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For a world without hunger

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Effects of climate change on sustainable food and nutrition security

with case studies in Kenya, Pakistan and Peru

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About the country chapters

For the following three country chapters, precipitation and temperature projections of 18 global climate models (GCMs) were evaluated and presented graphically. These model simulations formed the basis of the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC 2014a). The corresponding diagrams in the country chapters present the mean changes in the model set for two scenarios and two time periods. The climate scenarios refer to RCP2.6 and RCP8.5. RCP stands for Representative Concentration Pathways (Meinshausen et al. 2011; van Vuuren et al. 2011). Figures 2.6 and 8.5 indicate the track of the radiative forcing in W/m^2 for the climate models that will be reached by the end of the 21st century. In RCP2.6, a greenhouse gas concentration of 400 ppm CO_2- equivalent (low concentration) and in RCP8.5 1370 ppm CO_2- equivalent (very high) will be assumed for the year 2100. In between, there are additionally the RCPs 4.5 and 6.0, which were not evaluated in this study. With the selection of RCPs 2.6 and 8.5, the complete range of the scenarios is thus covered. RCP2.6 describes a very optimistic scenario, in which the 2°C goal (global mean temperatures under 2°C compared to the pre-industrial period) can be met. In RCP8.5, in contrast, the global mean temperatures lie around +5°C higher than in the pre-industrial period. Up until just before the middle of the 21st century, in both scenarios the trends for temperature and precipitation developments, globally regarded, usually lie relatively closely together but, from 2040 onwards, take very different paths. Regionally, however, different developments may be visible even before 2040.

1. Kenya

Currently, 44 million people live in Kenya, (as of 2012). According to the scenarios of the United Nations, by 2030 the Kenyan population will rise by 75% to 77 million inhabitants and will more than double by 2050, with approximately 97 million inhabitants (UNDP 2013). In the Human Development Index (HDI), Kenya lies 147th out of 187 places. (UNPD 2014). In the Global Hunger Index, the situation is classified as "serious". (Von Grebmer et al. 2014). The agricultural sector, in which 75% of the population is employed, generates 30% of the GDP, which corresponds to 1300 US$ per inhabitant and year (World Bank 2015, ILO 2009). In the north of Kenya, it is mainly pastoral systems that are widespread. These are the drier regions which, in the past, were regularly affected by droughts and famines. Altogether in Kenya, more than 10 million people suffer from inadequate nutrition and chronic food and nutrition insecurity, and between two and four million are permanently dependent on food aid. 35% of children under five years are under-developed (stunted) (UNICEF 2013b).

1.1. Climate

1.1.1. Historical climate

In Kenya, arid to humid climate conditions prevail. In total, the amount of precipitation varies from fewer than 300 mm in the north to up to 1100 mm at Lake Victoria. The regions around Lake Victoria are therefore very well-suited to agriculture. In the arid areas in the north, it is generally pastoral systems (goat and cattle farming) instead (Moore et al. 2012). The precipitation falls in two more or less distinct rainy seasons, approximately from March to June and from September to December. Above all, abatement and length of the rainy season have clear regional patterns (Mugalavai et al. 2008). As Kenya lies on the Equator, temperatures do not vary as greatly (13-28°C average temperature). There is, nevertheless, a certain seasonality with the coldest temperatures in July/August and the warmest temperatures in February/March. In the dry regions, droughts, sandstorms, flash floods, wildfires and heatwaves (Middleton et al. 2013) endanger the four pillars of food and nutrition security.

1.1.2. Climate projections

For Kenya in the middle of the 21st century, an increase in temperatures by 1.0°C to 2.0°C can be expected compared with the reference period (1970-1999). At the end of the 21st century, the range lies between 1.0°C and almost 4.0°C. For the determination of the rise in temperature to the pre-industrial period, approximately 0.7°C must be added. However, the totals of the mean annual precipitation show no significant, but a generally positive, trend, which will become clear primarily in the second half of the 21st century.

Table 1-1 shows the projected temperature changes for the two RCPs and time periods. In all parts of the country, a rise in the mean annual temperatures is expected, developing in the direction of west to east.

Table 1-1: Temperature projections

Scenario	2030-2059	2070-2099
RCP 2.6	+1.1 - 1.3°C	+1.1 - 1.3°C
RCP 8.5	+1.5 - 1.8°C	+3.4 - 3.9°C

Table 1-2 shows the changes in the mean annual precipitation in Kenya. In the country average, the development in all time periods and scenarios is positively but spatially differentiated. In the period 2030-2059, the increase in the west of the country is particularly high. In the period 2070-2099, however, the precipitation increases most significantly in the north of the country.

Table 1-2: Precipitation projections

Scenario	2030-2059	2070-2099
RCP 2.6	+10.0 – 25.0%	+5.0 –15.0%
RCP 8.5	+5.0 – 30.0%	+15.0 – 50.0%

1.2. Food and nutrition security

1.2.1. Sufficient availability

Current yield level and yield gap

Of the total Kenyan land area, 46% is used for agriculture and 9% as arable land (World Bank 2015). According to the estimations of Fischer and Shah (2010), 25% of the Kenyan unprotected grass and shrub land area (not forest) is very well or well-suited to arable use. On the land area used for agriculture, about 45% is used for the cultivation of maize[1] and 20% for beans, i.e. two thirds of the land area is used for these two cultures alone (FAO Country Stat 2015). On the remaining land area, many different cultures are cultivated, such as tea, cow pea, sorghum, potatoes, pigeon pea, wheat and coffee (FAO Country Stat 2015) [all cultures with over 100,000 hectares area, sequence for 2013]. The yields of maize are at 1.6 t/ha, those of beans at 0.5 t/ha (FAO Stat 2015). In 2013, the Kenyan maize production amounted to 3.4 million tons (FAO Stat 2015), of which 75% was produced by small farmers. Besides maize, the potato is a further important staple food. The potato achieves yields of 7-10 t/ha and thus makes a substantial contribution to food and nutrition security in Kenya (Kaguongo et al. 2014).

Van Ittersum et al. (2013) show that the achieved Kenyan maize yields remain significantly below their actual potential. With a comparable water supply, the maize yields in Kenya are 87% lower than, for example, in Nebraska (USA). The smaller yields can be attributed to low soil fertility, unavailability of resources and limited knowledge of how to deal with such limitations, but also unfavourable distribution of precipitation (Van Ittersum et al. 2013). Especially the availability of fertiliser is frequently insufficient in sub-Saharan Africa (SSA). Although Kenya tends to rank among those countries with better access to resources, the fertiliser usage rate is very low (Tittonell and Giller 2013; Marenya and Barrett 2009). Due to nutrient deficiency or unbalanced nutrient intake (exclusively nitrogen fertilisation), vegetable production does not achieve its actual yield potential and suffers at the same time from low nitrogen efficiency (Tittonell et al. 2008).

[1] Corn is the most important (staple) food in Kenya, therefore we regularly use maize in this country chapter as a case example for the effects of climate change on the four pillars of food and nutrition security. The results can be partially transferred to other plants cultivated in Kenya.

Effects of climate change on plant production

For C_3 and C_4 plants[2], tropical temperatures mean that more photosynthesis-produced energy is required for respiration and, thus, the net photosynthesis rate sinks (Rötter and Van de Geijn 1999). A further temperature increase will exceed the temperatures required for optimal growth in tropical regions. Cultivation conditions will worsen as a result of the rise in extreme temperatures and droughts. In addition, extreme precipitation and flooding will increase due to the rising absolute humidity and sinking relative humidity. As a result, soil degradations, nutrient leaching and flood damage to plants and, thus, falling crop yields are to be expected. (Müller et al. 2014).

Due to higher evapo-transpiration, rising temperatures have a negative effect on the water supply of the plant. Especially in the northern and eastern regions of Kenya, the water supply for plants is already insufficient under today's conditions. This can potentially be compensated by rising precipitation quantities and increased CO_2 concentrations (less stomatal opening). Under RCP8.5 the temperature rise from the middle of the 21st century will be so marked that evaporation losses could exceed the precipitation rise and worsen the water supply for plants. In C_3 plants especially, the poorer water supply will lead to sinking yields.

Apart from the direct climatic yield reduction factors, indirect effects also have a yield-reducing impact. These are, for example, degenerated soils through erosion or diseases and parasites such as, e.g., *Maize Lethal Necrosis* (Khadioli et al. 2014; Wangai et al. 2012). In higher temperatures, maize parasites such as Lepidoptera (Chilo partellus) can potentially develop better and more rapidly. In the primary maize cultivation regions in particular (in the humid highlands), the pest pressure will increase at rising temperatures. In the northern coastal regions of Kenya, the pest pressure could reduce, but this is not one of the main maize cultivation regions (Khadioli et al. 2014).

Animal husbandry and fishery

Particularly in the arid and semi-arid areas of Kenya, animal husbandry is very important. It contributes only 3.3% to the GDP, but employs 90% of the labour force in the arid and semi-arid areas. Within the animal husbandry sector, milk production is the most important industry. However, in the south of Kenya too, animal husbandry is an important food base, especially for the Massai (FEWS NET 2013). Through investments in the animal husbandry (better fodder plants or soil water conservation methods), higher incomes could be generated within the animal husbandry sector. Sensibly designed measures can be simultaneously an adaptation to climate change and reduce the emission of greenhouse gases (Bryan et al. 2012). At the coasts, at Lake Victoria and Lake Turkana, fishing is of great importance. In the region around Lake Victoria, for example, half of household income is generated from fishing (FEWS NET 2013).

Post-harvest losses along the value creation chain

Not only do diseases and pests during cultivation threaten the availability of food, but post-harvest losses in Kenya are also high. According to estimates of the FAO, most losses in SSA within the value

[2] During photosynthesis, C_3 and C_4 plants bind CO_2 in different ways. In the case of high air temperatures and scarce water, plants close their stomata to save water. Through this, the absorption of CO_2 for photosynthesis is also restricted. C_4 plants have a more efficient mechanism than C_3 plants to absorb more CO_2 for the plant in the case of high air temperatures and scarce water. In tropical and sub-tropical dry climate zones, C_4 plants (such as amaranth, millet, maize and sugar cane) develop more biomass than C_3 plants (such as, e.g., potatoes and beans).

creation chain result from post-harvest losses. Further losses after cultivation and post-harvest losses arise in the processing and distribution, before the food reaches the consumers. The FAO estimates the losses for grain, fruits, vegetables, fish and milk products through processing and distribution in SSA at approximately 75%. The total losses in SSA vary between 20 and 60% depending upon foodstuff (FAO 2015).

The post-harvest losses within the potato value creation chain are estimated by Kaguongo et al. (2014) for Kenya at 19% (12-25% depending upon distribution channel) of the total production. As the potato, as the second most important staple food, is especially cultivated by small farmers, the impacts on food and nutrition security are very great. In contrast to maize, the potato is more difficult to store (as it has a very high water content) and many storage-related diseases can arise. As a result of deficient storage facilities, in Kenya 5-8% of the maize production is lost after the harvest due to the maize weevil pest (*Sitophilus zeamais*) and larger grain borer (*Prostephanus truncatus*). According to De Groote et al. (2013), these post-harvest losses would be avoidable to a great extent through use of simple, airtight plastic sacks (*polypropylene*) or metal silos.

1.2.2. Secure access to food

In Kenya, 45% of the population live below the poverty line (World Bank 2015). Thus, for a majority of the population, access to food is not ensured or only to a limited extent. Due to a poor education level, limited economic influence opportunities (high unemployment rate >40%) and limited access to social services (e.g. clean drinking water and power), for many people access to food is made more difficult. This particularly affects the arid and semi-arid areas (FEWS NET 2013).

Food imports

The production of staple foods is not sufficient in all regions of Kenya. Particularly in the arid regions, the gaps between supply and demand must be filled by local and international markets and domestic production must be supplemented by wheat, rice and maize imports. Wheat and rice production is not particularly great in Kenya, therefore the imported portion is, comparative to the total production, relatively high. Compared to the Kenyan maize production, the import portion of wheat amounts to 8% and rice to 4%. Overall, in recent years, the portion of imported maize decreased in relation to maize production and in 2010-2011 amounted to an average 7% per year, previously (2002-2007) it was just 4%. As a consequence of two bad harvests in 2008 and 2009 the maize import in 2009 amounted to 62% for domestic production (FAO Stat 2015). Food imports are only possible if the corresponding purchasing power is available. As half of Kenyan agriculture operates on a subsistence farming basis, many Kenyans cannot participate in the trade. Due to changing climate conditions, there is an increasing probability that droughts such as in 2008/2009 will occur more frequently in future (FEWS NET 2013, Ariga et al. 2010) and that, consequently, larger quantities of food must be imported more often.

Access to markets and staple food prices

As net purchasers, the largest part (70%) of the Kenyan population is dependent on markets. Alongside people in urban regions, this particularly affects small farmers with little land, or pastoralists (FEWS NET 2013). Within the country, the food must be transported from the agriculturally advantaged regions around Lake Victoria to the north. The time required to reach the next port or the next larger market is significantly longer for the regions in the north (Guo 2014). As a result, higher transaction costs, higher prices and a higher price volatility arise. Especially in those regions which are far from ports or from Nairobi, there are differences in price movements and standards (Short et al. 2012). Rising basic food prices, triggered by changing climate conditions and regional weather extremes, could affect the price volatility and, in arid regions particularly, lead to food bottlenecks.

Badly maintained roads in the north of Kenya (only 14% of the roads are paved) are the reason for poor market access (FEWS NET 2013). But it is not only access to food markets that is often poorly developed, but access to the markets for agricultural resources (e.g. for fertiliser) too. An improvement in market access could at least lead to an improvement of the fertiliser usage rate on degraded soils (Marenya et al. 2009). Also relevant in the case of degraded soils are other nutrients, the nutrient availability and knowledge about the use of such soils.

Kassie et al. (2014) show that female-led households in Kenya often have lower food and nutrition security. In female-led households (proportion in Kenya is 34%) there is often a lack of access to agricultural resources, markets, credit and information. If women had the same access to these resources, yields could rise by 20-30% and malnutrition could be reduced by 12-17% (FAO 2011). Female-managed yields and households are especially affected by changing climate conditions, due to the limited access to resources and, thereby, the limited adaptation possibility (Mutimba et al. 2010).

1.2.3. Needs-based use and exploitation of food

Hidden hunger and value-increasing and value-decreasing ingredients

Undernourishment is an omnipresent and chronic problem in Kenya. Children under five years old are particularly affected by quantitatively and nutritively insufficient food and suffer from underweight, stunting and wasting (Otieno et al. 2013). In total, 35% of Kenyan children are affected by stunting and 66% by insufficient vitamin A supply (UNICEF 2013b). Increasingly in Kenya, the problem of "double burden of malnutrition" is to be observed, i.e. alongside the problem of undernourishment and malnutrition, there is also overweight (adiposity) as a consequence of a one-sided, high-fat diet (Keino 2014).

One-sided nutrition (e.g. with the maize porridge ugali) leads to micronutrient deficiency. With one-sided nutrition, essential amino acids, minerals and vitamins especially are often absorbed in insufficient quantities. Fundamentally, in Kenya, vitamin A and iron are not sufficiently contained in the diet (UNICEF 2013b; FEWS NET 2013). Through rising atmospheric CO_2 concentration, minerals such as iron and zinc will decrease in the food, which increases the danger of hidden hunger (Myers et al. 2014).

Undesirable, value-decreasing ingredients in the food lead to lower nutritive utilisation possibilities and potentially also to health impairments. For Kenya, the most important pollutions in foodstuffs are mykotoxins, such as aflatoxin and heavy metals, such as cadmium and cobalt (Ongoma 2013; Oyoo Okoth et al. 2013). In particular, the pollution of maize with aflatoxins in Kenya leads to losses or health burdens in the population (Kimatu et al. 2012). Consequences of aflatoxins are immunodeficiency, cancer and even deaths. As a consequence of changing climate conditions (rising temperatures and precipitation) the development conditions for aflatoxins improve (Ongoma improve 2013; Lewis et al. 2005; Trenk & Hartman 1970).

Quality of food and reduction of food and nutrition security through diseases

More frequently occurring flooding, caused by climate change (Müller et al. 2014), increases the transmission of germs and worsen sanitary conditions. As a result, the usability of foodstuffs reduces. The usability of food is reduced by the contamination of foodstuffs with unclean washing and cooking water. This and poor sanitary conditions (no soap, "flying toilets") cause diarrhoeal diseases and lead to a lower metabolic nutrient availability (FEWS NET 2013).

As a consequence of climate change, water-based diseases such as cholera and typhus could increase (FEWS NET 2013). Rising temperatures and precipitation likewise benefit vector-based diseases such as malaria (Connolly Boutin & Smit 2015; Omumbo et al. 2004). Through the increase of these diseases, the use of the food can worsen and, thereby, have a negative influence on food and nutrition security.

1.2.4. Temporal stability

The temporal stability of the first three columns of food and nutrition security is imperative for a continuous supply. In the following examples the stability of food production will be explained in relation to droughts and political stability.

(i) Climatic extremes such as droughts and long dry seasons can endanger the stability of food production. With these extremes, climate migration is, thus, often connected to locations with lower agricultural productivity. Droughts (2007-2008, 2010-2011, 2013-2014) repeatedly led to harvest failures and famines in Kenya (Rembold et al. 2014). The drought in the Horn of Africa in 2011 showed that 3.75 million Kenyans were dependent on food aid. As a result of the absent rains from March to May (-30%), the harvests were significantly smaller, which caused local food prices to rise. The water shortages caused cattle to die of thirst, led to diseases caused by water shortage (diarrhoea and worm infections) among the population in pastoral areas and to rising water prices (FEWS NET 2013; Motoshita et al. 2010).

In the past, unstable political conditions and ethnic conflicts led to armed conflicts (Burke et al. 2009). For example, in the unrest following the disputed elections in 2007, there were hundreds of deaths and 0.3 million tons of maize was destroyed. Furthermore, the instability and the riots led to a decrease in the 2008 yields of around 20%. In the north of Kenya as well, many pastoralists were affected by conflicts about raw materials (CDC, IISD, Saferworld 2009). Successive droughts in the years 2008 and 2009, in combination with sharp global rises in world market prices for food, led to a clearly increased need for maize imports in Kenya in 2009. Due to the price rises and the lower incomes of the population (smaller harvests, unrest) food aid increased (FEWS NET 2013). The pastoral zones in the north of Kenya were particularly badly affected.

1.3. Need for action

Despite substantial progress in breeding which, in South-East Asia in particular, led to clear increased yields (the Green Revolution), this yield potential in Kenya was not able to be implemented thus far. Sánchez (2010, 2015) shows that through better seeds and fertiliser use, a trebling of the yields in Malawi was made possible. The spreading of nitrogen fertiliser correlates strongly with the emission of greenhouse gases. However, the yield increases per kg N are significantly higher and require smaller changes in land use. Thus, the greenhouse gas emissions per kg of maize yield,[3] at a higher yield level, are lower than at a low yield level (Bellarby et al. 2014).

In all, more efficient seeds, due to hybrid or line breeding can improve the income of small farmers. Mathenge et al. (2014) show in their statistical investigation that the use of hybrid seeds in Kenya could reduce poverty. This happens through the increase in annual income, but also through long-term welfare effects (ownership, reduction of poverty inequality). Adenle et al. (2013) discuss the potential for the reduction of poverty and increase in food and nutrition security through the use of genetically modified plants in Africa. For Kenya, they emphasise that genetically modified plants should initially only be introduced for fibres (cotton) and later for fodder and human food. Just as in Europe, however, political and societal acceptance is also important here. Variants of sorghum or maize which have a higher nutritive value are also conceivable. Today, this area is being extensively researched by both science and industry, including in Kenya (Gilbert 2010). A further example of joint research by science and industry is the project for *Water Efficient Maize for Africa* (WEMA) using classic and molecular-genetic breeding methods (Eisenstein 2013).

The use of intercropping[4] of maize and legumes can reduce the nitrogen need that must be supplied by fertilisation. As a result, fewer resources need to be purchased and the production and use of mineral nitrogen, which is associated with high greenhouse gas emissions, could be reduced. Depending upon the cultivated legumes and cultivation form, nitrogen fertilisation could be significantly reduced under Kenyan cultivation conditions (Mucheru Muna et al. 2010). In general, higher incomes can be generated as a result of intercropping. In the arid areas of Kenya, incomes could be increased, for example, through agro-forestry, which would reduce the vulnerability of subsistence farmers in the face of climate shocks (Thorlakson et al. 2012). Via the use of "push-pull" techniques, pest and weed pressure can be reduced with biological methods. The most well-known example with this technique is where the main culture of maize or sorghum is cultivated together with the *desmodium* plant, in order to give the *Striga* weed no opportunity to grow (push) and to keep away the African stem borer (pull) (Murage et al. 2015).

The cultivation of vegetables can lead, on the one hand, to a diversification of the food base and thus prevent micronutrient deficiencies. On the other hand, additional incomes can also be generated by sales, which likewise has a positive impact on the nutritional situation (Muriithi & Matz 2015). However, the urban cultivation of vegetables (*urban sack gardening*) in particular comes with the danger of increased heavy metal exposure in the food (Gallaher et al. 2015).

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[3] In general, a critical view must be taken of efficiencies, that is, how many units of input are required for one unit of output. Through the increased yields by nitrogen fertilisation, greenhouse gas emissions reduce, but the nitrogen use efficiency also reduces. That means, the increase in the efficiency of an input factor simultaneously determines the efficiency of another input factor.
intercropping, two cultures are cultivated simultaneously, the priority, however, lies on the main culture and the secondary culture is planted, e.g., between the rows of the main culture.

2. Pakistan

With a population of approximately 180 million inhabitants, Pakistan is the 6th most densely populated country in the world. Extreme weather conditions, with high temperatures (up to 50°C), droughts, heavy rain events and the harsh terrain are causes for the particularly high vulnerability of eco-systems and the agriculture of Pakistan to the climate and its changes (Ahmad et al. 2013; IUCN 2009). 45% of the population is employed in agriculture, which in 2008 contributed about 20% to the GDP and 70% to foreign-exchange trading (Zhu et al. 2013; IUCN 2009; Iqbal et al. 2009). Water availability is the most important limiting factor for agriculture, the largest water user (approx. 90%). About 85% of agricultural products are achieved through irrigation farming, which cover not only the food demand but are also an important raw material supplier for industry, primarily cotton for the textile industry (Archer et al., 2010). Besides the general harsh environmental conditions, Pakistan is regularly afflicted by cyclically recurring droughts, floods and earthquakes, which cause high economic damage and bring millions of people into extremely insecure nutritional situations. The rapidly growing population (2.4% per year; IUCN 2009), militant activities in border areas, high inflation, the rising water demand and the inefficient use of water in the irrigation system, as well as far too low water storage capacities endanger the industrial development of the country and intensify the volatile food and nutrition security situation.

2.1. Climate and hydrology

2.1.1. Recent climate and hydrology trends of the last few decades

In Pakistan, a predominantly arid to semi-arid climate prevails, with annual precipitation of between 150 mm and 250 mm. In the highland valleys in the north of the country, sub-humid to humid conditions are to be found, in which annual precipitation totals of up to 1500 mm occur (Archer et al. 2010). The main rainy season is between July and September, in the west of the country additionally between December and April. The monsoon contributes to around 65%-80% of the annual precipitation (Asif 2013).

Pakistan is afflicted regularly by droughts and floods. The latter appear to have become more frequent in recent years, such as, for example, the two catastrophic events in 2010 and 2011 (Zhu et al. 2013). Iqbal et al. (2009) observed an accumulation of events such as heavy rain, floods, droughts and storms in the recent past. Xie et al. (2013) refute this for drought events. A trend analysis showed that there was no trend underlying the occurrence of droughts in the period 1960-2007. Drought periods which are followed by wet periods occur, however, with a certain regularity about every 16 years, which usually affect the entire country (Xie et al. 2013).

Temperature and precipitation trends

The development of different extreme temperature and precipitation indices in the period 1971-2000 show a heterogeneous pattern across Pakistan (Sheikh et al. 2015). A rising trend of the maximum daytime temperature was, for example, "only" observed at 56% of the stations in Pakistan. A clearly decreasing trend was observed in Karakorum (north west Himalayas) in nocturnal maximum temperatures, that is, in the summer at the time when the glacial melt begins (Sheikh et al. 2015). The general rise in the mean annual temperature thus results primarily from the rising winter temperatures. There are numerous indications for a propagation of the glaciers in Karakorum since the

1990s (Sheikh et al. 2015). This statement is confirmed by Sharif et al. (2013), who determine a decreased contribution of the glacier melt to the outflow into the Indus.[5] The contribution to the total outflow lies between 50% and 80% (Zhu et al. 2013).

The trends of the precipitation indicators can be summarised as follows: The number of successive days with precipitation (>1 mm), as well as the intensity of daily precipitation have increased in Pakistan at 60% of stations, the number of stations at which a rising trend in heavy rain events (>20 mm/day) was recorded lies at 74% and the maximum 1 to 5-day precipitation totals have increased at two-thirds of the stations (Sheikh et al. 2015). The rising annual precipitation could have offset the mass balance of the glaciers in the north west Himalayas in relation to the rise in temperature (evaporation and melting) (Sheikh et al. 2015; Hewitt 2005).

Water resources of the Indus

The Indus, the most important lifeline in Pakistan, is characterised in the upper course by different flow regimes (Sharif et al. 2013; Archer et al. 2010). The highest situated river basin areas (glacial), whose highest mountains reach up to 7000 m AMSL, provide their run-off through the glacial run-off, river basin areas at medium altitude (nival), in contrast, are fed mainly by the snow thaws, and lower-lying river basin areas are shaped both by glacial and nival regimes as well as by precipitation (Sharif et al. 2013; Archer et al. 2010). Trend analyses of the seasonality and volume of the run-off are, therefore, to be regarded with a spatially differentiated approach and the future effects of climate change are, due to the spatial resolution and precision of global climate models in the illustration of climatic processes, and the low data availability for validation in extreme altitudes, difficult to estimate and associated with high levels of uncertainties. The observed cooling of the summer temperatures in the Karakorum (Sheikh et al. 2015; Sharif et al. 2013) led, in the period 1960 to 1998, to a reduction of the glacial contribution to the total run-off of the Indus and makes it clear that this phenomenon represents an exception in comparison to other glacial river basin areas (Sharif et al. 2013). The nival river basin areas of the Indus, which are dominated by spring thaws, showed, in contrast, a predominantly rising trend, which is accompanied by an increasing trend in the winter precipitation (snow) (Sharif et al. 2013). There is no clear trend in the temporal behaviour either at the onset of the thaw run-off nor at the peak of the run-off volume (Sharif et al. 2013). As, however, volumes and seasonality of the run-off of the Indus depend strongly on the thaw and glacier melts, the hydrological regime and, thus, the water availability in Pakistan, is very vulnerable to changes in the temperature and precipitation in the high mountains (Sharif et al. 2013) and could have extensive consequences for the water management, agricultural sector, food and nutrition security and the entire economy of Pakistan (Archer et al. 2010). On the other hand, Archer et al. (2013) see that the sustainability of water resources and the eco-systems (humid areas, river delta) of the Indus are threatened rather by socio-economic than by climatic change.

[5] **Remark on the error of the IPCC AR4 (2007) on the glacier melt in the Himalayas.** Many articles, which are quoted here, are based on the incorrect information in the 4th assessment report of the IPCC, accordingly, the glaciers in the Himalayas could melt completely by **2035**. In the original source, however, **the year stated was 2350**! Correspondingly, false conclusions were drawn over the future water availability in Pakistan, which, naturally, have not been transferred into this report. In the 5th assessment report (IPCC, 2014c) one span of a 2% increase to 29% decrease by 2035 is indicated and for 2100 an average reduction of the Himalayan glaciers of between 45% (RCP 4.5) and 68% (RCP 8.5).

2.1.2. Climate projections

For Pakistan by the middle of the 21st century, an increase in temperatures can be expected of 1.8°C to 3°C compared with the reference period (1970-1999). At the end of the 21st century, the range lies between 1.8°C and almost 6°C. For the determination of the rise in temperature to the pre-industrial period, approximately 0.7°C must be added.

Table 2-1 shows the projected temperature changes for the two RCPs and time periods. In all parts of the country, a rise of the mean annual temperatures is expected, which is more strongly pronounced in the north than in the south.

Table 2-1: Temperature projections

Scenario	2030-2059	2070-2099
RCP 2.6	+1.4 - 1.8°C	+1.3 - 1.8°C
RCP 8.5	+2.0 - 2.8°C	+4.0 - 6.0°C

Table 2-2 shows the changes in the mean annual precipitation in Pakistan. In the country average, the development in all time periods and scenarios is positively but spatially differentiated. For the south of the country as well as the high mountains in the north, rising annual precipitation is projected. Nearly all scenarios also show a decrease in the precipitation in the passage between high mountains and low country in the provinces of NWFP, FATA, southern Kashmir and northern Punjab.

Table 2-2: Precipitation projections

Scenario	2030-2059	2070-2099
RCP 2.6	+5.0 – (-)5.0%	+15.0 – (-) 10.0%
RCP 8.5	0.0 – (+) 10.0%	+20.0 – (-) 10.0%

2.2. Food and nutrition security

61% of the districts in Pakistan are considered as undersupplied in food (Asif 2013). On average, the poorest 20% of the population spend more than 70% of their income on food (FAO 2011), in the country average it is around 50% (WFP 2014). The rural population in particular, which constitutes about two-thirds of the total population, and of whom 80% count as poor, faces great challenges with regard to food and nutrition security (IFAD 2012a). The economic access to food as well as its use remain the main limiting factors for food and nutrition security at household level (WFP 2014). More than half of the population of Pakistan consumes less than the recommended calorific quantity of 2100 kcal per person per day (WFP 2014). In the mountainous regions, there are many isolated communities, which suffer from chronic poverty (IFPRI 2015). Fragile eco-systems and the fissured landscape make agriculture and access to markets and other services more difficult (IFPRI 2015).

Despite the increase in the production of main grain varieties in recent years, the development of food and nutrition security in Pakistan is negative. Reasons for this are given as militant activities, natural disasters and economic instability (IFPRI 2015). Militant activities have serious financial consequences for Pakistan, which contribute to the spreading of unemployment, migration and to an extremely high inflation rate, which reached 16% in 2010 (IFPRI 2015).

Due to its geographical position, the frequency of extreme natural events and the high number of people exposed to these events, Pakistan is extremely vulnerable to natural disasters (WFP 2011). Included in this are earthquakes, storms, droughts and floods, whereby the latter are among the most frequently occurring disasters (WFP 2011). Floods of different magnitudes with sometimes devastating consequences occurred in the years 2009, 2010, 2011, 2012, 2013 and 2014, which in each case claimed hundreds to thousands of victims and economically affected millions of people. The floods in 2010 affected, e.g., one-fifth of the area of the country, this also included 570,000 ha of agricultural land in the Punjab region (Oxfam 2013). Important infrastructure was destroyed and left 20 million people without sufficient access to food, clean drinking water, health care and electricity (Kirsch et al. 2012; IFPRI 2015). As a result of the destruction of agricultural land and the death of livestock, the income of the affected households fell by 75% in urban areas and 90% in rural areas (Kirsch et al. 2012; Oxfam 2015) and the number of direct fatalities is estimated to be at least 1700 people (Kirsch et al. 2012). 80% of food reserves fell victim to the flood (Kirsch et al. 2012). The proportion of the population with insecure access to food rose between 2003 and 2009 from 38% to 50% (83 million) and it is assumed that the number rose to 90 million after the flood in 2010 (IFPRI 2015). But extreme maximum daytime temperatures also lead to health problems and reduced capacity. In June 2015 there were 830 deaths due to a heat wave.[6]

Although the contribution of agricultural production to the GDP in Pakistan decreased over recent decades, it still amounts to 20% and contributes to livelihoods of 45% of the population (Zhu et al. 2013; Archer et al. 2010 IUCN 2009; Iqbal et al. 2009). In addition, the textile industry, which has an export portion of 64%, is dependent on cotton production. The grain product export share amounts to about 11% (Archer et al. 2010). Wheat production is a significant mainstay for Pakistani food and nutrition security (IFPRI 2015; WFP 2011). In addition, rice production could be doubled since 1980 and is one of the main export products (IFPRI 2015; WPF 2011). The food and nutrition security in Pakistan is extremely dependent on the natural water resources, which is used mainly for agricultural irrigation. About 73% of the Indus run-off is directed into the irrigation system (Archer et al. 2010). This value is an indicator (Alcamo et al. 2003) for high water stress of the river system and its adjacent eco-systems. Due to the low water availability per capita, Pakistan was ranked in 2010 in 7th place for extreme risk of water scarcity in the "Water Security Index".[7] The relatively small water reservoir capacities in Pakistan only allow storage of up to 30 days (Asif 2013; GWP/IWMI 2011). As such, sufficient water cannot always be made available through the irrigation system (Asif 2013). The "Asian Development Bank" recommends a storage capacity of 1000 days for countries with a comparable climate.[8]

Climate change, which probably brings with it an increased probability of occurrence of natural disasters (Zhu et al. 2013; Piracha & Majeed 2011; Iqbal et al. 2009), presents a threat to the development goals of livelihood, health and education of the country (Piracha & Majeed 2011). In contrast, sustainable use of water resources is impaired mainly by socio-economic factors (population development, inefficient water management, etc.) (Archer et al. 2010). Pakistan's population could grow from about 180 million today to 218 million in 2025 or 270 million in 2050.[9]

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[6] http://www.sueddeutsche.de/politik/pakistan-erdrueckende-hitze-1.2535906

[7] https://www.maplecroft.com/about/news/water-security.html

[8] http://www.bloomberg.com/news/articles/2015-04-22/even-china-won-t-finance-this-pakistan-dam-as-water-fight-looms

[9] http://esa.un.org/wpp/unpp/p2k0data.asp (average variant of the UN)

Principal reasons for the deficiencies in food and nutrition security:

- Environmental factors
  - Harsh environmental conditions (e.g. high temperatures, fissured terrain)
  - Weather-related extreme events (floods and droughts)
- Environment and resources management
  - Insufficient efficiencies (high losses) in the irrigation system
  - Low water reservoir capacities
  - Land and soil degradation
- Socio-economic factors
  - Chronic poverty of large population sections
  - Population growth rate of 2%-2.4% per year
  - Militant activities
  - Losses in the value creation chain

2.2.1. Sufficient availability

Increasing air temperatures in Pakistan lead to a shortened vegetation period and threaten the productivity of agriculture, for which remarkable losses were simulated in wheat, maize and rice (Zhu et al. 2013). The losses in wheat yields in arid and semi-arid regions caused by temperature could amount to around 6% to 10% per 1°C temperature rise (Sultana et al. 2009; Ahmad et al. 2013; Ahmad et al. 2014). That would correspond to a reduction in the wheat yields of around 10 to 30% by 2050. The humid regions could, however, experience positive developments up to an increase of up to 4°C (Sultana et al. 2009), but these constitute only a small portion of the whole agricultural land area. In southern Pakistan, reductions of 15-20% by 2040 are projected for main grain varieties (IUCN 2009). The yield reductions for rice due to climate could amount to around 15-18% by 2080 (Iqbal et al. 2009). Livestock farming is also threatened and could experience losses of 20-30% by 2040. This would lead to extreme price developments in milk and meat products in Pakistan (IUCN 2009).

Due to the fast population growth, which intensifies the problem of water scarcity, Zhu et al. (2014) and Archer et al. (2010), see that, even without the effects of climate change, food and nutrition security in Pakistan is threatened. Pakistan will evolve into a net import country and the population growth and climate change could lead to grain imports increasing by 55% to 100% by 2050 (Zhu et al. 2014). The availability of wheat kg/capita could decrease in the Punjab region from the present 198 kg/head (2012) to 84 kg/head in 2050 (Tariq et al. 2014). Included in this is a population increase from 96.3 million (2012) to 157.6 million (2050) in the Punjab region.

The future availability of the water resources for all types of use, resulting from changed climate conditions, can hardly be estimated. Recent temperature and precipitation developments in the upper course of the Indus are not comparable with high mountains in other regions. The different run-off regimes (glacier melt, thaw and precipitation) and processes in the upper course are extremely complex and can offset each other reciprocally. So a smaller supply could be compensated by the glaciers, due to reduced summer temperatures, by an increased thaw, as a result of rising winter precipitation. As such, the temporal behaviour of the run-off could change, but its quantity not so much. It should be pointed out once again that, after the publication of the 4th assessment report of the IPCC in 2007[5)], many horror scenarios regarding the melting of the Himalayan glaciers were drawn, from which false conclusions were derived about the future water availability.

Changed run-off regimes (glacier, management) could negatively affect inland fisheries (IUCN 2009). Reduced run-offs of the Indus through excessive usage as well as the rising sea level threaten the mangrove forests of the Indus delta within the coastal areas, which possess a great economic value for Pakistan. They are an important source of firewood and food for the local population and valuable habitats for shrimps, of which 90% are exported (Piracha & Majeed 2011; Briscoe & Qamar 2006).

Main causes for the predicted reduction in agricultural productivity and/or crop losses:

- Reduced duration of the growth period due to rising temperatures (Iqbal et al. 2009).
- Weather-related extreme events
    - Droughts
    - Floods, triggered by extreme precipitation.
- Glacial melt and retreat
    - According to the findings of the 5th assessment report of the IPCC (IPCC 2014c), by 2035 the glaciers in the Himalayas will either experience a growth of 2% or a retreat of 29%. By 2100, an average retreat of between 45% (RCP 4.5) and 68% (RCP 8.5) is expected.
    - For the near future, therefore, both a decrease and an increase in the contribution of the glacial melt can be reckoned with, along with the associated water of the Indus. An intensified glacial melt could contribute to floods (Iqbal et al. 2009), which could lead to widespread destruction of crops. A decrease in the glacial run-off could lead to a reduced total run-off, if this is not compensated by other phenomena (increased snow melt and/or precipitation) (Sharif et al. 2013; Archer et al. 2010).
    - In the distant future (towards the end of the century) an increased contribution of the glacial melt to the total run-off of the Indus is to be reckoned with.
- Soil quality
    - Salinisation (Iqbal et al. 2009).
    - Back water (Iqbal et al. 2009).
    - Water and wind erosion (Iqbal et al. 2009).
- Pests
    - Increased risk of pest infestations and (plant) diseases (IFAD 2012a; IUCN 2009)

2.2.2. More secure access to food

Climate change will probably not foster a more secure access to food at household level in the future. In terms of productivity in the subsistence economy, the same conditions are applicable here as at national level. Rising temperatures could lead to crop losses (Sultana et al. 2009; Ahmad et al. 2013; Ahmad et al. 2014), if adaptive measures (cultivation of heat-resistant varieties, changed sowing and harvest dates, etc.) on the part of the state are not supported, funded and implemented with information technology. Crop losses in the subsistence economy require increased purchase of food, for which, on average, already more than 50% of income is spent (WFP 2014; FAO 2011). An increased dependence on markets increases vulnerability to global market prices and their fluctuations.

Further dangers for food and nutrition security arise through climate-related disasters (droughts, floods), which could increase in the future. In the past, an increase in heavy precipitation was observed in Pakistan, which led to floods with catastrophic consequences (Sheikh et al. 2015).

Non-climatic factors such as militant activities, e.g. in parts of the border area with Afghanistan, lead to migration movements, in which those affected must endure more difficult conditions for food access (WPF 2014).

2.2.3. Needs-based use and exploitation of food

More than half of the population of Pakistan consumes less than the recommended calorific quantity of 2100 kcal per person per day (WFP 2014). Ongoing drought situations in the Thar region lead to alarming food and nutrition insecurity, resulting in sustained undernourishment and malnutrition, water shortages, health and income possibilities (WFP 2014). In the future, the maintenance of necessary quantities and the quality of the nutrition in Pakistan will be more dependent on global market prices (Zhu et al. 2014).

Apart from quantity losses with grain production due to rising temperatures, quality losses of agricultural products are also possible, with regard to their composition of (micro)nutrients. This would contribute to the phenomenon of "hidden hunger" that has consequences for health and capacity. For the preparation of food, clean drinking water in sufficient quality, as well as the necessary energy (electrical or fuel) is required. The availability of both resources is, among other things, dependent on climatic conditions.

The main dangers for the use and exploitation of food are, along with the continuous changes in the climatic conditions, extreme events such as droughts and floods and their after-effects, from which large parts of the population often only recover slowly. An accumulation of extreme situations would, thus, contribute over the long-term to food and nutrition insecurity.

2.2.4. Temporal stability

A temporal stability of the food and nutrition security is more likely in urban areas, through continuous access to markets and the availability of food there, than in rural regions, provided the necessary purchasing power is available. In rural regions, the availability of food (production by subsistence farming and storage possibilities) as well as access (seasonally-related) can fluctuate greatly.

Depending on the dependence on the quantity of the additional food purchases, households are dependent on food prices and their fluctuations on the markets. Although there is a general high vulnerability to prices, as expenditure for food in Pakistan, at an average of 50% of income, is rather high.

The temporal stability of food and nutrition security in Pakistan is, on the one hand, dependent on the income of the households, but in each case threatened by more or less frequently occurring extreme weather events.

2.3. Need for action

Climate change has both positive and negative effects on agriculture in Pakistan, although the latter could outweigh the former (Iqbal et al. 2009; Piracha & Majeed 2011). In order to minimise the negative effects of regularly recurring droughts and long-term climate changes, both aspects must be integrated into agricultural development strategies (Zhu et al. 2014).

The variability of future run-off regimes due to changed glacial supplies and the thaw is one of the challenges for irrigation agriculture. Regions, in which rain-fed agriculture dominates, are threatened by the variability of the precipitation as well as by the frequency of extreme precipitation events and floods (Iqbal et al. 2009). The regularity with which drought periods occur, allows assumption of a certain predictability, which is a chance for adaptation strategies (assuming that this predictability also applies for the future). On the part of water management there would be the possibility to fill the available water reservoirs during wetter periods and to limit the withdrawal, in order to cushion the water shortage during long-lasting drought periods (Zhu et al. 2014).

The natural water resources will probably not change significantly in its quantity in the short to medium-term - although perhaps in temporal behaviour. An increase in need due to population growth is, however, unavoidable. (Archer et al. 2010). Improved and more efficient water management, as well as investments in adapted irrigation technologies are, according to Zhu et al. (2014), the most promising measures to cover and ensure the water requirement for agriculture, industry, households and the Indus river delta until 2050 (Briscoe & Qamar 2006). Furthermore, measures must be taken that counteract land and soil degradation caused by salinisation, erosion and desertification (Iqbal et al. 2009; Piracha & Majeed 2011; GWP/IWMI 2011). In order to stop progression of the degradation of the eco-system of the Indus delta, measures are necessary which increase the fresh water flow (less withdrawal from the river through more efficient water use).

In recent years, Pakistan invested too little in the knowledge base about the complex Indus system and its maintenance. Bureaucracy, corruption, lack of transparency and the unequal water distribution swallow up valuable resources and fuel mistrust among water users (Briscoe & Qamar 2006). Among the positive facts are the fact that, in the past, Pakistan has got to grips, at least partially, with seemingly insurmountable problems, such as salinisation and waterlogging of the irrigation system. There is a well thought-out concept of water rights and regulations for distribution and usage, which represents a solid basis for an implementation, but it would need to be more consistently implemented (Briscoe & Qamar 2006).

According to Briscoe & Qamar (2006), there are the following significant challenges for sustainable management of the Indus irrigation system. 1. Development and promotion of world class capacities within the areas of natural sciences, engineering and social sciences in order to comprehend and solve the complexity with an inter-disciplinary approach. 2. Maintenance and repair, as well as extension of the irrigation infrastructure. 3. Development of an institutional framework concept and mechanisms, which increase and motivate sustainability, flexibility and productivity; this would involve extensive changes in the current water management approach and a shift of competences.

Concrete measures

- Increase in agricultural productivity
    - Investments in research, infrastructure and education (Zhu et al. 2014).
    - Heat and drought-resistant grain varieties and livestock breeds (Zhu et al. 2014; IUCN 2009; Iqbal et al. 2009; Wassmann et al. 2009).
    - Temporal shift of sowing dates to the colder months by 15-30 days (Ahmad et al. 2013; Sultana et al. 2009; Iqbal et al. 2009).

    - Adapted cultivation methods for rice (Iqbal et al. 2009; Wassmann et al. 2009).
    - Utilisation of the positive effect of rising temperatures on the productivity of wheat in humid regions (Sultana et al. 2009).
    - Leveling of fields (Ahmad et al., 2013)
    - Optimisation of efficiency and expansion of irrigation, technology (Zhu et al. 2014, Ahmad et al. 2013; GWP/IWMI 2011)
    - Fairer distribution of water in the irrigation system. Upstream areas receive sufficient water but downstream areas often insufficient (GWP/IWMI 2011)
    - Early warning systems for droughts, floods and storms (IUCN 2009; Iqbal et al. 2009).
    - Besides the agricultural irrigation through the irrigation system, more groundwater resources should be used. These contribute about 40% to the total irrigation water and are an important buffer during drought periods. Uncontrolled withdrawals are, however, a serious problem and challenge for the water management (GWP/IWMI 2011).
- Water reservoirs
    - Expansion of the water reservoir capacity (Zhu et al. 2014; Piracha & Majeed 2011)
    - Water can be stored only for up to 30 days (Asif 2013). For a better supply for agricultural production as well as for flood protection, capacities should be developed.
    - Improved management of storage and delivery (Zhu et al. 2014).
    - Solution to the problem of the decreasing storage volume due to sediment
    - Reforestation, e.g. in order to minimise the sediment load in the reservoirs (Asif 2013).
- Other
    - Greater capacities for food reserves, in order to provide during extreme events (IUCN 2009)
    - Reforestation, especially mangrove forests (IUCN 2009)

3. Peru

Peru currently has around 31 million inhabitants (as of 2015). Of whom, around three-quarters of the people live in cities (the population of Lima alone amounts to approximately ten million people) and only six million in rural areas (FAO Stat 2015). According to estimations by the FAO, the population of Peru will rise by 2050 by a further ten million people to 41 million (FAO Stat 2015). In the Human Development Index (HDI), Peru lies 82nd out of 187 places. (UNPD 2014). According to the Global Hunger Index, the threat is classified as "moderate" (Von Grebmer et al. 2014). This, however, relates to the whole country. In rural regions, in the rainforest or the highlands of the Andes, the nutritional situation is often significantly worse. At provincial level the value of the HDI can deviate by 400% and in the past ten years has even worsened in some regions (WHH/CO 2014). This is caused by the unequal development in urban and rural regions. 13% of the urban population are categorised in the group with the lowest socio-economic development level, in rural regions, in contrast, the figure is 84%. Although sufficient food for the entire population is produced in Peru, a total of at least eleven million people (38% of the population) suffer from hunger and chronic undernourishment[10]. The principal reasons are lack of availability and insufficient access to food.

In Peru, in total only 19% of the land area is used for agriculture, the largest part of this (78%) is pasture land. The proportion of arable land over the entire land area amounts to only 3% (FAO Stat 2015). Agriculture is in large parts highly dependent on the water resources of the Andes glaciers. These resources are greatly endangered, as it is assumed that the glaciers could melt almost entirely within the next two decades (ASP 2012; IDB 2012). Due to its geographical location, Peru ranks among the ten countries in the world most strongly threatened by climate change (GWP 2013). Climate change makes the challenges of agriculture more difficult, a problem Peru faces anyway (ITC 2015). But even without climate change, natural phenomena such as El Niño, extreme weather events, earthquakes and tsunamis present a challenge for food and nutrition security in Peru.

3. Climate

3.1.1. Recent climate, trends of the last decades, characterisation of the peculiarities (drought-prone, extreme events, etc.)

The amounts of annual precipitation in Peru are very diverse and reach from below 200 mm/a in the coastal regions to more than 3000 mm/a in the Selva. The highest temperatures are reached in the Selva and in the coastal regions. The highland is characterised by lower temperatures.

In Peru there are different precipitation regimes, which are characterised either by all-year precipitation, such as in the north east of the country, or in which arid periods (winter) and a rainy season (summer, September to April) can be differentiated with different intensities.

3.1.2. Climate projections

By the middle of the 21st century, an increase in temperatures by 1.0°C to 2.0°C can be expected compared with the reference period (1970-1999). At the end of the 21st century, the range lies

[10] http://www.foodsecurityportal.org/peru/resources

between 1.5°C and almost 4.5°C. For the determination of the rise in temperature to the pre-industrial period, approximately 0.7°C must be added. The total amounts of the mean annual precipitation show a positive trend, which is significantly more strongly pronounced under RCP8.5.

Table 3-1 shows the projected temperature changes for the two RCPs and time periods. In all parts of the country, a rise in the mean annual temperatures is expected, developing in the direction of west to east. As such, the Selva and the eastern Andes region experience the highest temperature rises.

Table 3-1: Temperature projections

Scenario	2030-2059	2070-2099
RCP 2.6	+1.25 - 1.75°C	+1.25 - 1.75°C
RCP 8.5	+1.75 - 2.5°C	+3.5 - 5.0°C

Table 3-2 shows the changes in the mean annual precipitation in Peru. In the country average, the development in all time periods and scenarios is positively but spatially differentiated. It is remarkable that the spatial change patterns in the north-east of the country differ in the two time periods. In the period P1, an increase is projected, in the period P2 a decrease in annual precipitation is projected. Although the annual average in both scenarios and periods is positive, the areas of the Selva and the southern coastal regions are generally affected by decreasing precipitation and for the Andes region (Sierra) as well as the middle and northern coastal regions, increases are projected.

Table 3-2: Precipitation projections

Scenario	2030-2059	2070-2099
RCP 2.6	-5.0 – (+)5.0%	-5.0 – (+)10.0%
RCP 8.5	-5.0 – (+)5.0%	-5.0 – (+)20.0%

Due to the general rise in the annual precipitation, the risk of floods and landslides on steep hillsides in urban regions could rise, where mainly the poorest people reside (World Bank, 2014). The temperature rise in recent decades led to a retreat of the glaciers in the tropical Andes since 1980 (IPCC 2013). A further huge melt is expected, in which by the end of the century, in the case of a 2°C scenario 90% of the Andes glacier or, in a 4°C world, a complete disappearance is assumed (World Bank 2014). 50-70% of the electricity in Peru is produced by hydro-power. This energy source will be severely restricted after the thawing of the glaciers (ASP 2012; IDP 2012). Model comparative studies show that under a rise in global temperatures, the frequency of extreme El Niño events increase, which trigger both droughts and floods (depending on the region in Peru) (World Bank 2014; GWP 2013).

3.2. Food and nutrition security

3.2.1. Sufficient availability

The most important cultivated crops in Peru are maize (500,000 ha), rice (400,000 ha), potatoes (300,000 ha), wheat and barley (both 150,000 ha) and quinoa with 35,000 ha (FAO Stat 2015). Across the many climate zones in which Peru is located, the cultivation suitability for the respective crops is very different. In the tropics (Selva), maize and other tropical crops can be cultivated. This is only possible on a limited basis in the highland (Sierra), due to lower temperatures, and in the coastal regions (Costa) due to the low water supply. In the higher altitudes of the Andes, the water supply is frequently problematic (as the amount of precipitation is low (approx. 500 mm/year), on the other hand, the shallow soils only have a very low water storage capacity.

The yields for potatoes lie at 13 t/ha, for rice at 7 t/ha, for maize at 3 t/ha, for barley and wheat at 1.5 t/ha and for quinoa at 1.0 t/ha (FAO Stat 2015). These yields are higher than, e.g., the Kenyan yields, but there is still a lot of upward potential (e.g. Van Ittersum et al. 2013). Cabello et al. (2012) show that improved varieties achieve both higher and more stable yields. Land races (traditional varieties) are more susceptible to drought stress than the improved varieties.

The projected climate changes can have wide-ranging consequences for agricultural production and the water availability as a consequence. Due to the spatial heterogeneity of the climate and the landscape of Peru, the different landscape areas must be considered in differentiated terms.

Selva (rain and cloud forests)

The decreases in precipitation projected for the Selva probably represent no danger for people and eco-system, as it concerns a high-precipitation region. The strong temperature increases in this region especially could, however, endanger the cocoa and coffee cultivation, which represent important export products and local income sources. Small exceedances of temperature tolerance limits lead thereby to quality losses, large exceedances can lead to crop losses or failures. Particularly sensitive is the coffee variety Arabica (IDB 2012). For the neighbouring country of Ecuador, losses due to climate change of 20% by 2080 for cocoa and coffee are assumed (IDB 2012).

Sierra (Andes region and highlands)

For the Sierra region, higher annual precipitation volumes are expected in future. The resulting opportunities and risks are dependent on the type of precipitation increase. If the plus in the annual volume is produced primarily through heavy rain events, the danger of soil erosion, landslides and crop losses rises. There are trends towards a shift in precipitation behaviours in the period between August and October which apparently are already noticeable today.[11] In many regions of Peru, this corresponds to the beginning of the rainy season and is thus of exceptional importance for agriculture. Without adaptation measures and reliable short to medium-term weather forecasts, there exists the danger of crop losses.

Until now in the Andes, often only barley, oats and potatoes are cultivable for temperature-related reasons. With rising temperatures, the suitability of C_4 plants such as maize also rises. C_3 plants such as soya or wheat could be cultivated in higher lying regions. The spread of potato pests could also take on a new dimension under changed climate conditions in the tropical Andes regions, as previously unaffected areas could be opened up to pests (Crespo Pérez et al. 2015, IDB 2012). Furthermore, temperature rises and water stress limit the yields of potatoes (Cabello et al. 2012; IDB 2012).

The decrease, or the complete melting of the Andes glaciers, would have far-reaching consequences for water availability in the Andes region. This would mainly affect the dry season between June and August, in which the glacial melt has, to date, made a continuous contribution to the water resource.

It is mainly women, children and the indigenous population in high altitudes of the Andes who will be exposed to an increased risk through floods and water shortages caused by changes in the glacial melt

[11] Most exposed are subsistence farmers who rely on rainfall patterns which are already changing[12]

and snow behaviours (World Bank 2014). In the northern and central Sierra, the food and nutrition security of more than five million people is endangered, where increased occurrence of frost and droughts threatens agriculture and animal husbandry.[12]

Costa (coastal regions)

In the dry coastal regions - in which around 53% of the population live (GWP 2013) - it is primarily irrigation farming that is practised. The agricultural water need is covered in large parts from the glacial melt. Under the projected climate change conditions for the 21st century, there is a high risk that in the dry season (June and August) the water availability will be a long way from sufficient. The projected increase in the annual precipitation in the coastal region will probably not be able to offset this loss.

In the coastal regions of Peru, fishing plays a central role for nutrition and the economy. Due to climatic change, the fish stocks and, thus, the food basis for the inhabitants of the coastal regions are threatened (Allison et al. 2009). Due to the projected temperature increases, the significance of the fishing industry for the economy, as well as the small adaptation potential, Peru, from the perspective of fishery, is among the countries with the highest vulnerability to climate changes (Allison et al. 2009).

3.2.2. Secure access to food

For the issue of food and nutrition security from the contributions of subsistence farming, the same points apply as were detailed under 3.2.1. It should also be mentioned that 50% of the Peruvian population live below the poverty line and many small farmers suffer chronic undernourishment (IFAD 2012b).

The portion of food which is not covered by subsistence farming must be purchased additionally. In Peru there is large income disparity and a wide gap from urban to rural population. In Minaflores Lima, the average income is 19$ per day and in the poorest region Chugay La Libertad about 1$ per day.[13] The effective purchasing power for food depends thereby on food prices, which are affected by climate change not only regionally but also globally. Although Peru was able to register a growth rate of the gross domestic product of 6.4% between 2002 and 2012 and the average income per head rose by 50%, extreme poverty and unequal income distribution plague the country (IFAD 2012b). Despite many regions which count as food and nutrition insecure in Peru, in the past 15 years the country has become an exporter of fruits and vegetables (e.g.: asparagus, artichokes and grapes) (Meade et al. 2010). From this development, however, too few people profit.

In many regions in the Andes and in the rainforest, the infrastructure is significantly worse due to the low population density than in the coastal regions. Roads are often not particularly well developed and/or are sometimes impassable due to landslides. As a result of climate change (increase in extreme events) there is a danger that the number of impassable roads increases. The strong urbanisation trend in Peru (particularly to Lima) makes rural areas more unattractive and hinders infrastructure projects. These would be necessary to facilitate the distribution of food and, at the same time, would counteract a price increase in the products to be transported to poorly accessible regions.

[12] http://www.perusupportgroup.org.uk/news-article-692.html
[13] http://www.perusupportgroup.org.uk/news-article-692.html

3.2.3. Needs-based use and exploitation of food

Around eleven million people, more than one-third of the population, cannot cover the minimum calorific requirement of 2100 kcal and more than 18% of children under five years suffer from chronic undernourishment.[14]. "Hidden hunger" or anaemia is another serious problem of food and nutrition security, from which 50% of children under five years and 42% of pregnant women suffer. Undernourishment and micronutrient deficiency are not only associated with poverty but with low education levels in mothers, as well as new nutritional habits in the cities. (WHH/CO 2014).

For food preparation, water in sufficient quantity and quality is necessary. The water quality is strongly endangered, particularly in regions in which mineral resources are degraded. Climate change can contribute here to a reduction in the resource availability and thus also indirectly to decreased quality, if pollutant concentrations rise due to smaller water volumes.

As a consequence of changed climate conditions, potato diversity could be lost, this reduces the advantage of further food diversity (Burlingame et al. 2009).

3.2.4. Temporal stability

The reasons that contribute to the high number of undernourished and malnourished people in Peru, resulted from difficult access to food, inadequate childcare and support, malnutrition and low education levels.[14]

The temporal stability of the availability, the access to and the use of food is highly endangered in the medium to long-term by the water resources of the melting Andes glaciers and the effects of El-Niño (droughts and floods, fish scarcity at the Pacific coast).

3.3. Need for action

Due to the large disparity in income, living standards and the nutritional situation between rural and urban regions, the sustainable development of rural regions should be prioritised. Here, the strengthening of the subsistence economy is of particular importance, in order to reduce the dependence on external resources (including food). For this, investments must be made, which target a diversification of agricultural production in harmony with climate change. In this context, the support of small farmers is promising (Bellon et al. 2015). The majority of the surveyed exporters of agricultural products in Peru ascribe the same importance to the challenges of climate change as to logistical and transport-related challenges (ITC 2015). With climate change, the cultivation suitability for many agricultural products will change. Due to the extreme altitude differences in Peru, potential cultivation areas will not necessarily reduce but will shift to other altitudes. Precipitation patterns, primarily at the beginning of the rainy season, could change. These realisations must, on the one hand, be researched further, in order to understand the possible consequences and to adapt conventional cultivation methods (e.g. adapted heat and drought-resistant varieties, irrigation techniques, changed sowing dates, currently unfarmed regions). This knowledge must be brought over to the population through research and education programmes, in which the rural population has the opportunity to participate actively, in order to bring in their local knowledge. Furthermore, incentives for farmers must be created, so that climate-adapted practices are implemented (IDB 2012).

[14] http://www.foodsecurityportal.org/peru/resources

It is predominantly people in poorly accessible regions who are affected by droughts and floods, which are mainly attributed to the El-Niño-phenomenon in Peru. In order to be able to provide effective aid in such situations, a development of the infrastructure (primarily roads) is necessary (IDB 2012).

For the improvement of the food and nutrition security and in order to counteract the phenomenon of hidden hunger caused by poor nutrition and malnutrition, aid and education programmes are needed. Within this sector, NGOs could make a valuable contribution, but whose work, so far, has no significant tradition in Peru (WHH/CO 2014).

The melting of the Andes glaciers is a serious problem for the water supply in areas that are strongly dependent on this resource. In the medium-term, the melting of the glaciers will lead to higher water resources, on a long-term basis, however, to water shortages, mainly in regions of low precipitation, such as the highly populated coastal regions. According to GWP (2013), there is a high potential for saving water as the current inefficiency in water usage in all sectors is estimated at 60%.

Measures (summary)

- Agricultural production
    - Research and education programmes for the adaptation of cultivation to climate change (other altitudes, other sowing dates, improved varieties, spreading of pests and diseases)
    - Increase in water use efficiency. The inefficiency of water use and all sectors is estimated at 60% (GWP 2013).
- Education programmes for the prevention of undernourishment and malnutrition
    - Stronger integration and/or establishment of NGOs in the health sector, in elderly and nursing care and in environmental protection (WHH/CO 2014).
- Improvement of the infrastructure (primarily roads) (IDB 2012).
- Water management
    - Preparation and debate about the water scarcity situation, which will occur after extensive retreat of the Andes glaciers.
    - Water saving programmes in cities and in agriculture

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