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Climate impacts on food security and nutrition

A review of existing knowledge

Contents

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EXECUTIVE SUMMARY

Among the most significant impacts of climate change is the potential increase of food insecurity and malnutrition. The aim of this primer is to summarise the current state of knowledge on the impacts of climate change on food security and nutrition.

Climate change exacerbates the risks of hunger and undernutrition through two main mechanisms:

Extreme weather events

Under climate change, the frequency and intensity of some disasters such as droughts, floods and storms could increase, with an adverse impact on livelihoods and food security. Climate-related disasters have the potential to destroy crops, critical infrastructure, and key community assets therefore deteriorating livelihoods and exacerbating poverty.

Long-term and gradual climate risks

Sea-level will rise as a result of climate change, affecting livelihoods in coastal areas and river deltas. Accelerated glacial melt will also affect the quantity and reliability of water available. Under warming trends, glacial melt could accelerate, and the melt season would begin earlier in the year.

In addition, climate change could affect all dimensions of food security and nutrition in complex ways:

Food production

Changes in climatic conditions have already affected the production of some staple crops, and future climate change threatens to exacerbate this. Higher temperatures will have an impact on yields while changes in rainfall could affect both crop quality and quantity.

Food access

Climate change could increase the prices of major crops in some regions. For the most vulnerable people, lower agricultural output would also mean lower income. Under these conditions, the poorest people — who already use most of their income on food — would have to sacrifice additional income to meet their nutritional requirements.

Food utilisation

Climate-related risks affect calorie intake, particularly in areas where chronic food insecurity is already a significant problem. Changing climatic conditions could also create a vicious cycle of disease and hunger.

Nutrition

Nutrition is also likely to be affected by climate change through related impacts on food security, dietary diversity, care practices and health.

1. Introduction

SUMMARY

- Climate change will act as a hunger risk multiplier exacerbating current vulnerabilities, with one study projecting up to 20% more people at risk of hunger.
- Climate change could affect all dimensions of food security in complex ways.

Almost one billion people experienced hunger in 2010 (FAO/WFP, 2010): The most vulnerable people cannot access enough of the major macronutrients (carbohydrates, fats and protein). Perhaps another billion are thought to suffer from 'hidden hunger', in which important micronutrients (such as vitamins and minerals) are missing from their diet, with consequent risks of physical and mental impairment (Foresight, 2011).

Undernutrition remains one of the world's most serious but least addressed socioeconomic and health problems (FAO/WFP, 20120; Horton ***et al.***, 2009; SUN, 2010). The human and socioeconomic costs of undernutrition are enormous, falling hardest on the poorest, especially on women and children (Horton ***et al.***, 2009; SUN, 2010). The millions of the world's people who have experienced undernutrition early in life face many challenges as they grow up. They encounter an increased risk of illness and death when young, experience difficulties at school, and are often not able to make a full contribution to the social and economic development of their households, communities and nations when they become adults (Nabarro, 2010).

Climate change threatens to exacerbate existing threats to food security and livelihoods due to a combination of factors that include the increasing frequency and intensity of climate hazards, diminishing agricultural yields and reduced production in vulnerable regions, rising health and sanitation risks, increasing water scarcity, and intensifying conflicts over scarce resources, which would lead to new humanitarian crises as well as increasing displacement (IPCC, 2007). Climate change is expected to affect all of the components that influence food security: availability, access, stability and utilisation.

The overall **availability** of food is affected by changes in agricultural yields as well as changes in arable land. Changes in food production, together with other factors, could impact food prices, which would affect the ability of poor households to access food markets and could reduce dietary diversity. Decreased water availability and quality in some areas could result in increased health and sanitation problems such as diarrheal disease which, together with changes in vector-borne disease patterns, has the potential to increase malnutrition, and negatively affect food **utilisation**. Extreme weather effects disrupt the **stability** of food supply as well as people's livelihoods. Increases in extreme weather, such as floods and drought, as a result of climate change, would exacerbate this trend and could have a negative impact on livelihoods that depend on climate-sensitive activities such as rain-fed agriculture and livestock rearing. (cf. Schmidhuber and Tubiello, 2007).

KEY FIGURES ON UNDERNUTRITION

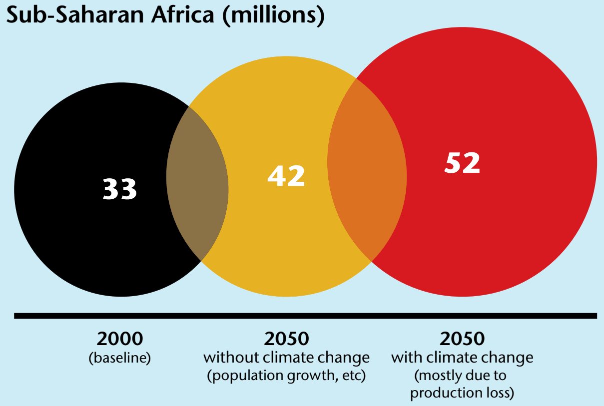
- Malnutrition is the underlying cause of 35% of childhood deaths, which is more than 2.5 million deaths per year.
- For all developing countries, nearly one-third or 165 million children younger than 5 years are stunted (low 'height-for-age');
- There are 52 million acutely malnourished children globally, and 29 million of these severe acutely malnourished.

Source: Black ***et al.***, 2008

FOOD SECURITY DIMENSION	CONSEQUENCES OF CLIMATE CHANGE
AVAILABILITY ***(sufficient quantity of food for consumption)***	• Reduced agricultural production in some areas locally (especially at tropical latitudes) could affect dietary diversity • Changes in the suitability of land for crop production • Changes in precipitation patterns could affect the sustainability of rain-fed agriculture in some areas • Increases in temperature could lead to longer growing seasons in temperate regions and reduced frost damage • CO_2 fertilisation could increase yields for those crops with the physiology to benefit from CO_2 enrichment
ACCESS ***(ability to obtain food regularly through own production or purchase)***	• Lower yields in some areas could result in higher food prices • Loss of income due to the potential increase in damage to agricultural production
STABILITY ***(risk of losing access to resources required to consume food)***	• Instability of food supplies due to an increase in extreme events • Instability of incomes from agriculture
UTILISATION ***(quality and safety of food, including nutrition aspects)***	• Food security and health impacts include increased malnutrition • Ability to utilise food might decrease where changes in climate increase disease • Impact on food safety due to changes in pests and water pollution

Understanding the specific impacts of climate change on food security is challenging because vulnerabilities are unevenly spread across the world and ultimately depend on the ability of communities and countries to cope with risks. In the context of food security, some regions of the world might experience gains under climate change, but developing countries are likely to be negatively affected.

Number of malnourished children in Sub-Saharan Africa (millions)

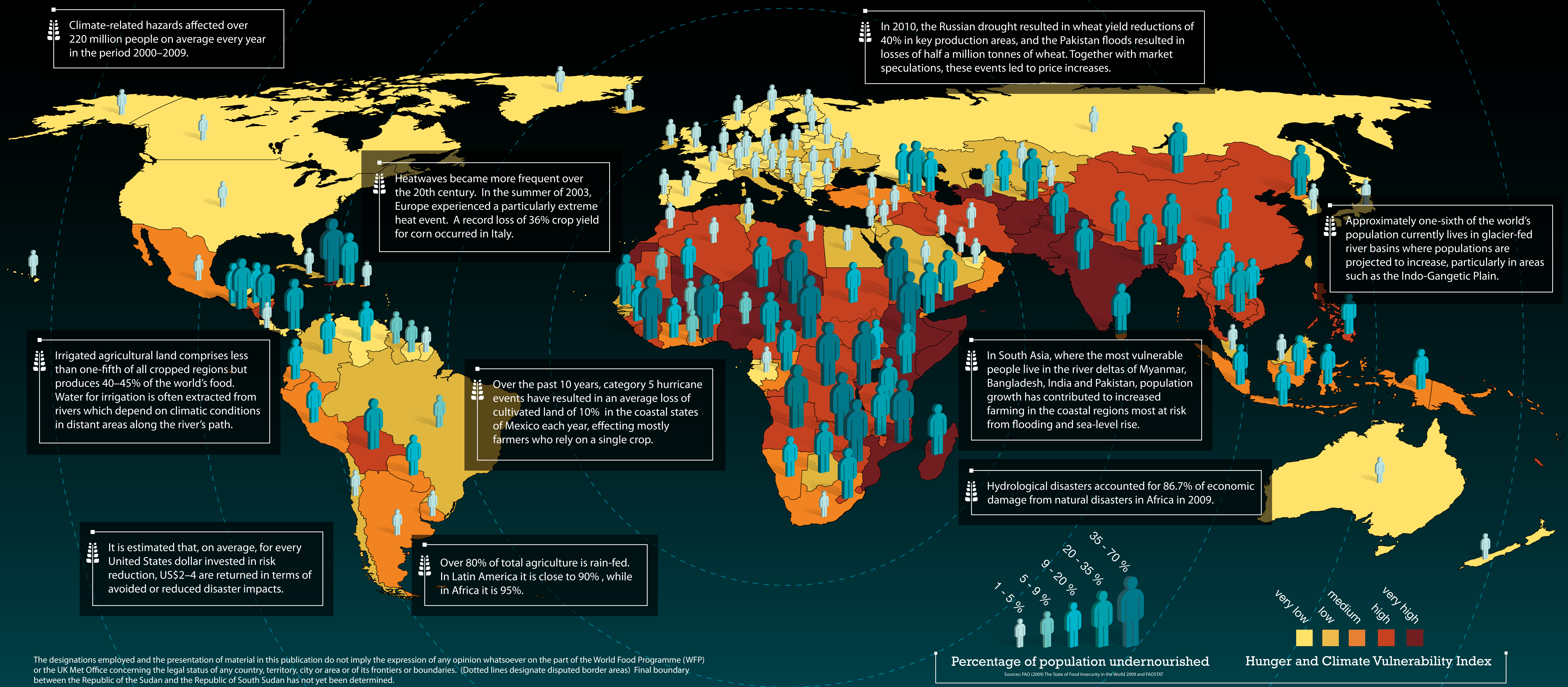


Source: Nelson ***et al.***, 2009; graphics by WFP

Projections suggest that the number of people at risk of hunger will increase by 10–20% by 2050 due to climate change, with 65% of this population in Sub-Saharan Africa. The number of malnourished children could increase by up to 21% (24 million children), with the majority being in Africa (Parry ***et al.***, 2009; Nelson ***et al.***, 2009).

The purpose of this technical paper is to review the current state of knowledge on the relationship between climate change and food security and nutrition to provide an evidence base for current discussions. Firstly, the paper provides an analysis of empirical evidence and model results to highlight the relationship between climate change and different components of food security. Secondly, the paper examines the relationship between extreme weather events, including both rapid-onset and slow-onset disasters, and food security. A summary of key messages is provided for each section.

Food insecurity and climate change



The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the World Food Programme (WFP) or the UK Met Office concerning the legal status of any country, territory, city or area or of its frontiers or boundaries. (Dotted lines designate disputed border areas) Final boundary between the Republic of the Sudan and the Republic of South Sudan has not yet been determined.

WHERE DO THE FOOD INSECURE LIVE?

The most food insecure people live in the poorest and most marginal areas of Asia, Africa and Latin America, where environmental degradation and climate change are likely to exacerbate current threats to food security. The majority of food insecure people live in Asia, where high poverty rates and high disaster magnitudes affect food security. In Sub-Saharan Africa, the most food insecure communities live in highly degraded environments where climate change could increase degradation rates.

In Latin America, the most food insecure generally live in poor urban and rural settings where climate-related disasters affect poverty and food insecurity trends. Initial analysis by the United Nations World Food Programme and the UK Met Office Hadley Centre shows that current climate risks and food insecurity intersect in the most vulnerable areas of the world: West Africa, East Africa, Southern Africa, and South Asia. This is due to a combination of exposure to climate risks such as floods, droughts and storms, as well as high poverty rates and high sensitivity to climate change.

2. Climate change

DEFINITIONS: ***CLIMATE CHANGE AND CLIMATE VARIABILITY***

An important distinction should be made between climate change and climate variability. The former refers to the long-term trend in weather, generally over decades or centuries. This includes long-term changes or trends in the average climate (such as annual average temperature or precipitation) or trends in climate extremes (such as the frequency of intense rainfall events). However, people experience climate as individual weather events, which naturally fluctuate on an annual, seasonal and decadal basis. In addition to natural variation, climate change will mean a shift in the patterns of weather events, over the long term. The magnitude of these climatic changes over the following decades and towards the end of the century will depend on how successful policies are at reducing greenhouse gas emissions and how sensitive the climate system is. (cf. IPCC, 2007).

2.1 LONG-TERM CLIMATE CHANGE

2.1.1 Temperature rise

Global average temperature is expected to rise as a result of climate change, and the spatial pattern of this rise is such that all areas will see an increase in temperature. By the 2050s the global average temperature is projected to have risen between 2–4 °C above the pre-industrial climate; however, this average value masks differences in local temperature rises. In general, the land will see greater increases than the oceans. The largest increases in mean temperature are projected for the high latitude regions of the northern hemisphere, with lesser increases in tropical and sub-tropical areas. Most of Canada and Russia are projected to experience significant warming. The Amazon region and parts of China could also see temperature increases above those experienced elsewhere. South Asia and Southeast Asia are the regions where the lowest increases in mean temperature are projected. (Christensen ***et al.***, 2007).

2.1.2 Changes in precipitation patterns

There is less confidence in the climate model projections of changes in precipitation patterns than changes in temperature. Observed large-scale patterns of precipitation are represented well in many global climate models, leading to high confidence in projections of general circulation and large-scale precipitation patterns. However, there is less certainty in regional projections. Rainfall records in many parts of the world (e.g. Africa and the Middle East) are sparse, particularly with respect to intense events, and satellite measurements of rainfall over the oceans are still being developed. The lack of these types of data hinders climate model verification and development. An additional problem is that most climate models do not resolve monsoon events and hence their associated rainfall well (Randall ***et al.***, 2007).

In general, increases in temperature will result in a more active hydrological cycle, meaning more rainfall overall. But changes in the patterns and seasonality of rainfall regionally, mean that some areas will still see less rainfall, and changes in the timing and intensity of rainfall events could also have a significant impact locally. (Meehl *et al.*, 2007)

2.1.3 Changes in other variables and weather patterns

Changes in the climate will be felt not only through increasing temperatures and changing rainfall patterns, but also through rising sea-levels, changes in storms and storm tracks, glacier melt and changes in large-scale circulations. These changes to the global Earth system will be experienced locally as changes in water availability, drought, storm surge damage and land loss. Although many aspects of these changes will be negative, for some areas there will also be positive changes, particularly at lower levels of climate change. (Parry ***et al,*** 2007)

2.1.4 Seasonal climate patterns

The seasonal cycles of hunger and undernutrition are generally strongly correlated with climatic-related factors — especially in rural areas. In Sahel and the Horn of Africa climate-related factors strongly influence crop and animal production, income, diseases and undernutrition. In Bangladesh, floods and cyclones tend to follow seasonal patterns — with important food and nutrition security implications. Seasonal peaks of hunger and undernutrition are also shaped by human or socioeconomic factors, such as high food prices or low income opportunities. For the past few years seasonality has changed. Rural communities across the world report that both the timing and the pattern of seasonal rains are changing dramatically. For example, rainfall is reported to be more erratic, shorter and heavier; even within recognisable seasons, 'unseasonal' events such as heavier rains, drier spells, unusual storms, dense fogs and temperature fluctuations are increasing. (Devereux and Sabates-Wheeler, 2012).

2.2 IMPACTS OF SEA-LEVEL RISE AND REMOTE CLIMATE

2.2.1 Sea-level rise

SUMMARY

- Climate change will contribute to sea-level rise.
- Sea-level rise, particularly in low lying coastal zones and river deltas, can have a significant effect on livelihoods and food security by destroying crops and critical livelihood assets.

Although little research has been carried out on the impacts of sea-level rise on food security, it is important to assess the potential effects, particularly in the context of low elevation coastal zones. Sea-level rise from thermal expansion of the oceans and melting ice might affect food security in two ways: on one hand, it can result in inundation of coastal agricultural lands, especially where the capacity for the introduction or modification of sea defences is relatively low or non-existent; on the other hand, it can result in increased groundwater salinisation which affects the quantity and quality of water available for human use (Adams, 1989).

In the context of food security, the highest vulnerabilities are greatest where sea-level rise occurs in conjunction with rural coastal zones. Several river deltas are favourable to agricultural production due to the fertility of fluvial soils. In combination with tectonic rise and fall, global mean sea-level rise is expected to be 2 m by 2100 (IPCC, 2007); this is especially problematic in densely populated, low elevation coastal zones. Globally, 650 million people currently live in coastal settlements and are exposed to sea-level rise (McGranahan *et al.*, 2007). In Asia and North Africa — where the most vulnerable people live in the river deltas of Myanmar, Bangladesh, India, Pakistan and Egypt — farming areas in the coastal regions are exposed to sea-level rise (Webster, 2008).

2.2.2 Remote climate risks

SUMMARY

- Remote changes in climatic conditions can affect food security elsewhere.
- Changes in river-flow could be detrimental to agricultural production: seasonal increases in river- flow could lead to flooding, while low river-flow during the dry season could result in water scarcity.
- Accelerated glacial melt under global warming could also contribute to changes in the amount of water available for agriculture and domestic use: initially glacial melt could lead to an increase in the amount of water but in the long run water flow would become more variable.

Remote climate impacts may also be critical: for example, agriculture along the Nile in Egypt depends on rainfall in the upper parts of the Nile such as the Ethiopian Highlands. In some rivers, including the Nile, climate change could potentially increase flow throughout the year benefiting agricultural production (Gornall *et al.*, 2010).

In other catchments, such as the Ganges, an increase in runoff results from an increase in peak flow during the monsoon period, but dry season river-flow is still very low. Without sufficient storage of peak season flow, water scarcity may affect food security despite overall annual increases in water availability. Moreover, seasonal increases in peak flow may also damage cropland through flooding (Gornall *et al.*, 2010).

The Niger River Basin, which provides water for several marginal livelihoods in the Sahel, is another critical basin that could experience a decrease in flow. During the 20th century, the river's mean annual discharge declined by 40–60% together with a decline in rainfall of around 30%. In the future, the Basin could be affected by changes in rainfall and runoff of about 10% although the limited data do not allow for more certain predictions (Millar, 2007).

An additional remote source of water is glacier- and snow-melt, which influences river-flow, especially in mid- to high-latitudes where warming predictions are very high. Warming in winter is accompanied by lower precipitation falling as snow and an earlier melt season. Changing patterns of snow alter how water is stored and released. Temperature changes also affect the timing of runoff, causing earlier peak flow in spring. Additional river-flow might be considered beneficial to agriculture, but only if there is an ability to store runoff during surplus times. Globally, few rivers currently have appropriate storage capacity to cope with large shifts in seasonality. Where there are no storage capacities, the excess water will be lost to oceans (Barnett *et al.*, 2005, Juen *et al.*, 2007). Approximately one-sixth of the world's population currently lives in glacier-fed river basins where populations are projected to increase, particularly in areas such as the Indo-Gangetic Plain; these population pressures will result in lower water availability and greater stress on food security (Stern, 2007).

Observations indicate that the majority of glaciers around the world are undergoing shrinkage (Zemp *et al.*, 2008). Melting glaciers will initially increase river-flow seasonally, increasing the risk of glacier lake outburst floods (Juen *et al.*, 2007), and this is especially problematic in densely populated river deltas that are fed by glaciers. Water stored in Himalayan glaciers account for approximately 12,000 km^3 of fresh water feeding rivers such as the Indus, Ganges and Brahmaputra (Cruz *et al.*, 2007). Currently over 500 million people rely on these rivers for domestic and agricultural purposes. Climate change may create seasonal flow scarcities during the dry season (Kehrwald *et al.*, 2008). Combined with expected population growth, coastal inundation from sea-level rise and increased population density, this may lead to further water scarcity and exacerbate food insecurity in the region.

2.3 IMPACTS OF EXTREME WEATHER EVENTS

SUMMARY

- Climate change is projected to result in more intense, frequent and longer extreme events such as droughts and floods, with negative consequences on food security in the most vulnerable communities.
- Extreme weather events can also complicate food logistics and distribution.

This section summarises the state of knowledge on the impact of extreme climate-related events and disasters on food security.

Climate change will have an effect on the frequency, intensity and duration of extreme weather events which could negatively affect food security in some of the most vulnerable areas.

The impacts of temperature and precipitation on crop production and food access must also be analysed in relation to the frequency, intensity and duration of extreme weather events which can affect food stability. Recurrent extreme weather events, such as droughts, heatwaves and floods, deteriorate livelihoods and undermine the capacity of communities to adapt to moderate shocks as well as their ability to purchase food, increasing the need for food assistance. In addition, more frequent and intense extreme weather events can complicate the logistics of food storage and distribution during emergencies (Keating, 2010).

Due to their heavy reliance on climate-sensitive activities such as rain-fed agriculture, food security and livelihood trends, Sub-Saharan Africa and Asia are particularly vulnerable to the impact of increasing extreme events (Easterling and Apps, 2005), particularly droughts (Giannini *et al.* 2008) and floods (Rodriguez-Llanes *et al.* 2011).

THE GENDERED IMPACT OF EXTREME WEATHER AND CLIMATE-RELATED EVENTS

Men and women are affected differently by extreme climate-related disasters. In inequitable societies, women are more vulnerable than men (and up to 14 times likelier to die as a result of a disaster) due to socially constructed gender roles that affect access to resources. In Sub-Saharan Africa, for instance, women are often acknowledged as owners of crops, but not of land. The role of women in ensuring household food security and their dependence on natural resources to do this, reinforces their vulnerability to disasters (Neumayer and Pluemper, 2007).

In post-disaster situations women are often more vulnerable than men, as their care-giving roles expand after a disaster and experience shows that their access to resources for recovery is often constrained (ISDR *et al.*, 2009).

Women also lack access to adequate and timely climate information. For example, in Peru, early warning messages about the arrival of El Niño were only transmitted to the fishermen, who were warned that fish quantities were going to be severely affected with serious economic implications. Women were not alerted since they were not directly involved in fishing — but, in fact, they managed the household budgets. Had women known about the onset of El Niño, they would have saved more household funds and budgeted differently to prepare for the event, reducing the eventual economic impact (Anderson, 2002).

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2.3.1 Droughts

SUMMARY

Droughts have adverse impacts on food security, affecting the quantity and quality of yields.

Droughts also lead to significant economic losses, especially in Africa.

Observed trend: ***Some regions have experienced more intense and more prolonged droughts (West Africa, East Asia), but opposite trends have been observed in other regions.***

Meteorological droughts (resulting from insufficient rainfall) are expected to increase in duration, frequency and intensity (Burke *et al.*, 2006). Droughts result in agricultural losses and are a major driver of food insecurity. Simlarly, drought has been the primary cause of interannual yield variations in some regions of the world (Hlavinka *et al.*, 2006). Globally, the areas sown for the major crops (barley, maize, rice, sorghum, soya bean and wheat) have seen an increase in the percentage of area affected by drought since the 1960s, from approximately 5–10% to approximately 12–25% (Li *et al.*, 2009). This is especially problematic in the context of population growth. For example, in Africa alone, 650 million people are dependent on rainfed agriculture in environments that are affected by water scarcity, land degradation, recurrent droughts and floods, and this trend is expected to exacerbate under climate change and population growth (FAO, 2008).

Financial losses from droughts are also significant. In 2009, hydrological disasters alone accounted for approximately 90% of economic damage from natural disasters in Africa (Vos *et al.*, 2010) while in 2010, all disaster-related losses were due to hydrological events (Guha-Sapir *et al.*, 2011). The areas of major crop production (barley, maize, rice, sorghum, soya and wheat) have all experienced an increase in the area affected by hydrological drought which renders them sensitive to weather variability in the future (Li *et al.*, 2009).

Moreover, increasing evidence highlights the sensitivity of key production areas to climate variability: the 2010 Russian drought resulted in wheat yield reductions of 40% in such areas (USDA, 2010). Indeed, the adverse impacts of drought may offset some benefits of carbon fertilisation and increased temperature and season length in mid- to high-latitudes. Models of global climate, crop production and water resources suggest that in Russia the frequency of food production shortfalls due to drought are likely to double in many of the main growing areas in the 2020s, and may triple in the 2070s, with significant implications for crop production and stability. (Alcamo *et al.* 2007)

2.3.2 Floods

SUMMARY

Floods can destroy crops, livelihood assets and agricultural land.

Observed trend: ***No observed trend at the global level.***

Projection: ***Possible low agreement among models, but an increase in frequency of heavy precipitation events could lead to flooding. Other factors such as snow melt could also increase flooding.***

Food security may also be affected by excessive rainfall. The impact of climate change on flood events is less certain. Globally, total rain falling during heavy rainfall events is increasing, and models suggest that there will be more heavy rainfall events as the climate warms (Held and Soden, 2006).

Evidence has linked climate change to a doubling of risk of extreme wet weather in the Northern Hemisphere (Pall *et al.*, 2011). Further attribution work by Min *et al.* (2011) suggests that increased rainfall intensity in the latter half of the twentieth century cannot be explained by estimates of natural variability alone, suggesting that there might be some influence from anthropogenic global warming.

In the context of food security, heavy rainfall leading to flooding can destroy entire crops over wide areas, as well as devastating food stores, assets (such as farming equipment) and agricultural land (due to sedimentation) (Falloon and Betts, 2010). Further studies on the impacts of current climate variability in the United Kingdom, Kettlewell *et al.* (1999) showed that heavy rainfall in August can be linked to lower grain quality due to fungal infections.

2.3.3 Tropical cyclones

SUMMARY

Tropical cyclones can destroy crops, agricultural land, infrastructure, and key livelihoods assets, thereby exacerbating existing vulnerabilities.

Observed trend: ***Increase in frequency of tropical cyclones but considerable debate on whether this is due to climate change or due to improved observational methods.***

Projection: ***Possible decrease in frequency but increase in intensity of tropical cyclones in some regions.***

Vulnerability: ***Higher vulnerability due to a combination of population growth and accumulation of wealth in exposed coastal areas.***

Tropical cyclones can also impact on food security and nutrition. Some studies (e.g. Gray, 1990) suggest tropical cyclones may become more intense in the future with stronger winds and heavier precipitation but regional variations in cyclone formation are less understood. Recent studies using high resolution models also indicate the possibility of a decrease in future global tropical cyclone frequency, but with increased intensity and duration (Knutson *et al.*, 2010; also MacDonald *et al.*, 2005; Bengtsson *et al.*, 2007; Gualdi *et al.*, 2008).

Tropical cyclones also have the potential to devastate a region, causing loss of life and widespread destruction to agricultural crops and lands, infrastructure, and livelihoods (Meehl *et al.*, 2007). Cyclone Nargis, for instance, resulted in significant societal losses in Myanmar. Communities and regions 40 km inland were inundated due to storm surges (Webster, 2008); soil salinisation made 50,000 acres of rice cropland unfit for planting (Stover and Vinck, 2008); and rice seeds, fertilisers, farm machinery and valuable land were lost, thereby affecting the winter 2008/2009 rice crop (FAO/WFP, 2009).

3. Climate impacts on food security

This section summarises the key research findings on the climate change impacts on food security and nutrition, with a focus on production, food prices, climate extremes, long-term climate hazards, pests and diseases, nutrition and health, and food safety.

3.1 CLIMATE CHANGE AND FOOD PRODUCTION

SUMMARY

- Climate change could affect staple crop production, especially in the most vulnerable and food insecure countries.
- Empirical evidence suggests that recent increases in temperature have already had a negative effect on yield for some key crops.
- In the future, higher temperature could result in even lower yields for some crops in some regions, while changes in precipitation could affect crop production in key areas.

Climate change affects food production in complex ways. Direct impacts include changes in agro-ecological conditions; indirect impacts include changes in economic growth and distribution of incomes, which in turn affect demand for agricultural produce. Empirical evidence suggests that increases in temperature in the period 1980–2008 have already resulted in average global maize and wheat yield reductions of 3.8% and 5.5% respectively, compared to a non-climate scenario (Lobell **et al.**, 2011a). To date, climate trends have been largely offset by gains derived from technology, carbon dioxide fertilisation, and other factors (Lobell **et al.**, 2011a). Future changes in climate patterns coupled with population dynamics could result in higher vulnerability.

In tropical latitudes, where much of the current food security problems exist, increases in temperature are expected to be predominantly detrimental. The quality and quantity of cropland available is projected to decrease under climate change: in Sub-Saharan Africa especially, land for double cropping could decline by between 10 and 20 million hectares and land suitable for triple cropping could decline by 5 to 10 million hectares (Fischer *et al.*, 2002). Further regional analyses corroborate these findings. In West Africa, for example, crop yields could decrease by approximately 11% due to adverse effects of increased temperatures and lower precipitation (Roudier *et al.*, in press).

More specific country-level analyses show that adverse climate trends could reduce the quantity of land available for crop production in some countries. In Kenya, for instance, a long-term study by FEWS NET (2010) notes that long rains have declined more than 100 millimetres since the mid-1970s — and this trend could continue. If this trend continues, food security would be affected due to a reduction in available prime arable land, which could affect critical surplus maize growing areas in central Kenya (Williams and Funk, 2010).

Crop and climate models have also been used to assess the potential impact of climate change on the availability of food (Rosenzweig and Parry, 1994; Arnell *et al.*, 2001; Parry *et al.*, 2004; Lobell and Field, 2007). Generally, the results indicate that changes in temperature and precipitation due to anthropogenic greenhouse gas emissions will affect land suitability and crop yields. The research suggests that higher temperatures will predominantly benefit agricultural production in the temperate latitudes, as the areas for potential production expand, the growing season length increases, cold weather events are reduced and, for many areas, precipitation increases (IPCC, 2007).

However, increases in local temperatures can generate devastating agricultural losses, and can be critical if they coincide with key stages of crop development (Wollenweber *et al.*, 2003). The yields of many crops can be drastically reduced by temperatures above 32 °C during the flowering stage: for instance, rice grain sterility occurs in temperatures in the mid-30s (Porter and Gawith, 1999; Wheeler *et al.*, 2000; Vara Prasad *et al.*, 2003; Hatfield *et al.*, 2011). Experimental work by Mohammed and Tarpley (2009) similarly suggests that rice yields were reduced by 90% when ambient temperatures increased from 27 °C to 32 °C, and temperatures above 35 °C resulted in zero yields. The results are supported by experience: the 2003 European heatwave affected crops and resulted in yield losses of up to 36% in Italy for corn (Stott *et al.*, 2003).

Empirical studies using historical crop-trial data have highlighted the adverse impact of temperature on maize yields in Africa (Lobell *et al.*, 2011b). By combining crop production data from 20,000 maize trials with daily meteorological data, Lobell *et al.* (2011b) show that for each degree-day spent above 30 °C, the final yield was reduced by 1% under optimal rain-fed conditions and by 1.7% under drought conditions. In addition, Lobell *et al.* (2011b) suggest that approximately 65% of maize-growing areas could experience yield losses for 1 °C of warming under optimal rain-fed management, whereas 100% of areas would experience significant losses under drought conditions. The results highlight the role of moisture in improving the ability of maize crops to cope with heat.

Similarly, shifts in mean precipitation patterns affect vulnerable rain-fed agricultural plots. Globally, over 80% of all agriculture is rain-fed; in Latin America it is close to 90%, whereas in Africa it is around 95% (Wani *et al.*, 2009). By contrast, irrigated agricultural land comprises less than one-fifth of all regions but produces between 40 and 45% of the world's food and depends on water availability which is likely to be affected by climatic changes (Döll and Siebert, 2002).

Water resources are predicted to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates *et al.*, 2008). Hundreds of millions of people risk being exposed to a growing scarcity of water (Pachauri and Reisinger, 2007). Climate change-related alterations in rainfall, surface water availability and water quality will impact on the incidence of water-related diseases (Confalonieri *et al.*, 2007). Closely interlinked with water scarcity is agricultural and food production, which will become riskier in many developing countries as the climate continues to change.

3.2 CLIMATE CHANGE IMPACTS ON FOOD ACCESS AND LIVELIHOODS

SUMMARY

- Recent events have highlighted the impact of food price increases on the most vulnerable people.
- Climate change could increase prices of major crops in the coming decades. The poorest people, who already use most of their income on food, would have to sacrifice additional income.
- Climate change could also affect rural incomes as agricultural production falls.

Climate change could also affect food access — that is, the ability of individuals, communities and countries to obtain sufficient quantities of good-quality food. Over the last thirty years, falling real prices for food and rising real incomes have increased purchasing power in many developing countries but recent market volatility has highlighted the vulnerability of poor and marginal households to price shocks.

The relationships between climate change and food access are complex, especially because it is difficult to quantify and model the impacts of economic growth. Moreover, any benefits associated with income growth might be offset by increases in prices. If income levels rise moderately but remain low, and the amount of income spent on food remains high, increases in food prices will exacerbate food insecurity trends (Schmidhuber and Tubiello, 2007).

Empirical evidence suggests that climate variability can impact livelihoods. For example, historical evidence in Ethiopia suggests that there is a strong correlation between economic growth and rainfall variability. Wetter years are associated with higher GDP growth, whereas dryer years are associated with lower or even negative growth (Conway and Schipper, 2010). While correlation does not imply causation, this relationship suggests that climate could affect livelihoods in the absence of adaptation measures. Conway and Schipper (2010) also note that the relationship between climate and economic growth has been weaker since 2000, probably linked to economic diversification away from agriculture. This type of complex relationship illustrates why it is difficult to quantify the range of climate-livelihoods links.

Some studies have quantified the potential impacts of rising temperatures on food prices (e.g. Fischer *et al.*, 2002; Nelson *et al.*, 2009). Increasing food prices reduce dietary diversity, which reduces dietary quality and hence increase malnutrition, in particular stunting and micronutrient deficiencies (Brinkman *et al.*, 2009). Some studies have quantified the potential impacts of rising temperatures on food prices (e.g. Fischer *et al.*, 2002; Nelson *et al.*, 2009). The studies suggest that food prices are expected to rise moderately in line with moderate increases of temperature — after 2050, however, food prices are expected to increase more rapidly. A study by the International Food Policy Research Institute (Nelson *et al.*, 2010) suggests that by 2050 real prices might increase by 87–106% for maize, 55–78% for rice, and 54–58% for wheat relative to the 2010 baseline as a result of adverse climate-change impacts. Further research suggests the potential for much larger food price changes in the nearer term, with the price of major staples rising by 10–60% by 2030 and increasing poverty levels by 20–50% in some parts of South Asia and Sub-Saharan Africa (Hertel *et al.*, 2010).

Climate change could also have an impact on rural incomes: given that agriculture is highly sensitive to climate patterns, changes in temperature and rainfall can reduce agricultural output and therefore reduce rural incomes (Morton, 2007). Mendehlson *et al.*, (2007) also show that historically climate is highly correlated to agricultural incomes — in particular, regions with moderate temperature and sufficient rainfall support higher rural incomes. Under climate change, super-optimal temperatures and erratic precipitation are likely to result in higher rural poverty, and therefore lower rural income for food.

3.3 CLIMATE CHANGE IMPACTS ON NUTRITION AND UTILISATION

SUMMARY

- Climate change exacerbates undernutrition through three causal pathways related to (or though combined effects on) food security, care practices and health.
- Quantifying the effects of climate change on undernutrition is a complex exercise, due to the multiple causal pathways leading to undernutrition.
- However recent studies suggest that climate extremes such as floods and droughts might have a negative impact on nutrition outcomes.
- Climate change can also increase the incidence of diseases, such as malaria, thereby increasing the caloric requirements of affected populations and reducing the body's absorption and utilisation of essential nutrients, effectively increasing overall nutritional needs.

Undernutrition is the consequence of inadequate dietary intake and disease, which in turn result from household food insecurity, inadequate care, an unhealthy environment and lack of health services. These three underlying causes of undernutrition are determined by environmental, economic, and socio-political contextual factors, with poverty having a central role.

Climate change can exacerbate undernutrition. For example, reduced calorie intake due to lower food availability could affect nutrition outcomes. Inadequate care practices could be exacerbated due to difficulty in accessing clean drinking water. Potential increases in food prices due to climate change could reduce dietary diversity and hence reduce nutritional value of the diet, which impacts on nutritional status. Finally, health will be impacted through changing disease patterns as a result of climate change.

3.3.1 Climate change and health

Some scientists argue that climate change is the biggest global health threat of the 21st century, and is already contributing to the global burden of disease and premature death (e.g. Costello ***et al.***, 2009). Important future trends for human health include an increase in the number of people suffering from death, disease and injury from heatwaves, floods, storms, fires and droughts; changes in the range of infectious disease vectors; and an increase in the burden of diarrhoeal diseases (Confalonieri ***et al.***, 2007). Climate change impacts on health eventually both increase nutritional needs and reduce the absorption of nutrients and their utilisation by the body.

Climate change will have an impact on sanitation systems, and water quality and availability through changes in precipitation patterns and the availability and seasonality of glacial meltwater. Further, climate change might impact on different diseases including diarrhoea, respiratory illness, as well as waterborne, food-borne, and vector-borne diseases through changes in habitat suitability (Confalonieri *et al.*, 2007; IPCC, 2007).

The links between increasing temperatures and malaria incidents have been relatively well studied (e.g. Simon *et al.*, 2002): increases in temperature and humidity can increase the risk of malarial transmission by expanding the habitable areas of mosquitoes. This, in turn, can expose a larger number of people to malarial transmission. Some studies have quantified the impact of increased temperature on common forms of food poisoning: salmonellosis incidence, for example, increases lineally for each degree increase in temperature (D'Souza *et al.*, 2004; Kovats *et al.*, 2004). Similarly, increases in temperature have been associated with increased episodes of diarrhoea in adults and children: several studies report a strong correlation between monthly temperature and diarrhoeal episodes (e.g. Singh *et al.*, 2001). Diarrhoea, acute respiratory infection, measles and meningitis are all major food security and nutrition-related diseases. These increase the nutritional needs of affected people while simultaneously reducing the absorption of nutrients and their utilisation by the body. Increasingly poor health in a community also leads to a loss of labour productivity and a higher dependency ratio (Mao, 2009).

Climate change could also put further strain on the already heavy workload of women with negative impacts on their ability to provide proper care to infants and young children, heightening the risk of undernutrition (UNSCN, 2011).


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3.3.2 Quantifying climate impacts on nutrition

THE IMPACT OF DROUGHT ON MALNUTRITION

Disasters — particularly droughts — have severe detrimental impacts on nutrition. Empirical evidence highlights that children born during a drought are often likelier to suffer from malnourishment.

In **Ethiopia**, children who were born in an area affected by a disaster are 35.5% more likely to be malnourished; they are also 41% more likely to be stunted.

In **Kenya,** children born in drought-prone areas are 50.4% likelier to be stunted and 71.1% likelier to be severely stunted.

In **Niger**, the chance of being malnourished more than doubles for children between the ages of one and two who were born during a drought. Children born during a disaster, irrespective of the location are up to 55.5% likelier to be undernourished.

Source: Fuentes and Seck (2007)

Climate change could also have an impact on food security by affecting calorie consumption: recent empirical evidence suggests that climate-related shocks (particularly droughts) impact dietary diversity and reduce overall food consumption with long-term detrimental effects on stunting (Silventoinen, 2003; Gitau ***et al.***, 2005; IPCC, 2007).

In a simulation of calorie intake under climate change by the International Food Policy Research Institute (IFPRI), it is suggested that the number of malnourished children could fall by over 45% between 2010 and 2050 mostly due to socioeconomic development. More pessimistic scenarios which include adverse climate-change impacts, however, indicate that the number would only decrease by 2%. The benefits are greatest in middle-income developing countries which have the largest share of the world's population (projections suggest that the number of malnourished children could fall 10–50%). However, for low-income developing countries, the benefits are significantly smaller with a decline in malnourishment of 37% in the optimistic scenario and an ***increase*** of more than 18% in the pessimistic scenario (Nelson ***et al.***, 2010).

3.3.3. Food safety and pests

Rising temperatures might also impact indirectly on food security through effects on pests, although the interactions between climate and pest incidence are not fully quantified. As the climate warms, it is expected that the range of agricultural pests may expand, as the ability of pest populations to survive the winter and attack susceptible crops increases. Studies suggest that pests, such as aphids (Newman, 2004) and weevil larvae (Staley and Johnson, 2008) respond positively to higher carbon dioxide concentrations. Increased temperatures in winter also reduce the mortality of aphids enabling earlier and potentially larger dispersion (Zhou ***et al.***, 1995).

In Sub-Saharan Africa, evidential research shows that migration patterns of locusts may be influenced by rainfall patterns; therefore, climate change may impact the distribution of this pest (Cheke and Tratalos, 2007).

The risk of increased aflatoxin contamination in some areas due to changing rainfall patterns, too, may restrict the area over which certain crops like maize can be grown. Maize is a staple for millions of people in Africa, Asia and the Americas, but it is susceptible to climate influences as exemplified by recent experiences with aflatoxins in Kenya (Lewis *et al.*, 2005; Cotty and Jaime-Garcia, 2007).

Pathogens and diseases affecting crops may also be affected by climate change. This may be through impacts of unexpected warming, of prolonged drought on the resistance of crops to specific diseases and through increased pathogenicity of organisms by environmentally-induced mutations (Gregory *et al.*, 2009). Over the next 10–20 years, disease affecting oilseed rape could increase in severity and might spread to regions where it is currently not observed (Evans *et al.*, 2008).

4. Uncertainty and evidence-based planning

SUMMARY

- There are uncertainties associated with climate change due to the complexity of modelling atmospheric and social processes.
- It is difficult to attribute specific disasters to climate change but recent events such as the Pakistan floods could become more frequent under climate change.
- Policies addressing climate change should be based on existing knowledge, taking into account the range of possible impacts of climate change (for example, seasonal drought and seasonal floods).

There is a general consensus among the scientific community that the climate is changing, and there is some agreement on the ways in which it is changing; for example, through increasing global average temperature. However, the implications of global climate change at regional or local scales, and the impacts of these changes on other systems such as agricultures or markets are more complex. Because of this uncertainty, it is not feasible to talk about future challenges in definite terms — instead, the discourse should focus on risks (cf. Stern, 2007). Communicating the risk of particular events occurring as well as their concomitant impacts is an important first step towards using climate information to guide policymaking in a responsible manner.

An additional uncertainty arises in efforts to attribute specific events to anthropogenic climate change. Attribution is important: (i) to identify the extent of change that could occur due to anthropogenic emissions of greenhouse gases; and (ii) to highlight the potential impacts of climate change without adaptation measures. Efforts to improve methods of attributing anthropogenic forcing to specific events have taken place through collaborative efforts (for example, through the Attribution of Climate Events initiative maintained by the University Corporation for Atmospheric Research). Significant advancements have been made in attributing long-term processes such as climate shifts and decadal climate variations to climate change (Meehl *et al.*, 2009).

For climate-related events, too, there has been some progress: for example Pall *et al.* (2011) used long-term hydrometeorological information to show that the 2000 floods in the United Kingdom could not occur solely due to natural variability. Improvements in the availability and quality of high-resolution long-term data will result in better attribution and analysis.

Several uncertainties in the climate science exist, particularly in relation to the use of climate models at more precise spatial and temporal resolutions. In spite of these uncertainties, however, it is important to guide decisions for food security policy based on the available knowledge and evidence.

In order for policies to be robust, they should consider the range of possible impacts under climate change. While the majority of studies focus on estimates of the most likely scenarios, increases in temperature can have highly negative as well as positive impacts. Therefore, interventions should aim to both reduce risks (including the worst-case scenario) as well as exploiting potential benefits for effective adaptation outcomes (Hertel *et al.*, 2010).

5. Conclusion

There is an emerging consensus that changes in temperature and precipitation can have detrimental impacts on the food security of the most vulnerable people, in the absence of adaptation. However, the aggregate impact of climate change on food security is not fully understood. In particular, several of the impacts are difficult to quantify and depend on a range of assumptions. The available quantitative studies suggest that climate change will negatively affect food security at the global level in the long run. The research suggests that, at the global level, climate change will reduce crop yields and the land suitable for agricultural production with the greatest impacts in tropical latitudes where the greatest food security challenges persist.

Several quantitative assessments also suggest that food prices will increase as a result of climate change, thereby affecting the ability of poor farmers to purchase food. The impact of these food price rises will ultimately depend on the level of socioeconomic development: in the shorter term, it is expected that the greatest gains in food access will be in South Asia and Latin America with marginal gains in Sub-Saharan Africa. Although the conceptual links between climate change and food stability and utilisation are well understood, less is known about the quantitative impacts. For example, climate variability and climate extremes are likely to pose greater challenges for food stability. Climate impacts on pest and disease patterns will also affect the ability of the body to absorb and utilise nutrients, and at the same time disease increases nutrient needs.

Climate change could also increase the numbers of malnourished children, especially in the least developed countries. Some impacts may arise from remote changes in climate, due to dependence on rivers fed by precipitation, snowmelt and glacial melt occurring elsewhere. The evidence suggests that the impacts of climate change on food security will be spread unevenly, affecting the populations that are currently most at risk of hunger. Ultimately, how strongly the impacts of climate change are felt will depend on the ability to adapt to these changes.

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