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RESEARCH ARTICLE

Climate change, seasonality and household water security in rural Gambia: A qualitative exploration of the complex relationship between weather and water

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Abstract

Climate change could pose a threat to water security for many communities, particularly in settings where rainfall patterns are becoming more varied and there is higher frequency of extreme events, such as heavy rainfall and droughts. Understanding how rainfall affects water security—including water access, water quality and water use behaviours—can inform investment in more climate-resilient infrastructure and safeguard against future health risks. This study aims to explore how households in rural Gambia experienced water security in relation to seasonal rainfall patterns and extreme weather events. Data collection focused on two communities (Kiang West and Basse) with differing access to water infrastructure, within which some villages had greater access to groundwater sources, such as solar-powered boreholes, and others primarily used uncovered wells. 46 participants were interviewed in Spring 2022 using multiple qualitative methods, including in-depth interviews and transect walks. We found that people's experience of water security and rainfall (including seasonal rainfall, drought and heavy rainfall) was complex and varied according to the primary household water source. Both dry and rainy season posed challenges to household water security in terms of quality and quantity. Households with access to more resilient infrastructure, such as solar-powered boreholes, discussed a shift in the relationship between weather and water security, where they were less vulnerable to water shortages during dry conditions compared to those using wells. However, these sources did not fully resolve water security issues, as they experienced water shortages during cloudy conditions. Extreme weather events, such as heavy rainfall, heightened perceived water issues, as these events sometimes damaged water infrastructure and contaminated water sources. Seasonal workloads, that were higher in the rainy season, also jeopardised water security, as this limited time for water collection. Increased investment

paper. The codebook and interview guides are available in a repository referenced in the manuscript: https://datacompass.lshtm.ac.uk/id/eprint/3808/. From these documents it is possible to replicate the study. Due to privacy concerns, as this study was conducted in a small population, making the full transcripts available could make participants identifiable and breach their confidentiality. Thus, excerpts of anonymized transcripts may be requested directly from the corresponding author or from researchdatamanagement@lshtm.ac.uk. This will be shared if we can do so whilst still protecting privacy in accordance with the ethical approval obtained from the Gambian Ethics Committee and the LSHTM Observational/Interventions Research Ethics Committee (Ref: 26658).

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in infrastructure, maintenance, water-treatment and behavioural change is required to mitigate the risks.

1. Introduction

Water security is a multi-dimensional concept that encompasses water availability, accessibility and quality [1]. It can be broadly understood as the ability to access and benefit from adequate, reliable and safe water for health and well-being [2]. Stability, defined as the ability to have consistent, un-interrupted access to adequate supplies of safe water, is a key concept that underpins the other dimensions of water security, and this can be a challenge in many settings, with mechanical breakdowns, volatility of incomes and governance issues often resulting in unreliable water supplies [3].

Changes in rainfall patterns, including lower than average rainfall and increased number of heavy rainfall events, can result in reduced water availability and/or quality in both the long and short-term and therefore pose a possible threat to water security. Seasonal changes between rainy and dry patterns have been shown in some settings to result in modifications in water-related behaviours, such as selection of water source [4, 5], as availability of sources change between seasons [6]. How these choices of water source then affect the quality of water consumed can vary by setting [6–8]. Shifts in rainfall patterns, brought about by climatic change, could exacerbate these effects, as delays in the start of the rainy season, change in frequency or magnitude of extreme rainfall events, or reduced rainfall might limit availability of some sources.

Over the past few decades substantial investment has been made globally in water infrastructure so that communities have access to more groundwater sources, such as boreholes, rather than only surface water sources [9]. Groundwater sources are generally regarded to be higher quality and have lower risk of contamination than surface water sources [10]. Groundwater sources should also be more 'climate resilient', as they are less directly reliant on rainfall; however, even for communities that primarily rely on groundwater sources, high demand, coupled with reductions in rainfall still might result in shortages, as rainfall plays an important role in replenishing groundwater through the hydrological cycle [11, 12]. These changes in rainfall could also lead to long-term depletion of these sources exacerbating future water insecurity. Groundwater quality might also deteriorate in some settings due to climate change, for example climate change has been linked to salination of groundwater supplies, and subsequently water sources, due to rises in sea level [13]. Thus, access to groundwater sources alone may not ensure water security.

Water insecurity is linked to health with both insufficient water quantity and poor water quality associated with water-related diseases, undernutrition and other diseases [14–16]. Understanding the mechanisms through which weather patterns, including normal seasonal changes, might affect water security is critical to understanding the risks these changes pose for health. Capturing household experiences of the different aspects of water security during different seasons and weather events, can help to describe these mechanisms. Changes in weather patterns are projected to increase due to climate change [17] and the effects of these changes on water security and health might vary considerably in contexts with different climatic conditions and different access to water, sanitation and hygiene (WASH) infrastructure. Understanding these mechanisms is important for the designing of appropriate mitigation strategies of potential risks to health in the future.

The focus of this study is on two rural communities (Kiang West and Basse) in The Gambia, a low-income country in West Africa on the southern edge of the Sahel. The Gambia is experiencing a shift in its rainfall patterns [18, 19] and has a high existing seasonal health burden [20–30]; changes in weather patterns are likely to have substantial implications for the health of the population in the future. The Gambia, compared to other countries on the continent, appears to have a median level of groundwater recharge and a higher level of groundwater storage capacity, which means that groundwater sources should be fairly resilient to short-term changes in climate and have a slight risk of long-term depletion [31]. Saline intrusion brought about by climate change has been identified as a risk for agriculture in The Gambia [32], which could also have impacts for water access. Communities included in this study have different histories of investment and maintenance of groundwater infrastructure, providing an opportunity to explore the role of infrastructure in buffering communities' experiences of water security, which has not yet been studied.

The objectives of this study were therefore to understand: 1) The water security situation in rural communities in The Gambia and; 2) The relationship between weather patterns (including normal season changes) and water security.

2. Methods

In order to study the relationship between water security and weather patterns in Kiang West and Basse, multiple qualitative methods were used including in-depth interviews (IDIs) and participatory methods such as transect walks. In addition, field notes were taken throughout of any observations to add contextual understanding.

2.1 Study setting

The Gambia has two distinct seasons: a long dry season (November to May) and a short rainy season (June to October), with 98% of rainfall occurring in the rainy season [33]. The Gambia has experienced increasing inter-annual variability in rainfall patterns and a substantial decrease in overall rainfall (18, 19], with linear trends indicating a wet season decrease of 8.8 per mm per month per decade between 1960 and 2006 [34] (approximately 3–5% see Fig A in S1 Appendix). There has also been an overall decrease in the length of rainy season and a simultaneous increase in temperatures [34]. Recent data on evapotranspiration in The Gambia is not available, but the most recent data from 2009 shows an overall reduction [35]. Models suggest there may also be further decreases in rainfall and increases in evapotranspiration in the future [36, 37]. This in combination with population growth, which is expected to double by 2050 [38, 39], and increasing ambitions to move away from traditional rain-fed methods towards irrigation of crops to reduce import-dependency [40, 41], may put pressure on water resources in the future.

This study focuses on two regions: Kiang West (KW), located on the south bank of the river Gambia on the western side of the country, and Basse (BA) located in the most eastern part of the country. Both areas are in the tropical savannah climate zone (Aw), according to the Köppen-Geiger classification [34], but vary in terms of weather patterns. In Kiang West temperatures tend to be cooler and there is more vegetation, whereas Basse is more arid with perceptibly higher temperatures [42].

The two study areas differ in terms of standard WASH indicators. A national cross-sectional survey found that in Mansakonko (the administrative area which includes Kiang West) there were limited observations of hygiene facilities (45%), with even fewer being observed in Basse (24%) [43]. 36% of drinking water sources in Mansakonko tested positive for E.Coli, a marker of faecal contamination, compared to 65% in Basse; with the percentage of household stored drinking water testing positive for faecal contamination markers similar at both sites (86% Mansakonko and 87% in Basse) [43]. In most villages studied, there were committees that were responsible for managing operation and maintenance of existing water sources and committees managing health/ clean environment that ensured the community was kept clean to promote good health.

In the Gambia, water-related diseases are one of the main drivers of the health burden, with enteric infections being ranked as one of the primary causes for disability-adjusted life years (DALYs) lost for children under 5 [44]. At the Medical Research Council (MRC) clinic in Keneba in Kiang West, diseases that could be linked to water insecurity, such as diarrheal diseases and skin infections were two of the most common diagnoses amongst children under 5 [45]. In Basse, similarly high rates of diarrheal diseases have been found in a previous study [46], with pathogens such as Cryptosporidium found to peak in the rainy season [20, 21].

We selected 4 villages in Kiang West (KW) and 4 villages in Basse (BA), based on discussions with local experts, that had differing access to water (some had taps in their community and/or compound, whereas other had handpumps or wells). An additional pilot village was also selected in Kiang West. See Fig 1 for map of villages in the study.

2.2 Sample and selection of participants

We purposely sampled women and men with young children under the age of five as the primary participants for this study. As children under five are one of the groups most-vulnerable to water-related diseases, we chose to focus on the parents of children in this age group, who could give insights on water use and access for these households. Women were the main focus of the interviews, as women are usually responsible for water collection [28], domestic tasks using water and for childcare. In-depth interviews were conducted individually with the women selected. As polygamy is widely practiced in the area, it was initially anticipated that first wives or women in monogamous households might have different experiences and responsibilities related to water compared to second or third wives in polygamous households. However, during the interviews it became apparent that there were few differences between these groups, so we did not limit the data collection to ensure equal representation of both groups.

Men in the village who had children under five were included in the follow up interviews to give a broader perspective on water security, as they might have a differing perspective on water prioritisation and use. Village chiefs (Alkalos)/ elders were also interviewed in each village to give a broader background perspective on how resources are managed, and wider community issues related to water.

2.3 Data collection

Data were collected from April to May 2022 at the end of the dry season. For the first round of data collection conducted in April, semi-structured interviews with three women in each village (four in the pilot: two transect walks and two in-depth interviews) were conducted (see Table 1). A transect walk was also conducted with one of these women at the end of the interview (see Table 1), where they were asked to walk the research team through their household and/or community to key points where they interact with water and take photos of what they consider to be important.

During the follow up interviews conducted in May, one man in each village was interviewed using a refined topic guide. An Alkalo (village chief)/elder in each village was also interviewed using a broader topic guide that focused on community issues.

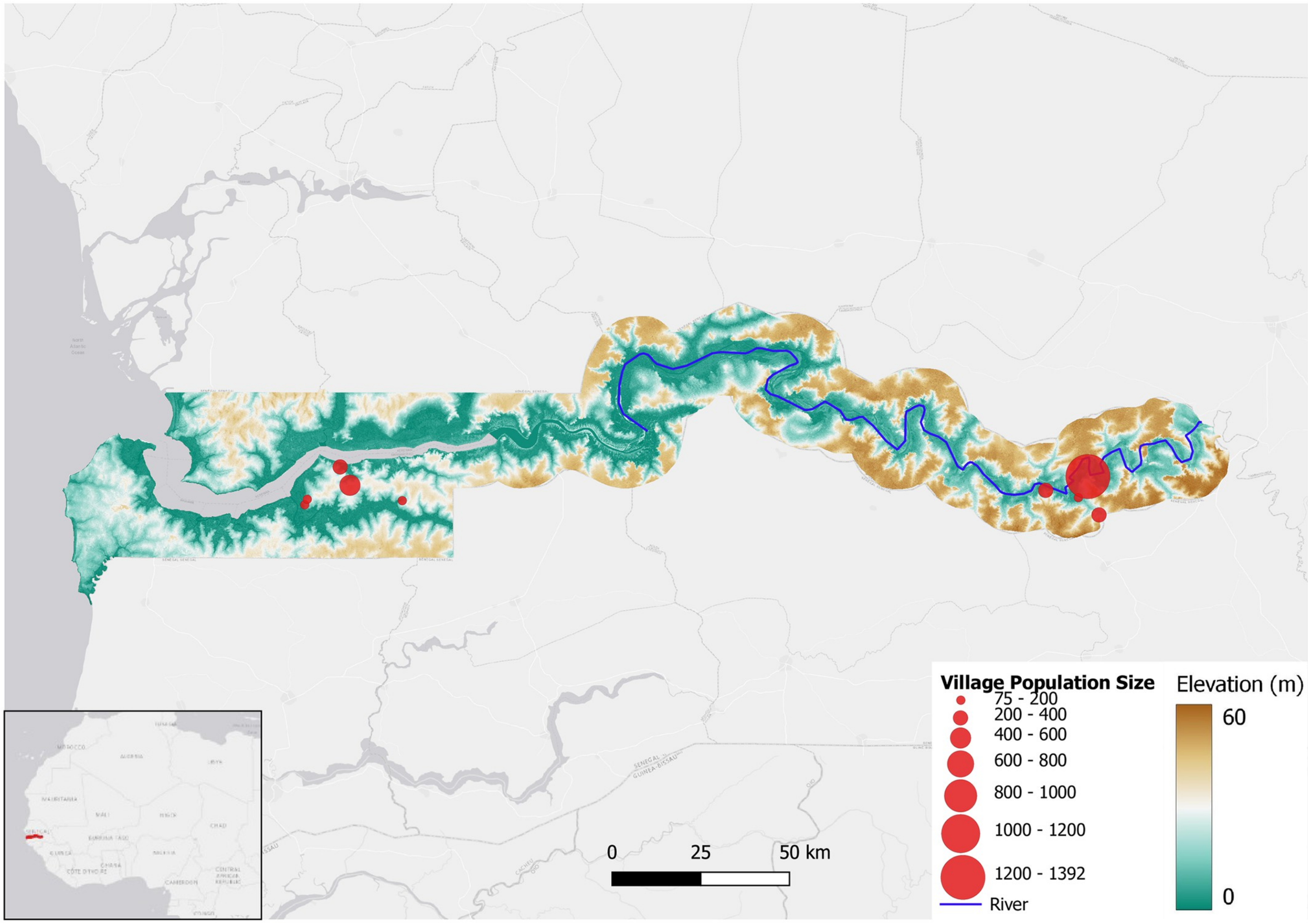

Fig 1. Map of study villages and the population size in The Gambia*. *This map was made in QGIS using the following base layers: Natural Earth "Rivers + lake centerlines" accessed from: https://www.naturalearthdata.com/downloads/10m-physical-vectors/10m-rivers-lake-centerlines/ Accessed 2024-05-19.; NASA JPL. NASA "Shuttle Radar Topography Mission Global 1" arc second. 2013, distributed by NASA EOSDIS Land Processes Distributed Active Archive Center, https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL1.003. Accessed 2024-03-06.; Gambia National Disaster Management Agency (NDMA) "Gambia—Subnational Administrative Boundaries" https://data.humdata.org/dataset/cod-ab-gmb? Accessed 2024-03-06.; ESRI "World Light Gray Base https://server.arcgisonline.com/arcgis/rest/services/Canvas/World_Light_Gray_Base/MapServer Accessed 2024-03-06.

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Table 1. Participants and interview breakdown.

Interview Type	Number of Participants	Objectives
1) In-depth Interview Women (IDI)	**18**–8 in BA; 10 in KW (2 pilot)	Understand key water-related behaviours, the water security situation, and the associations with weather and seasonal changes
2) Transect Walks (TW)	**10**–4 in BA; 6 in KW (2 pilot)	Same as IDI, and provide an insight into the environment and how this might shape water-related behaviours
3) In-depth interview men (IDI)	**9**–4 in BA; 5 in KW (1 pilot)	Provide a broader perspective on water security in the area, and the associations with weather and seasonal changes
4) In-depth interview Alkalo/elders	**9**–4 in BA; 5 in KW (1 pilot)	Provide a broader perspective on water management in the community and challenges to water security at the village level

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A total of 46 participants were interviewed: 28 women; 9 men and 9 village chiefs (Alkalos)/ elders (see Table 1 for the participant breakdown).

Data were collected by a team of three researchers (two field workers and IB). The field workers were both from villages around Kiang West, one was Fula (and fluent in Mandinka) and one was Mandinka. Interviews were conducted by the field workers in either Fula or Mandinka, depending on what was preferred by the participant. One interview with a village chief was conducted in English by IB. Throughout this period IB was primarily based in a village in Kiang West or in Basse and made detailed notes on any observations of the environment related to water use and access.

Prior to the interviews the field workers were trained by IB in the topic guides, and these were adapted to better fit the needs of the context. After piloting, this guide was further modified, and the interview process was also adapted iteratively based on the findings from the interviews. All topic guides are available at Bose et al., 2024 [47]. The interviews were carried out in the villages in a private location around participants' homes. The first round of interviews was conducted during Ramadan, so efforts were made to ensure that the interviews were not too taxing for either the participant or the field team.

2.4 Data transcription and analysis

All interviews were recorded, orally translated into English by the field worker, and transcribed by IB. The translation and transcription process was interspersed throughout the fieldwork period, so that the interview guides could be modified according to the findings emerging from the prior interviews. These transcripts were then checked by OC (social scientist at the MRC Unit The Gambia) for quality control purposes.

A thematic analysis approach was taken to analyse the data [48], using an iterative process of both inductive and deductive coding. Initial codes were developed based on the themes emerging from the data. This coding framework was then refined and re-grouped according to prior literature, the initial objectives of the study and an *a priori* conceptual framework developed during the design of the study (see Bose et al., 2024 [47] for coding framework). The follow-up questionnaire was also designed based on preliminary findings from the first round of interviews.

The verified English transcripts of the in-depth interviews were then uploaded into NVivo [49] and coded according to the refined thematic codebook. The field notes and photos were reviewed and summarised and then coded in NVivo [49].

2.5 Ethical approval

Prior to the interviews the community was sensitised on the objectives of the research and each participant provided written consent. The field team verbally read through the consent form in the language that they were most comfortable with and answered any questions they had. Many of the participants were not literate so provided thumbprints with impartial witnesses present, who also provided their thumbprint or signature. Participants were informed they could stop the interview at any time and did not have to discuss anything they did not feel comfortable with. All names during the transcription process were changed to unique identifiers to protect the participant's identity. Photographs were also stored using these unique identifiers.

This study was reviewed and approved by the Scientific Coordinating Committee of the MRC Unit The Gambia and ethics approval was provided by the Gambian Ethics Committee and the LSHTM Observational/Interventions Research Ethics Committee (Ref: 26658).

3. Results

3.1 Participant characteristics

Table 2 shows the socio-demographic characteristics of the participants. Most participants either identified as Mandinka (51%) or Fula (42%), with the majority of Fula participants based in Basse and the majority of Mandinka participants based in Kiang West. Most participants engaged in agriculture as their main source of income. Only one person reported business as their primary source of income, although a few reported having other sources of supplemental income, such as through construction, a small business or other activities. Most participants had not had any schooling (57% of women, 67% of men). All participants had access to a water source (usually multiple water sources) within their village or compound and there was at least one 'improved water source' available in each of the villages. The household size of participants varied from 4 to over 40, with communities in Basse typically reporting larger household sizes.

3.2 Water sources

Most participants reported regularly using multiple water sources in their villages to collect enough water to meet their domestic needs. Sources included taps fed by solar-powered pumps in boreholes, handpumps, wells (covered and uncovered) and in one instance the river (see photos of sources in Fig B-E in S1 Appendix). Some of these sources, such as the solar-

Table 2. Participant socio-demographic characteristics.

	All Sites		Kiang West		Basse	
	Women	Men*	Women	Men*	Women	Men*
Ethnicity						
Mandinka	15	4	12	3	3	1
Fula	10	5	1	2	9	3
Other	3	0	3	0	0	0
Average Age	32	44	32	44	33	45
Average Number of Children	5	11	5	10	4	13
~Average Household Size**	12	15	10	10	15	23
In polygamous households	14	4	7	1	7	3
Level of Education						
No School	16	6	6	3	10	3
Some Primary School	5	0	3	0	2	0
Completed Primary School or any level of secondary schooling	6	2	6	2	0	0
Arabic School	1	1	1	0	0	1
Household Main Income						
Farming	28	8	16	5	12	3
Business	0	1	0	0	0	1
Water Sources***						
Shared water tap in compound	3	-	3	-	0	-
Shared water tap in community	14	-	5	-	9	-
Handpump	22	-	13	-	9	-
Uncovered Well	19	-	9	-	10	-

*Not including Alkalo (village chief)/elder

** As defined by the participants, the total number sharing food and water

***Only reported by women

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powered pumps were relatively new, with some sources only constructed within the last year or two, but some sources had been present for over a decade. During the rainy season most participants also collected rainwater using large buckets that collected the runoff from their corrugate iron roofs.

There was a clear hierarchy in the consideration of sources that most participants made related to how they perceived the water quality, with water from covered sources, such as hand-pumps and solar-powered pumps, generally considered to be of higher quality. Many made a distinction between the water used for drinking and cooking, compared to the water for other purposes.

> *"The one we usually use for drinking and cooking, there is a tap just there [points to a tap]. We normally take our 20L gallons [water containers] and fetch the water for their use for cooking and drinking. The ones we use for baths, domestic animals, and other things we use the water from the open wells."*
>
> [IDI, Woman, 2nd wife, BA]

Most described using rainwater for cleaning, bathing and other activities, but the majority did not use it for drinking or cooking as they were not sure if it was clean. A few participants did, however, describe also using the water for drinking.

> *". . .when it is raining, we normally put our containers under the veranda. We collect the water from the rain, and we use that water for laundry and for washing other materials like our basins and other things, but we don't drink that one."*
>
> [IDI, Woman, 2nd wife, BA]

This hierarchy in sources was also often reflected in how water was stored in the home, with many having specific jars, sometimes with decorative coverings, that were used solely for drinking (see photos in Fig H in S1 Appendix). Other buckets or gallons storing water were kept to the side for other purposes (see photos in Fig I in S1 Appendix).

3.3 Water roles and responsibilities in the household

Women bore primary responsibility for water collection, with most participants, regardless of gender, reporting that women are responsible for collecting sufficient water for their home. In some households, children helped if they were old enough, and in some instances, men helped but this was mentioned less frequently and sometimes only in exceptional circumstances, such as when water needed to be sourced from some distance away. In many polygamous households, women ran their households separately from their co-wives and did not share any responsibilities related to water or food. But, in some instances, women in polygamous households described sharing these responsibilities with their co-wives and this seemed to ease their burden slightly. Some women, in both polygamous and monogamous households, also lived with their in-laws, so were also responsible for collecting water for their use.

Whilst women were responsible for collecting water, a few reported that they did not have the decision-making power on how water is used in the household, for example prioritising certain water-related activities or certain individuals. In these cases, they reported that that the head of the household (the man or the man's father) the mother in-law, if present, had the decision-making power. It was more common however, for women to report having autonomy over how water is used, which was also reported by some men.

"It the woman who is responsible [for controlling the use of water], as she is the one who brought the water here. She is responsible because she is the one who brings the water, and she is the one who stays in the house."

[IDI, Man, KW]

3.4 Water security

Whilst water was not scarce in these areas, there were challenges affecting the water security of many of the participants throughout the year.

Accessibility and availability. Mostly water sources were in close proximity, less than a 5–10 minute walk, to the participants homes or within their compounds, but none had access to piped water in their home. Even those with taps or wells in their compounds often had to also source water from outside, as respondents reported that they were not able to obtain sufficient water from these sources at the time it was needed or the water available was not considered to be of adequate quality for all of their needs. Some participants described the physical challenges of carrying water back to the compound and the time taken for fetching as a hinderance for their other domestic tasks. Some also described frequently having to travel outside of their village or pay someone with a donkey-pulled cart to fetch water.

". . .we go outside of the village to struggle for water. So, if you don't have money to bring your gallon from the nearest village, it becomes challenging."

[IDI, Woman, 1st wife, KW]

Though most people described everyone in the villages as having equal access to water, the data indicated that some individuals had greater challenges accessing water sources. This included new settlers in the village, who lived sometimes quite far from water sources, and people with disabilities that might have challenges to collect water.

Speaking of new settlers in her village: *"the distance is too far. So coming to fetch the water and go back takes a lot of their time and delays other activities."* [IDI, Woman, 1st wife, KW].

Social dynamics also seemed to impact access to water with some participants not collecting water from the sources closer to their homes, as they said there was a charge or for reasons that were not fully explained, which seemed likely driven by social factors, such as relationships within the village. Water sources were mostly described as freely available to all villagers, so the charge for sources described by a few individuals may have been specific to their position or relationships within the village and certain water sources. In these cases, participants opted to seek alternative water sources that did not have fees.

Stability of water availability and accessibility. The timing of water availability was frequently raised as an issue that made it difficult for respondents to always access water when it was needed. This was an issue commonly faced by participants that used water sources powered by solar panels. Participants described the taps only being able to provide water once the sun was at a certain height, and some communities also locked public taps to wait until the tank had been filled. Tanks were often not large enough to provide water that met the demand throughout the day, so participants had to use other sources or use other coping strategies to cope with water shortages.

". . .when we go to the borehole at times, we find no water in the tank, and you would like to wash your face and there is no water, as we wait until the sun rises for the borehole to be able

> *to give us water, and you cannot wait until such time so we then start fetching water from the local wells we have in the village."*
>
> [IDI, Woman, 1st wife, KW]

The demand on the sources from multiple villagers and having to share the water source with domestic animals also limited access, with many describing long queues at the water source and sometimes even disputes brought about by the waiting. This is heightened in areas where sources are only available at certain times during the day.

Mechanical breakdowns or failures of handpumps or solar-powered pumps were often described as a barrier to water access, which led to shortages in the village. Fixing this issue could take some time, as long as a couple of years in some cases, depending on the capacity of the village to collect enough funds for repairs and find the parts and labour required. Nobody described paying any fees to use water sources, but some did mention contributing to a fund to support repairs if required or, as previously mentioned, sometimes paying people to fetch water.

Quality. Perceptions of water quality is an important component of the experience of water security, driving source selection and how water is used in the household. In this context, perceptions around water quality were varied. Many participants did not perceive any issues, whereas others described water sources such as wells to not be of high quality due to the possibility of objects or insects falling inside. The colour, smell and taste of water (even that obtained from pumps or solar-powered boreholes) was described to be a problem in some villages, potentially due to infrastructural issues that enabled dirt to enter or the corrosion of metal in the water source.

In villages near the river, mainly in Kiang West, salinity of water sources was described as a major issue that also affected water collected from pumps or wells. The saltiness of the water made it difficult to drink or use for other domestic activities such as laundry.

> *". . .there is the pump, and the water there is very salty. Even your laundry because of salt, the soap can't clean the clothes."*
>
> [IDI, Woman, 1st wife, KW]

Water treatment was not widely practised. Some described using a cloth to filter the water, but other techniques were not usually used. Only one participant mentioned using chlorine to treat the water. Most when asked about treatment said they either did not have the skills or financial resources to treat water after collection.

> *"Because we are thinking of how to get water to drink, how you can expect us to look for treatment? Hence, we are thinking of how to get water to drink, you cannot expect us to go and buy medicine to treat the water in the well. Even though it is our wish to do it, but we cannot do it as we are poor and cannot do it."*
>
> [IDI, Woman, 2nd wife, BA]
>
> *"I personally don't think I have the capacity to do so [treat water]. Though it should be clean, I don't think I am able to treat the water."*
>
> [IDI, Woman, 1st wife, BA]

3.5 Seasonal factors affecting water security

Water security also seemed to vary seasonally due to both direct and non-direct weather effects.

Seasonal workloads (non-direct weather effects). A change in workload between dry and rainy season was noted by many participants, with most being heavily engaged in agriculture during the rainy season. This limited time available for domestic activities, including collecting water, cooking, cleaning and breastfeeding.

> *"Normally during wet season, it is far heavier in terms of household activities than dry season. You know in wet season, you always do domestic activities. . .[as well as working in the]. . .the rice field."*
>
> [IDI, Woman, 1st wife, BA]

Most participants described being busier in the rainy season. In places where water sources only functioned at certain times, the workload in rainy season made it more difficult to find time to collect water. Some respondents expressed concerns that seasonal workload made it difficult to ensure children had enough water at home while they were working the fields.

Direct weather effects. As many participants used rainwater for their domestic activities, on days during the rainy season where there was sufficient rainfall, it was easier to acquire sufficient water. Domestic animals also were sent to the bush to find their own water during the rainy season, but in the dry season were reliant on their owners providing water, increasing the water collection burden.

> *"in wet season, water problems are minimized because of rainwater."*
>
> [IDI, Woman, 1st wife, KW]

Furthermore, in the rainy season participants stated that it was easier to collect water from the wells; many wells and handpumps were reportedly more difficult to use in dry season as the water levels were too low. We observed some wells to be completely dry or water was very limited during this period (see photos in Fig F, G in S1 Appendix). This also put further pressure on the other water sources, as a more limited range of sources had to supply more people and animals.

> *"Because the water table is too low, we use donkey and rope to drag the water from the well. If the donkey doesn't assist to drag water from the well, you will find it difficult to get water."*
>
> [IDI, Woman, 1st wife, KW]

However, for those that primarily used solar-powered boreholes they described finding the rainy season more difficult as the clouds made it more difficult for the solar panels to work.

> *". . .at times in rainy season, we will stay for the whole day without water, as it is cloudy and there is no sunlight so the solar cannot fill the tank."*
>
> [IDI, Woman, 1st wife, BA]

This was described as particularly challenging on days where it was cloudy but there were not sufficient quantities of rainfall to supplement water collection.

"Even in wet season, it takes some days before rainwater comes, so we find it difficult to get water for household needs."

[IDI, Woman, 1st wife, KW]

In addition to water availability and access, some people reported changes in water quality depending on season. This also seemed to vary depending on the village and water source that was used, with some participants stating that the quality declined during the rainy season, possibly due to the rainwater flushing dirt into the source for uncovered sources or through any cracks of covered sources. Some also described the quality declining in the dry season, perhaps as there was not enough water to dilute any dirt that was in the water.

"the dry and rainy season have changes. Though the rainy season, the water taste is bad, but we have more water then. But for the dry season, it is tasty but difficult to have."

[IDI, Man, BA]

"At times when the well gets dry. At that time the small amount you have from it, it tastes bitter."

[IDI, Woman, 2nd wife, KW]

3.6 Weather events and water security

Most people could recall a time when they had experienced a heavy rain event, low rainfall, drought or a delay in the onset of the rainy season. However, when asked about how these events affected their water security, most focused on the implications for agriculture and wider infrastructural problems brought about by these events.

Heavy rains. Most people associated heavy rains and "running water", which is how minor flash flooding was described, with the destruction of infrastructure. Most could not recall how water access or availability was affected by heavy rains, but some noted that the infrastructure damage sometimes also affected their water sources and their water quality.

"that year, the rain was successful so people have plenty [of food] after harvesting. On the side of water, people face major difficulties in terms of buildings collapsing and others. That year even this well [pointing to the close by well by his compound] it created a hole somewhere else because of the flood of the water. . .. That year the water was very dirty"

[Alkalo/Elder, Man, KW]

Mostly participants emphasised how heavy rainfall affected their overall well-being, in terms of food and housing. In particular, people mentioned buildings collapsing, roofs leaking or being destroyed, and belongings being taken away. Some also mentioned how the heavy rains affected their food consumption, as the rain destroyed their food stores, or they lost income due to the destruction of their property, so had less income to buy food and other essential items.

"Our sugar was taken away, rice has been taken away and we didn't have any place to stay. The remaining food with us, we didn't even have a place where we could keep them."

[IDI, Woman, 2nd wife, BA]

Conversely, however, many people also associated heavy rains with a good harvest, but this was dependent on the severity of the rain, timing of the rains and the crops harvested.

> *"Heavy rain has risks and benefits. In terms of agriculture there are other varieties that needs a lot of water. Others need very small. The ones that need smaller water, when there is heavy rain then they are all spoiled. But these other ones, it gives us a better harvest."*
>
> [IDI, Woman, 3rd wife, KW]

Low rainfall/ drought. The concept of reduced rainfall was understood in different ways by participants, with some speaking of rain starting and then abruptly stopping and others thinking of an overall major lack of rain over the season, but most thought of low rainfall as there not being as much rain as they would normally expect.

As all participants engaged in some form of agricultural activities, the first thing that most people mentioned was how this had affected their harvest and the consequences for their food and income. Many participants mentioned how this reduced the food available for their household, limited the type of food they could cook, and made it more difficult to have seeds for planting in the next season, affecting their domestic animals' food consumption, and their income overall.

Few participants described how lower rainfall impacted their access to water, though some discussed how it was tougher to get water and they had to borrow from others or find other ways to cope, such as by limiting water use. Others spoke of disputes in the community over long queues at water sources and infrastructural adjustments that were made to help improve the water situation.

> *"It brought a lot of difficulties, especially the hand pump and the open well because the water does down. So, for the handpump we had to buy another pipe that could go further down, as by then when you pump it you will not have water, so you have to adjust the pipe."*
>
> [IDI, Man, BA]

Late rainfall. A delay in the start of the rainy season was difficult for many participants to distinguish from low rainfall or a rain event followed by a long delay before the next rain. There was a clear idea of when the rainy season should start, June 15th seemed to be commonly understood in Kiang West as the day that rain was expected, so participants planned their agricultural activities with that date in mind. Poor harvests and the impacts on income and food were the primary consequences mentioned. A few also discussed water shortages brought about by this delay and how they had to reduce their water use, for example by limiting bathing.

4. Discussion

Overall, availability of water sources in the communities visited in The Gambia appeared to be fairly good, with all communities having access to at least one water source in their village, so could be categorised as having a "basic level" of drinking water services according to WHO and UNICEF standards [16, 50]. Many households regularly used multiple sources to meet their domestic needs, as it was not possible to rely fully on one source. There was a clear hierarchy perceived amongst water sources linked with the perceived quality of water sources, as has also been found in other settings [4, 51]. However, when considering the broader definition of water security, there were clear constraints, particularly in the dimension of stability, with many households describing having insufficient water at some points for their domestic needs. In addition to unreliable water supplies, some did not have access to good quality water at all times. For those living close to the river this seemed to be due to salination, likely brought about by the impacts of climate change resulting in sea-level rises and saline-intrusion of groundwater sources [52]. Mechanical failures also resulted in water insecurity, which were sometimes brought about by weather issues, but sometimes was an entirely independent issue that could occur at any time.

The relationship between weather patterns and water security was complex with both rainy and dry season presenting different challenges for water security, which seemed to vary depending on the type of water source used by the household and also sometimes by the socio-demographic characteristics of the household. For many, particularly those using wells and handpumps, dry conditions posed a challenge, as water sources such as wells ran dry, and sources were shared in this period with domestic animals. Previous studies in other settings have found a similar relationship between water availability and dry conditions, and the increased demand in this period with sources by the community and domestic animals as a limiting factor for water access [53].

On the other hand, for many the wet season presented great challenges for water security. Despite recent investments in water infrastructure in some communities, in particular the introduction of solar-powered boreholes, many struggled to find sufficient water in cloudy conditions that were more common in the rainy season. Some also still perceived these sources to not be of adequate quality. These are issues likely arising from mechanical constraints, with poor water quality perhaps driven by cracks in the infrastructure or initial construction issues. The limited functionality during cloudy conditions may also be a constraint of the solar mechanisms utilised and the size of the tanks installed.

Understanding seasonal changes in water security requires consideration of the broader context of water insecurity in this setting. Seasonal workloads in the rainy season limits time for water collection. This intensifies issues in communities using solar-powered boreholes that functioned less well in rainy season. In communities that struggled to find water in the dry season, workload in the rainy season made it more difficult to find time to fetch higher quality water for drinking, and instead led them to rely on rainwater if there was sufficient rain at that time. The opposite seasonal relationship has been found in Ethiopia, where labour shortages limited water collection in the dry season when water sources were also more limited [54]. This is likely due to the different types of crops grown in these areas that require greater labour intensity during different periods (e.g., maize is a key crop in Ethiopia whereas rice is a key crop in The Gambia) and highlights the variation that may occur between different contexts and the close linkage between water security and food systems.

Many studies have documented seasonal changes in water source selection in other settings, in part due to the availability of rainwater[4, 6–8, 51, 54]. Many participants in this context also described rainwater as providing an additional water source during the rainy season. Sufficient water cannot always be collected from rainwater to meet daily needs, so during this period there is a complex dynamic relationship with water insecurity. On days where there is a lot of rainfall, this may help to slightly buffer shortages brought about by workload, and in some communities the additional challenge of limited functionality of solar-powered boreholes at this time. However, for many days during this period there will not be sufficient rainfall to buffer these challenges.

Furthermore, in this context we found that whilst rainwater allowed participants to have more water for domestic use, this was also viewed by most as a low-quality water source, and most preferred to not use this source for drinking or cooking. This is in contrast to other settings, such as a study in Ghana which found there was a preference for rainwater consumption [4]. Whilst rainwater can under some circumstances be used as a clean water source [55], most of our respondents considered rainwater unfit for drinking. This might be because water was collected that ran off from the roofs, so could easily collect dirt in the process. Also, as the containers are open, they could easily be used by animals without people's knowledge, particularly if they are away working in the fields at the time. These containers could also become vector breeding sites. Evidence from other settings has shown that there are a number of pathways that could result in contamination of rainwater, and previous studies highlight the importance of safeguarding measures and treatment before it can be safely used for consumption [56]. Several studies in other settings have also found that there can be seasonal changes in water use [54, 57], but that the quantity used in different seasons is not always linked to the perceptions of scarcity [58]. So even though seasonal shortages were described by many, we cannot be certain as to how that translates into water use at that time.

In addition to seasonal changes affecting quantity, some participants described a change in water quality that varied by season, though again whether it was perceived to be worse or better during the rainy season seemed dependent on the water source. In the dry season uncovered sources were perceived to taste worse and in rainy season covered sources that seemed to have some cracks tasted worse. Though we did not measure the contamination of the sources in this study, multiple studies have found that water quality can vary by season, with higher point of source contamination in the rainy season regardless of water source, which was more commonly found in tropical savannah climate zones [59] (the same zone as the communities in this study).

Extreme weather events seemed to exacerbate seasonal challenges, with heavy rainfall being associated with lower water quality and low rainfall/late rainfall being associated with more water shortages for some communities. The impact of heavy rain events on water quality has been shown in other settings to be reduced to some extent by infrastructure, with improved sources, such as piped water and boreholes, providing better protection from contamination [60]. Thus, greater investment in climate resilient infrastructure and maintenance of sources might help to mitigate some of these effects, as damage to infrastructure seemed to result in contamination of water sources during heavy rain events; and in dry season water sources that were not of sufficient depth to reach the groundwater, resulted in shortages. Mostly respondents when asked about weather events focused on the effects on agriculture and damage to their housing. Whilst these effects are not directly related to water insecurity, these have substantial implications for overall resource security, which in turn affect water security and health. The close linkages between food insecurity and water insecurity have also been documented in other settings [61, 62], which demonstrates the importance of taking a holistic lens on resource insecurity.

This study demonstrates the high temporal, and often seasonal, variation within water security. Recent efforts to measure household and individual water insecurity have relied primarily on cross-sectional surveys measuring water security conducted at one time point, capturing challenges for water security over the previous 4 weeks or 12 months [63–65]. Whilst these are useful to provide an overall picture of water insecurity, they may not be able to adequately capture the changes in water security occurring over the course of the year. This study indicates the need for more frequent data collection to fully capture water security or adapting the questions to capture the impacts of extreme weather events and seasonal changes, particularly in settings where seasonal rainfall and workloads may be highly linked to water security.

These findings also need to be considered in a light of the current projections on climate change, where rainfall patterns are anticipated to increase in variability, heavy rainfall events are likely to increase in intensity and delays in the onset of the rainy season are expected [66].

This may result in shifts in water availability, as well as quality. These changes may also have implications for agriculture and therefore seasonal workloads. Although it was not possible in this study to capture the effects of long terms changes in climate on water security, given the dynamic interplay found between rainfall and water security in this study, these changes could have substantial implications for water security in the future and should be considered in the planning of more climate-resilient WASH.

4.1 Limitations

This study was based on qualitative interviews with a total of 46 people based in Kiang West and Basse regions of The Gambia, so may be reflective of how they perceive the situation and cannot necessarily be generalised to represent experiences in other areas of the country. This study captured people's perceptions around different dimensions of water security, but no measurements were taken of water availability, quality and use. Further study is required to quantify how water quality, access and use might change in different weather conditions in this area.

This study was also conducted at the end of the dry season and though both seasons were discussed, it is possible that if this study had been conducted in the rainy season this may have led to different responses due to recall bias. Furthermore, the positionality of the field team, comprised of one foreign woman and two male fieldworkers from the Medical Research Council Unit The Gambia (MRCG), may have influenced the participants' responses. We tried to mitigate these risks by clearly explaining the purpose of the study and that no further interventions were planned, and we also tried to triangulate the findings by using multiple methods.

5. Conclusion

In the communities studied in The Gambia most people had access to multiple water sources; however, there were various factors that prevented many from being fully water secure. Seasonal changes and weather events led to many not having sufficient water for their domestic activities or not having water of adequate quality. Measurements of water insecurity need to take into consideration the fluctuations that can occur throughout the year, in order to fully understand the challenges faced by these households. Recent investments in water infrastructure have helped to modify seasonal changes in water access for some communities but not resolve all of these issues. In communities with access to solar-powered boreholes, cloudiness and mechanical issues still resulted in many facing water insecurity. Anticipated changes projected in weather patterns put communities at risk of greater water insecurity in the future. Increased investment in climate-resilient infrastructure and water treatment options is required to help further reduce these challenges and the potential risks to health.

Supporting information

S1 Appendix. Graph of long-term trends in rainfall and maximum surface air temperature in The Gambia, and photos from the study sites.
(DOCX)

S1 Checklist. Inclusivity in global research.
(DOCX)

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References

1. Young SL, Frongillo EA, Jamaluddine Z, Melgar-Quiñonez H, Pérez-Escamilla R, Ringler C, et al. Perspective: The Importance of Water Security for Ensuring Food Security, Good Nutrition, and Well-being. Advances in Nutrition. 2021; 12(4):1058–73. https://doi.org/10.1093/advances/nmab003 PMID: 33601407
2. Jepson WE, Wutich A, Colllins SM, Boateng GO, Young SL. Progress in household water insecurity metrics: a cross-disciplinary approach. WIREs Water. 2017; 4(3):e1214. https://doi.org/10.1002/wat2.1214
3. Venkataramanan V, Collins SM, Clark KA, Yeam J, Nowakowski VG, Young SL. Coping strategies for individual and household-level water insecurity: A systematic review. WIREs Water. 2020; 7(5):e1477.
4. Chew JF, Corlin L, Ona F, Pinto S, Fenyi-Baah E, Osei BG, et al. Water Source Preferences and Water Quality Perceptions among Women in the Eastern Region, Ghana: A Grounded Theory Study. International Journal of Environmental Research and Public Health. 2019; 16(20):3835. https://doi.org/10.3390/ijerph16203835 PMID: 31614511
5. Twisa S, Buchroithner MF. Seasonal and Annual Rainfall Variability and Their Impact on Rural Water Supply Services in the Wami River Basin, Tanzania. Water. 2019; 11(10):2055. https://doi.org/10.3390/w11102055
6. Thomson P, Bradley D, Katilu A, Katuva J, Lanzoni M, Koehler J, et al. Rainfall and groundwater use in rural Kenya. Science of The Total Environment. 2019; 649:722–30. https://doi.org/10.1016/j.scitotenv.2018.08.330 PMID: 30179812
7. Kelly E, Shields KF, Cronk R, Lee K, Behnke N, Klug T, et al. Seasonality, water use and community management of water systems in rural settings: Qualitative evidence from Ghana, Kenya, and Zambia. Science of the Total Environment. 2018; 628– 629:715–21. https://doi.org/10.1016/j.scitotenv.2018.02.045 PMID: 29454211
8. Pearson AL, Zwickle A, Namanya J, Rzotkiewicz A, Mwita E. Seasonal Shifts in Primary Water Source Type: A Comparison of Largely Pastoral Communities in Uganda and Tanzania. Int J Environ Res Public Health. 2016; 13(2):169. Epub 20160127. https://doi.org/10.3390/ijerph13020169 PMID: 26828507.
9. Howard G, Bartram J, World Health Organization, United Kingdom. Dept. for International Development, United States of America. University of North Carolina at Chapel Hill. Vision 2030: the resilience of water supply and sanitation in the face of climate change: technical report / Guy Howard, Jamie Bartram. Geneva: World Health Organization; 2010.

10. Howard G, Bartram J, Pedley S, Schmoll O, Chorus I, Berger P. Groundwater and public health. Protecting groundwater for health: managing the quality of drinking-water sources London, International Water Association Publishing. 2006:3–19.

11. Howard G, Calow R, Macdonald A, Bartram J. Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. Annual Review of Environment and Resources. 2016; 41 (1):253–76. https://doi.org/10.1146/annurev-environ-110615-085856

12. MacAllister DJ, MacDonald AM, Kebede S, Godfrey S, Calow R. Comparative performance of rural water supplies during drought. Nat Commun. 2020; 11(1):1099. Epub 2020/03/07. https://doi.org/10.1038/s41467-020-14839-3 PMID: 32132535.

13. Green TR, Taniguchi M, Kooi H, Gurdak JJ, Allen DM, Hiscock KM, et al. Beneath the surface of global change: Impacts of climate change on groundwater. Journal of Hydrology. 2011; 405(3–4):532–60.

14. Stelmach RD, Clasen T. Household Water Quantity and Health: A Systematic Review. International Journal of Environmental Research and Public Health. 2015; 12(6):5954–74. https://doi.org/10.3390/ijerph120605954 PMID: 26030467

15. Gundry S, Wright J, Conroy R. A systematic review of the health outcomes related to household water quality in developing countries. Journal of water and health. 2004; 2(1):1–13. PMID: 15384725

16. Jepson WE, Stoler J, Baek J, M Martínez J, U Salas FJ, Carrillo G. Cross-sectional study to measure household water insecurity and its health outcomes in urban Mexico. BMJ open. 2021; 11(3):e040825. https://doi.org/10.1136/bmjopen-2020-040825 PMID: 33674365

17. Arias P, Bellouin N, Coppola E, Jones R, Krinner G, Marotzke J, et al. Climate Change 2021: The Physical Science Basis. Contribution of Working Group14 I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Technical Summary. 2021.

18. Nicholson SE, Fink AH, Funk C. Assessing recovery and change in West Africa's rainfall regime from a 161-year record. International Journal of Climatology. 2018; 38(10):3770–86. https://doi.org/10.1002/joc.5530

19. Urquhart P. National climate change policy of the Gambia. In: Resources DoW, editor. 2016.

20. Hossain MJ, Saha D, Antonio M, Nasrin D, Blackwelder WC, Ikumapayi UN, et al. Cryptosporidium infection in rural Gambian children: Epidemiology and risk factors. PLoS Negl Trop Dis. 2019; 13(7): e0007607. Epub 2019/07/28. https://doi.org/10.1371/journal.pntd.0007607 PMID: 31348795

21. Chao DL, Roose A, Roh M, Kotloff KL, Proctor JL. The seasonality of diarrheal pathogens: A retrospective study of seven sites over three years. PLoS Negl Trop Dis. 2019; 13(8):e0007211. Epub 2019/08/16. https://doi.org/10.1371/journal.pntd.0007211 PMID: 31415558.

22. Sanneh B, Papa Sey A, Shah M, Tate J, Sonko M, Jagne S, et al. Impact of pentavalent rotavirus vaccine against severe rotavirus diarrhoea in The Gambia. Vaccine. 2018; 36(47):7179–84. https://doi.org/10.1016/j.vaccine.2018.02.091 PMID: 29544688

23. Jagne S. Hospital-based pre-vaccination surveillance of rotavirus gastroenteritis disease in infants less than 5 years of age in the Gambia: 2011–2014. Int J Sci: Basic Appl Res (IJSBAR). 2015; 20(1):129–38.

24. Emerson PM, Lindsay SW, Walraven GEL, Faal H, Bøgh C, Lowe K, et al. Effect of fly control on trachoma and diar rhoea. The Lancet. 1999; 353(9162):1401–3. https://doi.org/10.1016/S0140-6736(98)09158-2 PMID: 10227221

25. Armitage EP, Senghore E, Darboe S, Barry M, Camara J, Bah S, et al. High burden and seasonal variation of paediatric scabies and pyoderma prevalence in The Gambia: A cross-sectional study. PLoS neglected tropical diseases. 2019; 13(10):e0007801. https://doi.org/10.1371/journal.pntd.0007801 PMID: 31609963

26. Oduro AR, Conway DJ, Schellenberg D, Satoguina J, Greenwood BM, Bojang KA. Seroepidemiological and parasitological evaluation of the heterogeneity of malaria infection in the Gambia. Malaria Journal. 2013; 12(1):222. https://doi.org/10.1186/1475-2875-12-222 PMID: 23815826

27. Mwesigwa J, Okebe J, Affara M, Di Tanna GL, Nwakanma D, Janha O, et al. On-going malaria transmission in The Gambia despite high coverage of control interventions: a nationwide cross-sectional survey. Malaria Journal. 2015; 14(1):314. https://doi.org/10.1186/s12936-015-0829-6 PMID: 26268225

28. van der Sande MAB, Goetghebuer T, Sanneh M, Whittle HC, Weber MW. Seasonal variation in respiratory syncytial virus epidemics in the gambia, west africa. The Pediatric Infectious Disease Journal. 2004; 23(1):73–4. https://doi.org/10.1097/01.inf.0000105183.12781.06 PMID: 14743052

29. Nabwera HM, Fulford AJ, Moore SE, Prentice AM. Growth faltering in rural Gambian children after four decades of interventions: a retrospective cohort study. Lancet Glob Health. 2017; 5(2):e208–e16. Epub 2017/01/21. https://doi.org/10.1016/S2214-109X(16)30355-2 PMID: 28104187.

30. Rayco-Solon P, Fulford AJ, Prentice AM. Differential effects of seasonality on preterm birth and intrauterine growth restriction in rural Africans. The American Journal of Clinical Nutrition. 2005; 81(1):134–9. https://doi.org/10.1093/ajcn/81.1.134 PMID: 15640472

31. MacDonald AM, Lark RM, Taylor RG, Abiye T, Fallas HC, Favreau G, et al. Mapping groundwater recharge in Africa from ground observations and implications for water security. Environmental Research Letters. 2021; 16(3):034012.

32. Yaffa S, Bah A. The Impacts of Saline-Water Intrusion on the Lives and Livelihoods of Gambian Rice-Growing Farmers. 2018.

33. Jaiteh MS, Sarr B. Climate Change and Development in the Gambia. The Earth Institute, Columbia University; 2011.

34. World Bank. Climate Knowledge Portal [https://climateknowledgeportal.worldbank.org/country/gambia/climate-data-historical.

35. Actual Evapotranspiration [Internet]. 2020 [cited 14/03/2024]. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Funstats.un.org%2Funsd%2Fenvstats%2FQuestionnaires%2F2019%2FTables%2FActual%2520evapotranspiration.xlsx&wdOrigin=BROWSELINK.

36. Séne SMK, Faye C, Pande CB. Assessment of current and future trends in water resources in the Gambia River Basin in a context of climate change. Environmental Sciences Europe. 2024; 36(1):32. https://doi.org/10.1186/s12302-024-00848-2

37. Sylla MB, Faye A, Klutse NAB, Dimobe K. Projected increased risk of water deficit over major West African river basins under future climates. Climatic Change. 2018; 151(2):247–58.

38. UNFPA. Gambia: Population Trends [https://gambia.unfpa.org/en/topics/population-trends-5.

39. United Nations Department of Economic and Social Affairs Population Division. World Population Prospects 2022 2022 [https://population.un.org/wpp/.

40. Kinteh SL. The Gambia: Agriculture and Natural Resource (ANR) Policy 2017–202. In: Agriculture Mo, editor. 2017.

41. Government of The Gambia. The Gambia Second Generation National Agricultural Investment Plan-Food and Nutrition Security (GNAIP II-FNS) 2019–2026. In: Agriculture Mo, editor. Banjul, The Gambia.

42. Copernicus Climate Change Service (C3S). ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. 2017.

43. UNICEF, Gambia Bureau of Statistics. The Gambia Multiple Indicator Cluster Survey 2018. 2018.

44. IHME. Global Burden of Disease https://vizhub.healthdata.org/gbd-compare/2024 [cited 2024 20/02].

45. Hennig BJ, Unger SA, Dondeh BL, Hassan J, Hawkesworth S, Jarjou L, et al. Cohort profile: the Kiang West Longitudinal Population Study (KWLPS)—a platform for integrated research and health care provision in rural Gambia. International journal of epidemiology. 2017; 46(2):e13–e. https://doi.org/10.1093/ije/dyv206 PMID: 26559544

46. Kotloff KL, Nataro JP, Blackwelder WC, Nasrin D, Farag TH, Panchalingam S, et al. Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): a prospective, case-control study. The Lancet. 2013; 382(9888):209–22. https://doi.org/10.1016/S0140-6736(13)60844-2 PMID: 23680352

47. Bose I, Dreibelbis R, Green R, Murray K, Ceesay O, Kovats S. Data collection tools for: "Changing rainfall patterns, household water use and health: risks and household responses in rural Gambia" [Online]. London School of Hygiene & Tropical Medicine; (2024)Available from: https://datacompass.lshtm.ac.uk/id/eprint/3808/.

48. Braun V, Clarke V. Using thematic analysis in psychology. Qualitative research in psychology. 2006; 3 (2):77–101.

49. Lumivero. NVivo (Version 12). www.lumivero.com, 2017.

50. World Health Organisation, UNICEF. Joint Monitoring Programme 2022 households country consultation guidance. 2022.

51. Daly SW, Lowe J, Hornsby GM, Harris AR. Multiple water source use in low- and middle-income countries: a systematic review. Journal of Water and Health. 2021; 19(3):370–92. https://doi.org/10.2166/wh.2021.205 PMID: 34152293

52. Vineis P, Chan Q, Khan A. Climate change impacts on water salinity and health. Journal of Epidemiology and Global Health. 2011; 1(1):5–10. https://doi.org/10.1016/j.jegh.2011.09.001 PMID: 23856370

53. Yerian S, Hennink M, Greene LE, Kiptugen D, Buri J, Freeman MC. The role of women in water management and conflict resolution in Marsabit, Kenya. Environmental management. 2014; 54:1320–30. https://doi.org/10.1007/s00267-014-0356-1 PMID: 25167777

54. Tucker J, MacDonald A, Coulter L, Calow RC. Household water use, poverty and seasonality: Wealth effects, labour constraints, and minimal consumption in Ethiopia. Water Resources and Rural Development. 2014; 3:27–47. https://doi.org/10.1016/j.wrr.2014.04.001

55. Islam MM, Chou F-F, Kabir MR, Liaw C-H. Rainwater: A potential alternative source for scarce safe drinking and arsenic contaminated water in Bangladesh. Water resources management. 2010; 24:3987–4008.

56. Gwenzi W, Dunjana N, Pisa C, Tauro T, Nyamadzawo G. Water quality and public health risks associated with roof rainwater harvesting systems for potable supply: Review and perspectives. Sustainability of Water Quality and Ecology. 2015; 6:107–18. https://doi.org/10.1016/j.swaqe.2015.01.006

57. Broyles LM, Pakhtigian EL, Rosinger AY, Mejia A. Climate and hydrological seasonal effects on household water insecurity: A systematic review. Wiley Interdisciplinary Reviews: Water. 2022; 9(3):e1593.

58. Greenland K, Czerniewska A, Guye M, Legesse D, Ahmed Mume A, Shafi Abdurahman O, et al. Seasonal variation in water use for hygiene in Oromia, Ethiopia, and its implications for trachoma control: An intensive observational study. PLOS Neglected Tropical Diseases. 2022; 16(5):e0010424. https://doi.org/10.1371/journal.pntd.0010424 PMID: 35560031

59. Kostyla C, Bain R, Cronk R, Bartram J. Seasonal variation of fecal contamination in drinking water sources in developing countries: A systematic review. Science of The Total Environment. 2015; 514:333–43. https://doi.org/10.1016/j.scitotenv.2015.01.018 PMID: 25676921

60. Guo D, Thomas J, Lazaro AB, Matwewe F, Johnson F. Modelling the influence of short-term climate variability on drinking water quality in tropical developing countries: A case study in Tanzania. Science of The Total Environment. 2021; 763:142932. https://doi.org/10.1016/j.scitotenv.2020.142932 PMID: 33268262

61. Brewis A, Workman C, Wutich A, Jepson W, Young S. Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low- and middle-income countries. Am J Hum Biol. 2020; 32(1):e23309. Epub 2019/08/25. https://doi.org/10.1002/ajhb.23309 PMID: 31444940.

62. Wutich A, Brewis A. Food, water, and scarcity: toward a broader anthropology of resource insecurity. Current Anthropology. 2014; 55(4):444–68.

63. Young SL, Bethancourt HJ, Ritter ZR, Frongillo EA. Estimating national, demographic, and socioeconomic disparities in water insecurity experiences in low-income and middle-income countries in 2020–21: a cross-sectional, observational study using nationally representative survey data. The Lancet Planetary Health. 2022; 6(11):e880–e91. https://doi.org/10.1016/S2542-5196(22)00241-8 PMID: 36370726

64. Young SL, Boateng GO, Jamaluddine Z, Miller JD, Frongillo EA, Neilands TB, et al. The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. BMJ Global Health. 2019; 4(5):e001750. https://doi.org/10.1136/bmjgh-2019-001750 PMID: 31637027

65. Young SL, Bethancourt HJ, Ritter ZR, Frongillo EA. The Individual Water Insecurity Experiences (IWISE) Scale: reliability, equivalence and validity of an individual-level measure of water security. BMJ Global Health. 2021; 6(10):e006460. https://doi.org/10.1136/bmjgh-2021-006460 PMID: 34615660

66. Fitzpatrick RG, Parker DJ, Marsham JH, Rowell DP, Jackson LS, Finney D, et al. How a typical West African day in the future-climate compares with current-climate conditions in a convection-permitting and parameterised convection climate model. Climatic Change. 2020; 163:267–96.