Literature Review

Climate Impacts on Nutrition in Senegal

IRI

Introduction

Malnutrition, in all its forms—including obesity, undernutrition (stunting, wasting, underweight), and dietary risks for non-communicable diseases (NCDs)—is the leading cause of poor health globally (Swinburn et al., 2019). Climate variability and change stand to exacerbate malnutrition through effects on both the natural and social systems upon which humans depend, including food systems. In areas most highly affected by such changes but with the least adaptive capacity, such as West Africa, the deleterious effects of these changes are most likely to be felt, especially by the most vulnerable (Barros et al., 2014; Ouedraogo et al., 2018; Serdeczny et al., 2017).

Situated in the Sahel, Senegal is one of the many countries in Africa whose population derives its livelihoods mainly through rain-fed agriculture and on-farm activities (Alfani et al., 2019). As such, the nearly 70% of its population that depends upon the land through agricultural and livestock production are particularly vulnerable to the changes in precipitation and temperature brought about by climatic variability and change (Carranza et al., 2019; Ouedraogo et al., 2018; USAID, 2017). Moreover, West Africa has one of the highest burdens of malnutrition in the world, and the outlook on the health of its under-five population, which already suffers from a wasting prevalence of 9% and stunting of 16.5%, is likely to get worse under conditions of climate variability and change (Dunn & Johnson, 2018; Global Nutrition Report, 2019; Lazzaroni & Wagner, 2016).

In light of these changes, it is important to document and, where possible, quantify the risks that endanger the nutrition of the Senegalese people, their households, and communities, such that appropriate interventions, tools, and policies to prevent and mitigate these effects can be developed. Towards this end, this literature review examines the current documented evidence, from both peer-reviewed and grey literature, of climate impacts on nutrition in Senegal. The information and analysis incorporated here is intended to guide the development of climate services for the nutrition community and its related sectors in Senegal through the Adapting Agriculture to Climate Today, for Tomorrow Columbia World Project (ACToday).

Overview of Conceptual Frameworks for Analysis

This literature review follows the framework of Herforth and Harris outlining the three conceptual pathways between agriculture and nutrition—production, income, and women's empowerment (Herforth & Harris, 2014). Given the absence of a commonly used or standard framework for analyzing climate impacts on nutrition, this framework is adapted from the widely used UNICEF conceptual framework on malnutrition to examine linkages among climate, food systems, diets, and nutrition. The components of this framework are visualized in Figure 1 and intended to facilitate the identification of climate service solutions to improve diets and health, and ultimately reduce the burden of malnutrition. This review is therefore organized and structured according to these three conceptual pathways, walking through each of them and their components in the pages that follow.

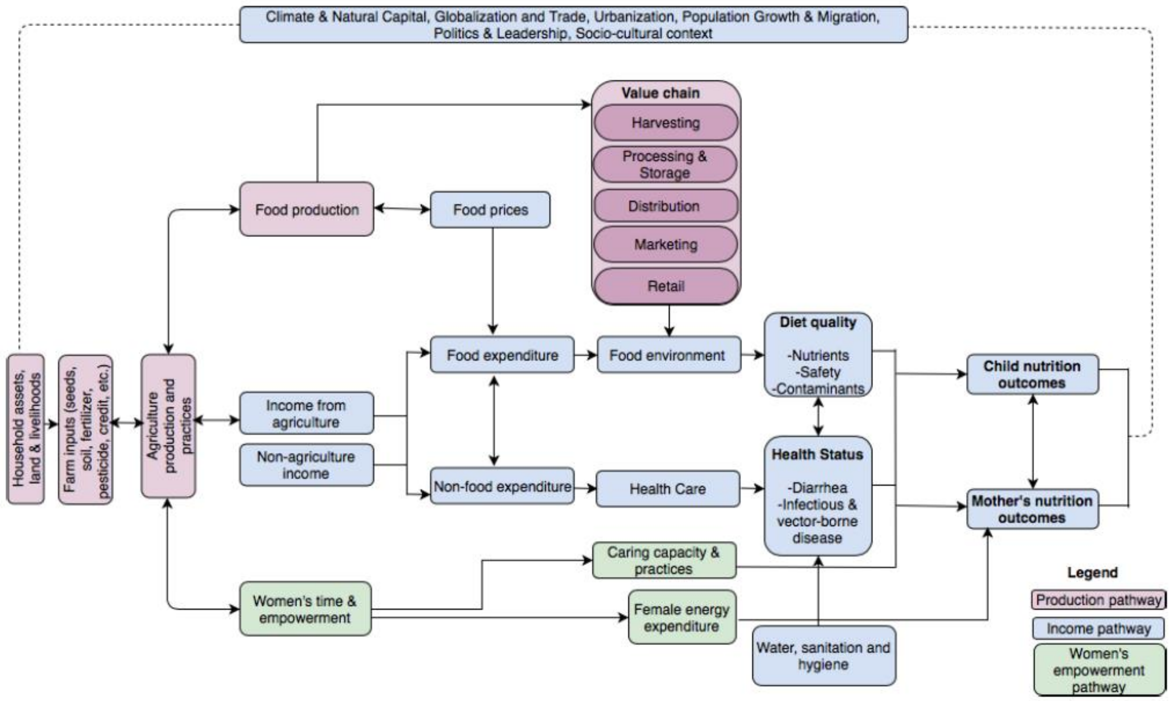

Figure 1: *How climate affects agriculture and nutrition pathways (Source: Adapted from Herforth & Harris, 2014)*

Climate Impacts on the Production Pathway

The production pathway is one of the three main pathways through which agricultural production influences nutrition outcomes. This pathway incorporates food production and the way food moves along the value chain. In this section, we will investigate the documented impacts and implications of climate variability and change on Senegal's production pathway, including household assets, land and livelihoods; farm inputs; agricultural and food production practices; and agricultural value chains, highlighting their links to nutrition.

Household Assets, Land, and Livelihoods

Climate variability and in particular shocks—both related to the natural environment and the economy—can lead, and already have led, to the loss of household assets, land, and livelihoods in Senegal. This, in turn, has implications upon the availability, affordability, access, and use of food.

Shocks

The literature surrounding shocks in Senegal covers the impact of both natural and non-natural climate-related shocks on nutritional status. The two most pronounced climate shocks with which Senegalese farmers must contend are droughts (natural) and economic shocks (non-natural), namely increasing purchase prices (Lazzaroni & Wagner, 2016). Future projections suggest that both types of shocks, largely as a result of increasing volatility in West African food production alongside world food prices, are likely to exacerbate rates of undernutrition in the West African Sahel (Haggblade et al., 2017).

Senegal's most vulnerable groups, including the more than one third of the population that lives below the poverty line or the 75% of families suffering from chronic poverty, face limited options in coping with these shocks (WFP, 2019). However, one of the coping strategies adopted in West Africa in dealing with shocks such as drought that affect productivity or prices, is to simply cut back on consumption (Camara, 2004; Hazard et al., 2008). Such reductions in consumption can occur in many ways, such as eating less expensive and less nutrient-dense foods like animal products, fruits, and vegetables, or cutting the number of meals and thus calories consumed per day (Haggblade et al., 2017). However, the end result of such self-imposed restrictions often means cutting high-protein and nutrient-rich foods, which especially for children under the age of 5, can mean increasing their risk of stunting and the perpetuation of chronic and inter-generational poverty (Haggblade et al., 2017).

The high frequency of climate shocks, especially recurring droughts, has already negatively impacted the health of Senegal's youngest generation. According to conservative estimates in a recent multiple shock analysis investigating child malnutrition in rural Senegal, the occurrence of drought explains 25% of the pooled child weight-for-age (underweight) standard deviation and 31% of income losses (Lazzaroni & Wagner, 2016). These droughts have serious repercussions on the nutritional status and food security situation of the most vulnerable households in rural Senegal (UNICEF & Action Against Hunger, 2016).

In this same vein, climate-related shocks such as higher purchase prices have also taken a toll on nutrition, and particularly child health. The literature identifies a breadth of research detailing the negative impacts of macro-economic shocks (Ferreira & Schady, 2009; Pongou et al., 2006) and commodity price changes (Cogneau & Jedwab, 2012) on child health in Africa, and specifically in Senegal (Lazzaroni & Wagner, 2016).

Low-income households in Senegal are markedly impacted by such price increases, especially in terms of caloric intake. Reductions in staple-food production due to production shocks like drought stress Sahelian West Africa's already thin markets for basic food items such as millet, sorghum, and maize and lead to price spikes that limit the poor's ability to access food (Haggblade et al., 2017). Moreover, world price shocks, especially for rice, the main staple crop of the Senegalese population, and the imports of which account for 65% of national consumption, put undue pressure on already vulnerable rural populations (Haggblade et al., 2017; Ouedraogo et al., 2018). During the 2008 world price spike, Thai milled rice almost tripled in price from US $316/mt in April 2007 to $907/mt in 2008, which the Sahel relies on for almost 60% of its total rice consumption and 10% of its total cereal consumption (Haggblade et al., 2017). Importantly, the need to consider interaction effects and combined effects of multiple shocks occurring simultaneously and not just as isolated events was identified as a research need that is currently thinly addressed (Lazzaroni & Wagner, 2016).

Farm Inputs

Farm inputs, including fundamentally, land and water, can and have already been influenced by climate variability in Senegal, leading to declines in soil quality and degradation of agricultural lands.

Land Degradation

Desertification and salinization were identified as the two main avenues of land degradation exacerbated by climate variability and change in Senegal, and negatively affecting agricultural production practices. As the availability of nutritious foods is dependent upon their agricultural production in the first place (Thomson

& Mason, 2018), these climate-driven phenomena have implications for both the food security and nutrition of people dependent on these lands.

With regard to desertification, robust evidence points to a pronounced reduction in water availability since 1960, especially around the Senegal River Basin, which is at least partially attributable to climate change, and exacerbated by state-imposed rice production policies (Aich et al., 2014; Ardoin-Bardin et al., 2009; Bodian et al., 2018; Faramarzi et al., 2013; Hanjra & Qureshi, 2010; Karambiri et al., 2011; Mahe et al., 2013; Mbaye et al., 2015; Ruelland et al., 2012; Sylla et al., 2018; Venema et al., 1997). As water is the main limiting factor for agricultural production in Senegal, the desertification around the Senegal River Basin and Valley poses a significant challenge to domestic food production, especially of the staple rice production (Venema et al., 1997).

In addition to this, the problem of salinization has also plagued Senegalese soils and contributes to food insecurity. In Senegal, the lands affected by salinization processes are estimated to be on the order of 1 million to 1.7 million hectares, or about 5-9% of the total land area (Diack et al., 2019; Gobin et al., 2004; Sadio, S. et al., 1989). Though information on the direct relationship between climate and salinization of lands is limited, changes in temperature and precipitation patterns are likely to affect the salt-water balance of fragile ecosystems, especially in the Senegal River Valley (Diack et al., 2019).

Agricultural and Food Production Practices

Crops

One of the most significant impacts of changing rainfall and temperature patterns in Senegal is on agricultural and food production systems, especially in Eastern Senegal. Reduction in crop yields, especially due to temperature impacts on tropical cereal staples such as maize and rice, threatens populations that are already food-insecure and agriculture-dependent for livelihoods (Brottem & Brooks, 2018; Roudier et al., 2011). For groundnuts, a staple grown by 27% of all households and 52% of households in extreme poverty (World Bank, 2017), crop models predict reductions in groundnut yields by 5-25% in areas where they are currently grown (CIAT and BFS/USAID, 2016). And for certain crops like maize, high temperatures may reduce their zinc and magnesium content (Myers et al., 2014; Thomson & Mason, 2018).

Moreover, as more than 90% of agricultural land is comprised of small-scale, family-based farms engaged in subsistence and rain-fed agriculture, insufficient precipitation and especially drought destroys household food security by wiping out crops intended for their own consumption (S. Bandyopadhyay et al., 2012; Hanjra & Qureshi, 2010). In addition, the associated loss of income makes the costs of engaging in safe and protective behaviors such as purchasing clean food and water problematic and, in some cases, prohibitive (S. Bandyopadhyay et al., 2012).

Following Senegal's 1996 Water Sector Reform, for example, one of the unique characteristics of the country's rural water supply systems is that they rely extensively on borehole water supplied by motorized pumps and managed by Borehole Users Associations (ASUFOR) which collect and manage water tariffs according to consumption volume (Hanatani & Fuse, 2012). More than 4.4 million people in 5,100 villages have water delivered to them through more than 10,800 public standpipes and 67,000 private connections, for which users are charged between 200-400 CFA francs for a cubic meter of water, or 10 CFA per 20L container (the size of a jerry can) (Hanatani & Fuse, 2012). While it is not uncommon to see women lining up and willing to wait and pay to fill jerry cans and buckets from what is generally regarded as a safe, improved water source, reductions in household income levels may influence payment behavior regardless of willingness to pay, thus affecting access to safe water for cooking, cleaning, and washing (S. Bandyopadhyay et al., 2012; Hanatani & Fuse, 2012).

As such, the nutritional status of children is compromised in times of water shortage or temperature extremes that lower crop yields (S. Bandyopadhyay et al., 2012). Moreover, water shortages and high temperatures are also associated with increased risk of diarrhea and diseases that interfere with nutrient absorption and overall health in Senegal (Constantin de Magny et al., 2007; Diouf et al., 2017; Dunn & Johnson, 2018; Levy et al., 2009, 2016; Magny et al., 2012; Thiam, Diène, Fuhrimann, et al., 2017; Thiam, Diène, Sy, et al., 2017).

Livestock

The Senegalese diet is mostly plant-based (Anderson et al., 2010) and based on cereals for over two-thirds of dietary energy supply (FAO, 2010). Thus, the reduction of crop yields and staples is important nutritionally and from a caloric standpoint. However, livestock as well represent an important local source of protein and contribute to the livelihoods of around 30% of Senegalese households, especially those in the drier northern region(FAO, 2005; Killebrew et al., 2010; Salmon et al., 2016). The nutritional implications of the climate impact upon livestock livelihoods will be discussed later in the section on "Impacts on Income Pathway," but for now, it is important to note that, in production terms, excessive temperatures and hot environments impair livestock productivity in many forms, including growth, meat and milk yield and quality, egg yield, and animal weight, alongside reproductive performance, metabolic and health status, and immune response (Nardone et al., 2010). These livestock include cattle, sheep, and goats. In Senegal, where milk production is already low with annual milk offtakes per animal (whole, fresh cow milk) averaging about 310 kilograms compared to 933 kilograms in South Asia, high temperatures may contribute to additional shifts to the powdered and imported milk that already makes up the bulk of domestic consumption (Kazybayeva et al., 2006). Moreover, because the provision of adequate quantities of water are a major prerequisite for milk production, growth, and animal health, droughts and dehydration due to inadequate rainfall may compound already suffering production and performance levels and limit an important source of local protein and micronutrients in Senegal (Brottem & Brooks, 2018).

It is also important to note that diversifying agricultural activities from crop production to livestock production is a documented adaptation strategy of farmers in the face of a varying and changing climate in Senegal (Brown, 2008). Research in the semi-arid area of Senegal analyzing the impact of climate on income diversification and food security demonstrates that large reductions in rainfall are closely tied to income diversification and particularly to the addition of livestock and commerce to make up for grain income deficits (Brown, 2008). However, the impacts on dietary diversity and nutrition outcomes from these livelihood transitions and diversification are unclear, as it may increase access to and consumption of livestock and dairy products in nearby towns and cities where they may be sold, or may influence rural consumption patterns if they are retained locally. Thus the nutritional implications of this trend are highlighted as an area for further investigation (Brown, 2008).

Poultry

As with livestock, poultry is also an important source of locally available protein and a contributor to livelihoods in Senegal, as most households are involved in raising poultry (FAO, 2005; Killebrew et al., 2010).

However, a wider discussion of climate impacts on livelihoods, beyond production, is included in the "Impacts on Income Pathway" section below.

While no literature documenting the impacts of climate-related stresses such as heat stress on Senegal's poultry was uncovered during this review, there was research investigating the impact of heat stress on poultry production more broadly in West Africa, and in particular in Nigeria (Ayo et al., 2011; Liverpool-Tasie et al., 2019). Ayo et al. (2011) note deleterious effects of heat stress on chickens, including declines in fertility, hatchability, and the general welfare of domestic chickens in Nigeria, while more recently Liverpool-Tasie et al. (2019) undertook the first study to explicitly explore climate change adaptation among poultry farmers in Africa. In doing so, Liverpool-Tasie et al. (2019) found that both increased temperatures and increased dry spells negatively influence poultry production in Africa through death, decreased egg production (in terms of quality and quantity), and reduced growth rates. The mechanism behind this decline in growth and productivity is largely the tendency of chickens to reduce their feed intake to regulate their internal temperature when confronted with heat stress (Nyoni et al., 2018).

Fisheries

Fish is the second main ingredient in Senegal's national dish of "ceebu jën" (rice and fish). It is incredibly important for the nourishment of the Senegalese population, accounting for more than 50% of its animal protein intake, and directly or indirectly employing 17% of the country's working population (World Bank, 2016). While the implications of climate change and variability upon fisheries-related livelihoods and nutrition will be discussed further in the section on "Impacts on Income Pathway," what is important to note here is that the fish supply in Senegal is already stressed, though it is difficult to disentangle the effects of climate change and variability from overexploitation (Ba et al., 2016; Lam et al., 2012; Ouedraogo et al., 2018). The number of artisanal fishermen in Senegal has been on a steady march upward from 126,800 in 1980 to 181,200 in 2014 to almost 200,000 in 2017, reducing fish stocks and increasing the distances fishermen must travel at sea to find fish (Ouedraogo et al., 2018). However, also at play is climate change which has seen a rise in the average sea surface temperature along the Senegalese coast (Ba et al., 2016). While most of the limited analyses of fisheries under climate change and variability are done regionally for West Africa (Belhabib et al., 2016; Lam et al., 2012), and Senegal-specific research is even more sparse, some evidence does somewhat encouragingly suggest that coastal pelagic fishes, which accounts for 64% of annual catches in Senegal, and in particular small pelagic fishes such as sardinella (*Sardinella aurita* and *Sardinella maderensis*), have not been and will not be largely affected from climatic changes (Ba et al., 2016). However, other research suggests that this shift of fishermen to sardinella fish- in the first place may have come about as a result of the impacts of climate change and its role in the collapse of the previously popular bluefish (*Pomatomus saltatrix*) variety (Belhabib et al., 2016).

Value Chain

Documented evidence of climate impacts on specific agricultural value chains in Senegal is thin, but aflatoxin was noted as a threat to crop production, and particularly to the maize and peanut crop value chains, that will likely be exacerbated by climate variability (Faye et al., 2018). Aflatoxins, a group of highly toxic cancer-causing mycotoxins, not only impact nutrition through the destruction of crops and agricultural commodities intended for food, but through their direct health impacts (Thomson & Mason, 2018). Studies in Benin, Togo, and the Gambia have linked aflatoxin exposure to kwashiorkor (severe protein malnutrition), liver cancer, and increased susceptibility to hepatitis (Imes, 2011).

Senegal, one of the largest West African producers of peanuts with production occurring in all districts of the country (Faye et al., 2018), increases its crops' likelihood of aflatoxin contamination when they are exposed to high humidity levels, improperly dried and stored, or transported (Imes, 2011). Because of its deficiencies in storage and post-handling processes, Africa is likely to become more affected by aflatoxin as the mycotoxins thrive in more hot and humid environments (Stepman, 2018). Yet despite the widespread cultivation of peanuts in almost every corner of the country, Senegal's status as one of the largest producers in the region, and the value chain's importance for food security and nutrition, poverty reduction, livestock feeding, and trade (R. Bandyopadhyay et al., 2016), this literature review uncovered no studies investigating the linkages between climate variability, aflatoxin, and food or nutrition security in Senegal specifically.

Climate Impacts on the Income Pathway

The income pathway is the second of the three main pathways through which agricultural production influences nutrition outcomes, and most of the evidence of this literature review of climate impacts on nutrition was found along this pathway. This pathway incorporates income from agricultural production as well as non-agriculture related activities. In this section, we will investigate the documented impacts of climate variability and change on Senegal's income pathway, including food and non-food expenditures, the food environment, health care, diet quality, health status, and water, sanitation, and hygiene (WASH) with special attention to women and children as particularly vulnerable groups.

Income from Agriculture (Livelihoods) and Non-agriculture

In the previous section, we explored the impacts of climate variability and change on the production pathway, highlighting crops, livestock, poultry, and fisheries as particularly important and affected products and sectors in Senegal. In this section, we expand upon the implications of these impacts for income generation and security, and their consequences for nutrition.

Crops

As mentioned in the previous section, one of the most significant impacts of changing rainfall and temperature patterns is on agricultural and food production systems in Senegal, especially through reductions in crop yields such as maize and rice (Brottem & Brooks, 2018; Roudier et al., 2011). Evidence documenting the repercussions of associated crop income losses on nutrition in Senegal is thin, but does suggest reduced consumption of more expensive and nutrient-rich foods such as animal products, fruits, and vegetables or simply of the quantity of less nutritious foods is a coping mechanism (Haggblade et al., 2017), as well as less safe WASH practices such as the opting out of purchasing safe water for drinking or cooking that lead to diarrheal diseases interfering with nutrient uptake and use (S. Bandyopadhyay et al., 2012).

Interestingly, in digging deeper to identify how crop-specific agricultural research investments could be prioritized to enable the production of more nutritious food under climate change, Manners & Etten (2018) found that generally speaking, investment levels tend to be slightly lower for crops better adapted to future climates and tend to decrease as crop nutrient richness increases (Manners & van Etten, 2018). In particular, starch-rich crops such as maize and rice receive substantially more research investment than justified by their nutrient composition, while more nutritious crops, such as the sweet potato, one of Senegal's primary crops, were found to be most strongly under-researched in regions with improving climate suitability (Manners & van Etten, 2018).

Livestock

Livestock contributes to the livelihoods of around 30% of Senegalese households, especially those in the drier northern region (FAO, 2005; Killebrew et al., 2010; Salmon et al., 2016). Cattle in particular represent an important input into household incomes and even act as insurance against weather risks in drought-prone areas (Lunde & Lindtjørn, 2013). Lunde & Lindtjørn (2013), the first study to address how historical variations in temperature and rainfall have influenced cattle populations in Africa, showed that from 1961-2008, these variables have been modulating, and sometimes controlling, the number of cattle in Africa through pathways such as direct heating (reducing feed consumption, animal health, and fertility) and vector-borne diseases.

Moreover, climate shocks such as droughts in arid and semi-arid tropical Africa have led to dramatic drops in herd sizes as well as disturbances in sex-and-age structures (Lesnoff et al., 2012). From a nutritional standpoint, these livestock are an important and even essential asset to the rural poor, who rely on production not just for the income that affords them the purchase of staple and nutritious foods, but as a source of local and affordable nutrition themselves (Roland-Holst & Otte, 2007).

Furthermore, with the high risks associated with crop production under increasingly erratic climatic conditions, these animals act as a safety net and even a form of savings and payment to access essential resources like food (Kazybayeva et al., 2006; Roland-Holst & Otte, 2007). This fact is not true of just rural areas but also of urban areas in remote regions where about 66% of households keep some kind of livestock (Kazybayeva et al., 2006). In other words, the low monetary return of the livestock sector in the economy (just 5.5% of national GDP but 37% of agricultural value) is due to the low productivity and low investment of the sector, not low importance in terms of livelihoods and food and nutritional access (FAO, 2005; Kazybayeva et al., 2006). What's more, livestock are of more relative importance to poorer Senegalese households but still only constitute about 10% of household income (Kazybayeva et al., 2006). The prevalence and importance of livestock in agricultural systems is also not uniform across Senegal, as the share of households keeping livestock varies from about 90% in pastoral areas such as Louga and Tambacounda to 67% in rural areas surrounding Dakar and Djiourbel; traditional pastoral production systems dominate in the north, east and southeast of Senegal, while agro-pastoral production systems dominate the coastal regions and the southwest of Senegal (Kazybayeva et al., 2006).

Climate variability and change threaten this important income and food source in Senegal through heat stress, changing the dynamics of vector-borne diseases affecting cattle, and reducing forage availability. The impacts of heat and water stress on livestock in West Africa have been documented and have already been discussed in the previous section on the production pathway. As for diseases, there is evidence that climate change has increased the risk of many vector-borne diseases affecting livestock in Senegal, including Rift Valley Fever (Bett et al., 2019; Sow et al., 2016; Talla et al., 2014; Tourre et al., 2009). Rift Valley Fever (RVF) is a mosquito-borne disease mainly affecting sheep, goats, cattle, and camels, though humans can also become infected (Bett et al., 2019), and there appear to be seasonal links. In East and southern Africa, RVF outbreaks have occurred following periods of above-normal precipitation, while in West Africa, the outbreaks that occurred in 1998, 2003, 2010, and 2012 all occurred just after a period of heavy precipitation immediately preceded by a dry period, suggesting that climate change is likely to expand the disease's geographical range alongside changing precipitation patterns (Bett et al., 2019). In Senegal already, RVF outbreaks have been historically reported following the development of flood irrigation systems, such as the Senegal Dam in 1987 and 1998, connecting the disease not just with standing water through precipitation but also with land use change (Bett et al., 2019), and evidence from East Africa in Kenya confirms that irrigated land in arid and semi-arid areas support endemic transmission of the disease (Mbotha et al., 2018). The Ferlo region in north-central Senegal has become prone to RVF since the late 1980s, following proliferation of the mosquito vector in temporary ponds and humid vegetation, with outbreaks leading to spontaneous abortions and perinatal mortality (Tourre et al., 2009). The linking of RVF with rainfall variability, density, and aggressiveness of vectors using the approach by Tourre et al. (2009) in Senegal led to recognition of the gravity of the issue by the Senegalese government and funding to extend the approach to all zones where cattle are exposed to risk (Tourre et al., 2009).

Regarding forage availability and climate, despite the importance of livestock in terms of livelihood and local food and nutrition security, this literature review uncovered little research investigating the impacts of climate change or variability on pasture grasses or quality or quantity of forage species in Senegal. While some evidence points out that the herbaceous biomass rangeland that comprises the bulk of the diet of livestock in the Senegalese Sahel and dominates the natural pastures upon which transhumant pastoralists rely is strongly influenced by rainfall (Ndiaye et al., 2015) and other evidence shows species composition of semi-arid savannah grassland strongly correlated to rainfall distribution more broadly in West Africa (Tagesson et al., 2015), little attention is paid to translating this information into actionable recommendations for decision-makers. This is despite the demand and expressed interest of Senegalese government's own Nutrition Coordination Unit (CLM) and World Food Programme to the IRI in February 2020 of better understanding the impacts of seasonality and rainfall on forage for livestock, food security, nutrition, and farmer-herder conflict.

Nonetheless, evidence from Lunde & Lindtjørn (2013) documents that farmers in the savannah zone of Senegal have observed fodder shortages in colder temperatures, and lower food consumption in the dry season, and the Western Sahel is especially sensitive to dry-season temperatures in terms of feed consumption. Similarly, in investigating farmers' perceptions of climate change and variability in villages in the semi-arid northern area of Senegal, Dieye & Roy (2012) found that pastoralists perceived their primary threat around constraints related to insufficient access to water and grazing land (Dieye & Roy, 2012). This concern is well-founded, as the process of desertification generally reduces the carrying capacity of rangelands, alongside the buffering capacity of agro-pastoral and pastoral systems (Nardone et al., 2010). Moreover, it is in line with observations of farmers across Africa, who associate changes in temperature and rainfall patterns with reduced feed sources, as well as a plethora of other issues including increased animal mortality, lower herd sizes, reduced water sources during the dry season, decreased animal productivity, and emergence of new animal diseases (Liverpool-Tasie et al., 2019).

Poultry

Similarly to livestock, poultry also represents an important contribution to livelihoods and a key source of locally available protein in Senegal (Killebrew et al., 2010). Most Senegalese households are involved in poultry raising, and the importance of this activity is particularly pronounced for the poorest segments of the Senegalese population (FAO, 2005). From a caloric perspective, poultry is not very significant, as poultry meat and eggs together account for just 1% of the total daily calories consumed on average in Senegal (Killebrew et al., 2010). However, in terms of availability and access to nutrients, poultry becomes important as a source of local protein, as most smallholders sell poultry to neighbors and relatives in close proximity, and its market value is thus difficult to capture and generally not appropriately reflective of its importance in the food system (Killebrew et al., 2010). Farmyard chickens kept by rural smallholder farmers account for approximately 70% of the country's total chicken stock (Killebrew et al., 2010).

Like livestock, poultry are particularly heat-sensitive animals (Carr et al., 2016; Lara & Rostagno, 2013). Heat negatively impacts young chickens and laying hens by reducing growth and egg production and decreasing poultry and egg quality and safety (Lara & Rostagno, 2013). And importantly, they are predominantly owned and tended to by women in Senegal, so any impacts upon poultry thus affect women's income and productive assets, the significance of which will be discussed more in the "Impacts on Women's Empowerment Pathway" section (Carr et al., 2016). Also noteworthy is the fact that domestic production has become increasingly important and grown in recent years following the government's 2006 ban on poultry imports, and thus consumption is 100% dependent on demand being met from within Senegal; this shift carries its own risks and pressures to ensure successful production in a changing climate (Killebrew et al., 2010).

Fisheries

A staple of Senegal's national dish accounting for more than 50% of Senegal's animal protein intake, the impacts of increasing scarcity of fish under climate change and variability extend beyond the loss of fish itself to the income derived from this activity and its influences on diet (World Bank, 2016). Fish and fisheries provide jobs for 7 million West and Central Africans, and its harvest and post-harvest sectors contribute 4% to Senegal's overall gross domestic product (GDP) and employs, either directly or indirectly, 17% of the country's working population (Lam et al., 2012; World Bank, 2016). This economic value generated from fisheries give people the purchasing power to buy other high-calorie and high-energy staples such as rice, wheat, and more nutritious foods such as vegetables and meat (Lam et al., 2012). A reduction in landings and fish stocks under the Special Report on Emission Scenarios (SRES) A1B scenario, a conservative greenhouse gas emissions scenario, for West Africa therefore means a loss in fisheries-related jobs and profitability to the tune of almost 50% for the region, with impacts upon the food security and nutrition of the Senegalese population, but also, because Senegal is a net exporter of fish, for those reliant on its fish stocks for their food and nutritional security as well (Lam et al., 2012).

Food Environment

The food environment, or the physical presence of food that affects a person's diet, is a factor that is being influenced through migration both within Senegal and abroad, and which is at least partially exacerbated by climatic changes. In the face of shortfalls in agricultural and pastoral production and land degradation exacerbated by climatic changes described earlier, some households rely on migration as a means to compensate for lost farm income (Brottem & Brooks, 2018; Roland-Holst & Otte, 2007). In a study conducted in Eastern Senegal, Brottem & Brooks (2018) found that almost one-third of the households surveyed had at least one migrant amongst its members. Moreover, 25% of pastoralist households reported that 75% or more of their incomes were derived from migrant remittances, though just 6% of agricultural households reported the same (Brottem & Brooks, 2018). This flow of people and money has nutritional implications, as those migrating, whether abroad or to cities within Senegal, are of course exposed to different built food environments but also because the money flowing back into households may influence access and choice of food as well. This literature review uncovered no research investigating the impacts of climate-driven (or as a factor) migration and accompanying remittances on nutrition in Senegal, through altered food environments or otherwise.

Other literature also documents migration, particularly seasonal migration for remittances, as a historically important response strategy for coping with declining agricultural productivity in Senegal (Brown, 2008; Glantz, 1987; Golan, 1994; Roland-Holst & Otte, 2007) and for supplementing diets and covering lost income (Kazybayeva et al., 2006). Such migrations often occur to nearby cities or towns, where agriculturalists or pastoralists will go to work as chauffeurs, apprentice chauffeurs, domestic laborers, traders, or even as students, with some returning each year for the growing season and others returning just for holidays or family events (Brown, 2008). Again, given that climate is demonstrably affecting agricultural productivity, this migration is at least partially attributable to climatic changes, though the dietary and nutritional implications of these movements both upon those moving and those back home are still undocumented within the literature.

Diet Quality

One of the most significant avenues through which dietary quality and diversity will be affected is through climate impacts on fishing and fisheries in Senegal, which being located in low-latitudinal region of West Africa, is to be affected most by climatic changes (Cheung, 2010). As has been discussed earlier in this review, fish is a particularly critical source of affordable protein, important micronutrients, and income in Senegal, accounting for more than 50% of the animal protein intake of its population(Jentoft & Chuenpagdee, 2015; Lam et al., 2012; World Bank, 2016). In fact, Senegal has the highest consumption of fish in West Africa, at about 27.8 kg per capita annually, providing essential micronutrients such as iron, iodine, zinc, calcium, and vitamins A and B which cannot be found in other staples such as rice, maize, or cassava (Kawarazuka, 2010; Roos et al., 2007). As almost half of all Senegalese women are anemic (iron-deficient), the effects of climate upon fish production and availability have special gender implications, which will be discussed more in the "Impacts on Women's Empowerment Pathway" section (*Global Nutrition Report: Senegal Nutrition Profile* , 2019). West Africans generally eat less animal protein than people in more developed countries but consume more fish, demonstrating the dependence on this important and cheap protein and nutrient source (Lam et al., 2012). Climatic changes impacting fish therefore represent a significant blow to diet quality, especially for women.

Health Status

The impacts of climate variability and change will increasingly influence human health, especially through waterborne diseases and conditions such as diarrhea (Thiam, Diène, Sy, et al., 2017). This is important because nutrition depends not just on ready access to appropriate nutritious foods, but the absence of diseases, such as those causing diarrhea, that reduce the body's capacity to benefit from the food (Thomson & Mason, 2018, p. 27).

Senegal, which already has the highest overall diarrheal prevalence in West Africa (Dunn & Johnson, 2018), is likely to have its diarrheal burden increase, especially for those under the age of 5 (Dunn, 2016; Thiam, Diène, Fuhrimann, et al., 2017; Thiam, Diène, Sy, et al., 2017). Diarrhea is already one of the leading causes of malnutrition in young children and is particularly harmful in that it induces a brutal cycle of decreased energy intake, micronutrient deficiencies, and increased vulnerability to infection (Dunn & Johnson, 2018). In Senegal, the Ministry of Health lists diarrhea as the third leading cause of mortality (responsible for 15% of deaths) and the second leading cause driving caregivers of children under 5 years old to seek medical consultation (Thiam, Diène, Fuhrimann, et al., 2017). Moreover, the impacts upon health and nutrition are not always limited to the short-term, but can lead to longer-term and even inter-generational cycles of poverty through stunting (low height for age), impaired intellectual development and performance in education, reduced economic productivity, impaired sexual performance, and increased risk of metabolic and cardiovascular disease (Black et al., 2008).

The relationship between climate and diarrheal disease is complex, but evidence suggests that climatic factors such as temperature and rainfall are associated with diarrhea (S. Bandyopadhyay et al., 2012; Constantin de Magny et al., 2007; Diouf et al., 2017; Dunn, 2016; Dunn & Johnson, 2018; Kraay et al., 2018; Levy et al., 2009, 2016; Magny et al., 2012; Thiam, Diène, Fuhrimann, et al., 2017; Thiam, Diène, Sy, et al., 2017).

The fairly recent study by Thiam, Diène, Sy, et al. (2017) in Mbour, Senegal was the first to use remote sensing data to assess the relationship between climatic factors and diarrheal incidence in Senegal, and found that increases in temperature were associated with an increase in the incidence of diarrhea in children under five years of age. On a wider scale, Bandyopadhyay et al. (2012) showed that precipitation is also at play, and shortages of rainfall in the dry season increase the prevalence of diarrhea across sub-Saharan Africa. Moreover, a more recent rigorous, systematic, and comprehensive review of the epidemiological literature examining the relationship between meteorological conditions (ambient temperature, heavy rainfall, drought, and flooding) and diarrheal diseases found a predominant trend for positive relationships between diarrhea and all four meteorological conditions, though there was an exception in the association for ambient temperature and viral diarrhea, which was negative (Levy et al., 2016).

Other papers looked more specifically at the connections between climatic variables and rotavirus, cholera, and even malaria—all of which cause diarrhea—in Senegal.

Rotavirus

Rotavirus is one of four pathogens responsible for most severe diarrheal diseases and previously not thought to be largely influenced by climate (Kraay et al., 2018). However, in another systematic review specifically for rotavirus in Africa (Levy et al., 2009), it was revealed that the pathogen actually exhibits distinct seasonality and responds to changes in climate, with the highest number of infections found at the colder and drier times of year. This finding is in line with the analysis undertaken by Thiam, Diène, Sy, et al. (2017) in the health district of Mbour, Senegal which found the predominant cause of infection for children in the cool dry season to be rotavirus, while in the hot rainy season it was bacterial (enteric infections). Kraay et al. (2018) as well demonstrated links between water, temperature and rotavirus, and found that environmental transmission through water sources (flowing or standing) is an important source of risk for tropical climates such as that of Senegal, at both the community and regional scale, that is intensified under conditions of water scarcity (Kraay et al., 2018).

Cholera

On bacterial causes of diarrhea and connection to climate in Senegal, Magny et al. (2012) retrospectively investigated whether climate was a factor in Senegal's cholera outbreak in 2005, which was the largest ever recorded by the World Health Organization at that time in Africa and the most severe of recorded outbreaks for Senegal since 1970. In doing so, the team found that heavy rainfall occurring during the wintering of 2005 in the Dakar region and at the origin of floods exacerbated the epidemic, which had only been underway in eleven regions before the floods. The influence of intense (abrupt and heavy) precipitation over densely populated regions like Dakar and Thies on cholera transmission was clearly observed (Magny et al., 2012), leading the team to recommend the development of high-resolution rainfall forecasts at subseasonal time scales and eventual development of an early warning system (Magny et al., 2012).

Malaria

Lastly, some of the literature focused on malaria as a climate-sensitive, vector-borne disease. Like the other aforementioned bacterial and viral causes of diarrhea, malaria is also linked with diarrhea, as anywhere from 5-38% of malaria cases are associated with diarrhea (Prasad & Virk, 1993), thus affecting absorption and use of nutrients, as well as the ability to engage fully in livelihoods (Diouf et al., 2017). Moreover, malaria is also closely associated with anemia (Thomson & Mason, 2018), and there is a significant association with stunting, sickle cell disorders, and alpha-thalassemia in children less than ten years of age in Senegal (Tine et al., 2012). A systematic literature review on interactions between malaria generally and malnutrition uncovered complex interactions between the two (Das et al., 2018), and evidence of malnutrition on malaria risk remains controversial and even contradictory. Nonetheless, chronic malnutrition was relatively consistently associated with severity of malaria (Das et al., 2018), and there is a clear, demonstrated link between malaria and seasonality (Diouf et al., 2017).

Several studies examined the influence of climatic factors on the epidemiology of malaria in Senegal (Delaunay, 1998; Fontenille et al., 1997; Grover-Kopec et al., 2006) and highlighted need for further research on transmission in Senegal. Meeting this need Diouf et al. (2017) studied the impact of climate variability on malaria transmission in Senegal and found that the risk of malaria is modulated by climate patterns such as the amount and intensity of rainfall, which is conducive to the multiplication and breeding of the *Anopheles* mosquito vectors. In the north of Senegal (Ferlo area), alternation between wet and dry seasons as well as the occurrence of extreme events like flood and drought plays a significant role in the mortality and morbidity of malaria (Diouf et al., 2017).

Indirect Causes of Diarrhea

In addition to these three pathological routes to diarrhea and malnutrition, drought and water scarcity also impact diarrhea through indirect routes, such as a reduction in crop yields. Given Senegal's dependence upon rain-fed agriculture, insufficient precipitation often devastates household food security by destroying crops intended for home consumption (S. Bandyopadhyay et al., 2012). During these times of stress following lower crop yields, the cost of then undertaking protective actions such as purchasing safe food and water can then become prohibitive, and the nutritional status of children can become severely compromised (S. Bandyopadhyay et al., 2012). In a self-reinforcing cycle, these children often become stunted and then more likely to contract diarrheal diseases further affecting their health and nutrition (S. Bandyopadhyay et al., 2012). A more complete mapping of the linkages between climatic changes and diarrhea, including indirect causes, can be found in Figure 2.

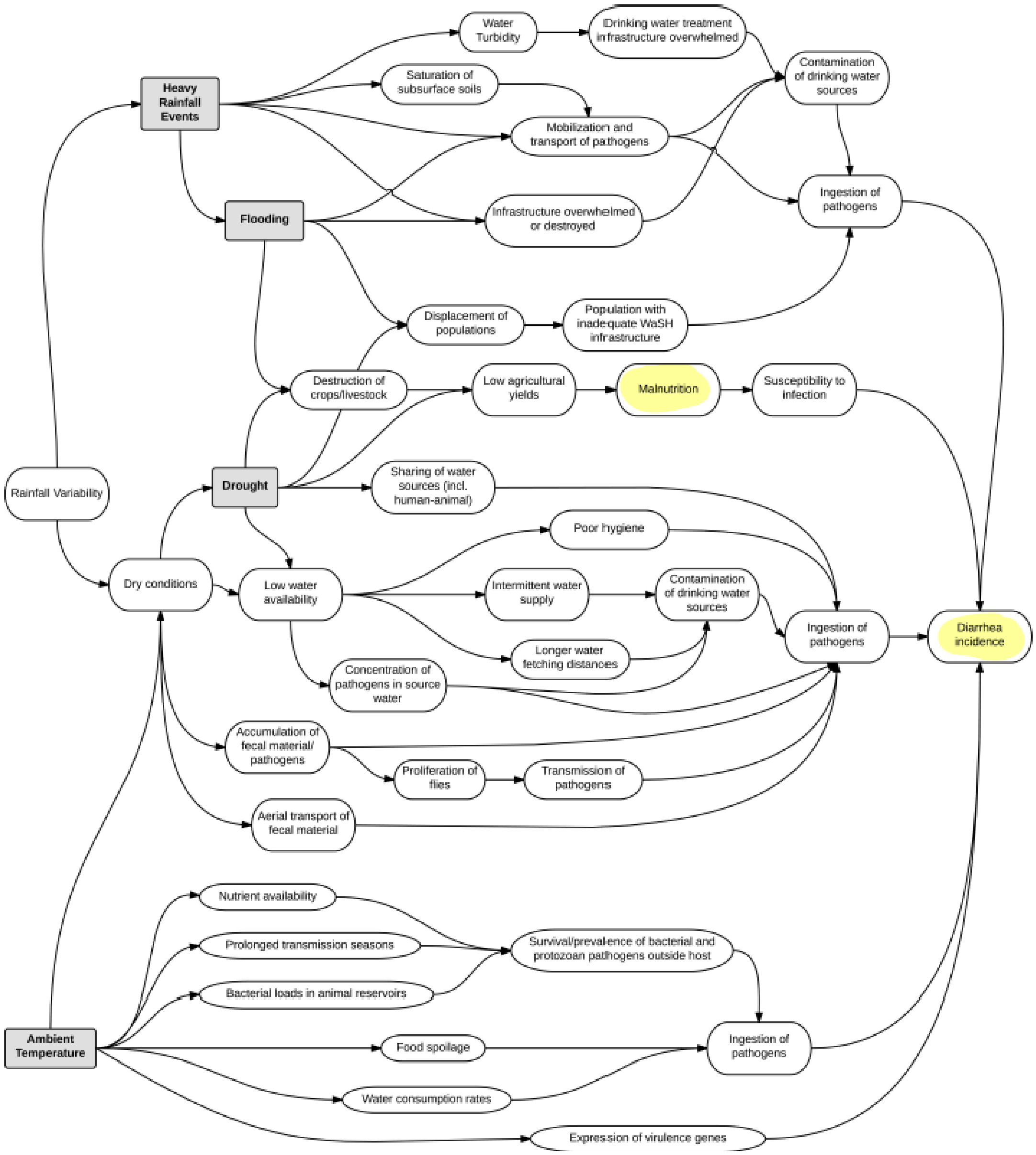

Figure 2: *Mechanisms by which meteorological conditions expected to be impacted by climate change could increase the risk of diarrheal diseases. (Source: Adapted from Levy et al. 2016)*

Water, Sanitation, and Hygiene

To decrease the risk of disease, especially becoming infected by the water-borne pathogens mentioned in the previous section, appropriate water, sanitation, and hygiene (WASH) practices are necessary, especially surrounding the food preparation process. This means clean water and appropriate hygiene practices, behavior, and infrastructure.

However, if water becomes less available or re-prioritized such as in the face of a drought, these sanitation and hygienic practices may become compromised, opening up risk of infection and concomitant impacts upon nutrition.

An investigation of the literature on water availability in Senegal revealed a consistent documentation of water resources negatively impacted by climate change in West Africa (Aich et al., 2014; Ardoin-Bardin et al., 2009; Faramarzi et al., 2013; Karambiri et al., 2011; Mahe et al., 2013; Ruelland et al., 2012). A decrease of about 10-40% in water availability is projected across the five major river basins of West Africa, with the largest negative changes projected for the Senegal and The Gambia due to a combination of precipitation decreases and evapotranspiration increases (Bodian et al., 2018; Sylla et al., 2018). Where drought occurs and water is scarce, there tend to be increased consumption of unsafe water and lowering of good hygiene practices (Fewtrell et al., 2005), which in turn increases exposure to environmental pathogens and contaminated food due to high temperatures associated with accelerated bacterial growth (Thiam, Diène, Sy, et al., 2017). In other words, one of the most immediate factors affecting nutrition, household food preparation, is affected.

Recurring droughts have already impacted water availability in Senegal, and these decreases in freshwater resources have far-reaching consequences for human health and ecosystems in arid and semi-arid climates (Mbaye et al., 2015). Especially in the Upper Senegal Basin, impacts have been felt as the Senegal River's annual average flow has fallen from 1374 m3/sec over the period 1903-1950 to 840 m3/sec in the period 1950-1972 and further decreased to only 419 m3/sec in the period from 1973-2002, impacting rain-fed agriculture, economic development, livelihoods, fishery and thus food security and nutrition (Bodian et al., 2018; Mbaye et al., 2015; Sylla et al., 2018).

Mothers' and Children's Nutrition Outcomes

Undernutrition in mothers has direct effects on maternal mortality and a child's healthy development and status, and amongst lactating women especially, it is critical to ensure good nutritional status which is also directly linked to child health (Oh et al., 2019). In Senegal, however, almost half (49.9%) of women suffer from anemia (Global Nutrition Report, 2019), and among pregnant women this number jumps to 58.1% (Oh et al., 2019). Climatic changes and variations negatively impacting iron-rich meat sources such as livestock, poultry, and fish production, as previously described in this review, therefore have serious health and nutritional implications for both mothers and children due to decreased access to this essential micronutrient.

In addition to this, water shortages such as during climatic shocks like droughts place severe limitations on children's health, and precipitation and temperature variation are paramount in determining diarrheal prevalence in children under three in Africa generally (S. Bandyopadhyay et al., 2012), as well as in Senegal (Constantin de Magny et al., 2007; Diouf et al., 2017; Dunn & Johnson, 2018; Levy et al., 2009, 2016; Magny et al., 2012; Thiam, Diène, Fuhrimann, et al., 2017; Thiam, Diène, Sy, et al., 2017).

Climate Impacts on Women's Empowerment Pathway

The third and final pathway for nutrition is the women's empowerment pathway. Because women are the primary care givers for infants and young children and because shortcomings in their care can have both immediate and more long-term and even intergenerational effects on the nutrition outcomes of their children and their offspring (Dewey & Begum, 2011), they are a particularly important group to consider in designing research or interventions targeting improved nutritional outcomes. Of the three pathways described in this review, however, evidence on impacts of climate on nutrition through the women's empowerment pathway was the most sparse. Nonetheless, what follows here is a consideration of the limited evidence found in the review.

Women's Empowerment and Time

While research into factors affecting nutritional practices among mothers in Senegal is lacking, Oh et al. (2019) recently investigated this question amongst mothers in Dakar, Senegal. While climate was not a consideration, one of the most important findings to come out of the study is that education and income levels, more than knowledge or attitudes, have the strongest relationship with healthy nutritional practices amongst mothers, leading the authors to recommend economic factors as a key consideration for the success of Senegalese nutrition projects (Oh et al., 2019). The inference of this finding in relation to climate means that climatic factors affecting women's income can reasonably be expected to also influence maternal nutrition practices in Senegal, at least in Dakar.

This means that climate impacts on livelihoods, sectors, or agricultural activities where women dominate or play a large role are likely to negatively affect their income and, in turn, nutrition practices. The three most important examples of this type of work cited in the literature are the fishery, poultry, horticulture, and livestock sectors.

With regard to the fisheries sector, recent statistics indicate that women represent more than one quarter (27%) of the labor force in Senegal's fisheries and aquaculture sector, have historically dominated more than 90% of the processing sector, and are generally considered "paramount" at all levels of the value chain (USAID, 2018). As such, any deleterious effects of climate upon fish quantity or quality, as described in previous sections of this review, have significant implications on the livelihood of women engaged in this sector.

As for poultry, as mentioned earlier in this review, they are predominantly owned and tended to by women, and thus any climatic effects negatively influencing fowl will by extension jeopardize their assets and sources of local nutrition (Carr et al., 2016). This is important because there tends to be a positive correlation between female financial empowerment and higher dietary diversity for both women and children (Carranza et al., 2019), which is related to Senegalese women generally prioritizing and spending their personal income more often on food, healthcare, and education for their children (Dia, F. et al., 2010). Women in Senegal also engage most heavily in horticulture, especially during the dry season, when it is common for husbands to allocate for their wives plots usually used for food crops for kitchen gardening including more nutritious garden vegetables for both home consumption and sale (Dia, F. et al., 2010; Linares, 2009; Maertens, 2009). These activities are already limited by water availability and proximity and thus sensitive to precipitation changes and drought.

Lastly, women in Senegal are usually responsible for free-ranging livestock such as sheep and goats (Carranza et al., 2019), and as with the fisheries and livestock sectors, have these assets compromised when livestock are impacted by climatic changes, as previously described in this review.

As for time, women in Senegal are also responsible for gathering water and firewood for cooking (Carranza et al., 2019), so the land degradation and decreased water availability described earlier in this review may increase the amount of time women spend looking for wood or water, which is time away from their children and child care duties (Dia, F. et al., 2010).

Other Important Considerations for Women

While women are an important subset of the population to be considered for the development of climate services, especially for nutrition, it is important that this group not be oversimplified as one homogenous block of people within Senegal. To do so is to miss out on important nuances and differences in needs, vulnerabilities, and opportunities (Carr et al., 2016). As Carr et al. (2016) point out, the experience of being a woman in Senegal is greatly shaped by the intersection of gender with other identity categories such as age group, seniority (in relation to the number of wives in a given household), ethnicity, and even ethnic group, and these identities are even fluid and shifting in different contexts. Among women in Senegal, there are varying levels of exposure, sensitivity, and adaptive capacity in the community and household (Carr et al., 2016), and these should be taken into account of the development of climate services for this group.

Conclusions and Recommendations

While the literature rarely explicitly addresses climate impacts on nutrition in Senegal, it does address the impacts of climate variability and change on a breadth of pathways known to influence nutrition outcomes. Those pathways include the production, income, and women's empowerment pathways and offer insights into the most important groups and entry points through which climate services might be developed.

It is important to note that in examining the literature on this topic, much of the research was either too wide (regional, West Africa) or too narrow (investigating one national region or district) in scope, with analysis seldomly performed at the national level. This trend has implications in the area of effecting change through policies or programs, as much of the success that Senegal has seen in creating its positive enabling environment for nutrition has come about as the result of policies, programs, and coordination at the national level (Kampman et al., 2017). Thus, in seeking to build the evidence base on this topic, studies that are more national in scope might be considered.

Nonetheless, a review of the existing literature provided a wealth of insight into the existing strengths and needs surrounding information gaps and the development of climate services and decision support systems to promote positive nutritional outcomes in the face of increasingly erratic precipitation and temperature patterns in Senegal. Concerning research needs, as mentioned within the review, documentation of climate impacts upon nutrition is weakest within the women's empowerment pathway, yet women are the subset of the population which exerts the most influence on children's health outcomes and in perpetuating or stopping intergenerational poverty. Even within the production and income sectors where evidence is most robust in documenting climatic influences upon nutrition—such as crops, livestock, poultry, fisheries—targeted research specifically documenting how women are affected by these impacts is limited. And even within areas such as WASH and water availability that are widely known to be significant determinants of nutritional status, evidence of behaviors and practices of Senegalese people, especially women and mothers, in the face of climatic uncertainty, changes, and variability is thin.

Further research and the development of climate services should give special consideration therefore to building the evidence base in relation to women and mothers, but also pay special attention to the livestock sector, as a shift to livestock activities was noted as an increasingly common adaptation strategy amongst agriculturalists in the literature and also because of its nutritional significance. With fish as well, it is difficult to overstate the importance of this food in terms of its significance in the national culture and cuisine ("ceebu jën") but also nutritionally as a vital source of protein and micronutrients for over half the population. Yet despite its importance, the Senegal-specific research delving into climate impacts on fisheries seems to have trouble conclusively disentangling the effects of over-exploitation versus climate. In order to effectively develop climate services for this vitally important sector, its dynamics and interplay with climatic changes and variability must be better understood.

Lastly, while the health and agricultural communities and fields are fairly distinct, it is important to note that nutritional outcomes are not exclusively influenced through agricultural pathways but also practices (WASH), behaviors, and pathogens that fall outside this sphere. Solutions to effectively safeguard and even improve nutritional status in the face of climate variability and change therefore need to be multidisciplinary in nature, or they will likely prove insufficient at fully addressing the problem. Moreover, the same kinds of information that can be developed and improved for agricultural purposes, such as high-resolution forecasts at sub-seasonal time scales, have also been identified as a need by the health community as a way forward for early warning and action for nutrition in Senegal, and especially waterborne epidemics impacting nutrition (Constantin de Magny et al., 2007; Magny et al., 2012; Thiam, Diène, Sy, et al., 2017).

ACToday may be able to pursue these aims through Senegal's national Nutrition Coordination Unit (CLM), which in a recent assessment of its capacities, stressed the enormity of the challenge that climate poses for food and nutritional security in Senegal and called for "substantial investments" into research investigating these linkages (Deussom N. et al., 2018).

Concretely, ACToday might consider investing in and developing research, tools, and activities in the following areas:

- Research investigating linkages between climate variability, aflatoxin, and food and nutrition security in Senegal
- Research aimed at better understanding and promoting production of more nutritious food crops (such as sweet potato) under climate variability and change for Senegal
- Research and tools to better understand, visualize, and adapt information on seasonal linkages of vector-borne diseases like Rift Valley Fever with rainfall variability, density, and aggressiveness on a wider national scale, and to inform a possible national early warning/early action system for outbreaks. Note that the Senegalese government recognizes the gravity of this issue and has itself previously allocated funding for research to assess RVF risk. (Tourre et al., 2009).
- Research investigating the impacts of climate variability on pasture grasses, and quality and quantity of forage species for livestock in Senegal, alongside the development tools to visualize these effects and support decision-making and planning around food and nutrition security interventions and avoidance of farmer-herder conflict. Note that this was requested both by the government's Nutrition Coordination Unit (CLM) and the World Food Programme (WFP) in conversations with

ACToday Senegal staff in February 2020, and this literature review corroborates their assertion that research on this topic and concomitant tools are indeed lacking.

- Activities and tools for translating existing evidence on precipitation impacts on rangeland and forage composition for West Africa and Senegal into actionable information and recommendations for decision-makers, through maproom visualizations, trainings, or otherwise.
- Research investigating impacts of heat and water stress on livestock to 1) inform identification of "hotspots" where food and nutritional insecurity or farmer-herder conflict are likely to occur, and 2) the possible development of decision support systems for the livestock sector, such as with the FAO's Predictive Livestock Early Warning System (PLEWS).
- Research investigating impacts of heat stress on poultry, bearing in mind national consumption of poultry for Senegal is now 100% dependent on demand being met from within Senegal since the government's ban on poultry imports in 2006.
- Research and activities exploring relationships between climate, migration (rural-urban within Senegal), and accompanying impacts of remittances on food consumption and nutrition in Senegal.
- Development of high-resolution rainfall forecasts at subseasonal time scales and eventual development of an early warning system for diarrheal diseases like cholera.
- Development of models analyzing interaction and combined effects of multiple shocks occurring simultaneously (for example, drought combined with world or local food price shocks on a given population) to more appropriately assess real-world situations confronting the Senegalese population
- Research into factors affecting nutritional practices among mothers in Senegal (more representatively, beyond what has only been done in Dakar), including climatic factors.

References

1. Aich, V., Liersch, S., Vetter, T., Huang, S., Tecklenburg, J., Hoffmann, P., Koch, H., Fournet, S., Krysanova, V., Müller, E. N., & Hattermann, F. F. (2014). Comparing impacts of climate change on streamflow in four large African river basins. *Hydrology and Earth System Sciences*, *18*(4), 1305–1321. https://doi.org/10.5194/hess-18-1305-2014
2. Alfani, F., Dabalen, A., Fisker, P., & Molini, V. (2019). Vulnerability to stunting in the West African Sahel. *Food Policy*, *83*, 39–47. https://doi.org/10.1016/j.foodpol.2018.11.002
3. Anderson, C. A., Bellamy, S., Figures, M., Zeigler-Johnson, C., Jalloh, M., Spangler, E., Coomes, M., Gueye, S., & Rebbeck, T. R. (2010). Dietary intake of Senegalese adults. *Nutrition Journal*, *9*, 7. https://doi.org/10.1186/1475-2891-9-7
4. Ardoin-Bardin, S., Dezetter, A., Servat, E., Paturel, J. E., Mahe, G., Niel, H., & Dieulin, C. (2009). Using general circulation model outputs to assess impacts of climate change on runoff for large hydrological catchments in West Africa. *Hydrological Sciences Journal*, *54*(1), 77–89. https://doi.org/10.1623/hysj.54.1.77
5. Ayo, J. O., Obidi, J. A., & Rekwot, P. I. (2011). Effects of Heat Stress on the Well-Being, Fertility, and Hatchability of Chickens in the Northern Guinea Savannah Zone of Nigeria: A Review. *ISRN Veterinary Science*, *2011*, e838606. https://doi.org/10.5402/2011/838606
6. Ba, K., Thiaw, M., Lazar, N., Sarr, A., Brochier, T., Ndiaye, I., Faye, A., Sadio, O., Panfili, J., Thiaw, O. T., & Brehmer, P. (2016). Resilience of Key Biological Parameters of the Senegalese Flat Sardinella to Overfishing and Climate Change. *PLoS ONE*, *11*(6). https://doi.org/10.1371/journal.pone.0156143
7. Bandyopadhyay, R., Ortega-Beltran, A., Akande, A., Mutegi, C., Atehnkeng, J., Kaptoge, L., Senghor, A. L., Adhikari, B. N., & Cotty, P. J. (2016). Biological control of aflatoxins in Africa: Current status and potential challenges in the face of climate change. *World Mycotoxin Journal*, *9*(5), 771–789. https://doi.org/10.3920/WMJ2016.2130
8. Bandyopadhyay, S., Kanji, S., & Wang, L. (2012). The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. *Applied Geography*, *33*, 63–72. https://doi.org/10.1016/j.apgeog.2011.07.017
9. Barros, V. R., Field, C. B., Dokken, D. J., Mastrandrea, M. D., & Mach, K. J. (Eds.). (2014). Africa. In *Climate Change 2014: Impacts, Adaptation and Vulnerability* (pp. 1199–1266). Cambridge University Press. https://doi.org/10.1017/CBO9781107415386.002
10. Belhabib, D., Lam, V. W. Y., & Cheung, W. W. L. (2016). Overview of West African fisheries under climate change: Impacts, vulnerabilities and adaptive responses of the artisanal and industrial sectors. *Marine Policy*, *71*, 15–28. https://doi.org/10.1016/j.marpol.2016.05.009
11. Bett, B., Lindahl, J., & Delia, G. (2019). Climate Change and Infectious Livestock Diseases: The Case of Rift Valley Fever and Tick-Borne Diseases. In T. S. Rosenstock, A. Nowak, & E. Girvetz (Eds.), *The Climate-Smart Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future* (pp. 29–37). Springer International Publishing. https://doi.org/10.1007/978-3-319-92798-5_3
12. Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M., Mathers, C., & Rivera, J. (2008). Maternal and child undernutrition: Global and regional exposures and health consequences. *The Lancet*, *371*(9608), 243–260. https://doi.org/10.1016/S0140-6736(07)61690-0
13. Bodian, A., Dezetter, A., Diop, L., Deme, A., Djaman, K., & Diop, A. (2018). Future Climate Change Impacts on Streamflows of Two Main West Africa River Basins: Senegal and Gambia. *Hydrology*, *5*(1), 21. https://doi.org/10.3390/hydrology5010021
14. Brottem, L., & Brooks, B. (2018). Crops and livestock under the sun: Obstacles to rural livelihood adaptations to hotter 21st century temperatures in eastern Senegal. *Land Degradation & Development*, *29*(1), 118–126. https://doi.org/10.1002/ldr.2844

15. Brown, M. (2008). Chapter 3: The Impact of Climate Change on Income Diversification and Food Security in Senegal. In *Land-Change Science in the Tropics, Changing Agricultural Landscapes* (pp. 33–52). Springer Science+Business Media, LLC.
16. Camara, O. M. (2004). *The impact of seasonal changes in real incomes and relative prices on households' consumption patterns in Bamako, Mali* [Ph.D., Michigan State University]. http://search.proquest.com/docview/305156320/abstract/62D15AEA8C3F4DDCPQ/1
17. Carr, E. R., Fleming, G., & Kalala, T. (2016). Understanding Women's Needs for Weather and Climate Information in Agrarian Settings: The Case of Ngetou Maleck, Senegal. *Weather, Climate, and Society; Boston*, *8*(3), 247–264. http://dx.doi.org.ezproxy.cul.columbia.edu/10.1175/WCAS-D-15-0075.1
18. Carranza, M., Niles, M. T., & Niles, M. T. (2019). Smallholder Farmers Spend Credit Primarily on Food: Gender Differences and Food Security Implications in a Changing Climate. *Frontiers in Sustainable Food Systems*, *3*. https://doi.org/10.3389/fsufs.2019.00056
19. Cheung, W. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, *16*(1), 24–35.
20. CIAT and BFS/USAID. (2016). *Climate-smart agriculture in Senegal* (CSA Country Profiles for Africa Series). International Center for Tropical Agriculture (CIAT); Bureau for Food Security, USAID.
21. Cogneau, D., & Jedwab, R. (2012). Commodity Price Shocks and Child Outcomes: The 1990 Cocoa Crisis in Côte d'Ivoire. *Economic Development and Cultural Change*, *60*(3), 507–534. https://doi.org/10.1086/664017
22. Constantin de Magny, G., Guégan, J.-F., Petit, M., & Cazelles, B. (2007). Regional-scale climate-variability synchrony of cholera epidemics in West Africa. *BMC Infectious Diseases*, *7*(1), 20. https://doi.org/10.1186/1471-2334-7-20
23. Das, D., Grais, R. F., Okiro, E. A., Stepniewska, K., Mansoor, R., Kam, S. van der, Terlouw, D. J., Tarning, J., Barnes, K. I., & Guerin, P. J. (2018). Complex interactions between malaria and malnutrition: A systematic literature review. *BMC Medicine*, *16*(1), 1–14. https://doi.org/10.1186/s12916-018-1177-5
24. Delaunay, V. (1998). *La situation démographique et épidémiologique dans la zone de Niakhar au Sénégal: 1984-1996 (version mise à jour et augmentée du rapport Chahnazarian 1992)*.
25. Deussom N., G., Wise, V., Solange Ndione, M., & Gadiaga, A. (2018). *Capacities of the Nutrition Sector in Senegal, Gabriel Deussom N., Victoria Wise, Marie Solange Ndione, Aida Gadiaga*. World Bank Group, Cellule de Lutte Contre La Malnutrition (CLM).
26. Dewey, K. G., & Begum, K. (2011). Long-term consequences of stunting in early life. *Maternal & Child Nutrition*, *7*(s3), 5–18. https://doi.org/10.1111/j.1740-8709.2011.00349.x
27. Dia, F., Wageningen University, Gerrit Antonides, Anke Niehof, & Johan van Ophem. (2010). *Intrahousehold resource allocation and well-being: The case of rural households in Senegal* [S.n.]. http://library.wur.nl/WebQuery/wurpubs/395597
28. Diack, M., Diop, T., & Ndiaye, R. (2019). Archive ouverte HAL - Restoration of Degraded Lands Affected by Salinization Process under Climate Change Conditions: Impacts on Food Security in the Senegal River Valley. In *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa* (pp. 275–288). Springer. https://hal.archives-ouvertes.fr/hal-02303144
29. Dieye, A. M., & Roy, D. P. (2012). A Study of Rural Senegalese Attitudes and Perceptions of Their Behavior to Changes in the Climate. *Environmental Management*, *50*(5), 929–941. https://doi.org/10.1007/s00267-012-9932-4
30. Diouf, I., Rodriguez-Fonseca, B., Deme, A., Caminade, C., Morse, A. P., Cisse, M., Sy, I., Dia, I., Ermert, V., Ndione, J.-A., & Gaye, A. T. (2017). Comparison of Malaria Simulations Driven by Meteorological Observations and Reanalysis Products in Senegal. *International Journal of Environmental Research and Public Health*, *14*(10). https://doi.org/10.3390/ijerph14101119

31. Dunn, G. (2016). *The Impact of Climate Variability and Conflict on Childhood Diarrhea and Malnutrition in West Africa* [D.P.H., City University of New York]. http://search.proquest.com/docview/1762745970/abstract/268D1E8E38554BC9PQ/1

32. Dunn, G., & Johnson, G. D. (2018). The geo-spatial distribution of childhood diarrheal disease in West Africa, 2008–2013: A covariate-adjusted cluster analysis. *Spatial and Spatio-Temporal Epidemiology*, *26*, 127–141. https://doi.org/10.1016/j.sste.2018.06.005

33. FAO. (2005). *Senegal Livestock Sector Brief*. Food and Agriculture Organization of the United Nations, Livestoc (FAO), Information, Sector, Analysis and Policy Branch (AGAL).

34. FAO. (2010). *Nutrition Country Profiles: Senegal Summary*. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/agn/nutrition/sen_en.stm

35. Faramarzi, M., Abbaspour, K. C., Ashraf Vaghefi, S., Farzaneh, M. R., Zehnder, A. J. B., Srinivasan, R., & Yang, H. (2013). Modeling impacts of climate change on freshwater availability in Africa. *Journal of Hydrology*, *480*, 85–101. https://doi.org/10.1016/j.jhydrol.2012.12.016

36. Faye, B., Webber, H., Diop, M., Mbaye, M. L., Owusu-Sekyere, J. D., Naab, J. B., & Gaiser, T. (2018). Potential impact of climate change on peanut yield in Senegal, West Africa. *Field Crops Research*, *219*, 148–159. https://doi.org/10.1016/j.fcr.2018.01.034

37. Ferreira, F. H. G., & Schady, N. (2009). Aggregate Economic Shocks, Child Schooling, and Child Health. *The World Bank Research Observer*, *24*(2), 147–181. https://doi.org/10.1093/wbro/lkp006

38. Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford, J. M. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *The Lancet Infectious Diseases*, *5*(1), 42–52. https://doi.org/10.1016/S1473-3099(04)01253-8

39. Fontenille, D., Lochouarn, L., Diatta, M., Sokhna, C., Dia, I., Diagne, N., Lemasson, J.-J., Ba, K., Tall, A., Rogier, C., & Trape, J.-F. (1997). Four years' entomological study of the transmission of seasonal malaria in Senegal and the bionomics of Anopheles gambiae and A. arabiensis. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, *91*(6), 647–652. https://doi.org/10.1016/S0035-9203(97)90506-X

40. Glantz, M. H. (1987). Drought and economic development in sub-Saharan Africa. *Wilhite, Donald A.; Easterling, William E.; Wod, Deborah A., Planning for Drought: Toward a Reduction of Societal Vulnerability, Boulder, CO., Westview Press, Incorporated, 1987*, 297–316.

41. Global Nutrition Report. (2019). *Global Nutrition Report: Senegal Nutrition Profile*. Global Nutrition Report. https://globalnutritionreport.org/resources/nutrition-profiles/

42. Gobin, A., Jones, R., Kirkby, M., Campling, P., Govers, G., Kosmas, C., & Gentile, A. R. (2004). Indicators for pan-European assessment and monitoring of soil erosion by water. *Environmental Science & Policy*, *7*(1), 25–38. https://doi.org/10.1016/j.envsci.2003.09.004

43. Golan, E. H. (1994). Sustainability and Migration: Experiments from the Senegalese Peanut Basin. *Annals of Regional Science*, *28*(1), 91–106.

44. Grover-Kopec, E. K., Blumenthal, M. B., Ceccato, P., Dinku, T., Omumbo, J. A., & Connor, S. J. (2006). Web-based climate information resources for malaria control in Africa. *Malaria Journal*, *5*, 38. https://doi.org/10.1186/1475-2875-5-38

45. Haggblade, S., Me-Nsope, N. M., & Staatz, J. M. (2017). Food security implications of staple food substitution in Sahelian West Africa. *Food Policy*, *71*, 27–38. https://doi.org/10.1016/j.foodpol.2017.06.003

46. Hanatani, A., & Fuse, K. (2012). Linking resource users' perceptions and collective action in commons management—An examination of water supply systems in Southern Senegal. *Water Policy; Oxford*, *14*(1), 127–147. http://dx.doi.org.ezproxy.cul.columbia.edu/10.2166/wp.2011.031

47. Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy*, *35*(5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006

48. Hazard, E., Troc, H., Valette, D., Norgrove, K., Marshall, J., & Woollcombe, A. (2008). *Rising Food Prices in the Sahel: The Urgency of Long-term Action*. Oxfam International.
49. Herforth, A., & Harris, J. (2014). *Understanding and applying primary pathways and principles | IFPRI : International Food Policy Research Institute*. International Food Policy Research Institute. https://www.ifpri.org/publication/understanding-and-applying-primary-pathways-and-principles
50. Imes, T. (2011). *The Implications of Aflatoxin Contamination for Local Food Safety in Senegal*. United States Department of Agriculture, Congressional Hunger Center. https://www.hungercenter.org/publications/the-implications-of-aflatoxin-contamination-for-local-food-safety-in-senegal/
51. Jentoft, S., & Chuenpagdee, R. (2015). Coordination, Development, and Governance of Senegal Small-Scale Fisheries. In *Interactive Governance for Small-Scale Fisheries: Global Reflections*. Springer.
52. Kampman, H., Zongrone, A., Rawat, R., & Becquey, E. (2017). How Senegal created an enabling environment for nutrition: A story of change—ScienceDirect. *Global Food Security*, *13*, 57–65. https://doi.org/10.1016/j.gfs.2017.02.005
53. Karambiri, H., Galiano, S. G. G., Giraldo, J. D., Yacouba, H., Ibrahim, B., Barbier, B., & Polcher, J. (2011). Assessing the impact of climate variability and climate change on runoff in West Africa: The case of Senegal and Nakambe River basins. *Atmospheric Science Letters*, *12*(1), 109–115. https://doi.org/10.1002/asl.317
54. Kawarazuka, N. (2010). The contribution of fish intake, aquaculture, and small-scale fisheries to improving nutrition: A literature review. *WorldFish Center Working Paper*, *2106*, 44.
55. Kazybayeva, S., Otte, J., & Roland-Holst, D. (2006). Livestock Production and Household Income Patterns in Rural Senegal. *Rural Development Research Consortium*, 16.
56. Killebrew, K., Plotnick, R., & Gugerty, M. K. (2010). *Poultry Market in West Africa: Senegal, EPAR Brief No. 86*. Evans School of Public Affairs, University of Washington.
57. Kraay, A. N. M., Brouwer, A. F., Lin, N., Collender, P. A., Remais, J. V., & Eisenberg, J. N. S. (2018). Modeling environmentally mediated rotavirus transmission: The role of temperature and hydrologic factors. *Proceedings of the National Academy of Sciences*, *115*(12), E2782–E2790. https://doi.org/10.1073/pnas.1719579115
58. Lam, V., Cheung, W., Swartz, W., & Sumalia, U. (2012). Climate change impacts on fisheries in West Africa: Implications for econom...: EBSCOhost. *African Journal of Marine Science*, *34*(1), 103–117. https://doi.org/10.2989/1814232X.2012.673294
59. Lara, L. J., & Rostagno, M. H. (2013). Impact of Heat Stress on Poultry Production. *Animals : An Open Access Journal from MDPI*, *3*(2), 356–369. https://doi.org/10.3390/ani3020356
60. Lazzaroni, S., & Wagner, N. (2016). Misfortunes never come singly: Structural change, multiple shocks and child malnutrition in rural Senegal. *Economics & Human Biology*, *23*, 246–262. https://doi.org/10.1016/j.ehb.2016.10.006
61. Lesnoff, M., Corniaux, C., & Hiernaux, P. (2012). Sensitivity analysis of the recovery dynamics of a cattle population following drought in the Sahel region. *Ecological Modelling*, *232*, 28–39. https://doi.org/10.1016/j.ecolmodel.2012.02.018
62. Levy, K., Hubbard, A. E., & Eisenberg, J. N. (2009). Seasonality of rotavirus disease in the tropics: A systematic review and meta-analysis. *International Journal of Epidemiology*, *38*(6), 1487–1496. https://doi.org/10.1093/ije/dyn260
63. Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the Impacts of Climate Change on Waterborne Diseases: A Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. *Environmental Science & Technology*, *50*(10), 4905–4922. https://doi.org/10.1021/acs.est.5b06186

64. Linares, O. F. (2009). From past to future agricultural expertise in Africa: Jola women of Senegal expand market-gardening. *Proceedings of the National Academy of Sciences*, *106*(50), 21074–21079. https://doi.org/10.1073/pnas.0910773106
65. Liverpool-Tasie, L. S. O., Sanou, A., & Tambo, J. A. (2019). Climate change adaptation among poultry farmers: Evidence from Nigeria. *Climatic Change*, *157*(3), 527–544. https://doi.org/10.1007/s10584-019-02574-8
66. Lunde, T. M., & Lindtjørn, B. (2013). Cattle and climate in Africa: How climate variability has influenced national cattle holdings from 1961–2008. *PeerJ*, *1*. https://doi.org/10.7717/peerj.55
67. Maertens, M. (2009). Horticulture exports, agro-industrialization, and farm–nonfarm linkages with the smallholder farm sector: Evidence from Senegal. *Agricultural Economics*, *40*(2), 219–229. https://doi.org/10.1111/j.1574-0862.2009.00371.x
68. Magny, G. C. de, Thiaw, W., Kumar, V., Manga, N. M., Diop, B. M., Gueye, L., Kamara, M., Roche, B., Murtugudde, R., & Colwell, R. R. (2012). Cholera outbreak in Senegal in 2005: Was climate a factor? *PLoS ONE*, *7*(8), e44577. https://doi.org/10.1371/journal.pone.0044577
69. Mahe, G., Lienou, G., Descroix, L., Bamba, F., Paturel, J. E., Laraque, A., Meddi, M., Habaieb, H., Adeaga, O., Dieulin, C., Kotti, F. C., & Khomsi, K. (2013). The rivers of Africa: Witness of climate change and human impact on the environment. *Hydrological Processes*, *27*(15), 2105–2114. https://doi.org/10.1002/hyp.9813
70. Manners, R., & van Etten, J. (2018). Are agricultural researchers working on the right crops to enable food and nutrition security under future climates? *Global Environmental Change*, *53*, 182–194. https://doi.org/10.1016/j.gloenvcha.2018.09.010
71. Mbaye M. L., Hagemann S., Haensler A., Stacke T., Gaye A. T., & Afouda A. (2015). Assessment of Climate Change Impact on Water Resources in the Upper Senegal Basin (West Africa). *American Journal of Climate Change*, *4*(1), 77–93. https://doi.org/10.4236/ajcc.2015.41008
72. Mbotha, D., Bett, B., Kairu-Wanyoike, S., Grace, D., Kihara, A., Wainaina, M., Hoppenheit, A., Clausen, P.-H., & Lindahl, J. (2018). Inter-epidemic Rift Valley fever virus seroconversions in an irrigation scheme in Bura, south-east Kenya. *Transboundary and Emerging Diseases*, *65*(1), e55–e62. https://doi.org/10.1111/tbed.12674
73. Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A. J., Carlisle, E., Dietterich, L. H., Fitzgerald, G., Hasegawa, T., Holbrook, N. M., Nelson, R. L., Ottman, M. J., Raboy, V., Sakai, H., Sartor, K. A., Schwartz, J., Seneweera, S., Tausz, M., & Usui, Y. (2014). Increasing CO 2 threatens human nutrition. *Nature*, *510*(7503), 139–142. https://doi.org/10.1038/nature13179
74. Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*, *130*(1), 57–69. https://doi.org/10.1016/j.livsci.2010.02.011
75. Ndiaye, C., Saliou, N., Traore, E., Samba, S. A. N., & Akpo, L. (2015). Predicting the amount of biomass produced grassland depending on the rainfall recorded in the Sahelian area of North – Senegal in West Africa. *International Journal of Advanced Research*, *3*, 382–396.
76. Nyoni, N. M. B., Grab, S., & Archer, E. R. M. (2018). Heat stress and chickens: Climate risk effects on rural poultry farming in low-income countries. *Climate and Development*, 1–8. https://doi.org/10.1080/17565529.2018.1442792
77. Oh, H.-K., Kang, S., Cho, S.-H., Ju, Y.-J., & Faye, D. (2019). Factors influencing nutritional practices among mothers in Dakar, Senegal. *PLoS ONE*, *14*(2), e0211787. https://doi.org/10.1371/journal.pone.0211787
78. Ouedraogo, I., Diouf, N. S., Ouedraogo, M., Ndiaye, O., & Zougmoré, R. B. (2018). Closing the Gap between Climate Information Producers and Users: Assessment of Needs and Uptake in Senegal. *Climate*, *6*(13). https://www.mdpi.com/2225-1154/6/1/13

79. Pongou, R., Salomon, J. A., & Ezzati, M. (2006). Health impacts of macroeconomic crises and policies: Determinants of variation in childhood malnutrition trends in Cameroon. *International Journal of Epidemiology*, *35*(3), 648–656. https://doi.org/10.1093/ije/dyl016

80. Prasad, R., & Virk, K. (1993). Malaria as a cause of diarrhea- a review. *Papua New Guinea Medical Journal*, *36*(4), 337–341.

81. Roland-Holst, D., & Otte, J. (2007). Livestock and livelihoods: Development goals and indicators applied to Senegal. *African Journal of Agricultural Research*, *26*(6), 240–251.

82. Roos, N., Wahab, Md. A., Chamnan, C., & Thilsted, S. H. (2007). The Role of Fish in Food-Based Strategies to Combat Vitamin A and Mineral Deficiencies in Developing Countries. *The Journal of Nutrition*, *137*(4), 1106–1109. https://doi.org/10.1093/jn/137.4.1106

83. Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, *21*(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

84. Ruelland, D., Ardoin-Bardin, S., Collet, L., & Roucou, P. (2012). Simulating future trends in hydrological regime of a large Sudano-Sahelian catchment under climate change. *Journal of Hydrology*, *424–425*, 207–216. https://doi.org/10.1016/j.jhydrol.2012.01.002

85. Sadio, S., Agricultural University, L.J. Pons, & L. van der Plas. (1989). *Pedogenese et potentialites forestieres des sols sulfates acides sales des Tannes du Sine Saloum, Senegal* [Sadio]. http://library.wur.nl/WebQuery/wurpubs/9560

86. Salmon, G. R., Marshall, K., Tebug, S. F., Missohou, A., Sourokou Sabi, S., & MacLeod, M. (2016). *Farmer attitudes to the improvement of productivity in Senegalese low input cattle systems*. Land Economy Research Group. https://www.ilri.org/publications/farmer-attitudes-improvement-productivity-senegalese-low-input-cattle-systems

87. Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions. *Regional Environmental Change*, *17*(6), 1585–1600. https://doi.org/10.1007/s10113-015-0910-2

88. Sow, A., Faye, O., Ba, Y., Diallo, D., Fall, G., Faye, O., Bob, N. S., Loucoubar, C., Richard, V., Dia, A. T., Diallo, M., Malvy, D., & Sall, A. A. (2016). Widespread Rift Valley Fever Emergence in Senegal in 2013–2014. *Open Forum Infectious Diseases*, *3*(3). https://doi.org/10.1093/ofid/ofw149

89. Stepman, F. (2018). Scaling-Up the Impact of Aflatoxin Research in Africa. The Role of Social Sciences. *Toxins*, *10*(4). https://doi.org/10.3390/toxins10040136

90. Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., Brinsden, H., Calvillo, A., De Schutter, O., Devarajan, R., Ezzati, M., Friel, S., Goenka, S., Hammond, R. A., Hastings, G., Hawkes, C., Herrero, M., Hovmand, P. S., Howden, M., … Dietz, W. H. (2019). The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. *The Lancet*, *393*(10173), 791–846. https://doi.org/10.1016/S0140-6736(18)32822-8

91. Sylla, M. B., Faye, A., Klutse, N. A. B., & Dimobe, K. (2018). Projected increased risk of water deficit over major West African river basins under future climates. *Climatic Change*, *151*(2), 247–258. https://doi.org/10.1007/s10584-018-2308-x

92. Tagesson, T., Fensholt, R., Guiro, I., Rasmussen, M. O., Huber, S., Mbow, C., Garcia, M., Horion, S., Sandholt, I., Holm-Rasmussen, B., Göttsche, F. M., Ridler, M.-E., Olén, N., Olsen, J. L., Ehammer, A., Madsen, M., Olesen, F. S., & Ardö, J. (2015). Ecosystem properties of semiarid savanna grassland in West Africa and its relationship with environmental variability. *Global Change Biology*, *21*(1), 250–264. https://doi.org/10.1111/gcb.12734

93. Talla, C., Diallo, D., Dia, I., Ba, Y., Ndione, J.-A., Sall, A. A., Morse, A., Diop, A., & Diallo, M. (2014). Statistical Modeling of the Abundance of Vectors of West African Rift Valley Fever in Barkédji, Senegal.

PLoS One; San Francisco, *9*(12), e114047. http://dx.doi.org.ezproxy.cul.columbia.edu/10.1371/journal.pone.0114047

94. Thiam, S., Diène, A. N., Fuhrimann, S., Winkler, M. S., Sy, I., Ndione, J. A., Schindler, C., Vounatsou, P., Utzinger, J., Faye, O., & Cissé, G. (2017). Prevalence of diarrhoea and risk factors among children under five years old in Mbour, Senegal: A cross-sectional study. *Infectious Diseases of Poverty*, *6*(1), 109. https://doi.org/10.1186/s40249-017-0323-1

95. Thiam, S., Diène, A. N., Sy, I., Winkler, M. S., Schindler, C., Ndione, J. A., Faye, O., Vounatsou, P., Utzinger, J., & Cissé, G. (2017). Association between Childhood Diarrhoeal Incidence and Climatic Factors in Urban and Rural Settings in the Health District of Mbour, Senegal. *International Journal of Environmental Research and Public Health*, *14*(9). https://doi.org/10.3390/ijerph14091049

96. Thomson, M. C., & Mason, S. J. (2018). *Climate Information for Public Health Action*. Taylor & Francis.

97. Tine, R. C. K., Ndiaye, M., Holm Hansson, H., Ndour, C. T., Faye, B., Alifrangis, M., Sylla, K., Ndiaye, J. L., Magnussen, P., Bygbjerg, I. C., & Gaye, O. (2012). The association between malaria parasitaemia, erythrocyte polymorphisms, malnutrition and anaemia in children less than 10 years in Senegal: A case control study. *BMC Research Notes*, *5*(1), 565–574. https://doi.org/10.1186/1756-0500-5-565

98. Tourre, Y. M., Lacaux, J.-P., Vignolles, C., & Lafaye, M. (2009). Climate impacts on environmental risks evaluated from space: A conceptual approach to the case of Rift Valley Fever in Senegal. *Global Health Action*, *2*. https://doi.org/10.3402/gha.v2i0.2053

99. UNICEF, & Action Against Hunger. (2016). *Nutrition Surveys and SMART Methodology in Sub-Saharan Africa* (pp. 25–35). United Nations Children's Fund.

100. USAID. (2017). *Climate Change Risk Profile: Senegal, Fact Sheet*. USAID.

101. USAID. (2018). *Empowering Women in Artisinal Processing of Fisheries Products*. United States Agency for International Development/COMFISH PLUS Project.

102. Venema, H. D., Schiller, E. J., Adamowski, K., & Thizy, J.-M. (1997). A Water Resources Planning Response to Climate Change in the Senegal River Basin. *Journal of Environmental Management*, *49*(1), 125–155. https://doi.org/10.1006/jema.1996.0120

103. WFP. (2019). *WFP Senegal Country Brief*. World Food Programme. https://www.wfp.org/countries/senegal

104. World Bank. (2016, August). *Senegal Takes Steps to Establish a Sustainable and Better-Governed Fisheries Sector* [Text/HTML]. World Bank. https://www.worldbank.org/en/news/feature/2016/08/08/senegal-takes-steps-to-establish-a-sustainable-and-better-governed-fisheries-sector

105. World Bank. (2017). *Groundnut Value Chain Competitiveness and Prospects for Development, Final report*. The World Bank, Agriculture Global Practice - West Africa (GFA01) Africa Region.