Evidence of Observed Climate Impacts on Smallholder Farmer Systems

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EPAR Technical Brief #386
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April 9, 2019

Below we offer some findings on observed or measured changes in precipitation, temperature or both, on system impacts. These findings are the result of a review of relevant documents cited in Kilroy (2015), references in the IPCC draft Special Report on Food Security, and targeted searches from 2015 - present for South Asia and Sub-Saharan Africa. Searches were conducted for the impacts of temperature and precipitation on five biophysical pathways and systems including impacts on crop and livestock yields, impacts to land and soil (e.g. cover and quality, soil moisture, etc.), impacts to water (e.g. salinization, changing water table, etc.), variable and changing growing seasons, extreme events and biotic stressors. This initial review focused on observed impacts of biophysical changes and excluded documents only mentioning biophysical changes, but not their impact (e.g. those that solely measure glacial retreat) and documents solely focused on adaptation. Documents related to the impact of climatic change on conflict and migration were excluded in this initial stage. Additionally, given the broader focus on smallholder farmers, this initial review excluded documents solely focused on impacts to urban areas.

Variable or Changing Growing Seasons

There is strong evidence that climatic changes are impacting growing seasons in South Asia and Sub-Saharan Africa. We found 22 studies which mention variable or changing growing seasons due to changes in temperature, precipitation, or both. Literature reflecting impacts due to or associated with increased temperature were found mostly in the Indian subcontinent (Hasan and Kumar, 2019; Telwala, 2013; Dimri and Dash, 2012; Miller et al., 2012; Cui and Graf, 2009; Xu et al, 2008), while impacts due to or associated with changes in precipitation were more widespread (Ayanlade et al., 2018; Salerno et al., 2019; Worku et al., 2018; Diem et al., 2017; Sanogo et al., 2017; Goenster et al., 2015; Roxy et al., 2015; Fiwa et al., 2014; Biggs and Watmough, 2012; Harvey et al., 2011; Kumar and Jain, 2011; Sarr, 2012; Batisani, 2010; Cui and Graf, 2009; Immerzeel, 2008; Xu et al., 2008). The strong evidence related to the impacts of temperature on variable or changing growing seasons in the Indian subcontinent may be due to the source of many of our documents; one hotspot region that Kilroy (2015) focuses on is glacial-fed river basins. However, additional supplemental searches produced results related to the Indian subcontinent as well.

Temperature

- Several studies found greater increases in temperature trends in winter compared to other seasons in the Himalayan region in India (Telwala, 2013; Dimri and Dash, 2012) and in the Tibetan Plateau (Cui and Graf, 2009; Xu et al, 2008); increased temperature trends were observed in all seasons.
- Miller et al. (2012) found changes in the timing of glacial runoff in the Hindu-Kush Himalayas as a result of more extreme temperatures.

- Hasan and Kumar (2019) found that farmers in the Kalapara sub-district of Bangladesh perceived that summer temperatures were increasing, but that winter temperatures were decreasing, which the authors note corresponds with scientific observations in the study locations.

Precipitation

- Several studies found an increase in seasonal precipitation in the Tibetan Plateau with the greatest increases occurring in spring (Cui and Graf, 2009; Xu et al., 2008), and in pre-monsoon, monsoon, and winter in India (Kumar and Jain, 2011). However, Kumar and Jain (2011) also found signs of weakening summer monsoon and strengthening winter monsoon in India. In the Brahmaputra basin, Immerzeel (2008) found evidence of increasing winter precipitation and decreasing summer precipitation, delaying the onset of monsoon.
- Several studies report changing temporal or geographic trends to precipitation on the Indian subcontinent. Martin et al. (2011) found that in the Indian Himalaya the maximum rainfall receiving months shifted from June-July to August-September. Roxy et al. (2015) found a 10-20% decrease in summer rainfall over central-east India during the past century and an increase in precipitation confined to a small domain along the west coast.
- Batisani (2010) found geographic variability in precipitation trends in Botswana, driven in some cases by a decrease in the number of rain days, and in others by fewer or less intense heavy rain days.
- Two studies report changed variability in precipitation during the rainy season, both in sub-Saharan Africa (Ayanlade et al., 2018; Goenster et al., 2015). In Nigeria, Ayanlade et al. (2018) report a change in the precipitation patterns during the growing season, with some months seeing more rain as compared to historical measurements and others less. They found that farmers adjusted their planting dates in response to the changes. In Sudan, Goenster et al. (2015) found that, although there was no change in the annual precipitation amount, there was an increase in low-rainfall days and a decrease in medium rainfall days. This change may impact crop production as low-rainfall days do not affect the overall water balance.
- Five studies found greater observed or perceived variability in growing seasons due to precipitation (Diem et al., 2017; Sanogo et al., 2016; Fiwa et al., 2014; Harvey et al., 2011; Sarr, 2012). Sarr (2012) found geographic and temporal changes in rainfall from 1930-2000, resulting in variable changes in the length of growing seasons in West Africa, including an increased length of growing season in the Eastern Sahel and a decreased length of growing season in the Western Sahel. Similarly, Fiwa et al. (2014) found that increased rainfall variability led to a shorter growing season in Malawi. Eighty-nine percent of smallholder farmers in Madagascar perceived greater variability in growing seasons (Harvey et al., 2011). Diem et al. (2017) found that increased rainfall variability led to delayed onset of both the short and long rainy seasons, decreased season duration, and decreased precipitation volume in Uganda.
- One study found an intensification of the seasonal rainfall cycle in western Uganda with the wet seasons becoming wetter and the dry seasons becoming dryer (Salerno et al., 2019).
- Worku et al. (2018) found a significant increase in summer rainfall and a decreasing trend in the spring rainfall in the Jemma Sub-Basin of the Upper Blue Nile Basin in Ethiopia. The authors note that this indicates a shift from a bimodal pattern of rainfall to a unimodal pattern of rainfall and hypothesize that this will strongly affect agricultural practices in the spring season.

Temperature & Precipitation

- Biggs and Watmough (2012) found that in Nepal the combination of a decrease in winter rainfall events and an increase in seasonal temperatures resulted in an increase in frequency of drought events.

Extreme Events

There is strong evidence that climatic changes are impacting the frequency and severity of extreme events in South Asia and Sub-Saharan Africa. We found 11 studies linking changes in extreme events to changes in temperature, precipitation, both, or unspecified climatic factors. Several studies found an increase in the number and severity of extreme temperature events in India (Dimri and Dash, 2012; Dash and Mamgain, 2011), as well as an increase in the number of heavy precipitation events in India (Dimri and Dash, 2012; Nandargi and Dhar, 2011; Goswami et al., 2006); Worku et al. (2008) also found an increase in extreme rainfall in Ethiopia. Three studies found an increase in the risk and frequency of glacial lake outburst floods in the Himalayan region (Din et al., 2014; Eriksson et al., 2009; Chen et al., 2007). Additionally, studies of farmer perception of climate change in the Himalaya and in Nigeria found that farmers reported perceiving an increase in the frequency and severity of extreme events (Ifeanyi-obi and Togun, 2017; Hussain et al., 2016); a study conducted by Cullen et al. (2018) found that 67% of respondents perceived an increase in extreme weather. Several studies found an increase in extreme events, including a perceived increase in drought frequency by 80% of farmers in the Koutiala and Yanf Sudano-Sahelian zone (Sanogo et al., 2016), and a perceived increase in both drought and cyclones in Bangladesh which the authors note is similar to findings from other studies (Hasan and Kumar, 2019). Neither of these findings were attributed to a specific climate factor (i.e. temperature, precipitation or both). One study found that increased cyclones induced by climate change have led to saline water intrusion of agricultural lands in Bangladesh, negatively impacting rice production; 96% of surveyed farmers named salinity intrusion as the main cause of declining rice production (Rabbani et al., 2013).

Temperature

- Studies found an increase in the severity of extreme temperatures, including an increase in the number of extreme warm nights defined as above the 99th percentile (Dash and Mamgain, 2011), as well as an increase (decrease) in the number of warm (cold) days and extreme warm (cold) days (Dimri and Dash, 2012) in India.
- Chen et al. (2007) found an increase in the risk of glacial lake outburst flooding (GLOF) in Tibet due to an increase in the size (47% increase in area) and number (11% more) of glacial lakes; these changes were associated with increased temperature in the region. In the Himalaya more broadly, Eriksson et al. (2009) found that the frequency of GLOF has increased in recent decades as temperature has increased; the study found that the average temperature in Nepal increased 0.6 °C per decade between 1977 and 2000.

Precipitation

- Several studies found an increase in the number of heavy precipitation events in India (Dimri and Dash, 2012; Nandargi and Dhar, 2011; Goswami et al., 2006) including an increase in one-day extreme precipitation events in the Himalaya region (Nandargi and Dhar, 2011).
- Worku et al. (2018) found an increasing trend in extreme rainfall indices throughout the Jemma sub-basin of the Upper Blue Nile basin in Ethiopia including extremely wet days (above the 99th percentile) and the maximum 5-day rainfall amount.

Temperature & Precipitation

- Farmers in several sub-basins in the Hindu-Kush Himalayan region reported an increase in extreme events including perceived greater frequency of floods and landslides triggered by heavy rainfall and floods in Pakistan, prolonged dry spells and drought in Nepal, and greater incidence of both drought and floods in India (Hussain et al., 2016). Similarly, farmers in Nigeria reported perceiving increased intensity and frequency of flooding (Ifeanyi-obi and Togun, 2017).

- Din et al. (2014) found that increased temperature and precipitation among other factors led to an increased probability of glacier lake outburst floods (GLOF) in Pakistan between 1990-2012.

Biotic Stressors

There is moderate evidence that climatic changes are impacting the prevalence and dispersal of biotic stressors in South Asia and Sub-Saharan Africa. We found four studies describing changes in the prevalence or dispersal of biotic stressors associated with observed or perceived increases in temperature, precipitation or both (Salerno et al., 2019; Hussain et al., 2016; Bebber, 2015; Jarmillo et al., 2011). Two additional studies describe perceived changes to the prevalence of biotic stressors due to unspecified climatic changes. Abid et al. (2016) note that the average percentage of farming households in Punjab, Pakistan that perceived an increase in animal diseases, insect attacks, crop pests, and weeds in the last ten to twenty years as climate change-related events were 37%, 34%, 27%, and 13% respectively. Similarly, Dhanya and Ramachandran (2016) report that among farmers in the semi-arid region of Tamil Nadu, India, approximately 30% perceived increasing pests and insect attacks as an effect of climate change and consequently plan to use more fertilizer, pesticide, and insecticide.

Temperature

- Households in the Koshi sub-basin of the Hindu-Kush Himalaya in Nepal reported perceiving an increase in both temperature and livestock diseases (Hussain et al., 2016).
- Jarmillo et al. (2011) noted that H. hampei can now be found at coffee plantations above 1,500 m due to recent increases in temperature, and is now prevalent and damaging in central and western Kenya, Uganda, southwestern Ethiopia, southeast and southwest Rwanda and on the eastern side of Mt. Kilimanjaro in Tanzania. The authors estimate that attacks on beans by coffee berry borers result in losses exceeding US $500 million annually and impact more than 25 million rural households involved in coffee production.
- Bebber (2015) note that observed dispersal rate of the invasive wood wasp Sirex noctilio in South Africa have increased with the increase in mean annual temperatures.

Precipitation

- Salerno et al. (2019) report an intensification of the seasonal rainfall cycle in western Uganda, resulting in longer and wetter growing seasons. This may reduce the negative impacts of higher temperatures on soil moisture, however, the authors note that recent long, wet growing seasons resulted in fungal and other disease outbreaks that substantially reduced potato and bean harvests.

Temperature & Precipitation

- Households in the Eastern Brahmaputra sub-basin of the Hindu-Kush Himalaya in India perceived an increase in the incidence of livestock disease, which the authors note is consistent with studies relating changes in temperature, rainfall patterns and humidity to the increased incidence of livestock disease (Hussain et al., 2016).

Impacts on Crop Yield

There is strong evidence that climatic changes are impacting crop yields in South Asia and Sub-Saharan Africa. We reviewed 12 studies which describe impacts to crop yield due to observed or perceived changes in temperature, precipitation or both. Several studies found that an increase in temperature results in a decrease in crop yield (Arshad et al., 2018; Ifeanyi-obi and Togun, 2017; Gupta et al., 2017; Tripathi et al., 2015;

Vermeulen et al., 2012), and that climate variability (both changes to temperature and precipitation) can account for more than 60% of variability in crop yield in some regions (Ray et al., 2015). Studies also found that shifts in rainfall patterns and the timing of rainfall have impacts on crop yield and crop production (Diem et al., 2017; Manandhar et al., 2011; Martin et al., 2010; Boulain et al., 2006), however timing was found to have greater impacts than total rainfall (Boulain et al., 2006). Two studies described changes to maize yields in Kenya and South Africa due to changes in temperature and precipitation (Mumo et al., 2018; Adisa et al., 2016). Additionally, multiple studies of farmer perception found that farmers perceive changes to temperature and precipitation impacting crop yield (Ifeanyi-obi and Togun, 2017; Diem et al., 20172017; Manandhar et al., 2011).

Temperature

- Gupta et al. (2017) find that in India a 1-degree Celsius increase in average daily minimum/maximum temperature lowers crop yield by 2-4%.
- Vermeulen et al. (2012) found that each day above 30 degrees Celsius reduced yield by 1% on average overall and by 1.7% on average under drought conditions.
- Tripathi et al. (2015) report that a key cause of low yield in the tropics is high temperature associated with limited soil moisture.
- Farmers in Nigeria reported perceiving that heat intensity and increased atmospheric temperature during crop storage lead to an increase in crop loss and a decrease in cocoyam yields (Ifeanyi-obi and Togun, 2017).
- Arshad et al. (2018) found that increased temperatures were associated with a negative impact on wheat and rice yields and led to increased production risk for farmers in Pakistan. The study also found that increased temperatures had a higher negative effect on wheat compared to rice.

Precipitation

- In Nepal, farmers reported impacts to rice due to late and insufficient rainfall in some years and due to flood in other years (Manandhar et al., 2011).
- Boulain et al. (2006) found that in Niger crop production is more sensitive to the timing of rainfall than to overall levels of precipitation.
- Martin et al. (2010) found that shifts in rainfall patterns influenced the crop calendar and resulted in reduced agricultural yields; as mentioned previously this study found that the maximum rainfall receiving months shifted from June-July to August-September.
- Diem et al. (2017) found that farmers reported the onset of both the short and the long rainy seasons in Uganda had been later and later every year, and that the rainy seasons themselves were shorter than they used to be by approximately three weeks. In addition, they reported the soil fertility was lower, resulting in lower crop yields.

Temperature & Precipitation

- A global study of yield variability and climate variability (both temperature and precipitation) found that 32-39% of maize, wheat and soybean yield variability can be explained by climate variability (Ray et al., 2015). Specifically, this study found that the greatest variability can be found outside the “maize grain belt” including in Africa and India, and that the greatest variability in rice yields can be found in central India. Additionally, the authors report that in the central Indian states of Madhya Pradesh, Chhattisgarh, and Karnataka climate variability accounts for more than 60% of variability in maize yield.

- Gentle and Maraseni (2012) found that in Nepal prolonged drought and limited winter rainfall were cited as reasons for decreased grazing land availability among local communities.
- Adisa et al. (2016) found that decreased precipitation and increased temperature, sometimes to the point of drought, impacted the growing season and led to greater variability in maize production in South Africa.
- Mumo et al. (2018) found that decreasing precipitation and increasing temperatures during the growing season have attributed to significantly decreased maize yields in Kenya over the past three decades.
- Several studies discuss farmer reported perceptions of crop yield loss due to multiple climate change related factors (Abid et al., 2016; Dhanya & Ramachandran, 2016).

Plant Species Density, Richness and Range

There is moderate evidence that climatic changes are impacting plant species, density, richness and range in South Asia and Sub-Saharan Africa. We found five studies describing changes to species density, type, richness and range associated with changes in temperature or both temperature and precipitation (M'mboroki et al., 2018; Mercy, 2015; Telwala et al., 2013; Gonzalez et al., 2012; Xu et al., 2008).

Temperature

- Several studies found a shift in the elevational range of plant species in the Himalaya. Telwala et al. (2013) found that 90% of plant species endemic to the Sikkim Himalaya shifted their elevational range, and that of the 124 species surveyed the median range shift was 240 m. Xu et al. (2008) estimated that over the past century tree-line species shifted by 110 m in the eastern Himalaya.

Precipitation

- Mercy (2015) found that lower levels and increased variability of rainfall led to land cover changes in Kenya including an overall decrease in forest cover, an increase in grass cover, and an increase in rock and bare land cover from 1995-2010. The authors suggest that the La Niña drought in 1999-2000 decreased green cover through the conversion of forested areas to agriculture.

Temperature & Precipitation

- Gonzalez et al. (2012) found that changes in tree density and species richness were significantly correlated with temperature and precipitation, and not correlated with topsoil organic carbon and population density in Senegal and Mauritania; they note that during the 20th century average tree species richness decreased in the overall study area. This study also finds a shift of the Sahel-Sudan and Sudan-Guinea ecotones southward during the 20th century.
- M'mboroki et al. (2017) found that increased temperature and variability in rainfall combined with decreased overall precipitation volume are correlated with changes in land cover types in Laikipia County, Kenya. Changes in major land cover types included a 40% reduction in grasslands, a 24% reduction in forest, and a 43% increase in shrub and bush land.

Impacts to Streamflow

There is limited evidence in the documents reviewed that climatic changes are impacting streamflow. We found two studies describing changes to streamflow associated with changes in temperature in the Indian subcontinent (Liu et al., 2012; Raha et al., 2012).

Temperature

- Two studies found increased streamflow or erosion due to glacial melt in the Himalayan region. Liu et al. (2012) found a strongly increasing trend over 20 years (1986-2006) in winter month streamflow in Tibet due to glacial retreat, and a strongly decreasing trend in streamflow in Bhutan over the last 20 years. Raha et al. (2012) found that glacial melt is accelerating the process of erosion in coast and estuarine zone due to increased summer flow in the Indian Sunderbans.

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