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Alleviating impacts of climate change on fishing communities using weather information to improve fishers' resilience

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This study contributes new knowledge in evaluating actions aimed at alleviating impacts of climate change on small-scale fishers and enhancing resilience in their households in West Africa. Evidence of the damage caused by climate change to the artisanal fisheries sector in West African countries is accumulating. Current measures in place for artisanal fishers to adapt to these changes include broad long-term pro-poor strategies designed to manage the persistent problem of overfishing and declining fish stocks. However, one immediate coping strategy is beginning to emerge, the more active use of reliable weather information. Based on 80 semi-structured interviews conducted in Senegal, Ghana, and Nigeria between 2021 and 2022, this study investigates claims that the use of weather information (WI) is helping West African artisanal fishers and those involved in secondary fishery activities to build more climate-resilient household income and food security. Unlike the long-term measures for mitigating the impact of climate change, results from the study show that by assessing the risk, their marine capture activities using weather information, fishers are immediately benefitting. Using the diffusion of the innovation theory to investigate the pattern of fishers' adoption and usage of weather information, we found that Senegalese marine artisanal fishers can be classified as "Early Adopters" of this innovation. However, this is not the case with inland fishers who remain skeptical and will only use weather information if they can ascertain its reliability. West Africa's inland fisheries sector is often neglected in climate change strategies: there is a lack of coordinated action to understand the weather information needs of these vulnerable fishers in order to coassess and codevelop bespoke weather products that offer benefits to them. However, West Africa's fisheries, especially those inland, are too important to ignore if the United Nations Sustainable Development Goals (UNSDGs), including no poverty and zero hunger, are to be achieved. To help this sector fully benefit from the use of weather information, this study recommends detailed research into the weather information needs of these fishers and user-friendly ways to engage with the fishers to transmit the information.

KEYWORDS

West Africa, inland artisanal fishers, marine artisanal fishers, weather information, diffusion of innovation

1 Introduction

West Africa is endowed with substantial marine and inland fisheries, broadly divided into industrial and artisanal sectors, both of which play major roles in the daily lives of communities (FAO Fisheries Department, 1996; Teh et al., 2016; Okeke-Ogbuafor et al., 2020). The industrial sector is an important foreign exchange earner for West African countries: most of their exportable fish are sold to European Union (EU) countries (Okafor-Yarwood et al., 2022). Unlike the industrial sector, which is mechanized, the artisanal fisheries sector is labor intensive and employs more people (Belhabib et al., 2015). However, due to the poor fishery management, including inadequate record keeping, it is difficult to estimate the actual number of people employed by the artisanal fisheries in West Africa (Belhabib et al., 2015; USAID, 2018). Nonetheless, it is claimed that about 6.7 million West Africans directly depend on this sector for food and income (Belhabib et al., 2015).

West Africa's fishery sectors are particularly vulnerable to the impacts of climate change. The complex links between the biogeochemical properties of West African waters, fish productivity, and distribution is poorly understood, and this complexity is compounded by the impact of climate change (Belhabib et al., 2016; Wilson et al., 2021). Extreme weather conditions linked to climate change are becoming more frequent and difficult to predict resulting in negative impacts on fisheries, fishers' livelihoods, and their associated communities. For example, adverse weather conditions damage fishing equipment, cause the loss of gear, and negatively affect the fish post-harvest sector (Monnereau and Oxenford, 2017). Rising sea temperature decreases fish reproduction and growth causing fish stocks to migrate toward colder waters away from the equator (White et al., 2022). Most artisanal fishers are now fishing further offshore to follow the migrating fish and moving to new fishing grounds in their own and other countries, thereby increasing the operational costs of fishing (Belhabib et al., 2016). Many fishers have also changed from small-sized to medium-sized boats (Monnereau and Oxenford, 2017).

The impact of climate change on West African fishers when combined with the persistent problem of overfishing increases the fishers' rates of poverty (Bahri et al., 2021; Belhabib et al., 2016; Sumaila and Tai, 2020; Stead, 2019). As the impact of climate change continues to soar globally, fish catches are predicted to decrease by 7.7% worldwide but could fall by over 50% in Nigeria and 60% in Ghana (Coalition for Fair Fisheries Arrangements, 2021). A total of four broad long-term measures have been proposed that could help reverse this decrease—marine protected areas (MPAs); co-management; wealth-creation strategies; and social welfare policies. The aim of MPAs is to protect breeding grounds for fish, thus replenishing declining fish stocks (Assis et al., 2021; Marcos et al., 2021). However, globally the value of MPAs for conserving fisheries is contested and the results are highly context-dependent (Caveen et al., 2014; Di Franco et al., 2016; Kituyi and Thomson, 2018; Trégarot et al., 2020). The second measure that has been taken to mitigate the impact of climate change is the promotion of co-management to strengthen relationships and trust between stakeholders in the fisheries, and for the collective action toward sustainable fisheries management and climate change adaptation for artisanal fisheries (Pittman et al., 2019). However, co-management is not a panacea (Bown et al., 2013). It raises many practical issues like which stakeholders should participate in decision making and how to prevent stronger stakeholder groups from dominating co-decision-making. The outcome of fisheries co-management arrangements are sometimes the products of internal or even external manipulations and discrimination of vulnerable stakeholders (artisanal fishers) by more influential stakeholders (industrial fishers) (Kaluma and Umar, 2021; Okafor-Yarwood et al., 2022).

The third approach is a wealth-creation strategy or fishing for profit, which focuses on the economic gains obtained directly or indirectly from industrial marine capture fisheries (Dyck and Sumaila, 2010; Okeke-Ogbuafor and Gray, 2021). But this trickle-down theory has been heavily criticized for the lack of evidence that it works. The fourth approach is the social welfare model which is designed to promote the well-being of fishers and their households, improving their income, nutrition, and food security (Belhabib et al., 2015; Cohen et al., 2019). One way of doing this is by scaling back the industrial fleet to stop fish just outside the inshore area from being vacuumed up by large-scale vessels. However, instead of boosting fishers' income and food security, such a policy may encourage overfishing by artisanal fishers (Okeke-Ogbuafor et al., 2020; Okeke-Ogbuafor et al., 2021). Therefore, despite these four measures taken to mitigate against climate change by communities, national governments, and international organizations, West African artisanal fishers and their households remain one of the worst-hit by the impact of climate change (Ojea et al., 2020). The African Science for Weather Information and Forecasting Technique (African-SWIFT) provides a fifth approach focused on the improved accuracy and communication of weather forecast information across a range of timescales (Parker et al., 2021). SWIFT, through its Testbed 3, says that the use of weather information by fishers and those involved in secondary activities can help West African fishers build resilience to climate change (Fletcher, 2021; Hill, 2021). Weather information is becoming more accurate as the skills of predictive models are improved by scientific and monitoring advances (Fletcher, 2021; Hill, 2021; Parker et al., 2021). Weather information is used by farmers to enhance their resilience to climate change. For example, pastoral, cash, and food crop farmers in West Africa are increasingly dependent on the accurate weather information to make management decisions, including when to plant their seedlings or the type of seedlings to plant, thus integrating weather information into their decision making (Nkiaka et al., 2019; Ouedraogo et al., 2021; Sarku et al., 2022). The value of weather information for fishers' safety at sea (Diouf et al., 2020; Mbaye et al., 2021; Opemo, 2018) has long been known, but its utility for the livelihood and income of West African fishers and those involved in secondary activities has been less researched and is not well-understood (Katikiro and Macusi, 2012; Lovei, 2017; Monnereau and Oxenford, 2017). This study fills this gap by examining the impact of climate change on livelihood and household income of West African artisanal fishers and the benefits of weather information to artisanal fishers and those involved in secondary activities.

2 Theoretical framework

The theoretical framework presented in this study is the diffusion of innovation theory pioneered by Everett Rogers (2003). Innovation is about an idea, process, discovery, or technology which is new to individuals and their communities. Diffusion is the process through which awareness of an innovation spreads over time within social structures or organizations. The diffusion of innovation theory developed by Rogers integrates communication and sociological theories of behavioral change to explain how an idea passes through different stages of adoption by its potential users. The structure of a social system influences how individuals make decisions about the adoption and usage of innovation and the speed of its diffusion. Rogers (2003) classifies individuals in a social system into five groups based on their attitude toward innovation. The "Innovators" are the first group to accept the innovation, and they are highly skilled in creating new ideas and technologies. The "Early Adopters" are the second group to accept the innovation, and they are more integrated into the social system than are the "Innovators." They are also more informed about the innovation than are the other members of the community. The "Early Majority" are followed by the "Late Majority" into adopting the innovation. The Late Majority group are reluctant to accept innovations because they are highly risk averse. This set is always the last to adopt innovation—they pick it up only when it has spread throughout the social system (Blythe et al., 2017; Ferster, 2017). Time plays an important role in the spread and adoption of new ideas. Socio-economic characteristics such as gender, income, and the level of education can also influence peoples' decisions about innovation (Blythe et al., 2017). The diffusion of innovation theory is used to analyze the spread of new ideas and technologies in a range of sectors, including health (Zhang et al., 2015; Dearing and Cox, 2018), agriculture (Dan et al., 2019; Lavoie et al., 2021), and aquaculture (Blythe et al., 2017; Kumar et al., 2018). For artisanal fisheries, our study will use this theory to frame the context and analyze the adoption of weather information by fishers in the three case-study countries.

With regard to the factors that motivate people to adopt innovations, according to Rogers (2003), there are five user-perceived qualities: relative advantage, trialability, observability, compatibility, and complexity. Relative advantage is seen as the most important determinant of an innovation adoption rate because it explains the degree to which a user perceives an innovation to be better or more useful than the existing alternatives (Sahin, 2006). Trialability is the capacity for an innovation to be tested with minimal investment and commitment. Innovations with a higher trialability are more likely to be adopted. Observability is about how visible the results of an innovation are to their users. Potential users are unlikely to adopt an innovation if they cannot see it being used by their peers or people within their network. Compatibility is how an innovation fits into the existing technical knowledge and within the values, beliefs, culture, and needs of potential users. The more an innovation can co-exist or integrate with the existing values, beliefs, and needs of potential users, the greater the chances for diffusion and adoption (Tornatzky and Klein, 1982; Scott et al., 2008; Wisdom et al., 2014). Last, complexity is the degree to which an innovation is perceived as difficult to understand and use (Rogers, 2003). Innovations that are hard to understand and use are less likely to be adopted by the potential users.

Traditionally, the agricultural and fishery sectors have used extension workers as change agents to promote the diffusion of new ideas and innovation (Blythe et al., 2017). However, persuading individuals and communities to accept weather information does not only require the services of trained knowledge brokers but also requires a regular supply of weather information and the match of weather information with the needs of artisanal fishers (Nkiaka et al., 2020; Singh and Singh, 2017; Sultan et al., 2020). As the impact of climate change on fishers and fisheries continues to rise and following the failure of marine protected areas, co-management the wealth-creation, and social welfare strategies to significantly alleviate the impact of climate change on fishers' and their households, this study investigates the patterns of adoption and usage of weather information by fishers, encouraged by change agents to assess the extent to which weather information (WI) is helping fishers build resilient livelihoods.

3 Research design and methods

This study makes use of the qualitative data collected in two phases from three case-study countries. The first phase of data collection was in December 2021, when a total of 50 semi-structured

TABLE 1 Number and composition of participants across case countries.

Category of participants	Senegal	Ghana	Nigeria
Primary sector			
Artisanal marine capture fishers and inland fishers	18	15	17
Secondary sector			
Fish mammies and fishmongers	3	9	8
National Agencies			
Staff of fishery agencies	2	2	1
Staff of meteorological agencies	2	1	2
Total number of participants	25	27	28

interviews were conducted with key informants (KIs) in Senegal, Ghana, and Nigeria. All 50 participants were recruited through snowball sampling and based on their knowledge or use of WI and willingness to participate in this study. Relying on snowball sampling to recruit participants can be biased as respondents are likely to recommend people who hold similar views to themselves. Thus, to encourage heterogeneity and obtain a variety of perspectives, a wide range of respondents were recruited from the fishery sectors and the meteorological agencies (Kirchherr and Charles, 2018; Allen, 2022). During this first phase, we interviewed five staff from the Ministries of Fisheries in the case countries; five staff from the meteorological agencies; 29 marine fishermen; and 11 fishmongers and women fish investors who finance fishers (fish mammies). A total of 20 interviews were conducted in Nigeria and 15 each in Ghana and Senegal. Interview questions focused on three areas: the impact of climate change on the activities of artisanal fisheries and fishers, and efforts at mitigating these impacts; the pattern of adoption and usage of WI by artisanal fishers both coastal and inland; and the ways in which WI products can be developed to suit the circumstances of different fishers. All the 29 fishers who participated during this phase were artisanal marine fishers. The second phase of interviews focused more on inland fishers and began in January 2022 when 30 respondents were recruited from Ghana, Senegal, and Nigeria (Table 1). Like the first phase, these respondents were recruited through snowball sampling. 21 of them were inland fishers and nine were fishmongers. To make the best use of the data collected for this study and to meet the research objectives, all data (first and second phase) were analyzed through "hybrid thematic content analysis" (Nowell et al., 2017; Xu and Zammit, 2020). Identified themes across datasets were threaded together, and the frequencies with which themes occurred were converted to percentages (i.e., of interviews in which they emerged).

4 Results

The results of the fieldwork are divided into three subsections- fishers' perceptions of 1) the impact of climate change on their activities; 2) efforts at mitigating the impact of climate change on them; and 3) the pattern of their adoption and usage of WI and across the case study countries.

4.1 Fishers' perceptions of the impact of climate change on their fishing activities

Although about 40% of the artisanal fishers who participated in this study were not familiar with the phrase "climate change," all the 50 artisanal fishers, the 20 women employed directly in fishing or secondary activities, and the 10 staff from fisheries and meteorological agencies agreed that the rivers, seas, and lakes are changing and that these changes are directly impacting the fishing activities. All 50 respondents directly involved in fishing mentioned rainfall loss and wind and temperature variations as the most important elements of weather and climate that are changing and impacting negatively on their fishing activities. Rainfall is good for fishing: KI-1 said marine artisanal fishers' welcome rainfall (though not with wind): "*if it rains heavily without strong winds, then we would catch plenty fish. . .rain brings fish" (KI-55)*. Similarly, about 65% of inland fishers believe that heavy rainfall is helpful because by increasing the volume of water in dry lakes and rivers, it increases the quantity of fish in them:

> "*When there is excessive rain sometimes leading to flooding, the water from the rain will enter every nook and cranny and our belief is that we are surrounded by water everywhere and where there is water there are fishes. So, with the heavy rainfall, all the fishes hiding are forced to come out. In fact, sometimes when you catch some fishes, you will see rust stain on their back signifying that they have stayed hidden for a long time in wherever they hid themselves. We catch different varieties of fish during this time. . . these fishes have stayed so long in their hiding places*" (KI-10).

However, the pattern of rainfall is changing and becoming less plentiful: "*rainfall in the past was heavy and frequent. . .*

our lakes and rivers are drying; it is very hard to catch a bowl of fish" (KI-17). KI-40 said "*Fish do not like shallow rivers, when the water begin to reduce, the fish know that the water is reducing, so they will look for where to hide and only a handful of them will be available. This makes our catch to reduce.*"

For the marine artisanal fishers, the wind is classed as the most dangerous element of weather and climate that affects their fishing activities: "*wind is very dangerous for our canoes…if it is windy, the sea is rough, it affects every fisherman, it causes accidents*" (KI-1). KI-2 said "*we cannot control the wind and the swells*". KI-19, another marine artisanal fisher, said "*it is very dangerous to go to the sea when it is windy*"; in addition, "*it is hard to catch any fish when it is windy*" (KI-45). Also, rising sea temperature is a problem. Although the fishers do not understand the science, most of them observed that the waters are getting unusually warmer; thus, according to KI-16 (marine artisanal fisher) "*it affects our fishing, we now travel far into the sea to look for fish.*"

Climate change affects not only fishers (marine and inland) but also those involved in secondary activities, including fishmongers and women investors (fish mammies). Indeed, it may affect secondary workers more than fishers: "*we can at least get one or two pieces of fish to eat and then sleep, but where will fish sellers find fish to buy, sell, and feed their family*?" (KI-1, marine artisanal fisherman). KI-33 (a fishmonger) said "*we need government and the authorities to help us…most of us have used up all our capital to feed our children, including monies borrowed from micro-finance banks of which we are paying interest on*". "*What am I going to do? No fish, so I grind maize and my family feeds on it morning, evening, and night*" (KI-31 inland fisherwoman), KI-51); an inland fisherman said "*when we get to the river these days, we spend several hours and catch little, tiny fishes…it was not so in the past*" (KI-51 inland fisherman). For the marine artisanal fishers, climate change has multiplied their problems: "*there is now a big change, fish is scarce, and I go very far to look for them…our fish is migrating, and we need to chase them. I start fishing from 3 a.m.*" (KI-1 fisherman). The operational cost of fishing is higher as compared to the past, so aside from spending more time in the sea, it has financial implications: "*I have been fishing for 35 years now, I did not travel far to catch fish, but nowadays, we do, and this very long-distance fishing consumes so much fuel*" (KI-57 fisherman). Another marine artisanal fisher (KI-18) says "*it is very expensive for us…we travel very far to catch fish*". As the cost of fishing continues to increase, K1-64 explains that it impacts household diets: "*believe me, you can spend so much to go to the sea and return with nothing…I mean when you sell the fish, there will be nothing left to feed your family, not even to buy bread.*" All 50 fishers stated that they need help to mitigate the impacts of climate change on their fishing activities.

4.2 Fishers' perceptions of efforts at mitigating the impact of climate change on them

Across the three case-study countries, open access fishing is the common policy in place to help fishers cope with the impact of climate change: "*we understand this, and this is why they* (artisanal fishers) *are allowed to fish without restriction…it is open access*" (KI-65, staff of fisheries agency). While this open-access fishing is meant to protect artisanal fishers from food insecurity, all the 29 marine capture fishers who participated in this study described this policy as futile, because it does not protect them from industrial fishing: "*industrial fishers practice irregular fishing…they fish from our own space* (inshore areas) *and the quantity of fish that they collect from our sea is affecting our own catch*" (KI-1, Senegalese artisanal fisherman). Likewise, KI-11, an artisanal fisherman from Ghana, says: "*everywhere in our water you will see big boats taking all our fish…what are we going to do*?" KI-16, another fisherman, said industrial fishers "*take all our fish, they* (industrial fishers) *are licensed to land demersal fish, but they catch our pelagic fish.*" However, KI-18, a staff of a fishing agency, pins some of the blame on artisanal fishers themselves:

> "*the fishing behavior of our artisanal fishermen also frustrates the process…they are hard to control, they fish without restrictions, and this is a big problem here, and then they blame the industrial fishermen for their inability to catch fish.*"

4.3 Fishers' perceptions of their adoption of weather information

4.3.1 Marine fishers in Senegal

About 55% of the respondents mentioned that weather information (WI) is currently helping fishermen cope with the impact of climate change. The WI Innovators are from international institutions, and they worked with national meteorological agencies in case-study countries: National Agency of Civil Aviation and Meteorology of Senegal (ANACIM); Ghana Meteorological Agency (GMet); and Nigerian Metrological Agency (NiMet). The Early Adopters include marine artisanal fishers from Senegal using motorized canoes who had earlier contact with Innovators (about 30% of respondents): "*for about six years, we have been getting support from outside organizations to improve our weather forecasting, and we are now sending weather climate information to fishermen for their safety on sea*" (K1-56, from ANACIM). This statement was confirmed by all the Senegalese artisanal marine fishers who participated in this study: "*we have been using these ANACIM* (weather information data) *for about 6–7 years*" (KI-1). ANACIM sends this product directly to their phones (KI-1, 66; 57). Television and radio are other communication channels through which these fishers access WI. KI-1 said, "*the service is much better now, if they* (ANACIM) *say it will rain, then it will.*"

For the Early Adopters, their decision to adopt this innovation is based on the following considerations: perceived relative advantage and observability; the innovation is not complex to understand and is compatible with their values and existing technical knowledge; and they can test this innovation with little investment. On relative advantage and observability, the fishers had previously relied on their traditional ways of reading the weather before fishing: "*by looking at the sea, stars, and sky, fishers can tell whether it is safe to go to the sea for fishing*" (KI-1); "*when the moon is dark, we get fish and when the moon is bright, we do not get fish*" (KI-23). However, according to KI-19, this information is not reliable: "*during those days, my father used to look at the moon and take his decisions, only for us to get halfway into the sea and return because of heavy winds*". In contrast to traditional weather predictions, fishers feel that the innovations in weather services saves them unnecessary journeys and fuel: "*if we hear that there would be storm at noon, we wake up very early to do our fishing*" (KI-2). With WI, these fishers can engage in supplementary livelihoods: "*if the forecast says that the weather will be bad, I will go and do another business*" (KI-3); "*once I hear that the weather is not good for fishing…I look for other things to do, so I can feed my children*" (KI-6). Like fishermen, women fishmongers in Senegal are increasingly using WI to make important decisions: "*I will not take any loan this season, they said there will be heavy wind and so we are not expecting fish*" (KI-37). Finally, most accidents are linked to the use of traditional weather forecasting: "*because these traditionalists* (fishers) *do not listen to ANACIM, and even when you tell them to wear vests, they decline…but things are changing out of 100 fishermen, more than 90 use ANACIM weather products*" (KI-6).

On complexity, compatibility, and trialability, a senior staff member of ANACIM said "*we are continuing to improve our products…for fishers that cannot read and write we normally use different colors of flag, like green, yellow, and red to demonstrate to fishers when it is safe to go to the sea*" (KI-56). Most fishers in Senegal are comfortable using this innovation, which is easy to access: "*personally before going to bed, I already know whether the sea will be rough or not, or whether it will be windy… ANACIM sends all these information*" (KI-1). KI-57 mentioned that phones, television, and the radio as channels through which they receive WI. The spread of WI in Senegal is also through networking: "*we have our Whatsapp group, we send information to our colleagues*" (KI-47). According to KI-48, a woman fishmonger, "*we get information* (WI) *from the fishers.*"

4.3.2 Marine fishers in Ghana and Nigeria

The Early Majority in Ghana are a set of artisanal marine fishers who accepted WI from the GMet (59% of respondents from Ghana): "*we have a database of marine artisanal fishers in Ghana…for those that we have their contact details, we send them WI and to be honest some of them appreciate and are using it*" (KI-13, staff member of fisheries agency). The Early Majority claim that WI is very helpful: "*the weather information that we get works for me…I cannot talk for others, but it should work for them as well*" (KI-59); "*whenever I receive this information on my phone, I plan my activities…if the information says that the weather will be rough, I look for other sources of income to feed my family until the weather changes*" (K1-18, fisherman). KI-66, a fisherman, said WI helps reduce his fishing operational costs:

> "*Before I started getting weather information on my phone, sometimes I made unnecessary journey to the sea and then when there was heavy wind, I had to rush out of the sea without anything to feed my family…I have 7 children, how to feed them becomes a problem*" (KI-70).

KI-67 said, "*all I know is that the traditional methods no longer work for me…I can no longer keep waiting for the moon, there is no fish in our water, the only thing that can stop me from going to the sea is when the forecast says there will be strong winds.*"

The Late Majority, who follow the Early Majority, are mostly marine artisanal fishers from Nigeria and women investors who sponsor fishermen, and they get WI from these fishermen: "*Mr X* (fisherman) *was the first person to talk to me about the weather information*" (KI-49). Women fish mammies benefit from WI: "*if the forecast says the weather will be fine, I look for money to support him* (fisherman), *if they say the weather will be bad, I will not borrow money to give him*" (KI-68).

On complexity, compatibility, and trialability, when compared to Senegal, the spread of WI in Ghana to both the Early and Late Majority is slower for several reasons, including the difficulty of understanding the weather information:

> "*this information is hard for some of our fishers to understand… some of these fishers do not understand English… Ghana is a multilingual country, we have over 50 languages, so how do we translate weather information into all these languages*?" (KI-66, staff member of fisheries agency).

4.3.3 Inland fishers from all three countries

Inland fishers from the three case countries are yet to adopt and use WI. Like other fishers who participated in this study, this set admit that climate change is affecting their fisheries: "*in the past, when I used to go to the river three or four times a day with my mother, we used to catch big fishes that filled our big basins… but now, you will go to the river and labor in vain for long hours, and then return home with only a handful of fish or no fish at all*" (KI-40). However, on relative advantage and observability, all fishers in this category attribute their changing weather patterns to the will of God and they are resigned to their fate: "*if God brings the rain, we thank him*" (KI-79). KI-80 said, "*all of these are the making of God . . . at the right time our rainfall will come and fill our river and like before we will start enjoying abundant fish*". This set of fishers depend on traditional methods for predicting their weather. For example, for rainfall, the signs are dark cloud and excessive heat; but if it becomes windy then "*we would know that it will no longer rain, the wind takes away our rain*" (KI-77). These fishers (76% of inland fishers) believe so strongly in their traditional methods that they distrust modern scientific meteorology. There were a few Late Majority in this category (47% of respondents) who joined this non-WI user group because a radio weather forecast had given them wrong information "*that program will tell us that there will be heavy winds and there would be no heavy wind*" (KI-76). On complexity, compatibility, and trialability, while this set of fishers do not routinely use WI, most of them will try it to test its accuracy: "*if they tell us that it will rain, we really want to see the rain*" (KI-75). Another reason for the low take-up rate of WI by inland fishers is because the fishery agencies focus on the marine sector: "*we send this information only to the marine artisanal fishers that use motorized canoes*" (KI-74 staff member of fisheries agency).

5 Discussion

There are four main questions for discussion in this section: 1) What is the extent of the impact of climate change on West Africa's artisanal fishery sectors and their fishers? 2) Have efforts at mitigating climate change helped fishers? 3) What is the proportion of artisanal fishers who make use of WI? 4) How can more fishers (especially inland) be encouraged to use WI?

On 1), the effect of climate change on artisanal fishers in West Africa, although it is hard to differentiate between the effects of illegal, unreported, and unregulated (IUU) industrial fishing and the effects of climate change on their fisheries, all the respondents in this study agreed that current patterns of rainfall, temperature, and wind are changing and these changes affect their fishing activities and thereby the quality of their lives (Muhala et al., 2021). But the level of vulnerability to climate change is not the same across the artisanal fishing sector (70% of all respondents). Inland fisheries, which also involve women, are more vulnerable than marine fisheries, which are mostly populated by men, because West African countries pay more attention to the marine artisanal fisheries than to the inland fisheries (Funge-Smith and Bennett, 2019; Lynch et al., 2016; Okeke-Ogbuafor et al., 2020; Smith and Basurto, 2019). Consequently, the often "neglected" inland fishers develop a lower adaptive capacity to cope with the impact of climate change (40% of respondents). Poorer than their male counterparts in the marine sector, the female inland fishers who depend on fishing from rivers, lakes, inland valleys, and streams are generally subjected to vague "open access fishing" regulations, which assume that fish is affordable and available to this group of fishers (Okeke-Ogbuafor et al., 2020).

On 2), the efforts at mitigating climate change, unlike, WI, which has immediate benefit to artisanal fishers (see Table 2), marine protected areas, co-management, wealth-creation, and social welfare measures have limited immediate benefits because they were developed to respond to the longer-term issues of poor fisheries management, overfishing, and declining fish stocks, which are currently undermining the livelihoods and incomes of West African artisanal fishers (Food and Agriculture Organization of the United Nations, 2015; Muhala et al., 2021; Okeke-Ogbuafor et al., 2021). While there is some merit in the argument that these four measures, if well-planned and implemented, could eventually help alleviate fishers' poverty, thus reduce their vulnerability and increase their adaptability to cope with the impact of climate change in the long-run, they are unlikely to have any immediate effect in reducing the fishing-dependent culture which currently threatens West Africa's already declining fish stock (Kituyi and Thomson, 2018). Unlike these long-term measures, the immediate effect of the use of WI is helping fishers and those involved in secondary activities assess the weather risks on their fishing activities.

On 3), the proportion of artisanal fishers adopting WI, the focus of the WI fishery agencies in the case countries is marine artisanal fishers and not their inland counterparts (46% of all respondents), so the larger proportion of users of WI come from the marine artisanal sector. This focus on marine artisanal fishers and the user-perceived qualities are particularly evident in Senegal (Rogers, 2003). Senegal has the advantage of time and management structures, which are especially important for the diffusion of innovation. International organizations have had a long engagement with partners in Senegal helping to improve their weather forecasting and communication (Muhala et al., 2021), while also understanding their users' needs. A total of 16 respondents from Senegal reported a significant improvement in the quality of WI that is currently sent to them when compared with the past. Senegal's fishers have gone beyond ANACIM's primary channels of communication to develop subchannels, including the use of WhatsApp groups, and word-of-mouth to convince more fishers and fishmongers employed in the secondary industry to adopt this innovation. The extensive adoption of WI by fishers in Senegal is due to the accuracy of its information and analysis which confers real-time advantages, including risk management during short- and long-term decision making, and this is helping to mitigate the impact of climate change on their fisheries. Ghana's high linguistic diversity slowed down the spread and adoption of weather information (see Section 4.3.2)

TABLE 2 Identified benefits of WI to fishers and those involved in secondary activities.

User	Risk and consequence	Benefit	% of respondents
Marine artisanal	Health and safety	Reduces operational costs: fishers reschedule fishing time	51
	Loss of life, properties, and increasing operational cost		
Fishmongers	Fish is highly perishable	Make rational decisions about whether to buy fish or where to sell quickly	56
	Loss of profit or business capital and impact on household income		
Fishers and fishmongers	Zero catch	Invest in supplementary livelihoods for income and food security	57
	Impact on household income, food security, and nutrition		
Artisanal marine fishers and fishmongers	Declining fish catch	Taking long-term decisions investing in alternative livelihoods	32
	Loss of business capital, inability to pay off or service loans, and impact on household income and food security		
Fish mammies	Loss creditworthiness and repay with high interest	Recalculate the cost of short-term servicing of loans and invest in other businesses	29

Source: data are collected from case countries in 2021 and 2022.

On 4), encouraging artisanal fishers, including inland fishers, to use WI, there is a clear need for more collaborative action between stakeholders. The artisanal fishers are too important to ignore in West Africa, a region with a growing number of malnourished children, and so fishery agencies should pay particular attention to them. More research on this sector (especially inland fisheries) could help us understand how climate change impacts them, and this knowledge would be helpful in customizing WI into a form that will be tailored to meet their needs. While most marine adopters of WI are benefitting from the usage, including using it to plan supplementary and alternative livelihoods, inland fishers are yet to benefit and climate change has continued to impact on their fishing and farming activities.

6 Conclusion

There is evidence that artisanal fishers in West Africa are willing to adopt and use WI. The Early Adopters in Senegal and the Early Majority in Ghana are increasingly using WI for assessing risks and making management decisions related to their fishing practices, which are helping them to enhance their resilience to climate change. With a population of over 213 million people with varying demographic characteristics and over 500 languages, we can speculate that it could take much more time for innovations to spread in Nigeria. Unlike the long-term measures for mitigating the impact of climate change, the use of weather information has immediate benefit for fishers. It is already helping many marine artisanal fishers and those involved in secondary fishing activities in Senegal to take proactive decisions, including investing in supplementary livelihoods with some fishers moving to alternative livelihoods, thus building resilient household incomes. There are two key considerations for the lower rate of adoption and usage of WI in Ghana and Nigeria, especially by inland fishers. First is the lack of coordinated action between stakeholders (researchers, representatives of local communities, Ministry of Fisheries, Meteorological Agency, and inland fishers) to understand the WI needs of inland fishers in order to coassess and codevelop bespoke weather products that offer benefits to this set of fishers. The second reason is cultural: most inland fishers still practice traditional fishing, holding strongly to their culture, and are skeptical about innovations and change. As a result, inland fishers remain most vulnerable to the impacts of climate change, yet this fishing sector is critical for food security, nutrition, and income. West Africa's fisheries, especially the inland sector, are too important to ignore, and to help this sector fully benefit from the use of WI, this study recommends a detailed study into the WI needs of these fishers.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

This research followed the research and ethics guidelines of University of Leeds. Participants provided their consent and were debriefed. The University of Leeds research ethics committee approved this research.

Author contributions

Conceptualization: NO-O, AT, AD, TG, and SS. Method: NO-O. Validation: AT, AD, SS, TG, and NO-O. Formal analysis: NO-O, AD, and AT. Formal writing—original draft preparation: NO-O and TG. Review and editing: all authors reviewed and edited the draft. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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