accidental consumption through daily activities	Water-borne diseases, poor drinking water quality
87	Source of water (surface or groundwater)	Yes		X		X	Drinking water *(groundwater less contaminated than surface water; surface water easier to source than groundwater, which might impact water availability)*	Cholera, diarrhoea, kidney disease (caused by dehydration)
88	Seasonal or permanent source for water	Yes		X			Inadequate potable water for drinking and sanitation (*in seasonal water sources like Lake Chilwa)*	Dehydration, WASH related health issues
89	Soil pH		X			X	Exposure to vector, availability of food (some crops might be affected)	Schistosomiasis, Malnutrition
90	Temperature		X	X	X	X	Lower food intake (lower crop yield, more diseases, and pests), quality & quantity of water (higher contamination due to more evaporation of water/less dilution capacity), prolonged exposure to heat, vector and parasite survival, replication, biting frequency, extrinsic incubation period, mortality rates,	Malnutrition, malaria, cardiovascular disease mortality, diarrhoea, cholera, yellow fever, chagas disease, low b birthweight, trypanosomiasis, schistosomiasis, heat-related stress, zoonotic cutaneous leishmaniasis (ZCL)
91	Transactional sex (participation)	Yes				X	Sexual activities	HIV
92	Type of crops/	Yes	X				Lower food intake (will affect income and recovery rates)	Malnutrition
93	Type and quality of protein	Yes	X				Inadequate protein intake *(due to low income and lack of fish)*	Child stunting, low immunity
94	Type of activity money spent on (self care vs. household care)	Yes				X	Lack of self care	Poor physical and mental health
95	Topography	Yes	X				Collecting water (difficult terrain can increase time and physical labour to collect water)	Fatigue
96	Upstream or downstream location of farm or household	Yes	X	X		X	Food intake *(crop yield will be affected by availability of irrigation water);* potable water *(groundwater may be less contaminated in upstream than downstream);* exposure to vectors *(upstream low vector population than downstream)*	Malnutrition, potable water related health issues, vector-borne diseases
97	Water sensitivity of crops		X				Food intake (through crop yield)	Malnutrition
98	Water temperature		X	X		X	Inadequate food intake *(affects fish supply),* consumption of contaminated water (more cholera germs and reduced water quality), mosquito bites *(increased water temperature provides ideal for breeding)*	Undernutrition, child stunting, cholera, malaria

99	Water source ownership (Public ownership vs. shared)	Yes		X			Lack of potable water *(or difficulty in accessing water)*	Dehydration, WASH related facilities
100	Water treatment facilities					X	Consuming contaminated water *(if facilities are unavailable or inefficient)*	Water-borne diseases
101	Water quality	Yes					Drinking water, washing clothes, bathing, recreational purpose	Cholera, diarrhoea
102	Water availability	Yes		X		X	Inadequate potable water for drinking and sanitation	Dehydration, WASH related health issues, urinogenital infections, mental anxiety
103	Workload	Yes	X	X	X	X	Increased physical labour	Fatigue, mental anxiety,
104	Work experience	Yes	X				Inadequate food intake due to low affordability	Malnutrition and poor health (general)
105	Parasite prevalence					X	Increase or decrease exposure to vector carrying disease *(affects transmission rates)*	Vector-borne diseases (malaria, dengue)
106	Parasite intensity					X		Vector-borne diseases (malaria, dengue)
107	Mosquito biting frequency					X		Vector-borne diseases (malaria, dengue)
108	Vector breeding sites					X		Vector-borne diseases (malaria, dengue)
109	Vectorial capacity					X		Vector-borne diseases (malaria, dengue)
110	Vector density					X		Vector-borne diseases (malaria, dengue)
111	Parasite Extrinsic incubation periods (EIP)					X		Vector-borne diseases (malaria, dengue)
112	Mortality rate of vectors					X		Vector-borne diseases (malaria, dengue)

3.4. Summary

: In the next chapter, the variables and their interactions are elaborated on, including their gender-specific roles.

Chapter 4: Discussion

Component 1& 2: Climate Change & Health and Gender, climate change and health

4.1. Introduction

112 variables were identified for the climate change and health nexus which included "73" for food security, "60" for communicable and non-communicable diseases, "33" for "ecological services", and "30" for "extreme weather". 53 variables were identified to be gender specific. In this chapter, the identified variables, their causal mechanisms, and associated health impacts per subsystem for *Components 1* & 2 are to be discussed.

4.2. Subsystems

4.2.1 Food security

"Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"- FAO, 1996 World Food Summit (FAO, 2006). Based on this definition, the FAO identifies four dimensions of food security–food availability, food accessibility, food utilization and food systems stability (definitions below):

Food *availability*	**Food *accessibility***	**Food *utilisation***	**Food *systems stability***
"Physical **AVAILABILITY** of food: Food availability addresses the supply side of food security and is determined by the level of food production, stock levels and net trade".	"Economic and physical **ACCESS** to food: An adequate supply of food at the national or international level does not in itself guarantee household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets and prices in achieving food security objectives."	"Food **UTILIZATION**: Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals".	**"STABILITY** of the other three dimensions over time Even if your food intake is adequate today, you are still considered to be food insecure if you have inadequate access to food on a periodic basis, risking a deterioration of your nutritional status. Adverse weather conditions, political instability, or economic factors (unemployment, rising food prices) may have an impact on your food security status" (FAO, 2008).

Table 1: Source: FAO, 2008, http://www.fao.org/3/al936e/al936e.pdf

Any uncertainties to one or more of the four dimensions can make a food system vulnerable (Poudel, 2017). As per the IPCC and the FAO, climate change will impact all the above four dimensions of food security (IPCC, 2007; FAO, 2008) with direct and indirect impacts on human physical and mental health at local, regional, national, and global levels. Furthermore, the type of food security–acute (long-term like famine) or transitory (short-term and temporary) will depend on the type, severity, and duration of the climate related drivers. For example, consecutive years of droughts or lack of rainfall may lead to a famine, but crop damage from wildfires, floods or landslides can lead to short-term food insecurity (FAO, 2008).

Although climate change is mainly associated with detrimental impacts on food security, some studies show that it may positively impact food productivity in some regions of the world. For example, some regions of Canada might experience an extended growing season and outdoor feeding season for livestock (Schnitter & Berry, 2019). However, from a global perspective, especially in low and middle-income countries, climate induced undernutrition significantly outweighs any local positive impacts it may have (FAO, 2017; Fanzo et al., 2018). The ultimate effect of climate change will vary from crop to crop and depend on each crop's optimal range of environmental conditions with fluctuations leading to detrimental impacts on productivity (Amin et al., 2015). For example, while optimum temperatures can enhance photosynthesis and increase crop yield, both high and low temperatures can damage crops by destabilizing their metabolic processes and structure, and by inflicting chilling injuries respectively. Similarly, while optimum levels of precipitation are vital for crops to absorb nutrients from soil, extreme or lack of rainfall can cause crop damage through soil erosion, root-rot, poor soil moisture content, wind erosion and so on and so forth. Fluctuations in other climate variables like relative humidity and daily sunshine can also impact crop growth and flowering by throwing certain processes like photosynthesis, leaf growth, nutrient absorption, pollination, and defense mechanisms out of balance (Amin et al., 2015).

The two main climatic variables influencing food security are average temperature and average precipitation, both projected to be moving in an upward trend since the 1880s and 1950s respectively, with the latter being highly erratic (NOAA, 2021; IPCC, 2021). While the role of climate change in regulating the first dimension of food security- "food availability" is obvious, it can also significantly influence the other three dimensions by interacting with multiple interrelated environmental, social, and economic variables. Projected increases in temperature, changes in rainfall patterns, and natural hazards like droughts and floods can disrupt agricultural productivity resulting in affecting millions globally, but the impacts faced by the rural small-holder farming communities in the tropics and sub-tropics are disproportionately higher due to their high dependency on rain-fed agriculture (Armah et al., 2019; Olayide & Alabi, 2018).

Although temperature and rainfall are the primary variables regulating crop yields, they do so by influencing other environmental variables and processes such as soil fertility, soil erosion, evapotranspiration and crop water requirement (CWR) (also called crop water demand or CWD), quality and quantity of irrigation water, (G.S. et al., 2019, Malkia, 2018), irrigation efficiency, access to irrigation, shade, crop pests and diseases (Goodarzi et al. 2019), and several socio-economic factors (income, education, livelihood diversification, gender, labour availability). For example, lack of rainfall can alter microclimate through diminished tree cover, reducing shade required by some crops and therefore diminishing their growth (Labbe et al., 2016). Rising temperature and extreme drought events can lower soil moisture content which can alter several soil functions and structure such as microbial respiration, cycling of nutrients like nitrogen and carbon, soil porosity (through compaction, hardening, sealing, and slaking), biotic population and rate of decomposition of organic matters which when combined can influence soil health and crop yield (Talukder et al., 2021).

Evapotranspiration (ETo) rates are highly regulated by temperature and, as the planet warms up, crop evapotranspiration rates also increase with it. Crop water availability (also measured by crop evapotranspiration) and increased temperature during the crop flowering stage can significantly influence crop yield, as vegetative growth is directly proportional to water evaporation rates (Bekele et al., 2019; G. S et al., 2019). Increased ETo rates coupled with decreased rainfall in countries like Ethiopia and Algeria (semi-arid) will increase crop water demands, forcing farms to become increasingly reliant on supplementary irrigation facilities (Bekele et al., 2019; Malkia and Etsouri, 2018). With the increased reliance on surface and groundwater for supplementary irrigation, water quality from such sources (which may as well be threatened by climate change due to increased total dissolved solids, run-off nutrients from other farms, fecal matter, etc.) could also potentially influence crop yield and crop contamination. Crop water demands also vary according to the type of crops and their specific water sensitivity. For example, lack of water impact water-intensive crops like paddy more than those with moderate water requirements such as wheat and berseem. At the same time, excessive rain can impact the latter more than the former (G.S. et al., 2019). Outcomes of climatic pressures can also vary within subspecies of the same crop grown under similar soil conditions. For example, a study in Bangladesh on four subspecies of rice reported very different outcomes in crop yields ranging from positive to negative when grown under the same minimum and maximum temperature, rainfall, relative humidity, and daily sunshine (Amin et al., 2015). Another study in the Karnali region of Nepal showed a shift in productivity by type of crop (decline in brown rice, wheat and barley crop yield and a rise in potato and local beans) with the changing temperature and rainfall trends in the region for the last 10 years (Thapa & Hussain, 2021).

Certain geographical locations like hilly areas and coastal regions are more vulnerable to climate induced declines in crop yield due to their existing disadvantages which is a consequence of several interacting environmental and socio-economic factors such as type of farming (subsistence) practiced, poor infrastructure and transport facilities, lack of market access (Thapa & Hussain, 2021; Shah & Dulal, 2015) high exposure to climate hazards, and poor labour availability. For example, a Nepalese study reported food poverty in mountainous regions to be 30% higher than in the plains (Hussain et al., 2016). Mountainous areas in Pakistan also reported to be as high as 60% food insecure (Suleri & Haq, 2009). Coastal regions like Trinidad and Tobago and Bangladesh face additional threats from sea level rise and saltwater intrusion, resulting in loss of cropping area (Shah & Dulal, 2015) and lack of water to irrigate crops. Both hilly and coastal regions are highly vulnerable to crop damage from natural disasters like cyclones and landslides, which are projected to increase in frequency and intensity as a result of climate change (Poudel, 2017).

Simulations from an agent-based modeling study suggested farming style to have a strong influence on future nutrition in the climate change scenario with peasant-oriented agroecology (sustainable mode of farming using and enhancing on-farm ecological processes with no external inputs or hired labour) showing higher production, lower or equal food prices and overall better rural health as compared to entrepreneurial (external inputs and market led) styles of farming (Lloyd et al., 2021). As a result of lower crop yields, agro-based households suffer from low and interrupted flow in household income and migrate away in search of supplementary income sources which may positively impact food affordability due to remittances but may negatively impact crop yield through reduced labour force. Climate induced impacts may also vary within the same geographical region. In the mountainous regions of Nepal and Pakistan, climate induced decline in winter snowfall has led to a shift in crop yield with local conditions becoming more suitable for early cultivation of potato and beans resulting in higher production of such crops whereas crop production in the valleys suffer from low productivity due to the lack of water availability (Thapa & Hussain, 2021).

Climate change induced fluctuations in the timing and length of seasons can also impact crop yield and crop quality as a result of altered sowing and harvesting seasons which may influence crops' growing period, vulnerability to diseases during harvesting and storage, labour shortages, and unpredictable downpours or droughts (Warnatzsch, 2020; Poudel, 2017; Shah and Dulal, 2015). The impacts of climate change in the agricultural sector could also trickle down to other sectors, such as livestock, which rely heavily on agricultural produce for fodder (Rojas-downing et al., 2017). For example, farmers growing two crops, one only for generating cash like berseem (livestock fodder) and another for household consumption and income like paddy can be potentially at a higher risk if unfavourable climatic conditions induced delayed sowing of one crop causes a delay in the sowing of the second crop resulting in overall poor crop yield. In this case, the farmer is not only food insecure due to reduced rice (paddy) availability but also lacks the monetary resources to buy food from other sources like stores or other farmers (G.S. et al., 2019). Additionally, the lack of fodder exposes the livestock owner to potential livelihood insecurity (due to lack of feed for his animals) and food insecurity (due to loss of income as well (G.S. et al., 2019).

Rising global temperatures and changes in precipitation are increasing the frequency and intensity of crops and livestock pests and diseases. For example, Hussain et al. found an increase in livestock diseases in hilly regions caused by the increasing warming trends in the region (Hussain et al., 2016). Rise in crop diseases like Aflatoxins caused by highly thermotolerant fungi that have better chances of survival in future high temperature scenarios has also seen a rise in occurrence (Paterson & Lima, 2017). Aflatoxins, a type of mycotoxin produced by certain kinds of fungi (mould) occur naturally in many parts of the world, infecting crops like maize, cottonseed, peanuts, and coffee. Aflatoxins are known carcinogens and can cause liver cancer, growth suppression, immune system modulation, and malnutrition in both humans and livestock (Payne and Brown, 1998, Rushing and Selim, 2019). Contamination can take place both pre and post harvest and is highly influenced by temperature and relative humidity in their immediate environment (WHO, 2018). Subtropical countries like Malawi are at a high risk of pre-harvest AFB1 contamination due to future climate changes with increasing temperatures and erratic rainfall patterns. These conditions will not only impact toxin concentration but also expand its geographic distribution. For example, in Malawi, there is a clear trend in the geographical expansion of AFB1 contamination (produced by *Aspergillus flavus*) from the warmer southern parts of Malawi to the cooler central and northern parts of the country which has been associated to the shortening of growing season and rise in favourable conditions for contamination during the pre-harvest period (Warnatzsch et al., 2020; WHO, 2018). Post harvest contamination mainly occurs if storage conditions are hot and humid, providing the ideal conditions for *A. flavus* to grow and metabolize toxins (WHO, 2018; Warnatzsch, 2020). Increase in crop and livestock diseases was also observed by respondents of a study in Nepal and attributed to the warming trends in the hilly regions.

Rising temperatures may also influence cropping area, rendering some farms located at lower elevations unsuitable for certain crops. Seeking cooler conditions, some small holder farmers may be forced to migrate to higher elevations. However, such adaptation strategies have their limitations, as the physical and chemical properties of soil from the highlands may not be suitable for crops from the lowlands, resulting in significant declines in crop yields (Tito et al., 2018). This mitigation strategy will also not be affective for those crops like potatoes which are already cultivated on hill tops. Farmers who are unable or unwilling to try any mitigation strategies may also have to face crop damage from increased foraging activities of some novel enemies, like birds, deer, and aphids, in warmer climate scenarios (Tito et al., 2018). Type of climate hazard can also impact food availability and can vary even within a country. For example, while northern parts of Nigeria suffer from increasing droughts, the southern parts of the country are threatened by soil erosion and flooding (Onafeso et al., 2015).

Socio-economic variables such as income, education, gender, and others can significantly influence food availability and accessibility at an individual and household level. In the climate change context, inequities and differences caused by such socio-economic factors can be further magnified in the absence of sufficient food supply, making certain groups like women or the elderly more vulnerable to climate change impacts than others. Adaptive capacity, (defined as "the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change" (IPCC, 2001) can therefore be an important measure of the household's or individual's vulnerability to food insecurity.

At the individual and household levels, social and economic variables often interact with environmental variables to influence their adaptive capacity for climate change. A typical example at the household level would be the interaction between plot size and soil fertility. Farmers with smaller plot size tend to over cultivate in order to maximize crop yield, rendering the soil infertile and less productive. As a result of lower crop yield, the household not only suffers from food unavailability but also lacks the surplus to sell for income (Armah, 2019). This affects the household's adaptive capacity through (i) lack of resources for health expenditure (2) lack of surplus food to store for the dry season (3) lack of monetary resources to invest in climate smart agricultural technology (4) lack of resources to hire labour (5) lack of resources to buy water for irrigation or maintain/own borewells during dry season and (6) lack of resources to purchase radios/mobiles to receive weather forecasts.

At an individual level, gender and type of crops can influence adaptive capacity to climate change. For example, female farmers tend to grow subsistence crops for household consumption only as opposed to cash crops which are mainly grown by their male counterparts. This can influence their adaptive capacity both positively and negatively. From the negative aspect, women will be less adaptive owing to their lower incomes caused by not selling or having any surplus to sell for cash, limiting their capacity to invest in climate smart agricultural technology. On the other hand, because women focus on household subsistence and not on income or profits driven by their role as the main food provider of the household, they tend to plan and store food supplies for the "rainy days" which increases their adaptive capacity during droughts and dry season as opposed to men who sell their produce to make immediate income with a high tendency to spend on themselves. At the household level the main social and economic factors at play are income, education level of household head, gender of household head, number of dependants, livelihood diversification, labour availability, plot size, land ownership, access to extensional services and climate smart technology, climate perception and awareness and willingness to adopt climate adaptations in agriculture (Armah, 2019; Onafeso et al., 2015; Lentisco & Lee, 2015; Mbuli et al., 2021).

Land ownership, plot size, quality of land, available labour, access to agricultural inputs like fertilizers and climate resistant seeds, agricultural extension services, climate-smart technology and knowledge all play a role in determining crop yield and the ability to maximize surplus for sale. Income affects the purchasing ability of agricultural inputs like fertilizer, drought resistant seeds, water for irrigation and external labour;

and increases the households' ability to own mobiles and televisions, which enable access to climate knowledge and weather forecasts.

Access to climate news positively influences climate change perception, awareness, and willingness to adopt climate smart agricultural strategies. Access to weather forecasts also enables farmers to take preventative measures against climate hazards.

Livelihood diversification positively affects income with households involved in diverse livelihood strategies such as livestock and agriculture or off-farm activities. Such households also have better chances of recovery from climate induced shocks than those that solely depend on a single livelihood source derived from a climate-sensitive sector like agriculture (Shah & Dulal, 2015). A study from South Africa showed better climate resiliency when households engaged in two or more climate-sensitive livelihood sources, like crop-livestock diversification, than relying on one specialized crop (Tibesigwa et al., 2015).

Lack of income can also affect farming labour as those with lower incomes may not be able to afford healthcare, which may affect their health and lead to low productivity (Li et al., 2021).

Type of crops–crops for consumption like maize and paddy versus cash crops like coffee and groundnut also play a role in determining household income levels (Chemura et al., 2020).

Plot size can impact food availability by regulating the size of yield available for consumption and surplus for sale. Larger plot sizes allow farmers to grow large quantities of crop for consumption and sell the surplus for income, whereas smaller plot sizes not only suffer from inadequate crop yield to cover household consumption and sale but also face the risk of reduced soil fertility due to overcultivation. In the climate change context, larger plot size increases the farmers' success and rate of recovery after climate shock (Labbe et al., 2016).

Land ownership is also an important variable in shaping climate vulnerability, with households farming in owned land having higher incomes (due to lower overheads) than those working as hired labour on others' farms or rent farming land). Land ownership aids the adaptive capacity to both invest in better agricultural strategies and more food accessibility due to higher purchasing power. However, the benefits of land ownership on household revenue can vary between sectors, with crop farmers benefitting more than livestock farmers who receive better runs from using communal lands to graze their animals (Tibesigwa et al., 2015).

Education plays a positive role in widening the range of income sources for a household and opens up employment opportunities with higher pay. Education can influence climate perception positively with studies reporting less likelihood of climate perception in illiterates than literates (primary school education)

(Mayala et al., 2015; Mishra et al., 2015; Li et al., 2021). Human perception of climate change is a subjective "measure of the role of social structure or condition in determining a system's exposure" and can affect how people identify climate change as a health risk and whether they are willing to take steps to adapt to the resulting changes or not (Ung et al., 2017). Theoretically (Social Cognitive Theory), people who perceive climate risks and are more aware of its negative impacts on health are more likely to change behaviour or take measures to take better care of themselves (Bandura, 2001; Ung et al., 2017). A study in China shows that farmers with higher perceptions of the severity of climate risks and benefits for addressing them had a positive impact on resource management and better technical facilitating conditions. This resulted in the improvement of overall health conditions through better food security and livelihood security (Li et al., 2021). However, it must not be taken for granted that high perception will automatically result in better health, as biosocial barriers like age and sociocultural barriers like gender and income can be major deterrents in incapacitating adaptation or mitigation to climate change. Additionally, studies show that people who have greater perception of climate change and of such barriers are less likely to report better health (Ung et al., 2017; Armah et al., 2019). Farmers' perception of the severity of the impending climate risk and benefits for addressing such risks can also significantly impact health risk management intentions (Li et al., 2021).

The gender of the household head also impacts income through access to agricultural inputs, extension services, agricultural knowledge and skills, land ownership, quantity (plot size) and quality of land (Carranza & Niles, 2019). Similarly, male versus female household head significantly influences household income with the former having an advantage over the latter mainly due to social and cultural norms. For example, both *de facto* (through marriage and in the absence of husband) and *de jure* (through spousal death or single) female headed households have been found to be poorer than male-headed households by many studies in rural Africa (Carranza & Niles, 2019; Jost et al., 2016). This is primarily due to females having less decision-making power, limited mobility, more social responsibilities, lack of education, lack of ownership and lower access to external resources (government and NGOs) in rural societies putting them at a disadvantageous situation (Nong et al.,2020). Perez et al. found formally registered public and private external organizations to have anti-women biases dealing primarily with men as they are recognised to be the official "farm-owner" (Perez et al., 2015). However, such differences are highly contextual with some studies showing female headed households being less vulnerable to climate shocks despite lower income levels primarily due to lower consumption levels and sustainable climate mitigation plans like long term food storage and access to diversified resources from remittances (in the case of *de facto*), and petty trade (Anderson et al., 2017; Daalen et al., 2020; Chidakwa et al., 2020; Wrigley-Asante, 2019).

Interestingly, income has also been associated positively to climate vulnerability by Nguyen et al. through an intermediate variable, consumption risk. This Vietnamese study found income to be positively correlated to household consumption risk, suggesting that households with higher income are more likely to have higher consumptions or have more dependants (i.e., children) which puts them in the higher risk category in the climate change scenario. The same study also found negative correlations between the number of household earners working away from home and consumption risk, with both negatively correlated with climate vulnerability. For example, migrant workers sending home remittances but not utilising any of the household resources (monetary in this study) reduce household consumption level but increase household income level and therefore reduce household climate vulnerability (Nguyen et al., 2015).

A healthy diet is essential for good health and nutrition and is comprised of a combination of carbohydrates like cereal and starchy staples, plant or animal proteins and fruits and vegetables (WHO, 2020). "Dietary diversity is a qualitative measure of food consumption that reflects household access to a variety of foods and is also a proxy for nutrient adequacy of the diet of individuals" (FAO, 2013:5). Climate change can magnify existing lack of dietary diversity in households by further limiting resources both in quantity and quality through reduced crop yield and income. Another important determinant of dietary diversity is gender as women and girls are more prone to having poorer diets than men both in quantity and quality.

The primary health impact of food insecurity is malnutrition, which is defined as "An abnormal physiological condition caused by inadequate, unbalanced or excessive intake of macronutrients and/or micronutrients. Malnutrition includes undernutrition (child stunting and wasting, and vitamin and mineral deficiencies) as well as overweight and obesity" (FAO:2021: 192) and can be found in many shapes and forms. "Malnutrition in all its forms increases susceptibility to food-borne diseases, zoonosis, physical injuries and mental health issues and vice versa, while healthy diets and healthy food systems help protect against these susceptibilities" (FAO, 2021:113). Undernutrition and low protein intake caused mainly by inadequate intake of calories and protein can lead to child stunting, low birth weight, anorexia, and poor immune systems. Loss of income and high food price–two highly plausible consequences of climate change can further exacerbate these health impacts related to food intake (Lloyd et al., 2018). A study examining the relationship between temperature, precipitation, and birth weight in 19 African countries associated low crop yield to impact birth weight at a level comparable to socio-economic factors like women's education and household electricity status (Grace, 2015). A modelling study with data on children aged 0-59 months across 18 countries in sub-Saharan Africa underscored this problem by illustrating the role of high temperature and low precipitations on reductions in child weight and increased risk of wasting in extreme heat scenarios (Thiede & Strube, 2020). Health issues like LBW and stunting caused by undernourishment usually have trickle-down effects on entire households through reduced labour and decline in crop yield which culminates into loss of income (Hasegawa et al., 2016) creating a vicious cycle between poverty and poor health and further self-reinforcing the existing poverty trap. LBW babies also face higher risk of mortality, and those that survive are more likely to develop vision, hearing and cognitive impairments impacting their education and livelihoods. Furthermore, it could potentially be an intergenerational health problem, as LBW girls are more likely to give birth to LBW infants (Grace, 2015). Households with the poorest income consume foods with twenty percent more carbohydrates and fifty percent less animal protein than the richest households (FAO, 2021). Protein quality and type in terms of animal versus plant protein are also determining factors of protein-intake-related health impacts (Kaimila et al., 2019).

In the food security subsystem, besides the direct health impacts, climate change can also have indirect effects, such as mental health. Multiple studies have found a prevalence of psychological stress and anxiety leading to sleep disorders, depression, and inability to cope with life in rural agricultural communities more so during the agricultural season due to climate related low crop productivity (Pailler & Tsaneva, 2018; Acharibasam & Anuga, 2018). Higher reliance on ecosystem or natural resources for livelihoods like farming and fishing can lead to maladaptive response-focused emotional regulation strategies in times of hardship which basically entails concealing or tolerating the stress leading to depression and future mental health problems (Acharibasam & Anuga, 2018). The cause of such responses varies between men and women, with the former reacting more to livelihood or income pressures while the latter to household pressures in terms of being able to provide for family (Wrigley-Asante et al., 2019).

Gender specific analysis

Gender plays a very crucial role in all four dimensions of food security, and while women play the role of being the primary provider for the household, they do not share their gender counterpart's privileges. In developing countries, women comprise almost half of the agricultural labour force, with the ratio going up to 60% in certain regions of Africa and Asia (Assan et al., 2018; FAO, 2021). However, there lies a sizeable gap between men and women in terms of access to resources and decision-making power, primarily led by socio-cultural and traditional norms, which perceive women as an inferior class to men. This leads to their marginalization, which enhances their vulnerability to climate change. In the context of climate change and food systems, women and girls are at a higher risk both due to their physiological systems and low socio-economic status. While biological differences between men and women play a more defined function during pregnancies and at later stages of lives, socio-economic inequities persist throughout their lives and play a more significant role in exacerbating existing health inequities. For example, in times of hardships, an intra-household adaptation strategy in countries like India and Bangladesh expects women to sacrifice the most due to their role as the household caregiver and consume less than men in countries like Bangladesh and India. As women are not considered being at par with their male counterparts in the household who enjoy the status of being the "breadwinners" (including cases when they are not), they are expected to eat their meals only after the entire household is fed. This age-old cultural practice also puts them at a disadvantage in times of food scarcity, as they usually end up consuming left-over carbohydrates, which are usually the cheapest food and more readily available in quantity. This exposes women and girls to not only suffer from undernutrition (in terms of quantity) but also malnourishment due to lack of dietary diversity and insufficient protein intake (Alston & Akhter, 2016).

Age is also a factor in defining food insecurity and here as well elderly women were found to be the highest in the vulnerability risk ladder followed by elderly men due to their economic conditions and low purchasing power (Omolo & Mafongoya, 2019).

As climate change continues to put pressure on natural resources like fisheries and farming, existing deep-rooted gender-based inequities become tools for further exacerbation of prevailing physical and mental health inequities faced by the specific gender at risk. In agricultural societies, although women are equally involved in terms of labour, the ownership rights lie in the hands of their male partners (Perez et al., 2015). In highly patriarchal male dominated agricultural societies like in the Indian-Gangetic plains of Bihar, women are only involved in managing invisible crops in invisible spaces like growing pulses and medicinal herbs in home gardens and perform invisible culinary and post-processing tasks (Ravera et al., 2019). In Ghana, women are expected to manage the sowing and weeding activities on the farm (Assan et al., 2018). For example, studies in rain-fed agro-based communities, farmers with bigger plot size, better quality of land and higher crop diversification (all more commonly associated with male farmers) recover faster after a climate shock than those with smaller sized plots or land with poor soil fertility (Perez et al., 2015; Assan et al., 2018; Belcore et al. 2020). A Ghanian study participant stated that when NGO sensitization programs facilitate women to become landowners, the local men would give less fertile land to females in order to restrain their economic growth (Assan et al., 2018).

In the same vein, land ownership, land-use rights, and access to extension services like agricultural inputs (drought-resistant seeds and fertilizers), access to financial assistance in the form of credits and loans and NGO support also assist in quicker recovery rates (Belcore et al., 2020). Access to agricultural inputs depend on access to formal markets which could also be skewed by gender as found in studies by Otieno et al. (2021) in the East African countries of Tanzania, Kenya, and Uganda and Ahmed & Eklund, 2021 in Bangladesh. In this study, women forced by inadequate access to formal markets rely on informal seed systems for three major food security groups in the region–beans, finger millet, and sorghum (Otieno et al., 2021).

Access to extension services, especially training and skill development, also depends on mobility both in terms of distance travelled from the farms or place of residence and self liberty to move around within their local communities. In some societies marital status and religious norms influence women's mobility as married women may not be allowed to travel outside their homes or to local markets (hubs for rural communities) without their husband's permission (Mudege et al., 2016) or travel to places on their own without being accompanied by a male family member due to religious norms (Ahmed & Eklund, 2021).

Women are less mobile than men due to socio-cultural norms and lack of monetary resources which restricts them to their local villages. Such restriction of mobility restricts their social network (Ahmed & Eklund, 2021), limits their climate perceptions, diminishes exposure and awareness of climate-smart farming technologies, reduces their ability to further improvement of skills through training organized by external parties (Duffy et al., 2021) and limits their access to superior quality of agricultural inputs like seeds (Otieno et al., 2021). Gender biases can also exist within formally registered public and private external organizations supporting agricultural and livestock production, with tendencies to only aid men and those farmers who are official landowners, who are often males (Perez et al., 2015).

Education is another important factor affecting women's perception of climate change or their capacity to absorb climate knowledge obtained from organized training sessions and mass media like radios and televisions (Henriksson et al., 2021; Duffy et al., 2021). Language skills and technical expertise which go hand in and hand with literacy are vital to successfully understand climate information, support, and adopt climate adaptation effectively (Archer, 2003). Weather forecasts to disseminate climate information is a potential enabler for climate adaptation and have been found to be more popular in Malawian men than women as a reliable and timely source of information as found in a study conducted by Henriksson et al., 2021. The results from this study found lower literacy levels in Malawian women to be a significant barrier along with inequitable access to radios and mobile phones in the uptake of climate information. This was reflected in women's preference for an interpreter (or information broker) to be their second source of information dissemination after radio in Henriksson et al.'s study (2021). In some cultures, educating young girls is considered being a financial waste and a poor investment from the parent's perspective as the benefits are reaped by their in-laws (Ahmed & Eklund, 2021). To some extent, it may be true as educated girls grow into literate women becoming valuable assets to any household contributing to overall household income and food security (Balikoowa et al., 2019) by engaging in off-farm activities, and gaining higher and easier access to credit and extensional services (Belcore et al., 2020).

Ethnicity can also influence women's climate perception and knowledge by challenging uptake of climate information caused by linguistic barriers as seen in a study in coastal Bangladesh where the ethnically minor Rakhine communities primarily used Burmese to communicate which varies considerably from the mainstream Bangla and as a result missed out from participating in the local Farmers Field Schools organized by NGOs (Ahmed & Eklud, 2021). Due to women's lower access to financial resources and household incomes (Perez et al., 2020), they are less likely to own personal electronic devices and therefore depend on their spouses for weather forecasts and early disaster warnings which could impact their capacity for climate risk mitigation (Partey et al., 2020).

Women lack access and skills for social networking, which can be due to their low education levels, poor social status, low decision-making power, marital status, and religious restrictions (Duffy et al., 2021, Henriksson et al., 2021; Ahmed & Eklund, 2021). For example, in Duffy et al.'s study in Malawi, women who attended the World Agroforestry Centre (ICRAF) Agroforestry Food Security Program (AFSP) training sessions faced difficulties in interpreting some information or felt a general lack of confidence in engaging or asking questions due to educational disparities and a general tendency to allow the male participants to take the lead in such settings. (Duffy et al., 2021). Lack of female participation in such training sessions was also attributed to the male-dominant leadership and all-male organizing committees who controlled the reigns in terms of participation and information sharing (Mudege et al., 2016). In coastal Bangladesh, religious norms restricted women to speak to men outside their own families, which may become a major barrier in their participation quality during training or professional development programs (Ahmed & Eklund, 2021). In one study, social networks were also found to be heavily clustered by gender with no gender-intermixing caused by cultural and religious norms and found to further inhibit women's access to agricultural inputs. This handicapped them as a group of leadership opportunities (Otieno et al., 2021).

Women also engage in income-generating activities for different reasons than men, with the former primarily driven by household needs while the latter by income generation (Musingizi, 2018). In agriculture, this difference in purpose could be seen in the type of crops grown by women versus men, with the latter growing more cash crops like cotton, cashews etc. while the former engaging in subsistence crops like maize and as a result generating lower incomes (Wrigley-Asante et al., 2019).

In small-scale fisheries, gender plays a significant role in the level of income either through participation or type of activities. In the developing world, like female farmers, women in fisheries also face numerous disadvantages than men in terms of access and decision-making power, which can lead to lower female participation in the sector. In Lake Wamala, Uganda, as much as 99% of fishers and 92.9% of fish processors and traders are from the male gender (Musingizi et al., 2018). In communities where women are more active in the fish-value chain, they are mostly engaged in low-value activities like cleaning, smoking, selling or being the broker for primary male fishermen (Chiwaula et al., 2018; Limuwa & Synnevåg, 2018). Where both are engaged in similar activities like selling smoked fish, the size of the fish sold by women is usually smaller than ones sold my men (Limuwa & Synnevåg, 2018). In the Ugandan study, the men were found to have a greater competitive advantage to adapt to climate induced declines in fish stocks due to (i) higher work experience as they enter and exit the sector earlier and later respectively than women, (ii) better knowledge of fish species (directly to their higher experience level, (iii) better skilled and more practice using different fishing gears enabling them to target multiple species, and as a result (iv) higher income facilitating higher purchase of fish (if not primary fishermen) to sell (Musingizi et al., 2018).

Male-outmigration (when male members of the family migrate elsewhere to seek out supplementary income sources) is an existing practice in communities that are highly reliant on natural resources for their livelihoods like rain-fed farming and fishing (Ahmed & Eklund, 2021; Chidakwa et al., 2020). Male/female outmigration was initially considered a temporary solution during the dry seasons with an expected return to usual livelihoods with the onset of monsoons (Masson et al., 2019). However, with the ongoing climate crisis straining livelihoods at a much greater scale through extended dry season and frequent droughts, frequent and intense floods, and more crop diseases and pests, outmigration is being adopted as a more permanent solution to increase household income. As a result male family members spend extended lengths of time working away from their families forcing female heads to assume the role of being the *de facto* household head in their absence (Ahmed & Eklund, 2021).

Male outmigration can have both positive and negative impacts on women. Male outmigration can exacerbate women's existing food insecurities primarily through loss of labour causing malnutrition, poor maternal health, long-term health issues and mental illness like anxiety and stress. Coastal Bangladesh, one of the most vulnerable regions to climate change is seeing a heightened rate of male outmigration leaving females to manage farms with limited technology in a highly patriarchal society where they face restrictions and suffer discrimination daily due to existing social, cultural, and religious norms. As a result, they not only face food insecurities from low crop yield but also unprecedented livelihood challenges due to meagre incomes from reduced crop surpluses. In this study, ethnicity played an unexpected role as women from ethno-religious majority group (Muslim women) were found to be more vulnerable than those from the minority religious group (Hindu women) which could be directly due to the traditions and beliefs of their respective religions (Ahmed & Eklund, 2021). In Chad, male outmigration has also seen an upward trend driven by crop failures, with a majority of the men not returning, or remarrying and resettling elsewhere, or simply not sending any resources back to their original households. In such scenarios, women are open to repeated exploitation due to their vulnerability caused by lower social status and continued lack of support, as they may not be allowed to remarry or access their ex-husband's properties (Masson et al., 2019). This lack of a sense of security can impact women physically and mentally.

In some communities, like the Kuamoni region of the Himalayan State of Uttarkhan, male out-migration was reported to have positive impacts on women's decision-making power and social status. This is due to the fact that although land ownership is still dominated by men, Kuamoni women have renegotiated the *de facto* land ownership arrangement in the absence of men, such that gender-based division of labour positioned women as the centre of the agricultural system and natural resource management with active roles in seed and crop management decisions and tasks while men earn off-farm wages (Ravera et al., 2019). Ravera et al. in their study suggested that women's higher status in education and health in this region as compared to other regions in India results from this renegotiated male-female power dynamics (Ravera et al., 2019).

Female migration is also increasingly becoming a trend in countries like Bangladesh, where it has been increasing at a rapid rate and comparable with male migration in certain villages. In such scenarios, male members of the family are at risk of being negatively impacted. Marital status plays an important role in female outmigration with the migrant population comprising mainly of unmarried or divorced women, as married women are less likely to migrate due to childcare obligations and societal taboos, as revealed by a study participant in Bangladesh. However, female migration is not as easily accepted by society as male migration, leading women to only consider migration as an option when male members cannot meet the household needs. Such large social costs associated with female migration might make it a climate maladaptation with high social risks and cascading impacts on the physical and mental health of women both at home and at their migrated destinations (Eversten & van der Geest, 2020).

Seasonal food shortages can also lead to increased domestic violence (including domestic sexual violence) against women, spurring from men facing difficulties providing for their families. This detrimentally impacts women's mental health and challenges their ability to cope with everyday life. This weakens them physically and mentally, with cascading negative effects on their labour efficiency and livelihoods (Masson et al., 2019).

Due to the combined impact of lack of land ownership and land use rights (Tanny et al., 2017), poor or no access to extension services (Jost et al., 2016), poor quality and quantity of land (when access is there) (Assan et al., 2018), type of agricultural or fishery activity, lack of education (Belcore et al., 2020), lower household income, ethnicity, labour shortages due to affordability and physical ability (Assan et al., 2018; Balikoowa et al., 2019), irrigation facilities, lack of mobility, poor perception of climate change urgency and lack of access to resources, outmigration, domestic violence, religious and socio-cultural norms, females are at a greater disadvantage than men in their recovery or adaptation efforts to climate induced shocks. However, this disadvantage must not be misunderstood as women lacking the capacity to adapt to climate change, as studies comparing male and female-headed households in terms of their livelihood vulnerability index found the latter to be more vulnerable but only by tiny margins (Balikoowa et al., 2019, Shah et al., 2013). According to FAO estimates, "if women had the same access to productive resources as men, they could increase yields on their farms by 20–30%, potentially resulting in 100-150 million fewer hungry people in the world" (FAO, 2021). Although climate change induced food security impacts everyone, women's low participation in climate adaptations is rooted in existing inequalities caused by traditional gender roles, social and cultural norms, and power dynamics between men and women. It is worth investigating if the tendency to restrain women's progress in these societies originates from male insecurities or fear of losing the one guaranteed solace in being the main decision-maker in times of increasing distress and unpredictability in their livelihoods. If so, will this protective nature get worse with worsening climatic conditions and if the answer is yes, then what is in store for women?

4.2.2 Ecosystem Services

Potable Water

Water is a basic human necessity. As per the UN General Assembly and the Human Rights Council:

> *"The right to water entitles everyone to have access to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use" (UN, 2010).*

And yet, globally, 785 million people suffer from lack of drinking water service and 2 billion drink waters contaminated with faeces (WHO, 2019). The 2020 edition of the World Water Development Report (WWDR 2020) declared climate change to be an imminent threat to water availability, quality, and quantity, undermining the basic rights to safe drinking water and sanitation for billions of people, and therefore a direct threat to Sustainable Development Goal 6- "Clean water and sanitation for all" (UNESCO, 2020).

Global warming is increasing evaporation rates from land and water. In regions where this phenomenon is coupled with decreased rainfall, there is a rapid loss of surface and ground water (Adhikari & Nejadhashemi, 2016). In agro-based communities, increased evapotranspiration rates can result in an increase in crop water requirements (CWR) (Malkia & Etsouri, 2018; Goodarzi et al., 2019; Tahboub, 2015) which can also affect groundwater recharge rates at which aquifers are replenished (Ajami, 2011; Goodarzi et al. 2019). Unsustainable water abstraction to increase crop yield when coupled with increased crop water requirements and unstable rainfall can severely diminish ground and surface water resources impacting human health directly through inadequate supply of potable water for drinking, domestic chores and recreational activities and increasing the risk of consumption and use of contaminated water due to the lack of alternatives. Using unsafe water for drinking, domestic activities and recreation can impact human health and well-being both directly and indirectly. Insufficient water consumption can lead to acute dehydration, kidney diseases, headaches, urinary tract infections and imbalance of electrolytes like sodium and potassium (WHO, 2017). Consuming contaminated water with fecal coliforms and trace metals can lead to water-borne diseases like diarrohea, giardia and cholera and cancers (WHO, 2017).

Globally, 144 million people depend on surface water (WHO, 2019). Water insecurity (in terms of surface water sources drying up due to climatic conditions) has been found to cause extreme worry and fatigue in inhabitants of semi-arid and arid regions of the world who heavily rely on open surface water bodies for their livelihoods like the Afar in Ethiopia and pastoralists and agropastoral communities in West Africa (Grace & Davenport, 2021). In addition to the risk of water unavailability due to evaporative loss, surface water is also highly susceptible to contamination.

While temperature and rainfall are the primary determinants of these two-surface water related risks, other intermediate variables also play a part. For example, temperature induced increase in evaporative loss of irrigation water from farms can reduce return flows to a stream or river, causing higher water stress to downstream farmers through lower stream flow rates (Malek, 2018). Lower stream flow rates (also a consequence of low rainfall can affect concentration of fecal coliforms in rivers, raising the risk of exposure to water-borne diseases through direct consumption of contaminated food and water or through cleaning and bathing. Another example where temperature impacts both quantity and quality of surface water body is through its influence on water temperatures. While warmer waters are more susceptible to evaporative loss leading to a decline in water availability, it also provides ideal conditions for eutrophication (causing general deterioration of water quality due to dissolved toxic substances like ammonia and hydrogen sulphide from decomposing organic substance in the absence of oxygen) and proliferation of *Vibrio Cholera* rendering the remaining water unusable for drinking and domestic activities (Lu et al., 2019). In addition to direct impacts like water availability and water quality, water temperature can also impact lake or river biota, which could, in turn, impact human health. For example, fish population has been found to decline in warmer waters provided their thermal tolerance is breached, which can affect human health through food insecurity and livelihood insecurity (Magadza et al., 2020; Muringai et al., 2020).

Heavy rainfall or floods can also potentially deteriorate water quality in open water sources like lakes and rivers by increasing the amounts of total suspended solids (TSS) and total nitrogen (TN) and total phosphate (TP) loads in the water through increased soil erosion (Thang et al., 2018; Wang et al., 2018). Regions facing frequent drought-flood abrupt alternation events will experience higher rates of soil erosion due to the acute lack of soil moisture and vegetation (Yang et al., 2019). Location of the open water body in terms of proximity to agricultural farms versus forests could also make a difference, with the former being more likely to be contaminated than the latter (Ervinia et al., 2019).

Socio-economic factors can also interact with environmental factors to influence water-related vulnerabilities. For example, poorer households have been found to rely on seasonal (open surface sources) as opposed to permanent water sources (groundwater) (Pearson et al., 2015). Studies show that groundwater sources mainly gain popularity during the dry season when surface water bodies dry up completely. In order to access groundwater, the water needs to be extracted from the aquifer through a well, which is basically a hole drilled into the ground and then the water is pulled out using a pipe and a pump. Such a setup, although simple, could be deemed less attractive due to the involved cost and labour. Therefore, households with poor income heavily rely on surface water and, as a result, increase their vulnerability to climate change induced water stress.

Vulnerability also depends on water source ownership–public (public common goods and open access) vs. shared (owned privately by wealthy households and shared with poorer households on case-to-case basis) where the latter is more disadvantageous to poorer households who have to not only depend on the owners' charity to access the resource but also have to migrate from one share source to another frequently. This causes physical fatigue and mental stress (Pearson et al., 2015).

Floods can also increase the risk of fecal coliforms in water bodies, raising the risk of water-borne diseases, especially in areas where open defecation is practised (Labbe et al., 2016) due to the lack of flushable toilets and cultural norms. Besides socio-economic factors, environmental factors like lack of water during drought conditions can also force people to use pit latrines despite the availability of flushable toilets as was seen in Ramotswa, Botswana during the 2013-2016 drought which led to high levels of nitrate pollution, fecal coliforms and caffeine in groundwater caused by human waste leaching (McGill et al., 2019).

In addition to temperature and rainfall, climate induced sea-level rise in coastal regions can also deteriorate water quality through high salinity and bromide concentration in groundwater. This could lead to an increase in the intake of salt and bromine through food and water, causing hypertension related diseases, cancers and reproductive illnesses (Kolb et al., 2017) in the local inhabitants. A lack of awareness of salt naturally occurring in food and water and social norms like consumption of salt as a condiment in countries like Bangladesh can further exacerbate the health risks of high salt consumption (Rasheed et al., 2016).

While sea-level rises have been associated mostly with negative health impacts, one study associated it to benefit water quality in tidal estuaries as it might dilute high concentration of fecal coliforms in regions where freshwater discharges are low (Liu et al., 2015)

Wild foods and medicinal plants and forest products (fuel)

Climate change can impact availability of and access to wild food plants (WFP) and wild medicinal plants, and wood for fuel directly through climatic variations and indirectly through deforestation caused by agricultural expansion driven by climate induced loss in crop productivity (Ogra & Badola, 2015; Wessels et al., 2021). Wild food plants like sweet potato are a staple in poor rural households, as they provide supplementary nutrition and add diversity to the diets (Wessels et al., 2021). Losing this additional source of food can not only impact consumers physically but also mentally, especially women who have the primary role of providing food for the household.

Reduced availability of fuelwood can impact household food security and livelihoods in communities where wood is the primary energy fuel. Climatic variations can impact wild medicinal plants by directly altering their lifecycle, distribution, and collection periods. This can significantly affect traditional healthcare systems, having an overall negative impact on human health (Maikhuri et al., 2018).

Gender specific analysis

Traditional gendered roles and norms in rural developing communities in Asia and Africa force women and girls to pay a higher price than men in times of climate induced deterioration in ecological services like water and forest products (Dickin et al., 2021; Shreshta et al., 2019). Gendered water related roles assign females, (especially younger women who help their mothers) with the responsibility of being the primary water collectors (Belcore et al., 2020). For example, a study in Nepal found 85% of the fetching activity to be carried out by women with men only willing to assist if the water source was within 1 kilometer of their residence. Women also spent 3 hours or more per day on water collection, whereas men only spent 15 minutes on the same activity. In the same study, women were also held responsible for locating new water sources, as they relied more on natural springs than piped water sources, as the latter was mostly used by men (Shreshta et al., 2019). Women who asked men for help may also receive frequent refusals due to the same gendered norms (Dickin et al., 2021). Due to the deforestation and drying up of surface water bodies, women and girls travel longer distances to collect water and fuelwood that increases their overall workload and come at the cost of diminished time for personal development, participation in other productive work and self-care. This restricts them to their current informal and subsistent economic activities (Belcore et al., 2020).

Geographical location and topography can also influence time to collect water with rugged terrains, resulting in women spending longer periods of time during the day collecting water (Shreshta et al., 2019). In African and Asian households, girls are primarily responsible for collecting water, which means they are often withdrawn from schools to fulfill their water collecting tasks which traps them into a vicious cycle of poor education and low income (due to lack of off-farm employment options) (Andersen et al., 2017; Belcore et al., 2019; Bryson et al., 2021; Ogra & Badola, 2015). Increased distances and time spent on water collection have been shown to reduce a sense of safety and security in women, which can negatively impact their mental and physical wellness (Shreshta et al., 2019).

Increased distances to water sources and time spent on collecting water are important indicators of women's drudgery (Crow & McPike, 2009). These are most likely to increase further with climate change affecting women physically through increased physical labour causing fatigue and mentally through a reduced sense of safety and security (Chidakwa et al., 2020) and increased levels of anxiety from the fear of not able to ensure adequate food and water to the household. Although being the primary provider of water in the family, women do not share the same water-related decision-making power as men. They are often found to be struggling to secure water for domestic tasks and irrigation where men can easily do so for their livelihood activities like livestock rearing and agriculture (Dickin et al.'s, 2021). During the dry season, women are first expected to adjust to limited water availability by reducing their domestic water usage in cleaning and cooking and increase their frequency of water fetching, which can further add to their workload (Shreshta et al., 2019).

Gender-related water insecurity is also influenced by socio-economic factors like income, class, ethnicity, and religion. Ethnicity and religion can also determine a household's vulnerability to water as shown in a study in Bangladesh where shared water sources were only open to Muslim women (the religious majority) and not to women from other ethnicities, further establishing the role of socio-cultural factors in climate change and health studies (Pearson et al., 2015). Water insecurity caused by unaffordability also impacts women more than men. Communities that rely on boreholes for water during the dry seasons can suffer from steep increases in maintenance and repair costs caused by increased wear and tear due to high demand in extended dry spells and heavy rainfalls in the wet season causing contamination of water (Bonsor et al., 2011). In Burkina Faso, a study found no uniformity in the household responsibility to bear such costs and instead it varied from household to household, with some paid by the women while others by men. The costs were also divided by women, men, children, and animals (Dickins et al., 2021). In patriarchal societies where women are disadvantaged in terms of income generation, such payment arrangements, that are highly likely to increase because of climate change can add to the existing financial burdens on women. However, traditional gendered water roles are being increasingly tested by changing climatic conditions with men taking part in water-related activities like collecting water from dug-out water holes and storage tanks with strict collection hours as seen in North-eastern hilly regions in India (Singh & Singh, 2015).

Being the main food preparer in households, and therefore caring the most about nutritional and caloric needs of the whole family, women suffer more than men from anxiety when they have to rely on store-bought foods (considered being less nutritious). With the decline in wild foods, women in poor rural households complained about feeling extremely threatened by the loss of such supplementary food sources and increased competition with other women leading to social conflicts (Ogra & Badola, 2015). Women also rely on forest products for their livelihoods and therefore any deterioration will affect them more than men. For example, women selling medicinal plants for supplementary income may suffer permanent loss of livelihood if timber forests are continued to replace natural forests. Lack of rights and decision-making power are significant barriers to gender-equitable adaptation to climate change, especially in patriarchal societies where women are forbidden to actively participate in public goods management and adaptation strategies. (Bhattarai, 2020).

4.2.3 Extreme weather events

Climate change has increased the frequency and intensity of extreme weather events like extreme heat days and natural disasters like droughts, floods, landslides, and cyclones. Vulnerability to such events and their resulting impacts on human health and livelihoods depend on the rate of exposure, extent and type of damage, recovery rate, and adaptation capacity which are in turn influenced by environmental factors such disaster frequency and intensity, type of disaster (slow or rapid onset), geographical location and local climate. Socio-economic factors like accommodation, income, awareness levels, access to healthcare services, gender, socio-cultural norms, and education, and physiological factors like age and pre-existing medical conditions also play significant roles.

Increased frequency of extreme events could impact recovery rate through lack of recovery time, constant need for additional resources (both income and labour) and insufficient time for preventative measure. Increased disaster intensity could influence recovery rates by magnifying the extent and type of damage (Certini, 2005). Human health impacts from extreme weather events can vary by frequency, intensity, and type of natural calamity (slow versus fast). For example, health impacts of seasonal droughts can be mitigated and controlled by taking the right preventative measures like food storage or proper shelter, but prolonged droughts can lead to crop failure and famines with the potential to give rise to violent conflicts and food riots (Buhaug et al., 2015). Intensity is another important factor in determining impact on human health. For example, a moderate flood (one with a smaller inundation range) might only lead to an increase in vector-borne diseases like malaria in the downstream regions, versus a more intense flood with a larger inundated area will impact both upstream and downstream areas. Additionally, an intense flood with the capacity to cause damage to accommodation may increase exposure risk to malaria by forcing people to sleep outside. It can also lead to a spatial shift in the prevalence of certain vector-borne diseases. A study in Uganda reported a change in malaria prevalence with more cases upstream than downstream of a river following a severe flood event, with waters inundating upstream regions and stagnating for longer periods of time due to poor drainage systems (Boyce, 2016). Flood damage on human health can also vary with intensity and can range from physical assets lost to injury or death. Results from a study in Vietnam associating flood intensity (at household and community level) to consumption vulnerability showed a negative and a positive correlation between the two at household and at community levels, respectively. The explanation behind this difference could be linked to recovery success rate and access to resources post floods (Nguyen, 2015).

Geographical location plays an important role in determining human health impacts of extreme events. For example, mountainous locations are more susceptible to landslides than floods, which can cause serious fatalities, including death (Ogra & Badola, 2015). Households on riverbanks and lakeshores face a higher risk to malaria during extreme flood events than those farther away from the water body (Boyce, 2016). Coastal regions have a higher susceptibility to physical and mental health impacts due to loss of potable water, crop damage, loss of physical and monetary properties, and increase in communicable diseases caused by sea level rise than inland locations (Ojakorotu & Olajide, 2018; Ung et al., 2016).

Physiological factors like age and pre-existing medical conditions can also significantly influence the level of impact on human health from extreme weather events like extreme heat. Older adults face higher risks due to their lack of physical, cognitive, and economic resources to avoid or mitigate effects of exposure to extreme events (McDermott-Levy et al., 2019). Individuals with pre-existing medical conditions like chronic lung diseases also face a higher risk of physical and mental health impacts during forest fires, thunderstorms, and extreme heat events (Gotschke et al., 2017).

Socio-economic factors - education, livelihood diversification, level of income, labour availability, source of livelihood (reliance on natural resources), number of dependants, number of family members generating income, gender, ethnicity, religion, and culture indirectly influence the level of vulnerability both at personal and household levels. For example, higher income households may have access to climate change knowledge through educational institutions and access to media outlets like computer, tv and radio. Higher income households are also at a lower risk of being food insecure or face difficulties in affording medical cures in scenarios where climate-related health and recovery expenditure increases due to natural disasters. Number of household dependants can also influence household vulnerability, especially households dependent on labour intensive livelihood sources like pastoralism and agriculture (Melka et al., 2019).

Gender Specific Analysis

Societal gender roles and norms and biological differences between females and males can lead to significant variances in impacts faced by women and men from extreme weather events (Memon et al., 2018). Biologically, more women than men have reported urinogenital infections after a flood event due to poor hygiene and sanitation conditions (Tanny et al., 2017). Women suffer more than men from anxiety and fear when flood induced damage to toilets and shower facilities force them to bathe outdoors (Tanny et al., 2017). Women are also required to remain in inundated and damaged properties post flood events to care for children and protect property and such immobility may increase their exposure risk to infectious diseases like diarrhoea, cholera and vector-borne diseases like malaria and dengue. In coastal Bangladesh, men migrate inland for work, and women who are left behind face the most destructive phase of the natural hazards by themselves (Ahmed & Eklund, 2021).

Men driven by societal masculinity ideals are more exposed to physical injuries and mortality during disasters while repairing flooded homes and drainages (Buyana et al., 2019). In some societies, a larger proportion of men than women are involved in outdoor occupations, which increases their risk of exposure to lightning and thunderstorms. In scenarios where extreme weather events have incurred damage to farmlands, a study found men to suffer more from anxiety from loss of property and risk to social status and personal dignity than women. (Daoud, 2021).

Extreme weather may increase male-outmigration rates which could increase women's workload both outside and inside their households, potentially worsening their physical and mental health and well-being (Ahmed & Eklund, 2021).

Religion and cultural beliefs also add to the increased vulnerability of women to extreme weather events as seen during floods and cyclone events in Bangladesh where fatality rates are higher in women than men due to the inability to swim and refusal to leave their home to avoid embarrassment of being seen in wet clothes (Burkart & Kinney, 2016). Religious restrictions such as women not being allowed to be in proximity of males outside of their family can force women to avoid evacuations and refuge shelters during natural disasters which may put them at a higher risk of death, injury, and communicable diseases (Nyantakyi-Frimpong, 2020).

Pregnant women are also more likely to suffer from maternal complications and mortality during flood events due to the lack of antenatal checkup and doctors with majority of the maternal deaths occurring on boats while transferring from the community to the hospital. The shocking aspect of such incidents is the poor lack of awareness amongst community members who associate such preventable deaths to natural phenomenon (Abdullah et al., 2019). In rural poor agrarian societies, weather-shocks can alter young women's life course transitions in terms of age at first union and childbearing, with parents marrying off their daughters earlier or later than expected to smooth out household financial pressures caused by reduced crop yield (in the absence of the "bride price" factor). Socio-economic factors like who is paying the bride price or dowry (bride or groom), and financial ability to pay the bride price and wedding costs could significantly influence this trend (Andriano & Behrman, 2020; Corno et al. 2016). Early marriages can come with highly dangerous health risks to adolescent girls who are more likely to suffer from marital rape and delivery complications like fistulas and still births caused by premature pregnancies (in terms of biological development) (Masson et al., 2019).

Women, especially if older, unmarried, divorced, or widowed face higher risks from extreme weather-related health impacts due to reduced capacity in terms of recovery success and rate, which heavily depends on levels of income, livelihood diversity, education, land ownership, social status, mobility, access to knowledge and skills, access to agricultural inputs and extension services, and NGO loans and credits (Melka et al., 2019). A study from central Vietnam found that post floods male respondents reported recovering 80% of their welfare losses within 5 years while females recovering only 70% within the same period. While women spent 41% to 86% of annual income to compensate for their well-being losses, men only spent 30–57% of their annual income (Hudson et al., 2019). However, some studies show female-headed households to be less vulnerable to climate change extreme events when compared to men due to their recovery strategy, long-term planning, and capacity to consider the welfare of the entire household over their own.

4.2.4 Communicable and non-communicable diseases

Communicable diseases are caused by microorganisms such as bacteria, viruses, parasites, and fungi that can be transmitted, directly or indirectly, from one person to another through insect bites or consumption of contaminated food or water (WHO, n.d.). As per this definition, communicable diseases can be vector-borne, zoonotic or infectious diseases and are sensitive to changes in climate change. Bett et al. categorizes the relationships between climate change and infectious diseases into two groups according to their pathways–direct and indirect. Under direct effects, environmental variables like temperature and precipitation mainly come into play as they directly influence host's ability to mount a response or increase or decrease vector and parasite development. For example, rising temperature can increase mosquito's metabolic activity, resulting in amplified biting frequency and therefore high malarial transmissibility (Bett et al., 2006). In the indirect effects, environmental (precipitation, wind, relative humidity) and socio-economic variables like livelihood loss can induce an ecosystem change resulting in the alteration of vector/parasite development or vector-pathogen-host contact. For example, high precipitation can lead to increased vegetation, causing higher rodent population and therefore an increase in the risk of zoonotic diseases like plague (Xu et al., 2015).

By altering environmental variables such as temperature, rainfall, relative humidity, vegetation density and others (see table), climate change can limit or exacerbate transmission of certain anthroponoses and zoonoses by influencing the behaviour, density, and activity of disease vectors and reservoirs (Patz et al., 2003). Temperature is a key determinant of indirectly transmitted anthroponoses by biological vectors such as mosquitoes, sandflies, and ticks and physical vectors, such as water (Patz et al., 2003; Abdolahnejad et al., 2021; Jonathan et al., 2018).

In mosquito-borne diseases like malaria and dengue, temperature can influence both vector (example: mosquitoes, ticks, and rodents) and parasite (viruses, protozoa, and bacteria) biology. While warmer temperatures can increase transmission rates (by providing ideal conditions to fasten vector life cycle and development rate, increase vector biting frequency, increase pathogen replication rate, and reduce extrinsic incubation periods (EIP) (defined as "time between vector feeding on an infected host and being able to transmit the pathogen" (Karmakar & Pradhan, 2019), temperatures outside the vector's thermal physiology can also dramatically lower transmission rates by affecting vector mortality and parasite's life cycle. For example: *Plasmodium falciparum* cannot complete its life cycle below 20°C (CDC, 2020), and temperatures above 35°C. Temperatures under 10°C can dramatically increase mortality rate and reduce or stop vectorial capacity in adult *Anopheles* mosquitoes (Beck-Johnson, 2017; Yamana et al., 2016; Murdock et al., 2016).

Along with average temperature, diurnal temperature range is critical to define malaria risk as simply considering mean monthly temperatures alone might underestimate or overestimate parasite development and in cooler and warmer conditions respectively (Blanford, 2013). While daily minimum temperature would be an ideal variable to predict a change in malaria transmission risk in cooler conditions with any increase in temperature resulting in an increase in transmission, daily maximum temperature would be appropriate for warmer conditions with any decrease in temperature leading to an increase in transmission (Lubinda et al., 2021; Taye et al., 2015).

Seasonal warming effects can also significantly influence vector development and therefore transmission risks in mosquito-borne diseases like dengue. While higher temperatures in spring and winter can facilitate the development of the *Aedes albopictus* mosquito (vector of Dengue Fever) by shortening the diapause period, warming effects in summer can inhibit development (Jia et al., 2017).

Differences in innate reproductive potentials in vectors can also impact prevalence of diseases in non conducive environmental conditions and in the presence of intervention and control measures as recovery rates vary from species to species. As an example, vectors of dengue and leishmaniasis can recover quickly and are therefore difficult to control, whereas tsetse flies–vectors of trypanosomiasis are easier to control due to their comparatively lower reproductive potential (Frape, 2018).

Temperature-induced changes in breeding habitats can also affect vector and carrier populations. For example, in the case of mosquito borne diseases, higher temperatures could increase the drying up of breeding habitats through evapotranspiration and infiltration and therefore vectors preferring small, turbid rainwater pools like *Anopheles gambiae* are more susceptible to face high mortality rates than those breeding in larger water bodies like *Anopheles funestus* (Yamana et al., 2016). An increase in temperature was also directly associated with an increase in Hantavirus Cardiopulmonary Syndrome (HCPS) - a viral disease transmitted by rodents (caused by Hantavirus (*Bunyaviridae*); 50% lethality and restricted to the Americas) in a study in the Cerrado and Atlantic forest regions where the increase in risk was attributed to an increase in natural vegetation growth which positively affected abundance of rodent population, improved rate of reproduction and survival, and aided virus survival and aerosolization in air improving HCPS transmission rates (Prist et al., 2017).

High temperatures have also been found to affect other arthropod vectors, like the triatomine bugs responsible for spreading Chagas disease. A study by Gonzalez et al. shows lower survival rates in triatomine bug *Meccus pallidipennis* infected with *T.cruzi* strains in higher temperatures due to reduced prophenoloxidase activity (responsible for the immune system in invertebrates) indicating a spatial shift in the disease towards cooler regions (Gonzalez-Rete et al., 2019).

In recent years, several studies have illustrated the role of climatic factors like temperature, precipitation, relative humidity in altering geographical range and transmission patterns of several infectious diseases by influencing the disease agents and their vectors (Bett et al., 2017; Escobar et al., 2016). Local and regional level epidemiological shifts in multiple vector-borne diseases within endemic areas can lead to highly deleterious cascading impacts, especially in countries with already strained national economics and poor capacity for preventative, diagnostic and control measures, and inadequate access to extension services due to their remote location (Bett et al., 2017). Additionally, the local populations' low historic immunity to certain emerging diseases can increase their vulnerability to the disease. For example, the Bakiga communities residing in the south-western Ugandan highland regions have no prior exposure to the malarial vector - *A.gambiae* and are therefore highly likely to be infected by the malarial parasite *Plasmodium falciparum* as compared to those in endemic areas due to no prior immunity as *A.gambiae* expands into the region (Labbe et al., 2016). Modelling studies in Ecuador and Africa show that disease transmission by Aedes mosquitoes like dengue fever, yellow fever and chikungunya might see a shift towards highland areas causing an increase in annual deaths in South America and Africa by 93% in the RCP 2.5 scenario by 2050, (Gaythorpe, 2020; Lippi et al., 2019).

Although evidence of such regional level shifts has been found in several vector-borne diseases including malaria, dengue, trypanosomiasis, yellow fever, chikungunya, and leishmaniasis infecting populations in novel areas, it can also lead to a reduction in the burden of some vector borne diseases (Escobar et al., 2016, Lord et al., 2018). Several recent malarial studies from Africa (where the disease is endemic and responsible for causing extensive loss to human life and socio-economic development) show a shift in the disease occurrence from the lowlands to the highland areas (Ayanlade et al., 2020; Abrha et al., 2019; Tanser et al., 2003; Alemu et al.,2011; Ngarakana-Gwasira, et al., 2016; Leedale et al., 2016). A modelling study in the Tigray region of Ethiopia predicts infected area to shift to the highlands and potentially increase by 93.8%, 113.9%, 161% and 149% in mid-century RCP 4.5, mid-century RCP 8.5, end-century RCP 4.5, and end-century RCP 8.5, respectively due to an expansion of mosquito suitable area (currently at 23.4%) to 45.36%, 50%, 61.2% and 58.3% during mid-century RCP 4.5, mid-century RCP 8.5, end-century RCP 4.5 and end-century RCP 8.5, respectively. This shift is mainly attributed to increases in precipitation during the coldest and the driest quarters of the year (Abrha, H., et al., 2019).

At the same time, climate variations could act as a limiting factor in the occurrence of malaria in certain countries. For example, in a modelling study for the years 2050 and 2100, results showed a decrease in malaria in India, southern Myanmar, southern Thailand, eastern Borneo, the region bordering Cambodia, Malaysia, and the Indonesian islands, and an increase in southern and south-eastern China and Taiwan (Khormi et al., 2016). Another study in Chile on Chagas disease under RCP 2.6, 4.5, 6.0 and 8.0 scenarios shows a potential expanse in the known ecological niche of the two main wild triatomine vectors (*M.spinolai and M.gajardoi)* mainly driven by the rise in temperature with a possibility of facing some restrictions due to host and refuge availability and quality (rocky outcrops, bromeliads or rock crevices) which again were determined by precipitation levels[2] (Garrido et al., 2019).

As ecological niches of diseases evolve regionally, some regions are exposed to new emerging diseases in addition to their existing endemic ones, while others may experience relief due to plausible extirpation. For example, in Odisha, India, since 2010, increased heat events have led to the emergence of other mosquito-borne diseases (dengue, Japanese encephalitis and chikungunya) besides malaria (Karmakar & Pradhan, 2019). However, it must be reiterated that such evolution of ecological niches, especially with rising temperatures, can also lead to range reductions and plausible extirpation of certain vectors as there cannot exceed their physiological upper limits like temperature. It must also be noted that extirpation of one of the many vectors of a disease does not indicate the end of transmission. As an example, results from an ecological niche model in Ecuador forecasted possible range reductions for vectors of arboviruses and leishmaniasis but mixed results for vectors of chagas disease with some vector species *(T. carrioni, T. dispar, R. ecuadoriensis)* declining or facing possible extirpation (*Triatoma dispar* provided no adaptations

[2] Moderate rainfall promotes plant communities and therefore positively affects small rodent population – the host population, but heavy precipitation can create excessively humid microenvironment promoting the growth of entomopathogenic fungus that can kill or injure the vector (Garrido et al., 2019).

to high temperatures occur in the vector) while another expanding its geographical distribution (*T. dimidata)* (Escobar et al., 2016).

Temperature is also a major determinant in the prevalence of zoonotic diseases through its influence on reservoir and vector populations. For example, in the case of plague, non-linear correlations were found between temperature, precipitation, and rodent population in Mongolia through the intermediate variable - vegetation (↑Temperature = ↑Normalized difference vegetation index (NDVI). Rodent habitat[3] and behaviour[4] were also found to significantly influence these relationships (Xu et al., 2015). With climate change affecting soil fertility, farmers may be forced to expand areas under cultivation bringing human populations along with their domestic animals closer to wild animals, raising the risk of zoonotic diseases like Ebola and SARS through pathogen spill over. Increased food insecurity due to climate induced loss of crop yield could force more poor households to turn to bushmeat as an alternative protein source which further adds to the risk of exposure to zoonotic diseases. Zoonotic diseases may also see a shift in prevalence as predicted by a modelling study on zoonotic cutaneous leishmaniasis (ZCL) – a zoonotic disease with a rodent reservoir and spread by sandflies. The results of this simulation showed a shift in distribution within one province in Central Iran primarily driven by annual and seasonal temperature variations (Abdolahnejad et al., 2020).

In water-borne diseases like cholera, pathogens are susceptible to changes in temperature during the environmental stage in their life cycle. For example, the causative agent of cholera, the Gram-negative bacterium *Vibrio cholerae* naturally occurs in aquatic sources like wetlands, estuaries, and stagnant water associated with algal blooms, which increase in warmer temperatures (Patz et al., 2003). Studies show that the highest concentration of cholera pathogens in surface and groundwater is during the hot, dry summer season with warmer water temperatures, increased evaporation, increased salinity, low freshwater discharge (low dilution capacity), increased organic matter (algae blooms) and higher aqueous temperature providing ideal conditions for swifter bacterial replication (Asadgol et al., 2019, Liu et al., 2015; Patz et al., 2003).

Precipitation is also an important determinant of vector-borne diseases through its direct impact on vector mortality (through increased relative humidity) and breeding habitats. For example, an increase in precipitation can have a positive impact on malaria transmission caused by higher mosquito biting frequency because of higher vector density[5] (caused by more breeding habitats) (Janko et al., 2018; Matthew, 2020). However, heavy rainfall can also impact transmission rates negatively immediately after the floods, as breeding habitats may be completely washed out (Boyce et al., 2016). This correlation

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[3] Gerbil density reacted negatively to an increase in vegetation as they prefer desert habitats than dense and high grasses.
[4] Daurian ground squirrel due to its solitary behaviour limiting the impact of fluctuations in their population density on plague transmissibility rate (**Xu et al., 2015**).
[5] defined as number of vectors per host (World Health Organisation)

between heavy rainfall and reduced vector density is also true with plague where the density of the flea vector takes a hit from high precipitation in wet regions, resulting in a decrease in plague prevalence (Xu et al., 2015). It is important to note here that with flooding events, although there might be a drop in malaria or dengue transmission immediately after the floods, there may be a significant increase in the disease incidence rates following the lapse period as new breeding habitats form over a wider area depending on the reach of the flood waters (Boyce, 2016).

Precipitation can also directly impact vegetation density, which protects mosquito breeding habitats and positively influences vector density and transmission rates. A study in Cote d'Ivoire showed a 0.1 unit increase in monthly Normalized Difference Vegetation Index (NDVI) (a commonly used indicator to measure photosynthetic green vegetation and often used as a surrogate variable for precipitation and relative humidity) to increase monthly malaria count by 7.3% (M'Bra et al., 2018). Along with regional or national scale changes in climatic conditions through alterations in temperature and precipitation, land use changes like deforestation can also affect microclimates by increasing or decreasing suitability for vector breeding and as a result modifying transmission risks within the local communities (Labbe et al., 2016).

The transmission of schistosomiasis[6] or bilharzia, a neglected tropical parasitic disease (NTD) with an intermediate host, a freshwater snail that is highly sensitive to temperature and precipitation due to its host's habitat requirements. As a result, it is highly likely that prevalence of this disease and its transmission patterns will undergo changes with the changing climate. A study from Zimbabwe where two of the six known species adapted to humans (*Schistosomiasis haematobium* and *Schistosomiasis mansoni)* causing urinogenital and intestinal schistosomiasis respectively are endemic have shown a downward trend since 1981, which the authors have associated with the local climate shifting towards drier and warmer conditions (Pedersen et al., 2017). However, another study in East Africa show a 20% increase in the infection risk mainly driven by temperature rise by *S. mansoni* over the next 20-50 years in Rwanda, Burundi, south-west Kenya and eastern Zambia with the risk of endemicity expanding to new regions (McCreesh et al., 2015). Warmer conditions have been associated with the distribution of the intermediate host and parasite maturation in China and Africa where 15.4°C and 5.8- 6.4°C were identified to be the thermal minimums for the development of the parasite - *Schistosoma japonicum* and snail host respectively (McCreesh et al., 2015; Stensgaard et al.,2016; Zhou et al., 2008; Yang et al., 2005). A unit called the growing degree-day (GDD), defined as "the amount of heat an organism needs to accumulate to achieve full development" (Yang & Bergquist, 2018: 2) has been used to monitor snail replication and maturation of the schistosome parasite stages inside the snail. Extreme temperature and high rainfall can also be linked to the increase in

[6] Number 3 in global burden of disease after malaria and tuberculosis in 2010), prevalent in subtropical and tropical areas (78 countries in Africa, Latin America, the Middle East, and Southeast Asia) with at least 90% of the infected requiring treatment living in Africa (CDC, 2018; WHO, 2021)

infection rate due to increased use of rivers and streams for recreational activities like swimming, washing, and bathing (Codjoe & Larbi, 2016). Modelling studies suggest a potential for larger than regional or national geographical expansion (Yang & Bergquist, 2018) because of rising temperatures which is further re-affirmed by the identified cases of *Schistosomiasis hematobia* in Portugal, Spain, and France (Berry et al., 2014).

It is also important to recognise that the influence of a variable can vary with type of disease, season, and geographical location. For example, a study in Nigeria shows a stronger correlation between temperature and meningitis than temperature and malaria in the northern dryer Sahel region than the southern part of Nigeria (where malaria is more prevalent) with higher meningitis occurrence during the dry season than the wet season (Ayanlade et al., 2020). On the other hand, in malarial studies in highland areas in Ethiopia (Abrha et al., 2019), temperature plays a more dominant role than precipitation in determining malarial transmission. Karmakar & Pradhan's study in Odisha, India found the distribution of four mosquito-borne diseases to vary according to their geographical location within the country with higher prevalence of dengue and chikungunya in coastal areas and malaria and Japanese encephalitis in highland plateaus (Karmakar & Pradhan, 2019).

One or a combination of variables can also directly and indirectly affect the function and impact of another variable on human health. Relative humidity, a product of temperature and precipitation, has an essential role in malarial and dengue transmission rates through its impact on mosquito mortality rates. Studies showing significantly higher mortality of the vector at low levels of relative humidity (<20%) and higher daily survival rate with higher humidity levels at a constant temperature (Matthew, 2020). Daily hours of sunshine (another variable for vector-borne diseases) can also influence mosquito density and breeding habitats by regulating surface temperature and evaporation rates (Tran et al., 2018).

Water-borne diseases are especially sensitive to changes in precipitation as it can directly influence its transmission in two ways. High evaporative loss coupled with low precipitation can increase the concentration of pathogens in water (fecal coliforms, *Escherichia coli* and *Vibrio Cholera*) and further elevate the chances of environment to person transmission risks. On the other hand, heavy rainfall or floods can increase the risk of human to environment transmission by the mixing of treated or raw water with contaminated water resulting in the increase of total suspended solids (TSS), and other biotic pathogens in water (Asadgol et al., 2019; Alexander et al., 2018; Guo et al., 2019; Labbe et al., 2016). For example, results from a study in Chobe River in northern Botswana using data from 2011-2017, showed the occurrence of two regular outbreaks during dry and wet seasons, with 1m drop in river height during the dry season corresponding to an estimate of 16.7% increase and a 10mm increase in rainfall during the wet season corresponding to an estimated 6.5% rise in under-5 diarrhoea cases despite an existing water treatment facility in operation. This study demonstrates the potential impact of climate induced increase in rainfall variability (through floods and droughts) in exacerbating vulnerability in populations with high surface water dependence (Alexander et al., 2018).

In times of water scarcity, especially in arid and semi-arid regions of the world, inhabitants are forced to use contaminated and untreated water from shallow wells, open surface water sources for drinking, domestic purposes, and irrigation despite the risk of suffering from acute diarrhoea (from cholera, norovirus, fecal coliforms) and mortality with trickle-down effects on livelihoods (Asadgol et al. 2019).

Meningitis is another deadly disease highly susceptible to climate change due to its sensitivity to relative number of aerosols ("solid and liquid particles suspended in the atmosphere influenced by the action of wind and precipitation/ITCZ") which along with temperature (see above) can significantly influence transmission of meningitis in meningitis prevalent areas such as the "meningitis belt" (Gambia to Ethiopia) in Sub-Saharan Africa (Ayanlade et al., 2020).

Lag time is another important variable, especially in detecting diseases caused by bacterial and viral infections as transmission risk can vary due to several other biological factors like vector life cycle, parasite extrinsic incubation rates, development of breeding habitats. For example, as mentioned in the extreme weather subsystem, malaria incidence rates drop immediately after high rainfall or flood events but rises exponentially following a lag period of approximately two weeks as stagnant pools are created by the receding flood waters (Sena et al., 2015). Another study on cholera infections in Iran also showed a lag time of 21 days which the author linked to time taken by pathogen to grow, exposure to infections, incubation period of parasite, disease detection and delayed report (Asadgol et al., 2019).

Temperature and precipitation can also lead to alterations in the lengths of the disease transmission seasons as shown in two studies from India suggesting an increase in malaria (Chaturvedi et al., 2021) and dengue seasons with the possibility of the latter to stretch by at least 2 months in many regions of the country with coastal states facing year long transmission making control measures very difficult and cost intensive (Kakarla et al., 2020, Karmakar & Pradhan, 2019).

While climatic parameters induce an increase in the transmission of infectious diseases like malaria through more conducive environmental conditions, demographic, and socio-economic and cultural factors like age, sex, income, access and affordability to healthcare facilities, affordability of preventative measures like mosquito nets, household education levels and awareness of climate change induced rise in communicable diseases, personal hygiene and household sanitation levels can significantly augment exposure mechanisms and influence severity of the risk in vulnerable populations (Lubinda et al., 2021). Level of income in a household determines its capacity to afford preventative measures like mosquito nets or sleep in "pakka" (well-finished) houses, which lowers or heightens the exposure risk to mosquito or other insects' bites. Income also determines a household's affordability in terms of healthcare facilities.

In addition to income, access to healthcare also depends on remoteness of location and proximity to hospitals and clinics. Local topography can also impact access to healthcare, as despite shorter distances, adverse terrain like dense forest or steep slopes can increase difficulty of access (Labbe et al., 2016). Unavailability of local healthcare facilities will impact the overall population negatively, but with a potential to harm women and children more than male adults due to their limited mobility.

Education plays an important role in the level of knowledge and awareness about communicable diseases and climate change which influences preventative measures and practices related to disease prevention and control at the household level as seen with dengue in Rahman et al. study in Lao People's Democratic Republic and Thailand (Rahman et al., 2021; Mayala et al., 2015). Another study in the highlands regions of southwestern Uganda reported people refusing to believe or accept the connection between rising mosquito prevalence and increasing malarial rates (Labbe et al., 2016).

Age is an important determinant in climate related communicable diseases, with children (infants and toddlers) being more susceptible than adults to diseases like malaria and diarrhoea (both potentially fatal in the age group under 5) (Odunola et al., 2018; WHO, 2020). In 2018, a study by Dasgupta suggested that children have a lower global optimal temperature threshold for malaria (19.3 degrees Celsius) than adults (20.8 degrees Celsius) and are therefore more susceptible to malaria caused mortality in the global warming scenario than adults (Dasgupta, 2018). However, a study in Zambia observed a consistent shift in malarial incidence in population aged ≥5 years from those aged under 5 years mainly driven by higher exposure to the vector through everyday activities in high-risk environments like fishing, farming, and attending schools and spending evening times outdoors which is peak biting time for the female *Anopheles* mosquitoes. Furthermore, adults are also less likely to sleep under mosquito nets than children, which magnifies their risk of exposure (Lubinda et al., 2021).

Poor sanitation in or around households like open waste disposal and stagnant water pools can provide breeding habitats for mosquitoes raising the risk of transmission through increased vector density and biting frequency. Poor sanitation in terms of using one surface water source to wash animals, bathe, clean cars, and motorcycles and for drinking water can be a highly likely cause for GI diseases (Labbe et al., 2016).

Comorbidity is another important variable that should be considered when planning public health interventions. For example, in the Chobey plains of northern Botswana there is a high prevalence of diarrhoea in the under-5 population, but the same region also suffers from high HIV burden which makes the infected individuals immunocompromised and also in need of diarrhoeal disease surveillance and intervention strategies (Alexander et al., 2018). Malaria and HIV is another classic example as both diseases are rampant in the developing world with HIV infections increasing the risk of the severity of malaria infections in patients (Alemu et al., 2013). Comorbidity also showed a positive association with perception levels of climate-related health risks in a cholera-malaria comorbidity study in (Boamah et al. 2017)

There were fewer articles on noncommunicable diseases than communicable diseases in the climate context, mainly due to the focus on rural regions where urban climatic issues like poor air quality or heat islands are non-existent. Ozone, heat related stress and kidney diseases, dehydration, micronutrient intake related diseases and mental illness were some of the climate-related noncommunicable diseases identified in the rural context. Increased mortality from ground-level ozone and fine particulate matter (PM 2.5) has been projected to increase globally other than in Africa, particularly in India and East Asia which is facing the burgeoning pressure of increased urbanization (Silva et al., 2017). In non-industrialized rural locations, there is a rising prevalence of heat-stress and UV radiation related illnesses associated with climate change, which may be due to decreased cloud cover and increased exposure (Barnes et al., 2019). Studies from coastal Ecuador, Andean regions and Upper West Region of Ghana reported a higher incidence of kidney diseases and skin cancers in farmers and hawkers who were regularly exposed to high heat and direct sun for prolonged periods of time (Arjona et al., 2016; Ephraim, 2020). Besides the period of exposure, the level of heat will potentially become greater with the current projected rise in temperature, adding to the severity of the illnesses. According to Johnson et al. (2016), the rise of kidney and metabolic diseases in agricultural workers could be caused by a survival mechanism where the human body reduces water loss by over-activation of survival pathways through releasing hormones like vasopressin and metabolic products like uric acid and fructose (Johnson et al., 2016). Additionally, the lack of drinking water (in areas with low precipitation levels), lack of awareness of such climate induced illnesses resulting in poor or no preventative measures and lack of access to healthcare and medical consultations could potentially worsen the severity of such environmentally driven emerging health issues.

Climate change has been associated with lower dietary selenium (Se) (Jones et al., 2016) intake - an essential micronutrient with deficiencies causing cardiomyopathy, congestive heart failure, impaired intestinal function (Smith et al., 2017). Dietary selenium mainly depends on soil Se concentrations which might be lost (upto 58% as shown in this study) through increased leaching due to changes in soil aridity [7] (Jones et al., 2016).

Another significant indirect health risk of climate changes also discussed in the above three subsystems is mental illness with studies showing climate related livelihood stress causing an increase in suicidal

[7] "The aridity index (AI, unitless) [i.e., the ratio of potential evapotranspiration (PET, mm/d) to precipitation (mm/d)"]; precipitation (mm/d) and evapotranspiration (ET, mm/d) (Jones et al., 2016).

tendencies, increased drug use, conjugal stress, alcohol consumption, and degraded human capacity to cope with trauma (Kabir, 2018).

Gender specific analysis

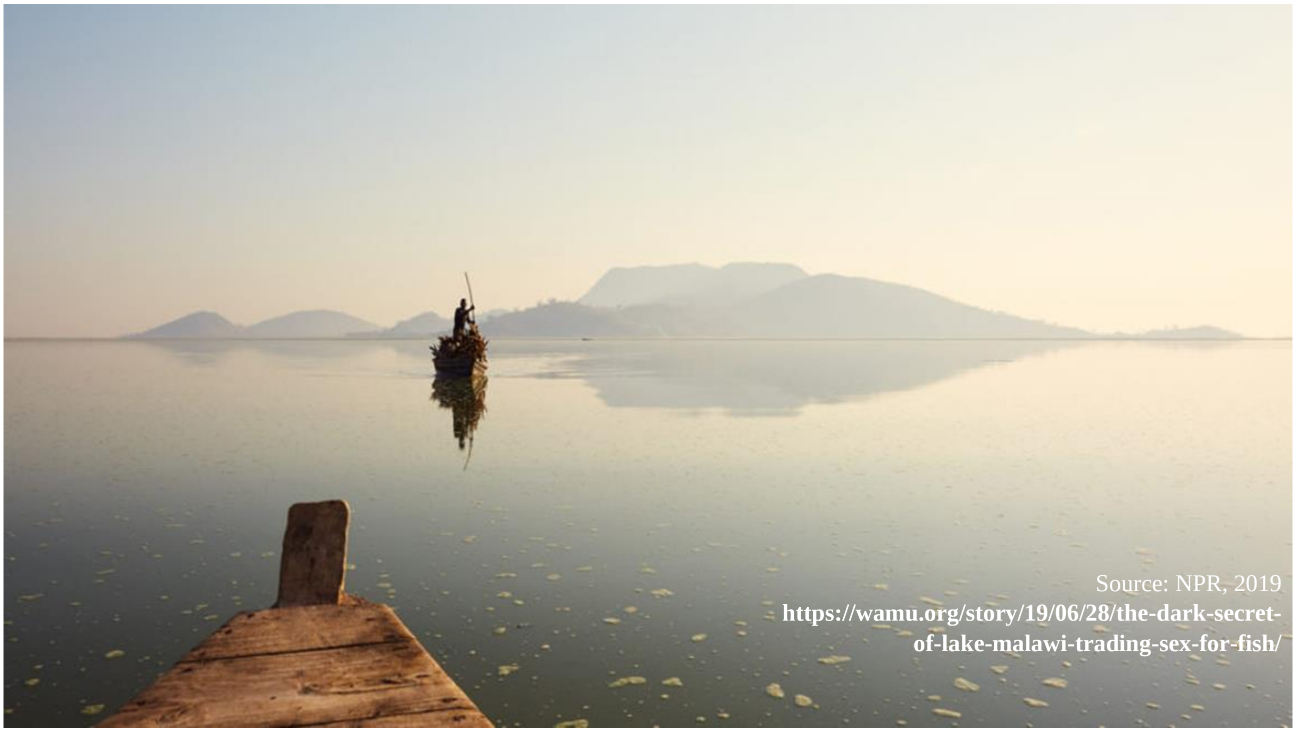
Gender roles plays an important role in this scenario as most farmers in the Global South are male and considered to be the primary breadwinner. Any loss of labour capacity could have a trickle-down effect and impact the entire household through income depending on number of dependants, livelihood diversity, number of working household members, land ownership, crop value, and access to credits, loans, and other extensional services. The most negatively impacted household member in such a scenario is the female head of the household who inherits not only her husband's responsibility but also the responsibility of caring for her sick spouse with less access to resources than her husband. As mentioned under the EW subsystem, gender roles hold women as custodians of domestic hygiene restricting their movement during and after floods increasing their vulnerability to communicable diseases like cholera and malaria (Buyana et al., 2019).

Pregnant women are extremely susceptible to extreme heat with prolonged exposure associated with potential adverse pregnancy outcomes like miscarriages and still-births (Asamoah et al., 2017). Other noncommunicable diseases such mental stress and anxiety, malnutrition, and dehydration and their link to gender have been discussed in the previous subsystems – food security, ecological services, and extreme weather.

4.3. Summary

Multiple social, economic, and environmental factors interact non-linearly to shape human health and well-being. The complex nature of these factors requires a holistic approach to understanding and a context-based application. In the next chapter, identified variables from Component 1 and 2 will be applied to the Lake Chilwa basin to identify gendered health impacts of climate change in a specific spatial context.

Chapter 5: Application to the Lake Chilwa Basin



5.1. Introduction:

In the following chapter, the four subsystems will be discussed in the context of the Chilwa basin with the aim to identify variables and their direct and indirect roles in defining health impacts of climate change from a gender perspective. Results of the systematic literature review (refer to methods (Chapter 3) will present the status of research on the topic. Findings from Components 1 and 2 will fill in the gaps that may arise from the systematic literature review and suggest new variables and correlations that could be further investigated to better establish the pathways through which climate change does or may affect the health and well-being of the men and women living in the basin. The chapter starts with a brief history of the lake and how it has changed over the years and continues to present its current conditions and how they might change in the climate change scenario and their associated health impacts. The chapter ends with suggested points of intervention to breach the gender gap between males and females and provide equitable conditions for both genders to better adapt to the impending climatic changes and improve their current health conditions and withstand any future risks that may come with climate change.

5.2. Results of the Literature review

90 articles were identified through the systematic research review that met the inclusion criteria for Component 3. The findings show the popularity of the lake amongst limnologists due to its unique physico-chemical properties, history of periodic dry-outs and vulnerability to climate change. Out of the 90 articles, only 11 were directly related to health issues in the region, with most of the articles focussed on cholera. Only 5 articles were dedicated to gender, with all five focussed on fisheries. Majority of the articles were focussed on the physical and biological changes in the lake caused by the fluctuations in lake water and its resulting impacts on fisheries. 35 hand searched articles including grey literature were also used to further re-affirm the mechanisms discussed below and to further gain a better perspective on the lake's history and projected future climatic changes.

5.3. History

Lake Chilwa, originally an open freshwater lake (connected to Lake Chiuta, the Lugenda River and finally Indian Ocean) until the late Pleistocene was radically transformed into a shallow saline closed lake by a 25 m sandbar formed by multiple spits across the northern end of the lake in the early Holocene period. (Lancaster, 1979 & 1981). Multiple major and minor streams feed the lake, the most important being Domasi, Likangala, Phalombe, Sombani and Mnembo (Jamu et al., 2003). When the lake was initially formed, it was 33.5m higher (Wilson, 2014) than its current level (2.7m) (ILEC, 2021). The lake is asymmetrical with the permanent swamp in the north and north-west being fed by smaller streams and the perennial rivers feeding the southern open water sector (Kalk, 1979). Lake Chilwa has two distinct seasons, cool and dry (April to November) and hot and wet (December to March) (Howard-Williams & Walker, 1974; Jørstad & Webersik, 2015; Njaya et al., 2011). The lake is the shallowest in November and December and deepest in April, May, and June (Kalk, 1979). Like many other closed tropical lakes around the world, the periodic fluctuations in water level are a salient feature of the hydrology and biology of Lake Chilwa (Cantrell, 1981; Lancaster, 1979; McLachlan, 1979) and has significant impacts on all that depend on the lake for sustenance. Earlier studies have reported daily

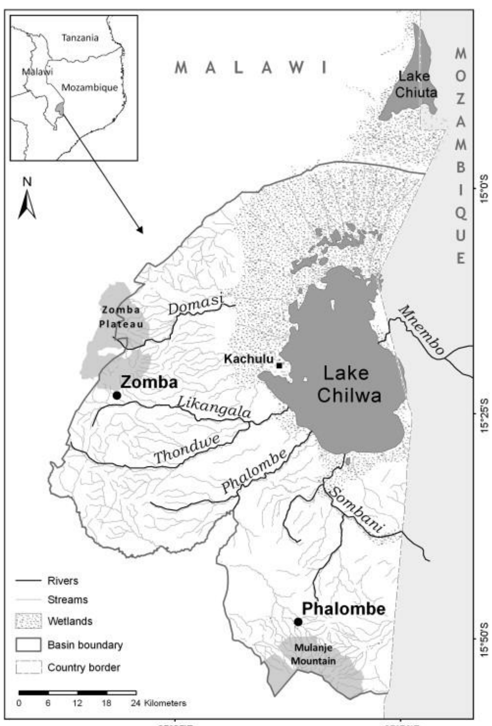


Figure 11 Major rivers feeding Lake Chilwa basin. Source: Njaya, 2011

evaporative losses as high as 5mm (Morgan, 1972) with seasonal fluctuations anywhere from 0.8m-1m (partial recession) and occasional complete dry outs (2-3m). (Lancaster, 1979).

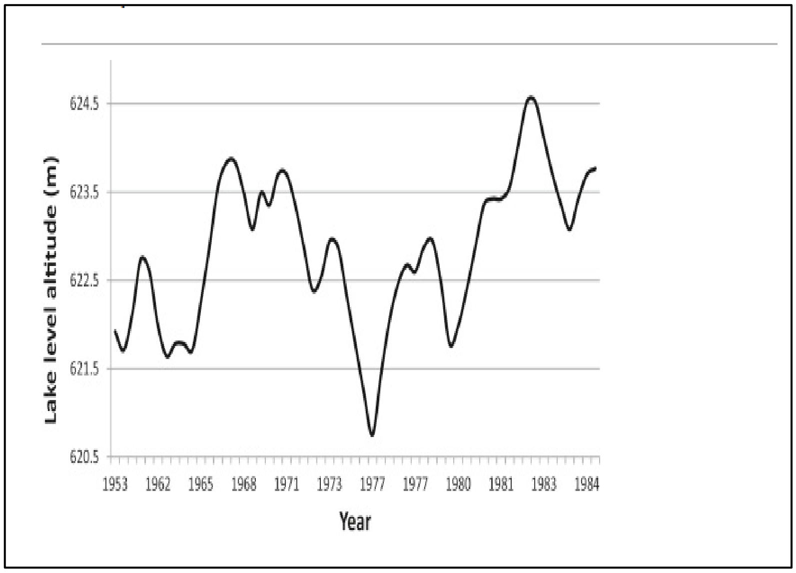


Figure 12: Water Level Fluctuations in the Lake Chilwa, 1953–1984. ***Source**: Nkhoma & Kayira, 2016*

The lake is surrounded by a littoral swamp comprised of *Typha domingensis* (due to its alkaline, brackish nature (Howard-Williams & Walker, 1974) and not *Cyperus papyrus* (more common in acidic waters), which is more commonly found in the swamps of other tropical lakes in Africa (Howard-William, 1979). The swamp differs in physical and chemical condition than the open lake (Howard-William & Lenton, 1975). The high salinity of the lake during the low water periods restricts the Typha to the periphery of the lake preventing the lakebed to be overly colonised, and therefore maintaining the open water section of the lake throughout the year, albeit with a considerable loss of water volume (Howard-Williams, 1975). The Typha swamp (controlled mainly by water depth gradient, salinity, and disturbance) (Howard-Williams & Walker, 1974) acts as a nutrient pump by absorbing nutrients (sodium (Na), phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K) and nitrogen (N)) from the soil and then pumping them out in the lake and therefore a very crucial regulator of nutrient and pollution levels in the water of Lake Chilwa (Howard-William & Lenton, 1975 & 1978).

The potential of the lake as a source for commercial fishery was identified as early as 1963 when the lake was reported to produce at least 9000 tonnes wet weight of fish (Furse et al., 1979). The lake has in the past produced almost half the total catch of fish in the country when its water levels were significantly high (1979 and 1990 with 24,310 tons and 23,559 tons respectively) (Morgan & Kalk, 1970; Wilson, 2014)

As per Furse et al.'s (1979) article, two scholars-Hickling and Lowe in 1942 and 1952 respectively had identified the condition of the lake and its water levels to have a major influence on fish catch and alluded this to two things - difficulty of fishing and high alkalinity of waters rendering it unsuitable for many fish species (Furse et al., 1979). Other earlier studies have identified turbidity, water colour, light intensity, and high alkalinity to be some of the major limiting factors in the lake's productivity (Bruton, 1985, Furse et al., 1979; Moss & Moss, 1969) which are change considerable with fluctuations in the lake water level.

Scholars have associated the relation between high water levels to high productivity through the increased availability of diatom crops at the bottom of the lake (Moss & Moss, 1969); inundation of the lake's northern marshes with all the cattle dung (from herding during the dry season) providing a rich nursery and habitat for fish, opening more area for fish production and fishing, and drowning and killing the Typha bushes releasing large quantities of nutrients from the organic matter into the open waters (Wilson, 2014).

At lower levels, besides an increase in alkalinity and salinity (due to lower dilution and higher evaporative loss) (Morgan & Kalk, 1970) in the lake's water, wind action can also resuspend the bottom sediments causing high turbidity in water affecting feeding efficiency of fish by restricting them to pelagic and inshore food resources and causing fish mortality through deoxygenation of water column (Bruton, 1985). Morgan & Kalk indicated conductivity of the lake to increase by 3 times in 1966 and 4 times in 1967, both after extreme dry out periods.

In the 1966-67 period, *Tilapia shirana chilwae*–a species endemic to the lake experienced high mortality rates as oxygen levels in the lake water fell below 0.6 mg/l, suspended matter from the lake bottom erosion reached above 12,860 ppm and alkalinity reached 61.6 meq/l. Morgan further explained that, despite Tilapia having high tolerance to heat, alkalinity, low oxygen levels, the extreme water temperatures in the lake reduced the fish's resistance to these other environmental stressors[8] (Morgan, 1972).

The shallowness of the lake also assists in the wind-driven water turbidity and salinization through quicker evaporative loss (Talling, 2001). The lake's physico-chemical conditions with the high availability of nitrogen and phosphates also make it prone to eutrophication which increases the algae cover on the surface waters cutting sunlight penetration to the bottom of the lake diminishing vegetation growth and thereby increasing the risk of deoxygenation (Macuiane et al., 2011). During recessions, as the Typha bushes decline in density and discharge nutrients, the water becomes overloaded with nutrients and as more surface area get exposed to the daylight, photosynthesis rates are enhanced aiding proliferation of algae blooms that aggressively cover the surface waters. As the algae decomposes, the available oxygen is used up causing further deoxygenation in the lake waters (Macuiane et al., 2011). Another study in 1969 also reported the loss of organic matter, phosphorus, and exchangeable sodium (Na) in lake sediments at low lake levels as

[8] Temperature and salinity alone cannot be the cause of mortality as T. chilwae can resist up to 42 degrees, but the two can reduce the species' resistance to other stress factors like high alkalinity and deoxygenation (Morgan, 1972).

a result of exposure to environmental like wind and sunlight to be responsible for low benthic communities (food sources for fish) which could challenge faunal re-colonisation capacity when water levels start to rise (McLachlan & McLachlan, 1969).

The area saw an influx of population due to a rise in its economic value, untapped natural resources during the national economic crisis of 1980s. In terms of fisheries management in Lake Chilwa, none existed, and fish was considered to be a "free good" available to anyone and everyone without a requirement of any license (Mvula & Haller, 2009, Agnew & Chipeta, 1979). In 1979, both small and large enterprises exploited the lake to their maximum ability as allowed by their fishing gear (ranged from basket traps, nets, spears to sophisticated gills or seine nets and fish), size of enterprise and means of livelihood (primary or secondary source) (Agnew & Chipeta, 1979). Scholars now attribute this continued unsustainable use of the common pool resources till date with fragmented management efforts that have remained unchanged since colonial times and as a result lacks integration between wildlife, agriculture, fisheries, and water departments (Mvula & Haller, 2009; Njaya, 2009).

5.4. The lake today

In the past few years, Lake Chilwa has seen both a delay and an inconsistency in the onset of its rainy season, which is also progressively getting shorter. For example, in 2011-2012, the rainy season started at the end of December (almost 2 months later than usual) and ended in February instead of March, and was frequently disturbed by periodic dry spells (Jørstad & Webersik, 2015). Although the lake has dried up to 8 to 10 times in the last century (1882, 1903, 1913-1916, 1922, 1934, 1943, 1948, 1968, 1973, and 1995 (Wilson, 2014), recent changes in extreme weather has altered the rhythm of the lake making the dry out events more frequent (Guardian, 2021).

With the lake being shallow, it is prone to drying and has taken about 1-2 years to refill and 3-4 years for fishery to recover (Jørstad & Webersik, 2015). A prominent Malawian environmental scientist Dr. Sosten Chiotha who has been studying the lake for 27 years attributes the recent changes to repeated low rainfall events induced by climate change and further elaborated that if during three consecutive rainy seasons precipitation levels are below 1000mm the lake is most likely to dry up (Guardian, 2021; Africa News, 2021). Another recent study conducted in 2021 suggested that the frequent lake dry outs are most likely triggered by the lake's lowered thresholds for dry up caused by increased anthropogenic pressures as the recent dry ups in 2012 and 2015 were caused by milder droughts as not all El Nino Southern Oscillations (ENSO) during that period caused lower rainfall in the region as opposed to previous dry outs that were mostly triggered by extreme drought events (Dulanya et al., 2013; Nash et al., 2018; Kambombe et al., 2021).

Malawi sits in the middle of two opposing climatic responses to El Niño contrasting regions–(south-eastern Africa that receives lower than average rainfall and is projected to experience drier and extreme droughts and the eastern equatorial Africa that receives more than average rainfall and is projected to experience more favourable conditions). This has caused ambiguity in the country's climate projections, with some models suggesting higher rainfall and others showing opposing climates in the northern and southern regions of the country (Johnson et al., 2016; Jørstad & Webersik, 2015; Nicholson et al., 2014). The level of Lake Chilwa is determined by rainfall in the catchment and on the lake itself (Wilson, 2014) and both temperature and rainfall play important roles in determining the lake's water levels. However, some uncertainty remains as to which out of the two have a greater influence with some studies proposing precipitation playing a more significant role than temperature and others showing no significant changes in precipitation but a significant rise in temperature over the next 40 years at the country level (Jørstad & Webersik, 2015; Morgan, 1972; Moss & Moss, 1969; Kambombe et al., 2021). Overall, at the country level, there is a consensus of an upward trend in temperature (1.1 to 3.0 ◦C by the 2060s and further by 1.5 to 5.0 ◦C by the 2090s) and downward trend in long-term precipitation levels with shorter periods of heavy rainfall with some potential variations at the regional level (Jørstad & Webersik, 2015) which might apply to Lake Chilwa. As per some studies including the 2007 IPCC report, the region will most likely see an increase in temperature by 2.6-4.7 degrees by 2075 and as a result will face a threat from decreased water resources (IPCC, 2007; Schuyt, 1999).

With the shifting of the lake towards more frequent dry-outs and the reported lowered threshold of the lake, the question is no longer if but when will the lake dry out and if the poverty-stricken inhabitants of the basin be ready to adapt in time?

5.5. Rich Picture

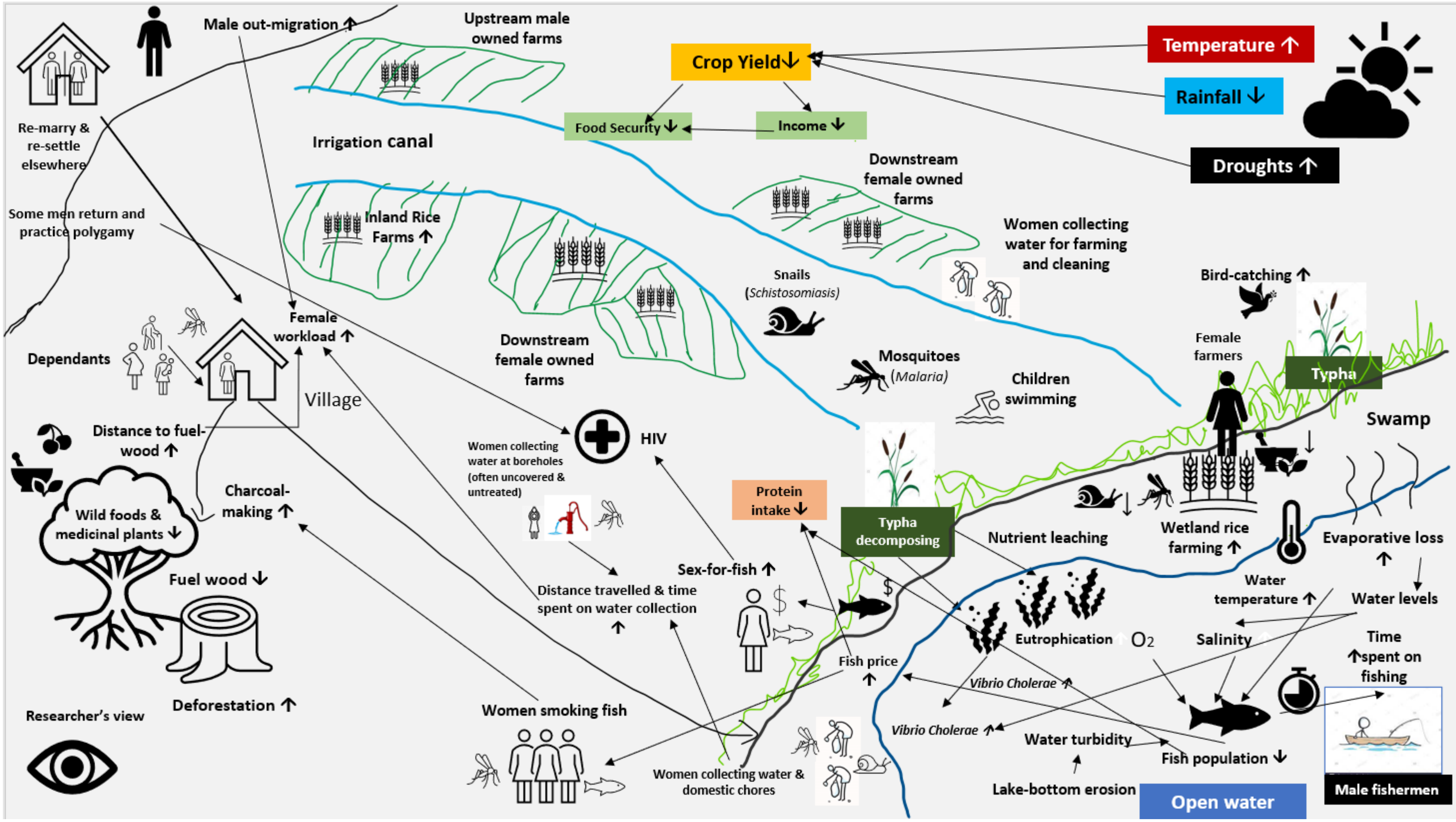


Figure 13: Rich picture of the Lake Chilwa basin in the climate change scenario

Rich Picture Explanation:

Figure 18 is a rich picture of the Lake Chilwa basin in the climate change scenario. The rich picture has been created with the purpose of illustrating the ecological changes that may take place in the lake and its basin as a result of climate change and its resulting impacts on the basin's inhabitants.

Climate induced increase in temperature, decrease in rainfall and more frequent droughts will lead to increased and more frequent lake dry out events. In the event of a recession, and ongoing evaporative loss of lake water, lake water levels will drop, resulting in increased water salinity and alkalinity. Due to reduced water depth, wind induced lake-bottom erosion may increase, leading to an increase in water turbidity. Increased air temperature and lack of water may cause the Typha bushes to die, resulting in nutrients leaching from them and into lake waters. Increased nutrient levels may enhance eutrophication levels in the lake and result in the covering of the water's surface with algae. Lack of light penetration into the lake waters due to increased algae cover may negatively affect fecundity of aquatic plants and gradually create hypoxic (lack of oxygen) regions in the lake. Increased water turbidity, water temperature, salinity, and decreased levels of water and oxygen may cause a decline in fish population. Increased water sediments and organic matter due to eutrophication and the rise in water temperature provide an ideal ground for swifter replication of *Vibrio Cholera,* increasing the concentration of the pathogen in water. Reduced lake water volumes also lead to the decrease in dilution and result in the increased exposure to the pathogen.

Reduced fish productivity will affect the male and female fishermen differently. Male fishermen who are primarily involved in fishing out in the lake may be forced to spend longer periods of time, which will increase their risk of cholera due to low sanitation and hygiene facilities. Additionally, due to being away from the shore for extended periods of time and may miss anti-cholera vaccination campaigns, increasing their susceptibility to the disease as compared to the women (*not represented in the rich picture*).

Women who are mostly involved in low-value chain activities like fish-smoking and processing will find it more difficult to buy fish from the fishermen due to increased fish price caused by the decline in fish yield. This will directly affect their income, which they might try to supplement through maladaptation like using transactional sex to pay for fish. This will increase their risk of being infected by HIV as culturally men prefer unsafe sex and are willing to pay extra for it *(not represented in the rich picture).*

Lack of fish may also force women to wait for longer periods of time and make frequent trips into the lake (due to receding lake waters) walking in muddy waters while carrying their babies on their backs. This may increase their accidental exposure to cholera infested waters and heat stress while waiting for boats *(not represented in the rich picture)*. Due to the stationary nature of fish smoking, women may be sitting in one position for extended periods of time, increasing their exposure to mosquito bites and therefore malaria.

Reduced fish may also affect their protein intake and undernutrition directly due to lack of consumption and indirectly through reduced purchasing power *(not represented in the rich picture)*.

Male out-migration, an age-old common practice in the region, may increase further due to a decline in fish catch. Male out-migration leads to women forced to fend for themselves and the household with all its dependants, including the aged and the sick. With increased workload in and out of the household, women suffer from time-poverty, increased physical labour and mental stress affecting their overall health negatively. Due to increased out-migration in the past, a shift in the division of labour has put women in charge of agriculture, which is an added exposure to increased workload as worsening environmental conditions will require them to spend extended periods of time labouring in the farms. With a decrease in crop yield due to reduced rainfall, women's sustenance will be affected negatively through reduced food availability and income. Although women enjoy matrilineal land rights, they are often deprived of other agriculture resources and are allotted land in downstream locations. The latter affects them negatively through reduced water availability from irrigation canals during the dry season and crop damage during the wet season as the male upstream farmers discharge excessive amounts of water. This affects their crop yield and levels of incomes.

Males who out-migrate may also re-marry and re-settle elsewhere, leaving women deprived for the rest of their lives as they are not allowed culturally to re-marry or access their husbands' properties. Some men come back and practice polygamy with multiple wives from multiple villages, exposing their wives to HIV as condoms are reserved for riskier extra-marital partners. Polygamy may also lead to increased conjugal conflicts with the men ultimately leaving the women for good (*not represented in rich picture*).

Gender roles assign women in Lake Chilwa to be the primary water and fuel-wood collectors in the household. With decreased crop yield, the basin's inhabitants expand the land under cultivation, leading to deforestation and reduced availability of fuelwood. This forces women to travel further into the forest and spend longer collecting wood, which they require for smoking fish, domestic chores and for selling. Reduced fuelwood may force women to engage in maladaptation like charcoal-making, causing further deforestation.

Deforestation also leads to the loss of wild fruits and vegetables, a supplementary source of food for households. Women who are the primary food providers in the household are forced to rely on store-bought foods, which affects them mentally, as nutrition quality is one of their primary concerns. Receding lake waters also increases access to the wetland, where rice farming is increasingly being practiced. As a result, medicinal plants that grow on the wetland are facing risk of extinction affecting women's traditional source of livelihoods and incapacitating them to use traditional medicines to cure the sick who may not have access to clinical healthcare due to fund limitations. Therefore, lack of medicinal plants affects women economically as well as mentally, due to the inability to fulfill their social duties (curing the sick). Increased rice farming is also encouraging the malpractice of bird-catching, as more birds are attracted to the rice grains providing ideal hunting conditions.

Receding lake waters also forces women to walk longer and wait longer to collect water, which may limit their time to engage in other productive tasks and therefore traps them in their current state of poverty. Women may also feel unsafe, which may affect their mental health and well-being *(not represented in rich picture)*.

Women are also exposed to vector-borne diseases like malaria and schistosomiasis due to their daily activities, occupation, and care-taking burden. Children have the highest risk of schistosomiasis due to their recreational activities, like swimming and playing in the irrigation canals, which also increases their mothers' exposure to the disease mainly due to unawareness. Females also frequently use canal waters to perform domestic chores like cleaning and laundry and collect water for irrigation during the dry season, which increases their risk of exposure to schistosomiasis (spread by snails) and malaria (spread by mosquitoes). Malarial mosquitoes prefer stagnant water to breed, which the irrigation canals provide during the dry season as the flow of water reduces. Women are also the primary farmers, and the snail population was found to be the highest in the wetland during lake dry outs. Women may also be exposed to snails and mosquitoes while collecting water from the lake.

5.6. Influence Diagrams

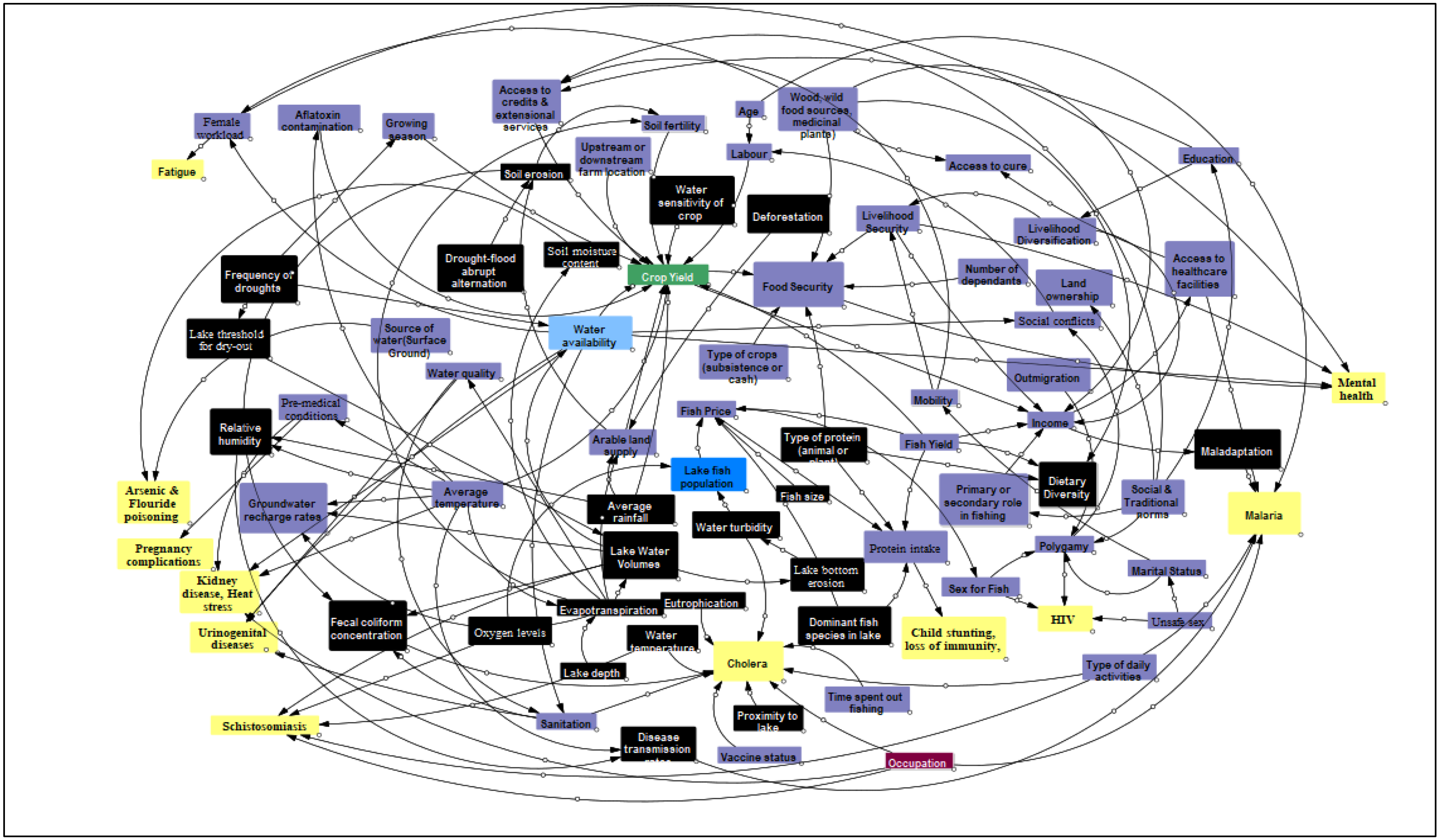


Figure 14: Influence Diagram representing health impacts of climate change (not gender specific) in the Lake Chilwa basin. The above influence diagram represents the multiple interactions between the variables of health impacts of climate change in the Lake Chilwa basin. The purple boxes represent gender sensitive variables (direct & indirect), and yellow boxes represent the different health impacts.

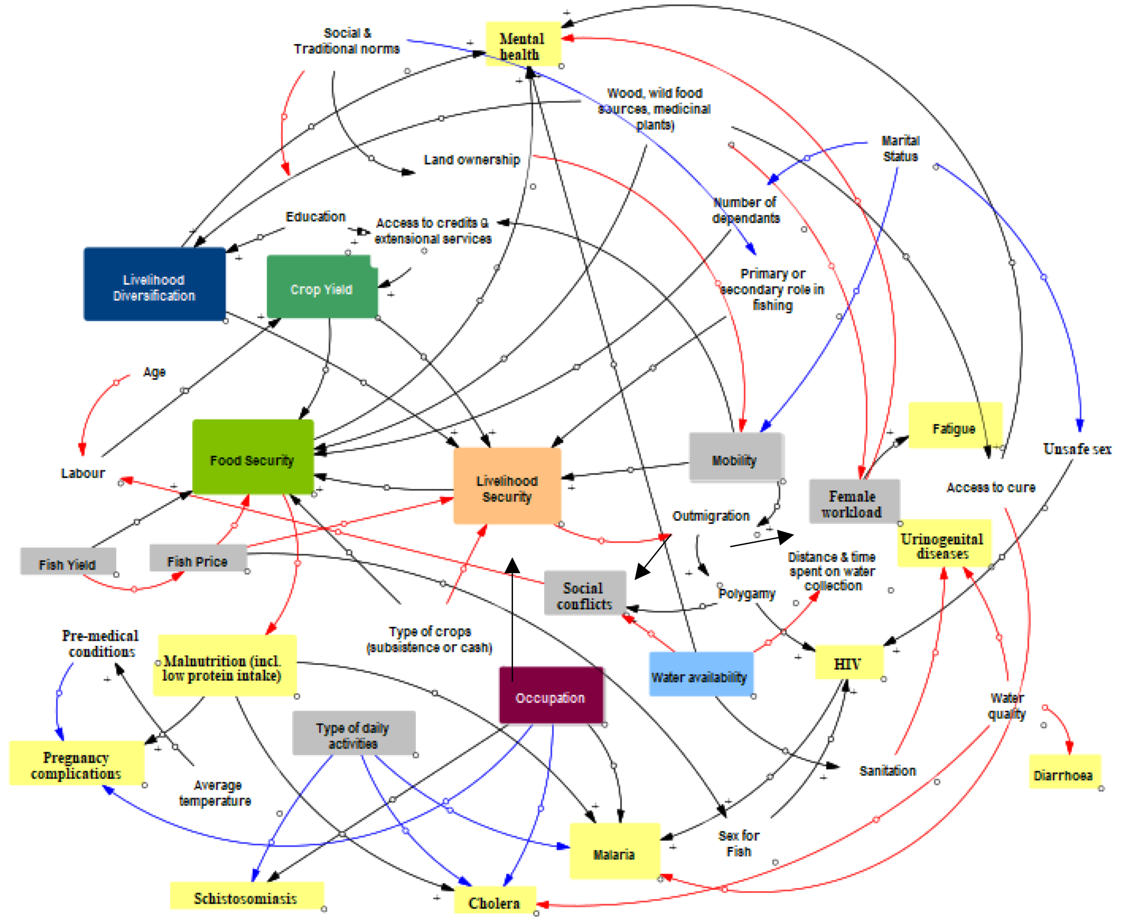


Figure 15: Gender specific health impacts of climate change in the Lake Chilwa basin.
Note: Only the most direct interactions have been used to create this influence diagram. The red arrows show a negative correlation between the variables and health impacts and between variable to variable. The black arrows show positive correlations. The blue arrows show a general link without any positive or negative correlation as they are not quantifiable. The multiple-coloured boxes (variables) are used to enhance aesthetics. The yellow boxes show the different gender specific health issues in the basin.

Table 4: Details on the links shown in the Influence Diagrams					
#	**Variables**	**Gender link**	**Explanation**	**Exposure (**	**Health Impact**
1	Anti-cholera vaccination status	Men have a higher tendency to be partially vaccinated, making them more susceptible to the disease	Men are not fully vaccinated against cholera and are therefore more susceptible to the disease than women	Drinking contaminated water	Cholera
2	Aflatoxin contamination	Women are primarily involved in farming activities facing higher threats to livelihoods	Aflatoxin risk is higher in drought prone conditions =loss of crops Crop damage = livelihood insecurity Consumption of contaminated grains	Consuming contaminated food	liver cancer, growth suppression, immune system modulation poor health (general)
3	Age	Elderly women fall in the lowest economic bracket and also are less able to work = highest vulnerability to climate change	Elderly women fall in the lowest economic bracket. Elderly women cannot work in farms and fisheries = lack of income. School-aged children's recreational activities (schistosomiasis). Children under 5 more susceptible to malaria due to low immunity.	Recreational activities (swimming, playing in canals)	Schistosomiasis, malaria,
4	Arable land supply	Women are more involved in farming than men.	Might increase with increased access to wetland area. More arable land = more crop yield=more income (women are more involved in farming so might benefit their household income) Poor soil conditions due to less rainfall might deteriorate farming in farms located inland. Loss of arable land due to low soil fertility can negatively affect income,		
5	Availability of wild fruits & vegetables	Women are the primary food providers in households and loss of wild fruits and vegetables affects them more than men.	Will decrease with increased deforestation Loss of supplementary food (women are the primary food providers, so this affects their mental health)	Inadequate food intake	Malnutrition, mental anxiety
6	Availability of wild medicinal plants	Women sell wild medicinal plants for supplementary income and are therefore more affected than men. Women are also responsible for looking after the sick and the aged and may use such plants as cure (when they cannot afford clinical healthcare)	Adverse climate negatively impacts medicinal plants through loss of habitat. Increased access to wetland (where some medicinal plants grow) could also affect availability. Loss of supplementary income for women Lack of cure (as poorer household cannot afford clinical healthcare)	Lack of alternative cure, healthcare unaffordability, inadequate food intake	Malnutrition, Poor health (general).

7	Availability of fuelwood	Women are the primary food providers needed wood to cook. Gender roles also assign them with the primary responsibility to collect wood. Women are involved smoking of fish which requires wood.	Might reduce due to deforestation. Lack of fuelwood will force women to travel further into the forest=increased female workload/Time poverty (no time to self care or rest) Time poverty - No time for other productive work, resulting in poor income Lack of fuelwood might affect women's income (they are primarily involved in fish-smoking)	Walking, physical labour, reduced sense of safety and no time for self-relaxation, lack of food and healthcare	Fatigue, causing mental anxiety, poor health (general), malnutrition
8	Average rainfall	Women are affected more due to the type of their daily activities.	Decrease in lake water levels=decline in lake fish population =Livelihood loss and income loss =Increased male-outmigration Reduced crop yield =Loss of crop yield= reduced food for consumption Decreased dilution capacity of lake waters = increased concentration of cholera germs. Decreased breeding habitats for snails. Potable water quality and quantity	Inadequate food/protein intake, sexual activities, more workload, collecting water	Malnutrition, lower protein intake, HIV, cholera, fatigue schistosomiasis
9	Average temperature	Women may be affected more than men by prolonged heat exposure if they spend longer times outside farming, collecting water, processing fish (highly dependent on type of activity)	Lake water levels, water temperature, evapotranspiration rates, Typha drying up releasing nutrients into lake waters = eutrophication + lack of oxygen =Decline in lake fish populations =Livelihood loss and income loss. Increased male- outmigration Change in malaria dynamics (prevalence might be higher in the highlands vs. lake shore). More wells and unprotected groundwater sources- breeding grounds for malaria (as lake water recedes). High chances of heat strokes and kidney diseases, as most of the population is involved in outdoor activities. Increased cholera germs in water due to swifter bacterial replication	Occupation, water well (uncovered drinking water sources), consuming contaminated water	Malaria, kidney diseases, heat-stroke, schistosomiasis, cholera, child stunting, mother and child anaemia, HIV, mental anxiety, fatigue
10	Access to agricultural inputs and extension services	Women have less access than men.	Affects crop yield= loss of income = lower climate adaptive capacity Loss of crop yield= reduced food for consumption		Malnutrition, poor health (general)
11	Comorbidity	Women have a higher HIV infection rate and therefore more susceptible to malaria	Malaria transmission rates will be affected by climate change More women might take part in transactional sex due to livelihood insecurity Women have higher HIV infection rates, making them more susceptible to severe malarial effects	Loss of immunity if HIV positive	Malaria, HIV
12	Crop yield	Women are the primary farmers in the Chilwa basin and will be affected more by reduced crop yield than men	Crop yield will go down due to reliance on rain for irrigation. Poor crop yield will lead to loss of livelihood. Food unavailable for consumption	Inadequate food intake	Malnutrition, poor health (general)

13	Disease Transmission intensity		Might decrease with schistosomiasis with increased droughts Malaria might shift with higher prevalence in the highlands than the lake shores. Cholera will increase due to higher concentrations in water.	Less/more disease vectors	Schistosomiasis, cholera, malaria
14	Distance & time to water source	Women are primarily responsible for collecting water	Distance will increase due to lake dry-out. Lack of time to do other productive work =livelihood insecurity. Increase physical labour, time poverty, and decreased sense of security	Excessive physical labour, reduced sense of safety and security	Fatigue, mental anxiety
15	Drought-flood abrupt alternation (DFAA)		May increase causing increased soil erosion, which can affect crop yield = loss of income		
16	Dominant fish species in lake	Lack of small pelagic fish might affect fish catch negatively, which will increase fish price, making them unaffordable to women	Bottom-dwellers may have a competitive advantage over smaller pelagic fish. Harder to catch bottom- dwellers with gill nets = low income (especially in poorer households who cannot afford advanced fishing gear). Lack of small fish will affect dietary diversity due to inadequate protein intake (fish price may increase, making them unaffordable for some) micronutrients n amount per fish (smaller fish are eaten as whole vs. only meat from larger fish is consumed) Loss of livelihood= unable to afford food and healthcare	Lack of protein intake, lack of dietary diversity, inadequate food intake	Malnutrition, child stunting, loss of immunity
17	Eutrophication rate	Women access the lakeshore for household chores and to collect water. Might be more exposed to algae blooms more than men.	Eutrophication will increase (chlorophyll a will increase). Will increase concentration of *Vibrio Cholerae* in water	Drinking water, accidental water consumption during walking to fishing boats, domestic activities, farming, daily activities	Cholera
18	Education/Literacy levels	Women have a higher rate of illiteracy	Women are restricted to low-value activities and reliant on nature resources for livelihood. Climate change will impact the natural resource base that women are primarily dependent on for livelihood. Climate change will impact infectious disease dynamics and lack of awareness linked to lack of education increases susceptibility to communicable diseases.	Exposure while domestic work and farming in the wetland area, caring for children	Schistosomiasis, malaria.

19	Evapotranspiration rate		Increased due to an increase in temperature affecting lake water levels, groundwater recovery rates, and agriculture. Decreased crop yield (especially rice as it is water intensive) = livelihood insecurity. Lower dilution capacity in lake = increased eutrophication=increased cholera. Groundwater quality might decline due to higher concentrations of arsenic, fluoride (lack of dilution)	Consuming contaminated water,	Cholera, WASH-related illness, cancer, fluorosis,
20	Fecal coliform concentration		May increase in water due to lower dilution capacity Lack of water = open defecation = more fecal coliforms in the lake. People will continue to consume lake water despite high contamination.	Drinking contaminated water, domestic chores, accidental consumption	Cholera
21	Female workload	Women have a higher workload than men	Climate change will increase time spent on farming, fishing, collecting water and fuelwood Female workload will increase	Physical labour	Fatigue, mental anxiety
22	Fish weight/size of fish	Smaller fish size might increase fish price, making it more difficult for women to buy for processing	Fish size will decrease= Low income. Fish price may increase = women cannot afford to buy for processing = low income =Sex-for-fish might increase as women will use transactional sex to buy fish	Sexual activities, inadequate protein intake	HIV, malnutrition, poor health (general), child stunting, child and mother anaemia, loss of immunity.
23	Fish yield	Smaller fish yield might increase fish price, making it more difficult for women to buy for processing	Decline in fish =Low income = inadequate fish for consumption. Fish price may increase = women cannot afford to buy for processing = low income + sex-for-fish might increase as women will use transactional sex to buy fish	Sexual activities, inadequate protein intake	HIV, malnutrition, poor health (general), child stunting, child and mother anaemia, loss of immunity.
24	Type & availability of fishing gear	Smaller fish yield might increase fish price, making it more difficult for women to buy for processing.	Gillnets cannot be used to catch bottom-dwellers. Poorer fishermen with less advanced gear will face a loss of income. Inadequate fish for consumption Fish price may increase = women cannot afford to buy for processing = low income + sex-for-fish might increase as women will use transactional sex to buy fish	Sexual activities, inadequate protein intake	HIV, malnutrition, poor health (general), child stunting, child and mother anaemia, loss of immunity

25	Fish price	Increase in fish price affects women involved in fish processing more than men	Increased fish price will make them less affordable to women fish processors =Low income + inadequate fish for consumption Sex-for-fish might increase as women will use transactional sex to buy fish	Sexual activities, inadequate protein intake	HIV, malnutrition, poor health (general), child stunting, child and mother anaemia, loss of immunity
26	Frequency of droughts		Increased droughts = increased lake dry outs		
27	Groundwater recharge rate	Women are the main water collectors. Reduced water availability affects their workload and time available for other productive work.	Increased evaporation may affect groundwater recharge rate. Decreased availability of groundwater (but not an imminent threat). Water quality might be negatively impacted due to lower dilution capacity.		WASH- related health issues, arsenic poisoning, fluorosis
28	Growing season (if altered)	Farming is dominated by women and any alterations to growing season affect them more than men	May get shorter with period dry periods requiring multiple replanting = higher costs + lower crop yield = loss of income + lack of food and healthcare due to unaffordability		
29	Household and communal conflicts	Women are more dependent on natural resources than men and any conflicts due to lack of supply will affect them more than men. Domestic abuse can also affect women's labour efficiency more than men	Diminished water sources may increase social/communal conflicts and reduce social capital Loss of livelihood may increase domestic violence. Domestic abuse will reduce labour efficiency and lead to loss of income. Domestic abuse will affect women's mental health	Domestic abuse	Mental anxiety and stress
30	Livelihood security	Women have less access to financial resources due to lower social status and are therefore less able to spend on farming units, advanced fish smoking technology affecting their income and therefore are less able to afford food and healthcare.	Reduced income = cannot afford better fishing gear = decline in fish catch. More involved in maladaptation - using mosquito nets for fishing = higher chances of malaria Lack of income = lack of healthcare due to unaffordability Lack of income = reduced food affordability Reduced income = lack of access to groundwater (in the future) or buy potable water	Inadequate food, inadequate clean water	poor health (general), malnutrition, dehydration, WASH-related health issues, malaria
31	Land ownership	Women are tied to their matrilineal land and therefore lack the option to migrate like men.	Matrilineal land ownership ties women to their lands, diminishing their migration options Lack of migration caused due to land ownership increases women's workload due to spousal absence and increased responsibilities in and out of the house	Increased physical labour (occupation and domestic chores, caring for dependants)	Fatigue, mental anxiety

32	Livelihood diversification	Women have less mobility and are therefore not able to engage in off-farm or off-fishing activities Low literacy levels and are therefore restricted to nature-resource based livelihoods.	Women suffer more from lack of livelihood diversification than men due to their inability to migrate & high illiteracy = lack of income		
33	Lake threshold for dry-out		Lake will dry out quicker and cause other associated issues like water unavailability, decline in fish.		
34	Out-migration rate	More male outmigration will increase female workload, affecting them disproportionately.	Will increase with more frequent lake recessions. Might increase income if remittances are sent to household. Will affect women more than men - (transactional sex, increased workload)	Sexual activities, increased workload, time poverty (no self-care)	Fatigue, mental anxiety, HIV
35	Marital status	Married women are more restricted in their mobility due to higher dependants (children). Also, more susceptible to sexually transmitted diseases	Married women will migrate less than single women and therefore face higher workload. Married women may have the primary responsibility to look after the sick and the aged, so will have higher workload. Participation in sex-for fish may be less in married women but high in women married to fishermen. Married women may be involved more in transactional sex due to the number of dependants. Married women taking part in unsafe sex is higher than their husbands, save the condoms for riskier extra-marital partners Married women are most likely to have children (dependants) so will have higher workload	Sexual activities, increased workload, time poverty (no self-care)	Fatigue, mental anxiety, HIV
36	Mobility	Women are less mobile than men due to gender stereotypes	May not participate in training programs (if outside villages) which might affect their livelihood options and income (through crop yield) Less mobile than men due to land ownership. Will increase workload.	Physical labour, time poverty	Fatigue, mental health
37	Number of dependants	More female workload	More dependants = more workload. More dependant = more anxiety from not able to provide adequately	More physical labour and mental stress	Fatigue, anxiety

38	Occupation	Women are more involved in farming and smoking of fish. Men are primarily fishermen or migrate away from the basin. The two have separate routes of exposure.	More women are involved in farming as men out migrate to find alternative sources of livelihood. Type of occupation would affect livelihood security. Natural resource based occupation would reduce livelihood security and therefore climate adaptive capacity. Women are more exposed to diseases related to irrigation water - schistosomiasis, malaria. Men spend longer out in the lake fishing, receiving no or partial cholera vaccines Women have to travel further into the lake to buy fish, forcing them to walk in muddy waters and are exposed to accidental intake of cholera contaminated water. Increased time spent in outdoor activities might increase the risk of heat stress and kidney diseases. Women may be bitten frequently by mosquitoes, as they remain stationary while selling or smoking their fish. Men may be bitten by mosquitoes as they tend to their fishing nets in the dark	Working in rice farms, using canal and lake water for domestic activities, walking in muddy waters to buy fish, smoking fish, working in the dark (getting bitten by mosquitoes)	Cholera, schistosomiasis, malaria
39	Oxygen levels in water	Women are more exposed to snails than men due to their daily activities	Increased eutrophication can lead to reduced oxygen levels in water, affecting fish populations. Loss of income due to lower fish yield Affects snail populations (higher mortality).	Might reduce exposure to snails	Schistosomiasis
40	Polygamy	Both women and men engage in polygamy	Outmigration rates will increase polygamy as men engage in casual sex or have multiple wives at multiple villages. Might reduce prevalence of schistosomiasis Polygamy is actively practiced in the society and increases risk of HIV in women. Polygamy causes conjugal conflicts with men leaving women alone to look after households.	Sexual activities	HIV, mental anxiety, fatigue
41	Pre-existing medical conditions	Pregnancy	Pregnant women will be at a higher risk of poor health conditions as a result of increased workload. Pregnant women might be at a higher risk of heat related health impacts. Pregnant women might face higher risk of low birth weight in the absence of adequate food intake and protein intake	Working outdoors in extreme heat	Pregnancy complications
42	Primary or secondary role in fishery & agriculture	Women perform secondary activities in fishing and primary in farming	Women are primarily involved in low-value activities like fish smoking = low income =low purchasing power		
43	Proximity to lake		Higher prevalence of malaria near lake. Higher prevalence of cholera near lake.	Daily activities	Malaria, cholera

44	Relative Humidity		May decrease due to rising temperatures and decline in rainfall Decreased relative humidity in air may lead to high vector mortality = decline in malaria	Mosquito bites (reduced)	Malaria
45	Salinity		High salinity in fish will affect fish population and water quality Decline in fish population= loss of income High salinity in drinking water & food = increase salt intake = increased chances of hypertension	Increased salt intake	Hypertension
46	Sanitation facilities	Biologically, women are more susceptible to suffering from health issues caused due to lack of hygiene. Men affected by cholera are unable to provide for the family, forcing women to face the brunt of the crisis.	Lack of water will lead to poor sanitation and hygiene, causing WASH-related diseases. Women might be at a higher risk due to biological differences. Cholera affected men cannot provide for the family and women are forced to take on additional responsibilities.	Lack of water for sanitation	Urinogenital diseases, fatigue, mental anxiety
47	Soil fertility	Women play a dominant role in farming and therefore are more affected by soil fertility than men	Soil fertility might worsen with decreased soil moisture (killing soil biota) affecting income and livelihoods + unavailability of food for consumption	Inadequate food intake	Malnutrition,
48	Soil erosion	Fish populations will be affected, which will increase fish price and affect women's livelihood more than men (as women cannot migrate to find alternate sources of income) Soil erosion will also affect soil fertility.	Might increase with sudden incidents of heavy rain following droughts (increased sediments in river water and deep pools affecting fish breeding and lake fish populations) Poor soil fertility = poor crop yield =lower income + food unavailable for consumption Decline in fish population = income Might further add to turbidity in lake increasing risk of cholera (cholera germs stick to sediments and other organic matter)	Domestic chores, occupational exposure, accidental exposure, lack of adequate food intake, healthcare unaffordability	Cholera, malnutrition,
49	Social norms	Women are considered being inferior to men. Gender roles	Women are considered being inferior to men = lack of agricultural inputs, extension services, land quality and location are inferior to those of men = Lower adaptive capacity Domestic chores, caring for children puts them at a higher exposure risk of disease vectors (physical ad biological) and carriers - mosquitoes, snails Polygamy is encouraged, sexual cleansing,	Daily activities, caring for children	Schistosomiasis, cholera, malaria, HIV
50	Traditional norms	Fishing is a man's job	Women are not allowed on boats and those who opt to be part of the crew face multiple barriers which restrict their participation to low-value activities = less income =lower adaptive capacity		

51	Type of daily activities	Women handle domestic and productive work and therefore have a higher workload and more exposure routes than men	More time during the day spent on collecting water and fuelwood and farming (Extended periods of time near water) Higher workload for women than men, time poverty, no time for self relaxation	Performing household and outdoor chores	Fatigue, mental anxiety, malaria, schistosomiasis, cholera
52	Time spent on fishing/agriculture	Women spend more hours farming or smoking fish will face time poverty and difficulties completing domestic chores. Time poverty will also affect women's self care routines and mental health	Wil increase due to reduced supply and unfavourable climate conditions (for e.g., replanting of rice due to periodic droughts during the growing season) Increased exposure to heat, causing heat related stress and kidney disease. Women are more involved in agriculture, increasing their vulnerability to health issues - dehydration, kidney disease, schistosomiasis, malaria, and mental anxiety (due to time poverty). Men spending longer fishing out in the lake will face increased risk of cholera.	Occupational exposure	Heat related stress, kidney disease, schistosomiasis, malaria, mental anxiety, cholera (men)
53	Type of protein (Animal or plant)	With less protein available, women might be at a higher risk of consuming inadequate amounts (provided they eat after the rest of the household is fed)	With reduced fish protein (animal protein), more plant protein might be sought out, which will affect overall protein intake (as animal protein is considered a better source than plant where quantities are limited).	Lack of protein intake	Child stunting, malnutrition, loss of immunity
54	Type of crops	Women dominate the farming sector.	Rice farmers may be affected more than those growing maize due to the higher water sensitivity of rice. Rice is a cash crop and maize a subsistence crop. Loss of rice may affect household income = reduced access to healthcare (due to reduced affordability) but growing more maize might be better for household food security due to increased food availability.		
55	Type of water source (surface or ground)	Women are the main collectors in the household	With the lake drying up, people have to rely on groundwater sources Groundwater is usually of better quality than surface water but harder to access, which affects water availability. Arsenic and fluoride are also present in the basin's groundwater sources	Lack of groundwater, drinking water	Dehydration, WASH- related health issues, arsenic/fluoride poisoning
56	Participation in unsafe sex	Women have low negotiating powers than men	Loss of livelihood might increase transactional sex, which increases the frequency of unsafe sex, as men will pay a higher price for it. Women have fewer negotiating powers and therefore at a higher risk from unsafe sex. Men also prefer unsafe sex due to risk- taking culture in the society.	Sexual activities	HIV

57	Upstream and downstream location	Female owned farms are usually located in downstream locations	Farms located upstream benefit more from irrigation schemes than farms downstream (women usually have their farms downstream) affecting crop yield and therefore income. Farms downstream rely on stagnant water from irrigation canals, which are hotspots for malarial mosquitoes	Collecting water from irrigation canals	Malaria
58	Water temperature		Increased water temperature will affect fish populations. Decline in fish population = loss of income. Swifter replication of Vibrio Cholera in water. Fewer fish available for consumption	Consuming contaminated water	Cholera
59	Water turbidity		Increased due to increased erosion of lake bottom = fish decline. Decline in fish population = loss of income. Leads to low lake light penetration = lack of plant growth in lake bottom Swifter replication of Vibrio Cholera in water. Fewer fish available for consumption	Inadequate food & fish (protein) intake	Malnutrition, child stunting, cholera
60	Water quantity	Women have to walk further into the lake to buy fish and collect water	Reduced water level depth= killing Typha = releasing nutrients in lake water = eutrophication = decline in oxygen levels. Increased access to wetland = increased rice farming and bird catching Income levels drop due to fish decline but might increase from increase rice farming and bird catching Increased cholera due to increased eutrophication. Reduced schistosomiasis due to lack of breeding habitats but increased exposure due to better access to the wetland (higher snails found on the wetland). Inhabitants might consume more arsenic contaminated rice as more wetland is utilised for rice farming.	accidental intake, groundwater consumption, occupation, recreational activities	Cholera, arsenic poisoning, schistosomiasis

5.6. Subsystems

5.6.1. Food Security:

Lake Chilwa, being the second largest lake in Malawi, is a source of sustenance to 1.5 million people living and working in the basin (Rebelo et al., 2011). Historically, the farmers in the basin practised fishing temporarily as their secondary source of livelihood during the dry season when rain-fed agriculture faced challenges (Schuyt, 2005). Fish productivity has seen a steady decline. According to a study in 2014, fish yield has declined from an average of 15,000 tonnes per year to 5000 tonnes since the 1970s (Kafumbata et al., 2014). However, now with more frequent dry-outs causing poor fish catches, the majority are taking up other alternatives like bird-catching and charcoal-making to meet their household needs (Njaya et al., 2011). Small scale inland fisheries like Lake Chilwa are an essential source of nutrition, income, and livelihood in rural communities in the developing world (Simmance et al., 2021). Malawians have a high perception of the threat posed by the ongoing climatic changes but have associated these threats to lack of rain rather than temperature, despite the latter progressively increasing over the years. Those involved in the fishery and agricultural sectors have adapted to these climatic pressures by using highly efficient illegal fishing nets, increasing fishing time, expanding farmland, working as casual labour in farms and fisheries, and off-farm activities (Limuwa et al., 2018).

The Lake Chilwa wetland has attracted a large migrant population due to its multiple ecosystem services and is now facing a crisis caused by the unsustainable exploitation of its limited natural resources pushing the natural ecosystems towards their planetary boundaries with the possibility to incapacitate their natural ability to withstand and recover from the worsening climatic conditions. The impact of such ecological degradation on human health is unforeseen as multiple stressors may interact and alter each other’s impacts and synergistically cause severe impacts that may be irreparable (Jackson et al., 2016).

Lake Chilwa has only 14 species of fish, out of which 3 species dominate (tilapias, clariids and small barbs) due to their high thermal and alkalinity tolerance and drought-resistant strategies (Delaney et al., 2007). Although the three dominant species have well adapted to the lake’s extreme conditions through drought-resistant strategies like exploiting the swamps, and using river inflows as spawning and refugia during periods of recessions (Macuiane et al., 2009; Delaney, 2007), these strategies might be tested with increased total suspended solids (TDS) and high electrical conductivity in the affluent river waters caused by vegetation removal, agricultural activities, river diversion, urbanization and charcoal production, as found in Likangala and Domasi rivers. With an increase in droughts resulting in the loss in soil moisture, soil erosion rates caused by such anthropogenic activities may increase, causing further TDS concentrations and higher electrical conductivity in water. With a decline in fish productivity, it is highly likely that the basin inhabitants will further engage in maladaptation, further aggravating the migratory and reproductive activities of fish species and, as a result threatening their population in the lake (Jamu et al., 2003; Jamu et al., 2011). Makwinja et al. also found that a few important deep pools in the Likangala River catchment that are used for spawning and feeding habitat by fish during the recession period have reduced in depth due to increased sedimentation (Makwinja et al., 2014) which might lead to increased evaporative water loss.

Fish size also seems to be reduced, as reported by some fish sellers in the region and human interruption in their lifecycle has been suggested to be the plausible explanation (Delaney et al., 2007). Due to high demand and limited supply, which has been an ongoing trend in fishery, fishermen in the basin are already actively overfishing and removing larger spawners. This malpractice is highly likely to increase with the worsening of climatic conditions (Njaya et al., 2011).

Fish-related livelihoods can impact household nutritional security through three main pathways: (i) lack of intake of essential nutrients and protein as some of the fish might be used for self consumption (ii) loss of income and buying power due to loss of fish to sell (iii) reduced economic status of women (who depend on fish processing and trading as their primary source of income) which may have a direct impact on household nutritional security with women being the primary food provider in the households (Kawarazuka & Béné, 2010). Overall, a loss of fish productivity will most obviously affect the population's nutrition levels in general, but the mechanisms through which a change in ecology affects human health are highly complex. For example, Jackson reported smaller pelagic fish (lower bodied fish) in the lake to be at a higher risk than bottom dwellers during recessions due to increased turbidity and decreased oxygen levels in the water. This may give *Clarias spp*. (a bottom dweller) a competitive advantage over the barbs and the tilapias (Jackson, 1961; Kirk, 1967; Piet, 1998). Loss of small fish like *Matemba (Barbus spp*.) will considerably hurt commercial fisheries, as they account for most of the fish catch[9] (FAO, 2005). Fishing bottom dwellers is harder with the commonly used fishing gear (gill nets) due to their slow-moving nature and low water flow (Delaney, 2007) and therefore will affect those fishermen more who are unable to afford advanced fishing gear than those who are able.

In such a scenario, where there is a decline in fish catch and a shortage of smaller fish, human health can be impacted through two mechanisms-(i) undernutrition due to fish unavailability and loss of income (due to inappropriate fishing gear to catch bottom dwellers); and (ii) loss of dietary quality, as consuming small fish is better in terms of micronutrient intake (especially of iron, zinc, calcium, and vitamin A) mainly as they are consumed whole (including bones, organs, and viscera) than larger fish from which only flesh is consumed, and smaller fish are also cheaper to buy than larger fish (Kaimila et al., 2019). As a result, poorer

[9] (*Barbus spp*. and *Mlamba (Clarias spp)* contributed 52 and 13 percent respectively of the catch (FAO, 2005). https://www.fao.org/fi/oldsite/fcp/en/mwi/profile.htm

households may see an increase in childhood stunting, maternal and child anemia and loss of immunity to communicable diseases both due to undernutrition and because of loss of dietary quality (Ngwira & Kazembe, 2015). Quality of protein intake, in terms of animal versus plant protein with the former considered to be a better option than the latter will also apply in Lake Chilwa's case as quantities of protein rich food are limited due to reduced fish supply and lack of purchasing power (Kaimila et al., 2019).

Farming gives less economic returns per square kilometer than fishing (Schuijt, 1999). Rapid expansion of subsistence agriculture has led to the shrinking of the wetland area in the lake Chilwa basin from over 2400 to 1750 km2. As the lake continues to recede, and fish productivity continues to decline, the wetland is increasingly being converted to cultivated land mainly for rice (Kafumbata et al., 2014). which requires water-logged conditions to grow.

Local people living on the basin are habituated to the lake's cyclic changes and alternate between fishing, farming, pastoralism, and migration during dry periods, but with the lake drying up faster than usual, farming and pastoralism that are also heavily reliant on rain and surface water may not be feasible choices in the future (Jørstad & Webersik, 2016). The region suffers from poor soil quality (Mungai et al., 2020) which could see further deterioration if the region experiences the same climatic trends of drought to heavy rainfall as projected for the rest of the country. High soil erosion reported in the upper regions of the basin due to anthropogenic pressures (increased deforestation and conversion of agricultural land into homestead development) has been associated with lower crop yields in the basin (Jamu et al., 2003). The southern and the central parts of Malawi has seen less favourable rainfall conditions than the north and as a result face a higher risk from low agricultural productivity than the north due to dense local population and competition with livestock over limited land (Mungai et al., 2020; Nicholson et al., 2014).

The two main staple crops grown in the basin are maize and rice (Schuyt, 2005) which are being increasingly threatened by unpredictable and frequent dry spells within the growing season requiring multiple replanting and therefore increasing costs which is discouraging farmers away from agriculture and pushing them further into poverty (Jørstad & Webersik, 2015). The extreme fluctuations in the lake and the decline in fisheries between 1967 and 1973 encouraged a shift from a quasi-subsistence to a partial cash economy in the lake (Kafumbata et al., 2014). Rice, a popular cash crop (and a subsistence crop) (Chilivumbo, 1971; Tiba, 2011) is an important source of income for the basin's inhabitants. It is highly water intensive and may suffer substantially with the projected lack of rainfall and receding lake waters. At the same time, this decline might be recovered through a gain in access to larger areas of wetland which is used to cultivate as a result of the receding lake waters. Although a maladaptation, and not sustainable in the long run, it is already in practice and supporting another source of livelihood (another maladaptation)– bird hunting. The rice grains are attracting more and more migratory birds to the wetland, where they are hunted for consumption and sale (Sofasi, 2007). Some farmers have opted to grow maize instead of rice, which is less water intensive and a staple crop in the region, which could be an important adaptation for improving food availability in the basin.

Although irrigation schemes are available and actively used, the benefits are not distributed equitably, as farms located upstream benefit significantly more from these schemes than those located downstream. A study reported farmers upstream to be starving the farms downstream by blocking the water in the irrigation canals during the dry season and releasing excessive amounts of water with the onset of the wet season, causing floods to cause crop damage downstream. This has caused substantial conflicts between the two, which could affect future collaborative efforts to adapt to climate change (Mvula & Haller, 2009). Another source of conflict caused by tribal tensions between the two tribes-Yaos and Mang'anja could also negatively impact the production relations over the access to natural resources (Nkhoma & Kayira, 2016).

Locust outbreaks are also a significant threat to crops and forage in eastern and southern Africa and have caused considerable damage as recently as 2020. The Lake Chilwa basin is the single known natural breeding site and outbreak area of red locusts in Malawi, with 4 major outbreaks recorded in the 1990s (Thindwa, 1999). In December 2013, the International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA, 2014) reported locust swarms breeding and laying eggs in the Lake Chilwa region which may lead to another outbreak with the sudden shift from drought conditions to heavy rains (FAO, 2021; IRLCO-CSA, 2014). Aflatoxin risk is also high in Malawi, as mentioned in Component 1, especially in worsening drought conditions and inappropriate storage facilities (Warnatzsch et al., 2020).

The soil in the wetland area has also been found to have high heavy metal concentration. Chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), arsenic (As), mercury (Hg) and cadmium (Cd) are increasingly being deposited into the soil by anthropogenic and geogenic activities (Mussa et al., 2020). Although the risk of consuming arsenic (As), cadmium (Cd) and lead (Pb) has been found to be low in Malawian rice (which also contains inadequate Ca, I, Se or Zn) (Joy et al., 2017), a 2017 study shows climate change induced decrease in soil water could potentially enhance the uptake of trace metals by crops such as rice resulting in higher risk of metal toxicity through rice consumption (Ge et al., 2016). Mussa et al. also found higher concentrations of arsenic in the wetland area as compared to the rest of the catchment which is concerning as lake recessions are enabling greater access to the wetland which is being actively utilized for rice cultivation. This may add to the risk of arsenic exposure through food (Mussa et al., 2020). Selenium deficiencies have also been reported in the region (Joy et al., 2017) with a possibility to worsen with climate induced alterations in soil organic component as discussed in Component 1 (Jones et al., 2017).

Nagoli & Chiwona-Karltun found fishing and farming to complement each other in terms of income where income from fishing was being used to buy farm inputs and food from farming supported the fishing communities. In such settings, climate change will affect both sectors and households that depend on this complementary livelihood arrangement. They may find themselves in a much worse situation than those who have off-farm employment activities (Nagoli & Chiwona-Karltun, 2017). Migration, which has been a popular adaptation during lake recessions, could also be considered a maladaptation, as (i) it excessively pressures ecological services at the receiving locations; (ii) may lead to conflicts because of increased competition., and (iii) the gendered health inequities that come out of this adaptation strategy, affects women's health and well-being significantly more than the men who have out-migrated.

With climate induced reduction in crop yield, farmers can no longer depend on subsistence farming to fulfill household food requirements and are becoming more reliant on store-bought food which is not only less nutritious but also expensive and further aggravates the financial burdens and food insecurity problems (Jørstad & Webersik, 2016).

With fishing being a primary source of livelihood in the basin, a decline in the lake's fish productivity will impact people's income and, in turn, aggravate the existing food insecurity in the basin. This will further exacerbate the existing health impacts related to food insecurity such as child stunting, child and mother anaemia, poor immunity, and high susceptibility to communicable diseases like cholera and HIV. Within this highly vulnerable population, women are at an elevated risk due to their social and economic status and biological functions. However, men may also be more susceptible to certain health conditions directly as a result of their occupational activities.

Malawi has a matrilineal social structure (a social system where kinship networks are linked to the family line of descent) and uxorilocality (husbands live in wives' villages) is practiced actively by the men in the region (Peters, 2002; Nagoli & Chiwona-Karltun, 2017). Although women primarily enjoy the land rights, their inferiority to men is deeply embedded in Malawian beliefs and social structures to the extent that popular sayings[10] have developed around such discriminatory norms. Like many other developing countries (discussed in Component 2), women's participation in leadership and decision-making is limited and division of labour is highly gendered (Nagoli & Chiwona-Karltun, 2017). Some examples of this gendered aspect in labour are (i) women not being allowed to fish in open waters or be seen working with men as reported by multiple scholars working in the region and (ii) women only participating in secondary activities like sun drying and marketing of small fish species (*Barbus spp. (matemba)* (Chiwaula et al., 2012; Nagoli

[10] "Ng'ombe yaikazi sikoka ngolo [A cow does not pull an ox-cart] simply implying that women cannot lead; Mkazi azimva nkhwali kulira [a good woman should hear a francolin crow]. This saying implies that a woman should rise up very early before others wake up; Wamkulu mbanja ndi mwamuna [the head of a household is a man]. In this case men have the final say in decision making process at household level." (Schuyt, 1999:138)

& Chiwona-Karltun, 2017). Manyungwa et al. also experienced similar observations during their research and explained that due to restrictions imposed on wives by their husbands, very few participate in actual fishing, and the few that join the fishing crew are discouraged due to social exclusions, household care burden and poor working conditions limiting them to the low value chain activities (Manyungwa et al., 2019).

Fish processing is the main income generating activity for women in the basin. A declining fish stock in the lake increases fish price and makes it harder for women to purchase fish, resulting in income loss. This further exacerbates household food insecurity (Jørstad & Webersik, 2016). Additionally, although women are actively engaged in fish processing, they lack access to better processing technologies due to lack of income, training and social inequities and therefore rely mostly on sun-drying, which has a higher chance of post-harvest losses through microbial contamination. This negatively impacts their income levels (Chiwaula et al., 2018). As discussed in Component 1&2, lack of income and lower social status are major barriers to improving household and individual adaptive capacity to climate change and in the Lake Chilwa context, women are more likely to these barriers more than men (Jørstad & Webersik, 2016).

Education is also a major determinant of income levels through its influence on livelihood diversification, access to credits and extensional services and taking part in training exercises (Adzawla & Baumüller, 2020). Women in the basin have far lower literacy levels than men, which restricts them to low-value chain activities relying heavily on natural resources, and therefore increasing their vulnerability to climate induced livelihood insecurity (Nagoli et al., 2019). Inequitable distribution of land in terms of quality is also in existence in the region where women own farms in downstream locations and often suffer low crop yields due to poor irrigation facilities (Nkhoma & Kayira, 2016). Other reasons for female farmers to have lower crop yields than male farmers are lack of access to labour, agricultural inputs and extensional services, which are mostly due to their lower income (Mukasa & Salami, 2016).

Since the 1900s, male outmigration and labour shortages forced small-holder agricultural farming to be restructured and women took up the role of being the main providers of subsistence food production. Lack of labour and lack of agricultural input caused a stagnation in agricultural production at this stage (O'Laughlin, 2002). With more frequent recessions, male out-migration will continue to rise, increasing female workload who are already expected to produce, reproduce, and perform household chores.

5.6.2. Ecological services

Groundwater and lake water in the Lake Chilwa basin have high ionic concentrations as compared to the streams feeding the lake (Missi et al., 2020). Concentrations of total dissolved solids (TDS), bicarbonate, fluoride and nitrate ion in groundwater were higher than WHO's recommended limits for potable water.

Rivett et al. also found widespread low concentrations of arsenic in groundwater, with a few above WHO's recommended limit of 10 µg/L (Rivett et al., 2020). WHO's guidelines for drinking water quality clearly lists arsenic, fluoride, and nitrite as three of the key chemicals in drinking water that cause long-term health impacts in developing countries and are not always easily detected even after a series of analytical tests (WHO, 2017). Nitrite, fluoride, and arsenic have been associated with methemoglobinemia and thyroid effects in bottle-fed infants; skeletal fluorosis in older adults (if consumed in excess) and dental fluorosis (if small amounts are consumed), dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular disease (WHO, 2017).

Groundwater quality is also influenced by elevation with lower total dissolved sediment and therefore better quality at higher altitudes than lower, primarily due to better river flow rates at higher elevation and less evaporative loss (Rivett et al., 2020). The Chilwa basin hosts over 9000 community water points, 5000 of which are groundwater sources and although groundwater extraction is quite low, concerns over recovery rates are on the rise due to climate induced frequent droughts in the region (Rivett et al., 2020). While evaporation plays an important role in determining lake water quality, natural water-rock interactions, and human pollution influence groundwater quality (Missi et al., 2020). As seen in component 1, evapotranspiration plays an important role in groundwater quantity (Wu et al., 2020) and with the projected temperature increase and low precipitation, it will play a significant role in groundwater recovery rates in this region.

Although no information was found on the role of climate change on groundwater contamination, which could be due to the low risk to the resource owing to its current unexploited state, climate induced unavailability of surface water could force more people to tap into groundwater resources as an alternative option. With the current lack of governance and high population density, risk of groundwater abstraction could lurk in the horizon and precautionary steps must be taken. As groundwater is less accessible due to required equipment like hand pumps, cost of maintenance and labour (to dig wells) involved, access related discriminations will be much larger than currently existing (as lake water can be easily accessed) and can lead to more conflicts, poor health due to inadequate consumption (dehydration), and increased consumption of contaminated water (fecal coliforms, trace metals, sediments). People will be forced to store more water which might increase mosquito-borne diseases as clean stagnant water[11] provides ideal breeding grounds for *Anopheles gambiae, Anopheles funestus and A. arabiensis*–the main malarial vectors in Malawi. (Okiro et al., 2014; Onen et al., 2021)

[11] *Anopheles culicifacies* and *Anopheles. subpictus* can breed in dirty muddy water with organic matter (Gunathilaka et al., 2013)

Pullanikkatil et al. (2020) reported “forty-eight species of edible wild animals (including birds), 28 species of edible wild plants and fungi, 22 species of medicinal plants, construction materials, ornamental flowers, firewood, honey, gum, reeds and thatch/weaving grasses” that are being derived and utilised by local communities in the Likangala River Catchment at Lake Chilwa. With the expansion of agricultural land driven by an increase in population in this catchment area, such provisional services could see decline leading to a spill-over effect to other catchments in the basin. Climate change could expedite the spill-over effect indirectly through reduced fish and agricultural productivity, forcing the local communities to further expand the land under cultivation to maintain sustenance (Pullanikkatil et al., 2020). Wild foods are also more actively consumed and relied upon by poorer households than those that are well-off, which is also the norm in the Chilwa basin and therefore the decline in such resources will disproportionately harm the former than the latter (Maseko et al., 2017; Meijer et al., 2016). Medicinal plants are also on the decline with increased deforestation and women often have to walk long distances to collect them, which might be further aggravated in the future climatic scenarios. In order to expand agriculture, lake, and riversides where some medicinal plants grow are being cleared to cultivate maize and rice. (Pullanikkatil et al., 2018).

Figure 13(a) Crystals, everlasting flowers *(Helichrysum herbaceum)* and passion fruit on sale to tourists on Zomba Mountain, (b)firewood collection, (c)sand mining along the Likangala River, and d bush mice sold along the road.

Source: Pullanikkatil, D., Mograbi, P.J., Palamuleni, L. et al. Unsustainable trade-offs: provisioning ecosystem services in rapidly changing Likangala River catchment in southern Malawi. Environ Dev Sustain 22, 1145–1164 (2020).

As seen in Component 2, women in Malawi have the primary responsibility of collecting water and fuelwood (Nagoli & Chiwona-Karltun, 2017) and a rapid decline of such natural resources will negatively impact women’s physical and mental health through increased workload, time poverty, lack of self-care, performance anxiety and increased intra-household conflicts. Land and water-based conflicts have already been reported in the region and with increasing pressures on the limited resources, such conflicts are likely to increase and may strain the existing strong sisterhood bonds within families, impacting social capital. This will further add to the burden on women, who will then have to fend on their own in isolation, especially as their husbands migrate away from the family (Nagoli & Chiwona-Karltun, 2017). Ethnicities may also come into play as seen in the study in Bangladesh (refer to Component 2) where ethnic minorities were not allowed to access some of the shared groundwater resources and required to travel from source to source which will further burden them and cause animosity between groups of women. Women are also generally poorer than men in Malawi due to their low social status, as discussed above, which means they may not have the ability to hire labour to transport water and will be limited to amounts that they can carry on their own. This will again strain them physically and mentally, as they will have to ration water for domestic activities. As women are mostly engaged and limited to fish smoking, which requires wood, lack of wood will affect them more than men who have the option to diversify their livelihoods.

Loss of wild food and medicinal products will also have a higher impact on women's income as they are the main participants in such occupations and use them as supplementary means of income. As seen in Component 2, women being the main food provider in the household, quality of nutrition is significantly of value to them and with the reduced availability of supplementary wild food products, and higher reliance on store bought foods (usually considered to be of lower quality), many women may suffer from mental anxiety. Gender roles in Malawi assigns women the responsibility to look after the sick and old members of the family and with poor monetary resources and lack of medicinal plants, women might face challenges to fulfill their caretaking duties which again could disturb their mental health and add to their already heavy workload.

5.6.3. Communicable Diseases:

Cholera is endemic in the Lake Chilwa basin and in the rest of the country, but outbreaks occur throughout the year, unlike the rest of the country, where occurrence is mostly limited to the wet season. Similar observations were also reported by the Malawian Cholera Surveillance Unit in the Ministry of Health (MOH) (as cited in Khonje et al., 2012) during the 2009-2010 cholera outbreak in Lake Chilwa.

Figure 14: Districts near Lake Chilwa that experienced Cholera outbreaks and their proximity to the lake**.** Source: Khonje et al., 2020

In figure 14, the three districts that experienced the cholera outbreak and their proximity to the lake are circled in red. The districts highlighted in yellow that did not suffer the same fate are further from the lake, showing a correlation between disease prevalence and proximity to the lake (Khonje et al., 2012). As discussed in Component 1, the risk of water-borne diseases during the wet season is from floods and heavy rains washing out soil and along with it physical, chemical, and biological contaminants like fecal matter, sediments, agricultural run-offs. This risk is especially higher in regions that are drought prone, as poor vegetation and lack of soil moisture make the soil more susceptible to soil erosion and washouts (Castillo et al., 2003). On the other hand, during the dry season, evaporation from surface water bodies like Lake Chilwa could lead to an increased concentration of existing fecal matter in the lake waters due to lower dilution rates. Another reason for higher cholera germs in the lake waters during the dry season could be related to larger algae blooms which occur due to the increased discharge of nutrients from the drying Typha. Epstein’s study in Bangladesh had associated algae blooms to the spread of cholera in Bangladesh in 1993 and which was re-affirmed by Ahmed et al. in 2002 (refer to Component 1) (Epsetein, 1993). With an increase in temperature and lake recessions, it can be safely assumed that the risk of cholera in this region could significantly increase due to favourable biological conditions for the bacteria to proliferate as well as exposure routes. As also discussed in Component 1, higher water temperatures and salinity also provide ideal conditions for *Vibrio Cholerae* to replicate faster. Therefore, the outbreaks in Lake Chilwa could be directly associated with the heavy reliance on the lake for livelihood, drinking water, farming, domestic activities, sanitation, and low access to healthcare and acute poverty.

Gender roles in division of labour play an important role in determining cholera risks in the basin population. In the basin, men were found to have a higher risk of infection than women, which was directly attributed to fishing as their occupation. Primary fishing activities are dominated by the men, with most fishermen owning boats and spending extended periods of time fishing in the open waters, and as a resulted restricted to use the lake waters for sanitation. Upon return, these men share communal facilities called *zimboweras*, which are known for poor hygiene and sanitation facilities for food and accommodation (Grandesso et al., 2018). Both practices increase their exposure to the cholera germ. Although cholera vaccines are available to the population through public health campaigns, fishermen often remain unvaccinated or partially vaccinated due to being absent during the vaccination campaigns (Sauvageot et al., 2017), or if available for the first dose, more likely to receive an ineffective second dose[12] due to the lack of proper storage facilities on their boats (Heyerdahl et al., 2018; Msyamboza et al., 2016). Fishermen are also less exposed to cholera awareness and programs and education materials and therefore to continue to use untreated water (Khone je et al., 2021).

Figure 15: A Lake Chilwa fisherman near his Zimbowera, Source: Grandesso et al., 2018 https://www.who.int/bulletin/volumes/96/12/17-206417.pdf

Proximity to the lake also influences the prevalence of the disease as found by an MSF campaign where higher number of infections were in people living on and around the lake which suggested their regular use of lake water for daily activities (Khonje et al., 2012). Women have also shown concern of exposing themselves and their infants to cholera as they must walk further into the muddy waters of lake (where

[12] The second dose in liquid form is provided to the fishermen who carry and store the dose in their boats that do not have proper cooling facilities and directed to take orally after a few weeks

Vibrio Cholera thrives (Khonje et al., 2012) to buy fish for processing and by chance can splash some of the water into their mouths (Manyungwa et al., 2019).

Another possible gendered route of exposure not identified in any article could be rice farming and domestic activities and as women comprise most of the agricultural labour in Lake Chilwa and perform all the domestic chores, they could be more exposed to the germs that are found mostly in water with lower flow rate (around the wetlands). At the same time, higher vaccination rates in women could provide more immunity than their gender counterpart.

Malaria

The lake provides ideal conditions in terms of soil moisture, relative humidity, stagnant water (swamps with Typha) for malaria, as observed by Haijson et al. As a result, proximity to the lake is an important determinant of malaria prevalence, with higher infection rates in communities closer to the lake than those in the highlands (Hajison et al., 2018). Although children under five are known to be the most vulnerable to the disease both near the lake and in the highland areas, the factors influencing their high infection rates differed between the locations with the former associated with proximity to the lake and use of mosquito nets while the latter with the presence of drinking water sources such as borewells or unprotected wells which are ideal breeding grounds for the vector (Haijson et al.,2018). Mathanga et al. also suggested illiteracy to play an important role in the high infection rates in children under 5 and associated this with unawareness of malarial prevention methods but Hajison et al. found the opposite and explained that this could be related to knowledge led negligence in their mothers (Hajison et al., 2018; Mathanga et al., 2016).

Increasing trends in temperature may cause a shift in malaria prevalence, with higher prevalence rates in the highland areas versus the lakeshores provided temperatures near the lake surpass the vectors and parasites' maximum thermal tolerance. Acute poverty in the basin and loss of livelihoods have led to mal-adaptations such as the use of free insecticide-treated mosquitoes distributed by the government for malaria control for fishing, protecting crops and displaying merchandise which was associated mainly to low agricultural productivity and food insecurity (Berthe et al., 2019). Climate change and loss of livelihoods might lead to the increase in maladaptation and as a result in malaria. Low productivities in fishing and agriculture might also force adults to spend longer amount of time outdoors, increasing their exposure to mosquito bites and, as a result, malaria. Comorbidity is also a determining factor in the disease's severity, as discussed earlier in Component 1 (Alemu et al., 2013).

Although no articles were found on gender specific risk of malaria in Lake Chilwa, some potential exposure pathways based on the gendered division of labour suggest women to be at a higher risk than men. For example, in Nkhoma & Kayira's study, female farmers were forced to access stagnant water from irrigation canals over the dry season due to the downstream location of their farms. This could be a potential source of exposure to malaria as the *Anopheles* mosquitoes are mostly found in stagnant water bodies (Nkhoma & Kayira, 2016). Women are also primarily responsible for collecting water and use the lake for domestic chores, which again increases their exposure to the disease vector. As mentioned before, the farming sector has seen a shift from male to female farmers, which again increases the women's exposure to mosquitoes, especially those involved in rice farming as it is usually done in water-logged areas which provide perfect breeding grounds for mosquitoes.

Schistosomiasis

The first investigation in 1935, as reported by Blair (1956) on urinary schistosomiasis or urinary bilharzia infections in Lake Chilwa, was conducted in 1935 when 47% of the basin's inhabitants were victims of the disease (Cantrell, 1981). Cantrell found the physico-chemical changes in the lake and its surrounding areas caused by the periodic water level fluctuations to have a significant influence on the prevalence of the disease, which seemed to be lower during the dry season. The study further explained that while high alkalinity and water conductivity during the recession period significantly reduced both the percentage of eggs hatching and lifespan of miracidia (as cited in Morgan 1972 & 1979), the distribution of the intermediate host was negatively affected by deoxygenation, water level fluctuations and changes in vegetation (Cantrell, 1981). However, the same study also found a relatively lower rate of decrease in snail distribution in the canoe channels as compared to the marshes, which saw a considerable drop in snail populations (Cantrell, 1981). With a rise of drier periods in the basin due to climate change, the basin population might experience a relief from the disease due to high host mortality. However, Cantrell in his study noted an increase in the disease after a minor recession in 1973-1974 and after heavy rains in 1978, which could reoccur in the current situation as rainfall continues to be erratic in the region with chances of short and heavy downpour. Such uncertainty and complexity due to multiple variables interacting with each other and high variations in terms of spatial distribution of the host within the basin demands more thorough research on the disease and its interactions with its environment to plan and implement preventative programmes in the basin.

In Morgan's 1979 study, only males were found to have a higher number of infections (as cited in Cantrell, 1981), which could be due to low female study participants or low female participation in lake related activities. However, recent studies found school-going children to have the highest prevalence of the disease mainly due to their recreational activities, i.e., swimming in irrigation canals, lakes, and rivers. Adults engaged in fishing and irrigated farming, like rice farming, also showed a higher risk of contracting the disease due to their exposure to water (Pullanikkatil et al., 2014). Another study showed a high prevalence of urogenital and intestinal schistosomiasis in school going children and their mothers and attributed this observation of women spending long periods of time doing domestic chores in contaminated water and a very high lack of awareness of the disease in them who also lacked any kind of formal education resulting in no detection of the disease in their children (Poole, 2014). In this sense, gender roles significant influences women's vulnerability to the disease due to the multiple routes of exposure through occupation, household chores and caretaking of their children. Furthermore, since women are mostly engaged in secondary activities in fisheries and agriculture such as fish processing, sowing, and weeding, they spend more time in water-logged surroundings, which could potentially further increase their exposure risk. Men who migrate more than women have the option to conduct off-farm activities which may or may not be close to water. Such is not the case for women who by default are restricted to their lands due to their societal status as the household caretaker and, in the Lake Chilwa context, due to their matrilineal societal responsibilities to protect the lands that they own through kinship. Lack of support from their husbands forces the women to spend longer hours exposed to the disease host (snails) farming and fishing and, as a result, again suffer from higher exposure risks.

Sexually Transmitted Diseases & HIV

As per the World Health Organization, Malawi is facing a heterosexual epidemic and has one of the highest prevalence rates of the disease in the world (estimated at 8.1%) with almost 21,000 newly diagnosed infections in 2020 (UNAIDS, 2020; WHO, 2005). Rural versus urban location has also been confirmed as a variable by the WHO, with higher prevalence in urban areas than rural (WHO, 2005). Nutor et al. reported regional and sub-regional variations in HIV prevalence in the country with the highest prevalence rates in the south-eastern region of the country with some of the highest rates in the Zomba, Mulanje, Blantyre, Phalombe, and Thyolo districts near Lake Chilwa (Nutor et al., 2020).

Although socio-economic and cultural factors are the direct causal factors in HIV prevalence, environmental factors in natural resource reliant populations like in the Chilwa basin have significant indirect roles in the spread of the disease. Sex-for-fish is a common practice in the basin that has been associated with high HIV transmission can be linked to both socio-economic and environmental causal factors with both playing significant roles in shaping the future of this trend. In this example, the complexity that rises from the interactions between poverty, gender roles, and climate change is obvious and extremely concerning. According to a 2009 report by the WorldFish Center and FAO, fishing communities are hot spots of the disease due to several reasons, including (i) high rates of sexually active single men; (ii) high migration rates; (iii) easy availability of cash with no investments or saving strategies/interests; (iv) poverty; (v) poor access to health infrastructure, contraceptives and testing centres; (vi) poor health and sanitation facilities and (vii) and cultural norm of risk-taking behaviour (Kambebwa et al., 2009).

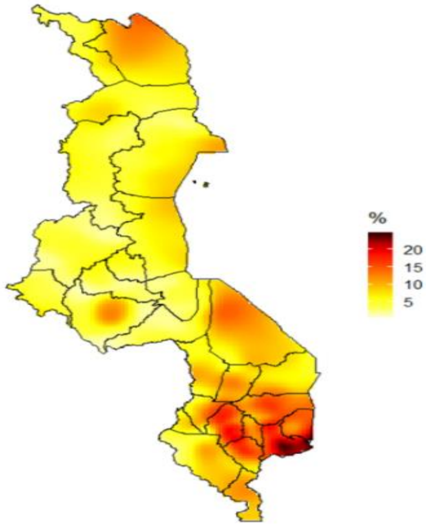


Figure 16: Heat map HIV prevalence in Malawi by district. Source: Nutor, J.J., Duah, H.O., Agbadi, P. et al. Spatial analysis of factors associated with HIV infection in Malawi: indicators for effective prevention. BMC Public Health 20, 1167 (2020). *https://doi.org/10.1186/s12889-020-09278-0*

Figure 17: Political map of Malawi. Source: WorldAtlas.com. *https://www.worldatlas.com/maps/malawi*

HIV prevalence is higher in females than males in the country which is also the case in Lake Chilwa (Poulin et al., 2011; Nutor et al., 2020). Gender roles, lower socio-economic status, cultural norms, and demographic factors have been associated with females' higher infection risk. Polygamy is actively practised in Malawi and in the Lake Chilwa basin where husbands often have more than one wife living in different villages (Pullanikatil et al., 2013; Nutor et al., 2020). Male out-migration is also high due to the high reliance on the lake which leads to high seasonal fluctuations in livelihood security, where men often engage in polygamous sexual relationships and may spread the disease to multiple women. Cultural norms like single girls being encouraged to practice sex to become good wives, widows forced to marry their husband's younger brother, sexual cleansing of women may also spread the disease (Nutor et al., 2020; Warria et al., 2018; Inungu et al., 2006; Agot et al., 2010). Unsafe sex is more common in females than males as they have lower negotiating power than men owing to their lower socio-economic status (Nutor et al., 2020). Marital status also plays a role with married women being more susceptible to the infection as men reserve condoms for extramarital partners that are perceived to be high-risk as reported by Chimbiri (2007) (cited in Feldacker, 2010) Low incomes and high financial burden also force women to engage in transactional sex (Lestico & Lee, 2015). Comorbodity (more prone to malaria, schistosomiasis, helminth-related disease, cholera, diarrhoea) and low immunity (low nutrition and inadequate protein intake) could also make females to face more severe effects from HIV than males. Although females in urban locations show a higher infection rate than rural locations (Feldacker, 2010; Nutor et al., 2020) and younger men are at a higher risk category than older due to high participation in transactional sex, the above discussion illustrates the complexity caused by the interactions between multiple factors affecting females in rural locations.

5.6.4. Extreme weather events:

The impacts of extreme weather events, which is mostly the impact of severe droughts in the case of Lake Chilwa have been interspersed into the subsystems discussed above. For example, the effects of droughts on food-related health issues such as malnutrition, child stunting, loss of immunity and mental anxiety through livelihood insecurity and decline in food availability and accessibility have been discussed under food security. The impact of droughts on availability of clean potable water and wild food and medicines causing water-borne diseases like cholera, diarrhoea, metal toxicity, malnutrition, and mental anxiety have been discussed under ecological services. The “communicable and non-communicable diseases” subsystem includes the effect of droughts on diseases like cholera and schistosomiasis through water quality and availability and sexually transmitted diseases like HIV through livelihood loss. Like the other three sub-systems, the impact of extreme weather events and their health consequences are more dire in females than males in Lake Chilwa because women lack the means to escape or recover due to their poor socio-economic status, less mobility and restricting gender roles. The primary effect of extreme events on women is through male-outmigration, which has cascading impacts through increased female workload.

The ongoing and projected increase in drought events in the region may have an indirect impact on the basin population through increased male outmigration rates. Lake Chilwa already experiences a high rate of male out-migration caused by seasonal lake recessions and low fish productivity. With the increase in climate induced lake dry-outs, the rate of male-outmigration in the region could increase resulting in a further increase in female workload who are unable to move with their husbands in fear of losing their matrilineal land rights (Schuyt, 1999). Some males remarry and settle in their new locations and simply don’t return, leaving the women behind to fend for themselves and their dependants for the rest of their lives (Schuyt, 1999). In the case that these men do return and are highly likely to have engaged in polygamy while being away, the women become sitting ducks to the disease that they bring with them (IRIN News, 2005). As polygamy is openly practised in the society, having two wives living in different villages is not uncommon (Schuyt, 2005). The matrilineal societal structure also encourages husbands to be less invested in their families as the wife’s brother is socially expected to look after his sisters and kids in the absence of their husband (Nagoli & Chiwona-Karltun, 2017). Women who are left behind may be forced to engage in “sex-for-fish”, a longstanding practice where women use transactional sex to bargain and pay for fish from fishermen. This is an established exposure route for the spread of sexually transmitted diseases like HIV.

Increase in fish price caused by declining fish productivity could further exacerbate the risk faced by females due to their lower purchasing power (Manyungwa et al., 2019). Women have also been reported to be unable to negotiate safer sex, which further increases their likelihood of contracting this deadly disease (IRIN News, 2005; NPR, 2019). Marital status could be a determinant in this exposure route, but some ambiguity was found due to opposing evidence. Manyunwa et al. reported some husbands restricting their wives to take part in the fishing sector, which could imply that marital status might lessen the exposure of married women to transactional sex. However, a 2009 study by Kambewa et al. found most female fish traders engaging in transactional sex to be married to boat owners and fishermen (Kambewa et al., 2009; Manyungwa et al., 2019). However, with increased livelihood insecurity caused by male-outmigration and increased competition and price for fish due to decline in catch, a further increase in the use of transactional sex for fish is highly plausible. In the climate change context, married women might be even more vulnerable to this specific exposure route due to their higher financial burdens caused by a higher number of household dependants left under their care (Wamu.org, 2019).

Chapter 6: Recommendation & Conclusion:

From the above discussions, it is well evident that although all inhabitants of the basin are extremely threatened by climate change, existing gender stereotypes in the social and cultural norms of these Malawian communities disproportionately place women at a higher risk category to climate change than men. It is also a very interesting case where privilege has become a hindrance to women's adaptive capacity. This is in reference to the matrilineal land rights that limit women's ability to migrate like men in search of alternative livelihood sources, which embeds them further into their existing poverty trap. In addition to their lower economic status, existing gender roles increase women's exposure to infectious diseases as described in the above discussions.

The Lake Chilwa Basin Climate Change Adaptation Programme (LCBCCAP), a seven-year programme ending in 2017, was geared towards improving the livelihoods of the 1.5 million inhabitants of the basin and enhancing the resilience of the natural resource base through an ecosystem-based approach. This programme illustrated the significance of recognizing gender as an important variable in the quest towards ameliorating the plight of climate change threats faced by poor rural natural-resource based communities. One of the guiding principles of this program was that males and females feel the effects of climate change differently and therefore require different enabling strategies to adapt to it. In the Lake Chilwa basin, women not only face challenges in their climate adaptation efforts due to poor economics but also due to their higher exposures to pathogens. It is also important to note that although women are at a higher risk than men, certain exposure pathways could be exclusive to men, like cholera in male fishermen.

Based on the rich picture below, and information identified through the systematic literature review, points of interventions are suggested to improve the current health status of men and women in the basin. The only exposure pathways identified exclusively for men in this review were for cholera while fishing out in the lake and malaria during tending to fish nets after dark. In both cases, lack of awareness was not a contributing factor, and men were forced to risk their health to earn their livelihoods. Conventional strategies like higher access to anti-malarial drugs, precautionary measures against mosquito bites, and better storage facilities for oral cholera vaccination in the fishing boats could alleviate such health impacts if properly monitored and promoted. Although, as mentioned earlier, awareness of these diseases is not completely absent, more awareness programs using promotional strategies to increase participation of men (who have a risk-taking behaviour) may also work.

With women, awareness programs related to climate change, climate adaptation and exposure routes to infectious diseases could make a bigger difference as existing literature shows women to have higher success in climate adaptation when adequately resourced. Livelihood diversification is another strategy that could benefit women more than men as existing literature suggests that they are more entrepreneurial than men. Women currently have lower livelihood diversification options than men, and therefore reducing this gap might achieve unpredictable benefits for the entire household. This might encourage better male acceptance. One of the main barriers identified in Component 2 was the insecurity felt by males in the household to allow women to gain economic equality. The extent of this insecurity, although associated with social and cultural norms, may also vary between households. In order to inspire behavioural change, role models are important, and with the current climatic pressures in this region, using a local role model to illustrate the economic benefits of a gender equal society might be an effective strategy.

A study in Component 2 already showed men having to participate more in gender stereotyped activities like water collection. If the same is promoted in the basin where men share the responsibility of securing water for the household, women can be relieved from having to spend hours and sometimes overnight waiting for water levels to rise in boreholes. This will not only improve household water security but also allow women to participate in other productive activities to enhance the economic status of the household. As discussed in Component 2, men are more insecure about their social status determined by their level of income than women. If this male behaviour is manipulated to prove that at a household level, involving women more as an equal than as an inferior can improve the economic status of the household, it might encourage men to overcome their existing insecurities and embrace the idea of gender equality. Women also have to be facilitated to be able to strategically communicate to improve their social status and decision-making power within the household.

Economic empowerment may give women more visibility within their households and improve their decision-making power. Solar fish dryers and energy efficient fish smoking kilns, as promoted by LCBCCAP, improved women's level of income through enhancing the value of fish products and reducing post-harvest losses while discouraging deforestation by not using wood to smoke fish (WorldFish, 2018). Such multi-pronged strategies not only protect the resource base from over-exploitation but also improves health and well-being of women (better nutrition, less transactional sex, and better healthcare) through enhancing their purchasing power. Since women's status is directly related to their economic contribution in households, programs like Give Directly (who provide cash transfers to people living in poverty) may provide women that leverage to improve their visibility.

Although long-lived practices like polygamy may be more sensitive and harder to break, continued reminder of the risk associated with such behaviour through awareness programs should be ongoing. Wherever possible, incentives for regular check-ups should be arranged to promote higher participation.

In order to effectively incorporate gender into planning and make progress towards gender equity in such heavily gendered societies, understanding the local context should be the top-most priority of any programme. Second, it is important that, as researchers, we approach a problem from a gender-neutral perspective and, although hard and quite natural to revert to labelling women as the most vulnerable sex, men should receive equal consideration in vulnerability assessments. Finally, lack of data is often referred to as the biggest hindrance in gender studies (Alston et al., 2018; Global Gender & Climate Alliance, 2016; McKune et al., 2015), and to overcome this barrier, women in the Global North, who have and are continuing to succeed in their efforts to gain gender equality through their hard work must work alongside their fellow male supporters to expand their outreach efforts, so more funding can go towards empirical data-driven gender studies in the Global South.

Lastly, as long as women's contributions are considered to be non-productive and their capacity undermined by their male partners, climate adaptation efforts in Lake Chilwa will not reach their full potential. To paraphrase Joseph Nagoli (country research lead, Worldfish Malawi), "Simply targeting women is not empowerment. Women's empowerment requires the inclusion of men as agents of change" (Worldfish, 2018).

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