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Introduction

Pakistan is considered to be a developing country, with extremely low average incomes (Ahmad & Farooq, 2010). The country's agriculture is very important for reaching food security (Murgai, Ali & Byerlee, 2001; Ahmad & Farooq, 2010). The country covers approximately 79.6 million ha of land, with 22-23 million in use for agriculture (Baig, Shahid & Straquadine, 2013; Ahmad et al., 2015), and virtually all arable land currently in use (Ahmad & Farooq, 2010). Wheat is the most important staple-crop (Dorosh, Malik & Krausova, 2010; Tariq et al., 2014; Ahmad et al., 2015; Khan, Jan & Shah, 2016). Sustainable and continued production of wheat is crucial to food security (Ahmad et al., 2015); however, Pakistan also imports wheat (Zhu et al., 2013), meaning their agricultural production is not sufficient.

Key Drivers of Food Security

Pakistan has 5 main drivers of regional food security: (1) water availability and irrigation; (2) weather and climate threats; (3) land and soil quality; (4) large population; and (5) farmer access to agricultural credit and education.

Water availability and irrigation

Around 92% of the country is classified as arid or semi-arid (FAO, 2011). Water is the single most influential factor for achieving agricultural food security (World Bank, 2007; FAO, 2011; Baig, Shahid & Straquadine, 2013; Kirby et al., 2016; Zulfiqar & Thapa, 2017), and the Indus Basin Irrigation System (IBIS) is crucial for delivering water (World Bank, 2007; FAO, 2011; Yu et al., 2013; CIAT & World Bank, 2017; Iftikhar & Mahmood, 2017). The Indus River Basin covers 72% of the country's land-area, and provides irrigation responsible for producing 90% of the country's food (Zhu et al., 2013), see figure 1. The water network is supported by glacial and monsoon fed Northern rivers (Aggarwal & Sivakumar, 2011; Yu et al., 2013), and supplemented with groundwater (World Bank, 2007; Yu et al., 2013; CIAT & World Bank, 2017).

Figure 1. Map of Pakistan and the Indus River Basin across Afghanistan, China, India and Iran, highlighting the spread of the network and major tributaries (figure collected from Zhu et al., 2013).

Water supply is highly vulnerable due to unpredictable weather patterns and groundwater dependence (Yu et al., 2013). IBIS has inefficiencies, related to seepage (Ibid), and inconsistent water delivery resulting in waterlogging and water-shortages (World Bank, 2007). Intensive groundwater collection has resulted in overuse and damage of aquifer systems (Aggarwal & Sivakumar, 2011; Yu et al., 2013; CIAT & World Bank, 2017; Zulfiqar & Thapa, 2017), and threatens water quality through salinization in the basin region (Condon et al., 2014). Freshwater access is increasingly becoming a fundamental constraint (Ahmad & Farooq, 2010).

Weather and climate threats

Agricultural productivity in Pakistan is impacted by droughts, heavy rains, temperature fluctuations, unpredictable weather, and extreme events (Ahmad et al., 2015; Ali & Erenstein, 2017; CIAT & World Bank, 2017; Zulfiqar & Thapa, 2017).

Future climate change predictions exacerbate current events (Aggarwal & Sivakumar, 2011; Kirby et al., 2016). Threats include: glacial retreats; unpredictable yearly snow melt; rising temperatures; and increased droughts and floods (Ahmad et al., 2015; Khan, Jan & Shah, 2016; Kirby et al., 2016; Ali & Erenstein, 2017; CIAT & World Bank, 2017). Figure 2 shows predicted changes in precipitation and temperatures. Monsoons and floods damage crop growth and threaten the integrity of the IBIS (Dorosh, Malik & Krausova, 2010). Climate change scenarios show a decrease in wheat-crop growth (Iqbal, Goheer & Khan, 2009; Ahmad et al., 2015), from changes in precipitation patterns, both increases and decreases (Zhu et al., 2013), and rising temperatures (Aggarwal & Sivakumar, 2011; Yu et al., 2013; Khan, Jan & Shah, 2016).

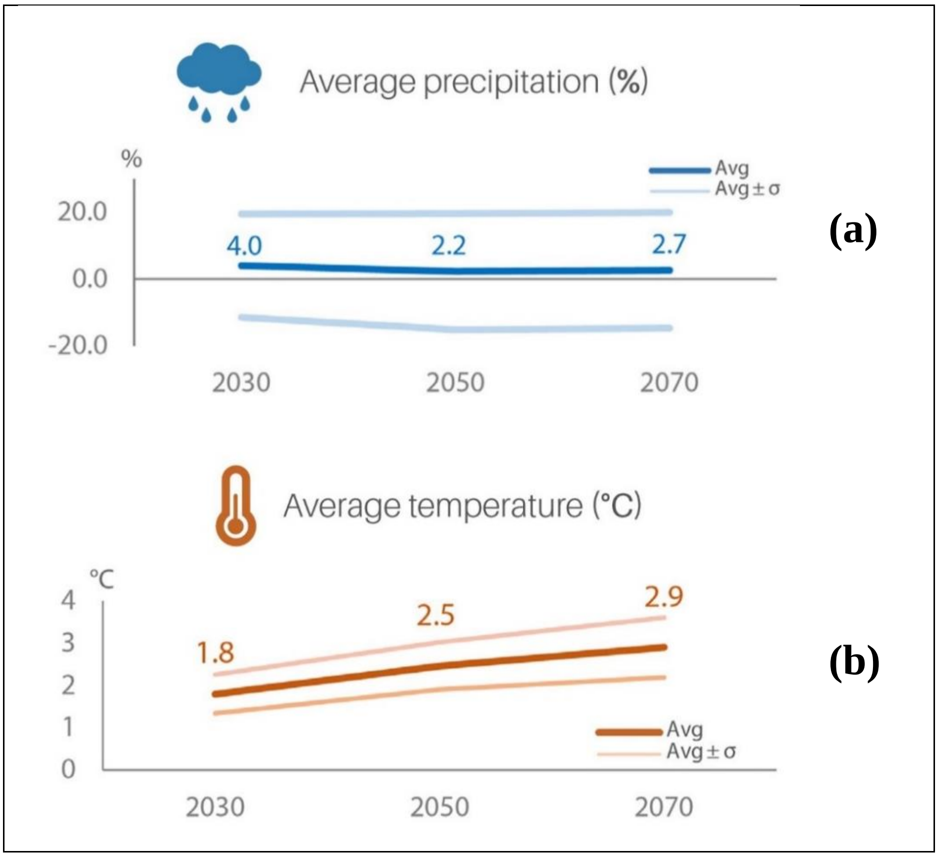

Figure 2. Average precipitation (a) and temperature (b) changes across Pakistan over the upcoming decades (images collected from CIAT & World Bank, 2017).

Soil quality

Pakistan's agricultural practices have led to decreases in agricultural soil quality, as a result of: high inorganic fertilizer use, pesticide use, exhaustion of surface water, and overuse of groundwater (Murgai, Ali, & Byerlee, 2001; Zulfiqar & Thapa, 2017). These practices threaten natural resource supply, agricultural productivity, and future sustainability (Ibid). Water use and irrigation patterns have resulted in soil salinization, waterlogging, and soil erosion patterns (World Bank, 2007; Ulah et al., 2018); figure 3 shows soil salinization patterns. Soil quality in Pakistan is highly vulnerable due to historical and current agricultural practices.

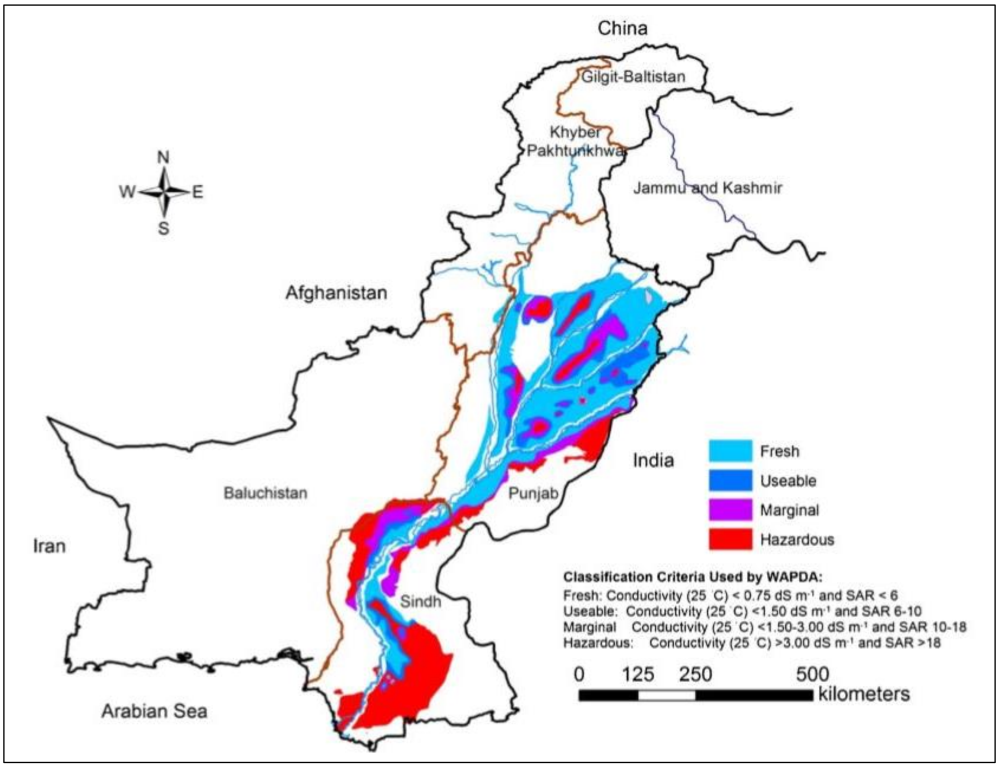

Figure 3. Soil salinity along the IBIS network due to excessive groundwater usage (image collected from Kirby et al., 2017).

Population size

Pakistan has approximately 230 million people, the 5th most populous country worldwide, with predictions showing a lowest population of just under 300 million people or upwards of 380 million by 2050 (UN Population Division, 2019). The increasingly large population imposes high agricultural output demands, requiring intensification to feed the growing population (Ahmad & Farooq, 2010; Ulah et al., 2018). The country demonstrates a reduction of biologically productive land per person (Zulfiqar & Thapa, 2017). Population size imposes a high vulnerability to national food security.

Access to agricultural credits and education

Access to capital through agricultural credits increases agricultural output (Hussain & Thapa, 2012; Saqib, Ahmad & Panezai, 2016; Iftikhar & Mahmood, 2017; Asghar & Salman, 2018). Credits provide farmers with the opportunity to invest in improved farming technology and practices (World Bank, 2003; Hussain & Thapa, 2012; Saqib, Ahmad & Panezai, 2016).

Education also impacts agricultural productivity (Ahmad, Mustafa & Iqbal, 2016; Saqib, Ahmad & Panezai, 2016); higher educated farmers can more easily maneuverer banking requirements for credit access (Saqib, Ahmad & Panezai, 2016), and are more aware of advanced agricultural practices and technologies (Asghar & Salman, 2018).

Credit outreach is available to less than 30% of farmers (CIAT & World Bank, 2017), and smallholders specifically have trouble accessing formal loaning sources (Hussain & Thapa, 2012; Saqib, Ahmad & Panezai, 2016). In developing countries, smallholders account for a large majority of agricultural production (Hussain & Thapa, 2012). Funds are in plentiful supply (Ibid); by continuing outreach, this driver has the potential to be a positive influence on food security.

Future Scenarios by 2050

Food security for Pakistan could look very different by 2050 depending on current and near future response patterns. Table 1 outlines 3 future scenario-cases discussing food security and biodiversity impacts.

Table 1. Scenario-outlines for food security and biodiversity impacts in Pakistan by 2050.

	Worst-Case Scenario	Best-Case Scenario	Most-likely scenario
Crop usage	Continued dependence on wheat-crop	Change in crop staples and diversification	Continued dependence on wheat-crop
Agricultural practices	Continued agricultural practices	Holistic agriculture practices	Climate Smart Agriculture practices
Irrigation system	No improvements or modifications to irrigation system	Irrigation improvement for efficiency and rain containment	Irrigation improvement for reinforcement and efficiency
Groundwater usage	Continued dependence on ground water	No groundwater dependence	Moderate dependence on ground water
Flood protection	No protections in place	Environmental restoration and basin improvement	Some protection in place through basin improvement
Farmer outreach	No improvement in farmer outreach for education and credits	Dramatic improvement in farmer outreach for education and credits	Some improvement in farmer outreach for education and credits

Worst-case scenario outcome

Continued production due to market demand will threaten national food security. An increase in population between 23 – 39% is expected, with wheat demonstrating a productivity decrease as a result of climate patterns. This will likely mean that wheat will be increasingly imported, and further threatens food security due to higher prices (Zhu et al., 2013).

The continued use of fertilizers, pesticides, and excessive irrigation to improve supply will have degraded agricultural lands and soil quality (Murgai, Ali, & Byerlee, 2001; Mahmood et al., 2016; Zulfiqar & Thapa, 2017). Pesticide runoff will cause direct biodiversity loss in contaminated ecosystems (Dudley & Alexander, 2017), and excess industrial fertilizer runoff will cause algal blooms, eutrophication, and biodiversity loss in freshwater (Ayoub, 1999), and decreases land-plant species and functional richness (Kidd et al., 2017).

There will be increased water demands and water shortages (Ahmad & Farooq, 2010; Zhu et al., 2013), and without the development of efficient rain water collection and storage, groundwater will be harvested more. The continuation of current water use trends predicts a near doubling of groundwater collection, which could deplete groundwater resources in the basin region (Kirby et al., 2016) and spread basin soil and water salinity (Yu et al., 2013). This would push crop systems into a continuous decline (Zulfiqar & Thapa, 2017). Water and soil salinity also threaten fresh water species within the water network; salinity studies show different salt-tolerance responses across taxa and feeding groups, suggesting that there will be dramatic changes in ecosystem structure and functioning (Castillo, A. et al., 2018).

Additionally, a lack of irrigation improvements and flood-protection measures will likely result in damage to the system from floods and monsoons, as experienced during the 2010 floods (Dorosh, Malik & Krausova, 2010). Severe damage to IBIS would collapse water supply and Pakistan's agriculture sector.

A lack of farmer outreach for credits and education will prevent farmers from adopting improved agricultural practices.

In this scenario food security will be highly threatened, as will environmental biodiversity.

Best-case scenario outcomes

Switching to new crops (Ali & Erenstein, 2017) and diversifying crop systems (Laghari et al., 2012; Ahmad, Mustafa & Iqbal, 2016; CIAT & World Bank, 2017; Zulfiqar & Thapa, 2017) will lead to increased agricultural output. Crop diversification improves biodiversity within the system (Altieri et al., 2015), and specifically improves the diversity and community structure of soil microbes (Zhou, Liu & Wu, 2017). Adopting crops that can survive in drought and flood conditions would be the most impactful for improving food security.

A more holistic approach to agriculture will improve food security and reduce environmental degradation (Ahmad & Farooq, 2010), this includes practices such as: crop suitability analysis and eco-region-specific planting; organic fertilizer use; and transitioning to integrated pest management (IPM) (Zulfiqar & Thapa, 2017). These practices can help reduce the dependence on industrial chemicals and practices that degrade soil quality (Ibid) and pollute natural-systems (Ulah et al., 2018).

The improvement of IBIS rainwater and flood collection will improve yearly water supply and mitigate the impact of heavy rainfalls (Baig, Shahid & Straquadine, 2013; Yu et al., 2013; Zhu et al., 2013), and coupled with other IBIS system efficiency improvements, will reduce groundwater dependence (World Bank, 2007; Kirby et al., 2016). These developments improve water security, and decrease biodiversity loss from excessive water consumption.

The development of ecosystem restoration projects of forest and wetland areas would improve local biodiversity in Pakistan. It would also increase basin-crop output by increasing water collection and preventing soil erosion, offering some level of flood protection (Dorosh, Malik & Krausova, 2010; Baig, Shahid & Straquadine, 2013; Laghari et al., 2012).

Farmer access to education, such as training and workshops, and improved government or bank outreach of agricultural credits will increase food security and biodiversity preservation by increasing the adoption of favourable agriculture practices amongst farmers (CIAT & World Bank, 2017; Iftikhar & Mahmood, 2017; Asghar & Salman, 2018).

In the best-case scenario, the impacts of climate change and population growth can be mitigated, and the adoption of favourable agricultural practices will both increase food security and ecosystem protection.

Most-likely scenario outcomes

Similar to the worst-case scenario, the continued dependence on wheat will undermine food security in Pakistan by 2050.

Wheat production will likely continue through the adoption of Climate Smart Agricultural (CSA) practices. CSA will help mitigate the impacts of climate related food security (Ahmad, Mustafa & Iqbal, 2016; Khan, Jan & Shah, 2016; Ali & Erenstein, 2017).

Certain practices have already been readily adopted, including drought tolerant seeds and seasonal adaptive planning (CIAT & World Bank, 2017). CSA strategies such as mixed crop, tree-incorporated systems and soil organic nutrient management (Bennett et al., 2014), may also develop. These less intensive agricultural practices will help improve crop resilience (Ibid), and will decrease future biodiversity loss compared to green revolution practices.

IBIS reinforcements and upgrades will likely happen to protect the system and improve efficiency, as the entire agriculture network is dependent upon its functioning; this would improve water use efficiency (World Bank, 2007), and increase crop production by 5-11% (Yu et al., 2013). Modifications would likely include some degree of flood collection and management, which would decrease groundwater dependence; it is unlikely that there would be a complete cessation of groundwater use. Decreasing ground water dependence will result in a slowing of continuing water and soil salinization, which will improve crop sustainability and ecosystem biodiversity.

By continuing the development of policies that support smallholder and rural farmer development through education and funding initiatives, Pakistan will have improved food security by encouraging the adoption preferred agricultural practices, such as CSA (Ali & Erenstein, 2017; CIAT & World Bank, 2017).

In this scenario food security will be threatened, and ecosystem degradation will continue to happen to some extent. The impacts experienced by 2050 may encourage a change in policy and may force the adoption of different crop-systems and resource preservation; this becomes increasingly more challenging as degradation continues.

Moving Forward

Highly biodiverse ecosystems have high stability and functionality (Loreau & Mazancourt, 2013; Mazancourt et al., 2013), and improved system resiliency, with high agrobiodiversity reducing crop-system vulnerability (Altieri et al., 2015). Food security has dependence on biodiversity, and improvement in Pakistan’s agricultural practices that reflect this dependence would greatly benefit food security by 2050.

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