Physical Climate Risk and Vulnerability Assessment

India Analysis

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Convened by Forum for the Future with support from Laudes Foundation, Cotton 2040 is a multi-stakeholder initiative with a mission to facilitate the shift to a sustainable global cotton industry which is resilient in a changing climate; which uses business models that support sustainable production and livelihoods; and where sustainably produced cotton is the norm. *Find out more: https://www.forumforthefuture.org/cotton-2040.*

This India analysis is one of two reports published as part of the Cotton 2040 Climate Adaptation workstream. An additional study provides a global analysis of physical climate risks to the cotton growing regions. Both reports, alongside an interactive climate impacts map and supporting resources are available at *http://www.acclimatise.uk.com/collaborations/cotton-2040/*.

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Foreword

Welcome to the India Climate Risk and Vulnerability Assessment report, which focuses on the climate risks to cotton growing and production. This work was completed by WTW, in partnership with international sustainability non-profit Forum for the Future, as part of the Cotton 2040 initiative. This detailed report, a flagship publication for Cotton 2040, is complemented by a broad Global report, both of which are generated in response to the lack of comprehensive, readily available information about how the climate crisis is likely to impact cotton production, its supply chain, and the nature of the industry over the coming decades.

The Cotton 2040 initiative was originally established to bring together existing initiatives to align around critical issues for - and accelerate the transition to - long term sustainability. In the context of climate breakdown, this goes beyond standards, certification or corporate commitments. Whether adequately prepared or not, the cotton system will be forced to change in the face of the dramatic changes that our warming climate will catalyse. With this report, our intention is to offer this data and analysis to spark a dialogue that will lead to joined up and informed action, and resilient responses that are deliberate, collaborative and systemic.

The cotton industry, like many others, is unprepared for the changes that the growing climate crisis is bringing. Already, the sector is hard-pressed to address deeply entrenched environmental, social and economic challenges[1] across its supply chains. As this report amply demonstrates, these pre-existing vulnerabilities and inequalities will be exacerbated and accelerated by a warming climate. In other words, those actors and elements of the value chain that are already vulnerable will come under even greater pressure, and suffer increasing pressures. Most industry-wide conversations and plans don't begin to address the scale of change that the climate crisis, if it continues on its current course (and even if ambitious steps are taken now), will force upon the industry, and the world.

India, as the world's largest cotton producing region, faces particular challenges that this report covers in detail. Climate threats will have profound effects, and in many cases present enormous difficulties for farmers and other actors across the value chain. These impacts will require a response that goes beyond incremental solutions to fundamental changes. We need to radically rethink where, how and why cotton is produced and traded, and what the future holds for this economically and culturally important fibre.

This is not just a theoretical exercise for the future. Change is not just on the horizon, it is happening now. In India there is already a clear pattern of an increasing number of days over 40°C, and changes to the monsoon patterns resulting in the extremes of floods and droughts. The trend towards increasing unpredictability and volatility of weather events is already in play. We are on the pathway to a different world, and the changes will only accelerate.

While the focus of this report starts with the physical impacts of climate breakdown, what emerges is the interrelationship between climate risk and climate vulnerability. The risks posed by a changing climate will, like the COVID-19 pandemic, expose and deepen pre-existing vulnerabilities and inequalities. In an already polarised society, the effects of climate change are likely to exacerbate gaps and tensions, straining the fabric of society and putting increasing pressure on already fragile supply chains. These converging risks, that span climate, livelihoods, economics, politics and security, demonstrate the deeply systemic threat that climate change poses. The

[1] *For a description of the challenges associated with the cotton industry, see the CottonUP Guide* http://cottonupguide.org/

effects of climate breakdown on cotton in India alone will have effects all across the global supply chain.

A systemic threat requires systemic solutions. In considering the impacts of climate change, it is critical to emphasise that if we are to develop an adequate response, our focus needs to look well beyond understanding the changes in the weather. We need to not only find ways to build environmental and social resilience into supply chains, but halt the downward spiral of the most vulnerable which will cost humanity and society so much more over time. Humanitarian crises have clearly demonstrated the economic argument for investing in resilience to avoid greater costs in responding to disasters.[i]

The information in this report needs to be considered not just for the changing environmental context for cotton production and processing in India, but for how the impacts of climate will affect actors all along the supply chain. There are darker possibilities to factor in, such as the likelihood of societal disruption fuelled by resource scarcity or unequal distribution, leading to conflict or even war. All of this will have impacts not just on production, but transportation and distribution of goods, and beyond. The assumptions on which current supply chains are based cannot be assumed as a viable or predictable part of the future.

We urge people and organisations involved in the cotton industry to use this data and analysis to think radically about the future of cotton in general, and India's role in particular. Part of the intent is that it be used by individual stakeholders to inform their procurement and other strategies. But we particularly call for the report to be used as a collaborative resource to make decisions together about how the industry needs to work, from how cotton is produced, transported, and used; to strategies, business models and more. We offer this report as a tool to inform thinking, and action, about mitigation as well as adaptation. The information it presents calls for nothing less than a collective reimagination and transformation of the cotton value chain to be sustainable, resilient and just.

Part A: Background, context and research objectives

This section will: (1) provide a summary of the current literature and understanding of the cotton-climate nexus with a focus on India; (2) present examples of how the cotton and textile sectors in India have been impacted over the last few decades by climatic changes; and (3) present a detailed summary of the nature of cotton cultivation and cotton processing in India.

1. Background: The climate-cotton nexus in India

The Intergovernmental Panel on Climate Change (IPCC) has stated that changes to the global climate are already being observed and future changes will continue to intensify over the coming decades.[ii] Due to the interrelated nature of the climate and the cultivation of agricultural crops, the agriculture sector is directly impacted by changes in the climate system, and therefore it is one of the major sectors under threat due to climate change across the world.[iii] As such, there is growing concern of the risks climate change presents to the cotton value chain (referred to henceforth as CVC) and to the textile industry more broadly.

1.1. Cotton's key climate sensitivities

Cotton (Genus: *Gossypium*) is grown predominantly in hot and dry climates, however it is sensitive to various climate parameters during different stages of crop development, including temperature and rainfall. Gradual changes in climate parameters, rapid shifts in extreme weather events, and increase in climate hazards all present increased risk to cotton cultivation.

Cotton has adapted to survive in temperate subtropical and tropical environments and is considered to be relatively resilient to drier and hotter conditions due to its vertical tap root compared to other agricultural crops.[iv] Various stages of crop development are sensitive to different temperature thresholds. While germination is optimum at temperatures of 18°C to 30°C, with minimum of 14°C and maximum of 40°C[v], temperatures between 27°C and 32°C is optimum for boll development and maturation, with yields greatly reduced above 38°C.[vi] Cotton has been known to grow at temperatures of 41.8°C in regions in northern India. Heat tolerant varieties are capable of withstanding extreme temperatures for short periods of time given that water is readily available. While it has not been established that 41.8°C is the upper limit, heat stress is a big constraint to increasing yields. Increasing global temperatures may exceed cotton's temperature threshold tolerance, exposing the crop to enhanced heat stress, and impacting cotton yield and quality.[vii]

The length of the total cotton growing period is about 150 to 180 days.[viii] The long growing season is a reason why cotton is so susceptible to disease and pests. While increasing atmospheric temperature may present an opportunity for some regions by lengthening the potential cotton growing season, regions which are already growing cotton in conditions close to the upper temperature threshold tolerance may be at significant risk. Furthermore, a warmer climate will favour pests and diseases, presenting a further threat to cotton.

In addition to specific temperature requirements, cotton is also sensitive to specific rainfall requirements at specific stages of crop development. During the early stages, relatively less water is required at 2 – 4 mm of water per day, however water requirements increase during leaf development and flowering to 5 – 7 mm per day.[ix] Overall, cotton requires between 700 – 1300 mm of water throughout the growing period[x], with a minimum of 500 mm suggested as a minimum threshold by some sources.[xi] Irrigated cotton requires a greater amount of water than rainfed cotton.[xii] While cotton is considered fairly drought tolerant as it is deep rooted with tap roots up to 3 metres deep, it is critical that the crop receives adequate water supply during these specific stages of crop development. Climate change is projected to increase rainfall in some regions while decreasing rainfall in other regions. Rains are projected to become more erratic and less reliable, increasing the risk to cotton.

At the other end of the spectrum, cotton is sensitive to excessive moisture and water logging, especially during the early season. Although the crop is relatively resistant to short periods of waterlogging, extreme rainfall events can inundate cotton plantations and cause widespread damage to agricultural crops. Continuous rain during flowering and boll opening will impair pollination and significantly impact the quality of the cotton fibre.[xiii] Heavy rainfall during flowering causes flower buds and young bolls to fall.[xiv] Heavy rainfall can also cause significant damage to soils, leading to soil erosion, the loss of nutrients from the soil, and increased run-off.[xv]

Periods of extreme rainfall events can saturate soils, reduce the frictional shear resistance of the soils, and may trigger debris flows or landslides in hilly regions. Depending on the debris to water ratio, debris flow or landslide can cover extensive areas and submerge any feature in its path. In rural regions, this may include agricultural fields, the damage to which can be detrimental to the survival of the crop. Climate change is projected to increase the intensity, frequency and duration of extreme rainfall events, which in turn may increase the risk of landslides in these regions.

The combination of long periods of high temperatures and dry conditions can create the conditions required for wildfires. If dry fuel is plentiful, wildfires can spread extensively and rapidly and cause significant loss and damage to human life and the rural community, to key infrastructure including utilities and transport routes, and to agricultural crops and livelihoods. Climate change will increase the intensity and frequency of wildfires across regions projected to experience warmer, drier conditions.[xvi]

Delicate young cotton seedlings can also be impacted significantly by strong winds, which may be associated with cyclones, tornadoes and hurricanes, as damaging wind speeds can 'sand-blast' seedlings, uproot the plant during early stages, blow fibre away from opened bolls, erode topsoil due to wind-erosion, and damage the quality of the cotton boll fibre by covering it in dust particles.[xvii] Impacts on key infrastructure may further impact cotton cultivation; for example, damage to electricity supply and irrigation systems which may restrict the ability of the farmer to tend to the crops, and cause trees and debris to block critical infrastructure routes. While the confidence in peoples' abilities to project wind strengths and impacts are currently low, there are suggestions that a warmer climate may give rise to stronger winds in some regions and weaker winds in other regions due to a shift in large-scale atmospheric circulation.[xviii] Furthermore, an increase in extreme weather events, such as tornadoes, cyclones and hurricanes, is projected to occur across some regions of India[xix], increasing the risk of damage to cotton crops from strong winds. Strong winds can also seriously affect young cotton seedlings which are not properly anchored by roots, in addition to impacting cotton at its maturity, as strong winds can blow away fibre from opened bolls and cause soiling of the fibre with dust.[xx]

1.2. A preliminary assessment of climate projections and impacts on the CVC

Climate change can cause direct damage to cotton crops either through gradual, incremental changes, such as atmospheric warming, or changes in total rainfall, or through sudden changes and extreme weather events such as flooding, hailstorms or heatwaves.

A report from the International Trade Centre (ITC) in 2011 presents a comparative analysis of climate impacts across several countries, and projects key climate impacts on cotton cultivation across India.[xxi] This study projects that climate change will increase the frequency at which the upper thresholds of the cotton crop are reached, increase regular exposure to extremely high heat stress and threaten cotton cultivation in the northernmost regions. The International Trade Centre (ITC) report states that regions that are already producing cotton at close to 40ºC would seem to be at a disadvantage considering future warming.

The 2011 ITC study further states that water availability for cotton irrigation is at risk across northern regions of India as a result of glacial and snowfield depletion in the Himalayan and Tibetan Plateau.[xxii] The report also projects increasing risks to rainfed cotton across the southern regions of India due to increasing variability in the intensity, frequency and duration of the monsoon rains, with longer periods of drought followed by heavy rainfall leading to increased flooding.

While the majority of studies project declining yields in irrigated cotton grown in hot northern regions that rely on glacial water, or in rainfed cotton grown in wet southern regions which rely on a stable and dependable monsoon, fewer studies explore the climate impacts on cotton cultivation in central regions. One study focusing on the central state of Maharashtra shows that a temperature rise of +1.85°C, +3.20°C and +3.95°C can lead to a ~3% (28 kg/ha), ~10% (268 kg/ha) and ~17% (477 kg/ha) reduction in cotton seed yield respectively.[xxiii] Climate change is projected to increase the intensity, frequency and duration of extreme weather events. Variability in rainfall threatens cotton yields as cotton cultivation requires both optimal temperature and sufficient rainfall during critical moments in the development of the crop.

Cotton cultivation provides an entry point for climate change impacts, with important implications for the value chain. When cotton crops are damaged as a result of increases in temperature or climate-induced pest attacks, the demand for better quality seed, pesticide and fertiliser greatly increases. This results in a higher cost of production per acre, which in turn results in lower expenditures on food and health and education for poorer, small-holder cotton farmers, ultimately pushing those rural households towards, or further below, the poverty line.

As one moves downstream along the value chain towards the cotton processing sector, the knock-on impacts accumulate.[xxiv] For example, cotton ginners, who are the first step in the cotton processing sector after the cotton is cultivated, mostly rely on local cotton and are therefore more vulnerable to changes in the domestic cotton production supply as a result of climate change when compared to actors downstream (spinners, weavers, ready-made garments, etc.).[xxv] Moreover, small ginning firms are more vulnerable to climate shocks as compared to large ones.

1.3. Observed changes and impacts: The climate-cotton nexus in action

The Global Climate Risk Index categorised India as the 5th most at risk country due to climate change in 2018, an increase from its ranking in 2017 at 14th.[xxvi] In 2019, INFORM ranked overall risk in India at 5.5, same as Côte d'Ivoire, Mauritania and Tanzania, and driven mainly by hazard and exposure indicators.[xxvii] In terms of its preparedness and response to climate change, the Notre Dame Global Adaptation Index (2017)[xxviii] ranks India low at 122nd (out of 192 countries).

India has experienced an increase in average annual temperature of +0.08°C per decade between 1901-2013, with substantially stronger warming of 0.14–0.25°C per decade over the last 30 years.[xxix] While there exists a lack of agreement on overall precipitation trends, there has been an increase in the frequency and intensity of heavy precipitation events.[xxx] Variability of the Indian summer monsoon has increased significantly since the 1950s.[xxxi] For several regions across India, this means an increase in long dry periods with low or no rainfall, intermittent with short, intense spells of rainfall.[xxxii]

Understanding the climate risks to various agricultural commodities is crucial for countries with a heavy reliance on agriculture. With over half of the population and most of the country's poorer citizens depending directly or indirectly on agricultural production, India is largely reliant on agriculture for food production, employment, livelihoods and provision of inputs to industries. The importance of the cotton-cultivating sector in India is explored in greater detail in **Section 2.1.**

Over the last few decades, the cotton sector in India has been severely impacted by extreme weather events and climate change. Impacts of a changing climate are already being observed directly on the cotton crop itself, on the start and duration for the growing season, and indirectly on the rest of the value chain. Farmers are beginning to adapt to this change.

In 2009, extreme rainfall and flooding across Punjab submerged cotton fields under 1.2 - 1.5m (4-5 feet) of water, saturating the soil for months. Due to a repeat of the disaster in 2011, farmers in Sri Muktsar Sahib decided to plant rice paddies instead of cotton, as rice crop can withstand water-logged conditions better than cotton. Farmers state how the monsoon rainfall used to be spread across the season, but that periods of rainfall are now more intense and frequent following dry spells.[xxxiii]

The textile industry contributes 5% of India's GDP.[xxxiv] Given the contribution of the sector, any adverse impact on cotton crops has implications for the business operation of textile manufacturers and, in turn, for the national economy. The importance of the cotton processing and textile sector in India is explored in greater detail in **Section 2.3.**

It has been recognised that heatwaves in India have increased in frequency over the last few years, with observations from a study in 2019 by the International Labour Organisation (ILO) identifying that populated areas in India have experienced some of the greatest increases in heat stress incidents since 1995.[xxxv] This has had significant impacts on people's work in areas such as agriculture and construction. One reason India's economy is susceptible to events like heat waves is its large informal sector, comprising people who work with no formal contracts, including manual farm labourers. The 2019 ILO study identified that by 2030, the Indian agriculture sector would lose 9% of its working hours to heat stress, a significant increase from 5.8% in 1995[2]. The study also identified that the Indian manufacturing sector would lose 5.3% of its working hours due to heat stress, also a significant increase from 2.9% in 1995. In total, by 2030, India will lose an equivalent to 34 million full-time jobs out of a total of 80 million globally due to heatwaves and heat-related stresses.[xxxvi]

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[2] The data are based on historical observations and on estimates obtained using the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century.

2. Context: India's cotton and textile sector

This section aims to develop an understanding of the nature of the cotton value chain and the textile industry in India prior to any assessment of future physical climate risks in order to interpret the results in an India-specific context.

2.1. India's cotton cultivation sector

India is the highest cotton producing country in the world (as of 2020).[xxxvii] While India ranks first place in terms of land area under cotton cultivation (38% of global cotton area), its yield ranks poorly (454.43kg/ha) compared to other countries such as the USA (955 kg/ha) and China (1764 kg/ha).[xxxviii]

The majority of cotton cultivation comes from ten major cotton growing states, which are grouped into three diverse agro-ecological zones (**Figure 1**). These are:

(i) Northern Zone - Punjab, Haryana and Rajasthan at 16.8% of national production,
(ii) Central Zone - Gujarat, Maharashtra and Madhya Pradesh at 54.6%, and
(iii) Southern Zone - Telangana, Andhra Pradesh, Karnataka and Tamil Nadu at 26.9%.

Cotton is a water-intensive crop. The quantity of irrigation water per hectare per season varies from 4,000 cubic metres in Orrisa to 8,000 cubic metres in Maharashtra.[xxxix] Approximately 62% of India's cotton is produced in rain-fed areas and 38% on irrigated lands.

The majority of cotton is grown on small scale farms of less than 1 hectare.[xl] Indian farmers grow four species of cultivated cotton; *Gossypium arboretum* and *herbaceum* (Asian cotton), *Gossypium barbadense* (Egyptian cotton) and *Gossypium hirsutum* (American upland cotton). The native variety of cotton, *G. arboretum* has been grown in India for over 5,000 years. Since the 1970's, an increase in more upland varieties which are more resistant to pests has been observed. Today, more than 80% of cotton grown in India are Bt cotton hybrids of the upland variety *G. hirsutum*.

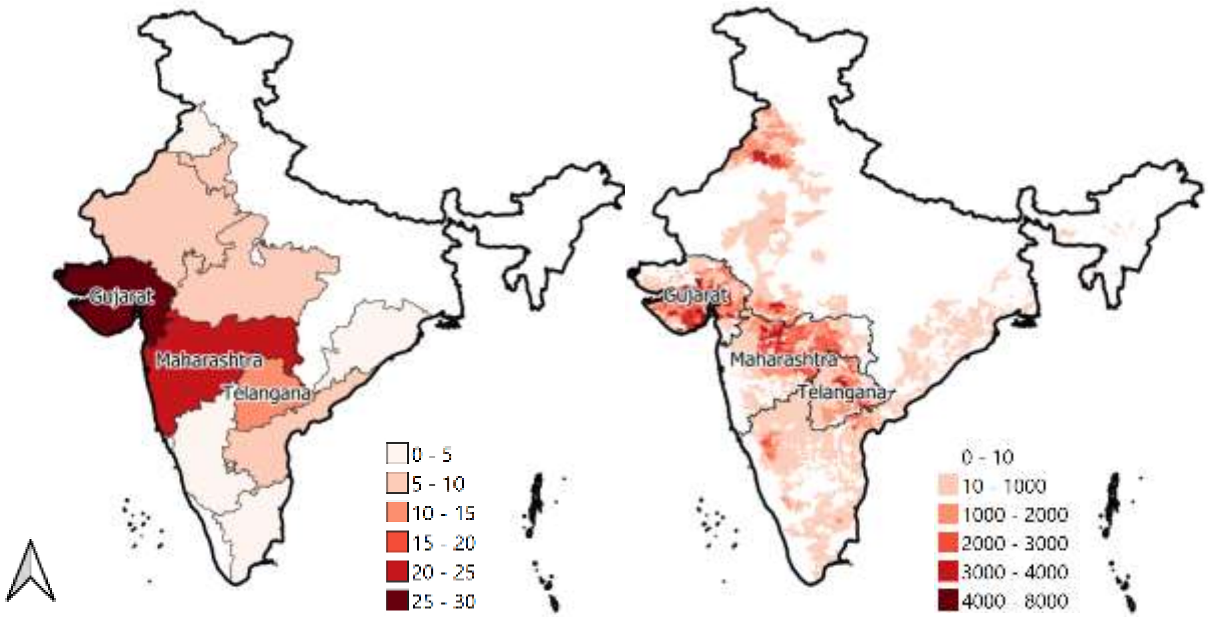

Figure 1: Percentage of national production on a state level as of 2019 (left) and total area growing cotton on a district level in hectares (right). Source: CICR (2019) and WRI (2020)

2.2. Climate profile for cotton growing regions

The main cotton growing states have varying and diverse climatic characteristics which ultimately influence the nature of cotton cultivation between and within each state with regards to the timing of seed sowing, the length of the cotton growing season, the variety of cotton and the nature of cotton irrigation.

In the northern cotton growing regions, the climate is arid, receiving an average total of 20 days of rainfall a year and extremely high temperatures of up to 51°C. The climate is adverse for the sowing season in May due to high temperatures which have historically hampered seed germination, however the growing period is limited to this 6 months' timeframe in order to avoid winter frost in December. The dry climate means that all cotton grown in the northern region is irrigated, mainly from glaciated rivers which originate in the Himalayas. Any rain which does fall is short in duration and intense, which leads to waterlogging issues and issues with soils becoming saline, impeding cotton growth and yields.

The southern cotton growing regions have a tropical climate which is highly influenced by the monsoon seasons (June-September). Rainfall fluctuates around 200mm in September-October and 0-5mm in January. Annual average temperatures are lower than in the northern regions at around 28°C throughout the year. The region grows rain-fed cotton to benefit from the monsoon rains. The region also benefits from the higher temperatures and lack of frost days, meaning that it can therefore also sow irrigated cotton in January. The eastern coastline is especially prone to extreme weather events, including flooding and cyclones.

The climate of the central cotton regions varies from hot, arid climate in Gujarat, humid-subtropical climate in Madhya Pradesh, to tropical wet and dry climate in Maharashtra. Rainfed cotton is the predominant crop across all states, however irrigated cotton is also grown. Madhya Pradesh and Maharashtra are influenced by the monsoon season, while Madhya Pradesh and Gujarat experience extreme annual temperature ranges of +/-20°C, which limits the growing season to May-December.

In the northern regions, cotton is grown as a kharif crop (monsoon season), which is sown in May and harvested in December before the winter frost, the majority of which is irrigated. Double cropping 'cotton-wheat' is a common practice in the north. In the southern regions, cotton is mainly a kharif crop, rain-fed by the monsoon rains and sown in September. In the southern regions, cotton can also be grown as a rabi crop (dry season), sown in January and harvested in June.

2.3. India's cotton processing and textile sector

Following cotton cultivation, the next rung in the cotton value chain is cotton processing, which includes ginning, spinning, weaving, knitting, and dyeing of cotton into lint, yarn and fabric. In India, roughly 60 million people are engaged directly or indirectly in the cotton value chain[xli], with about 40-50 million people employed in the cotton trade and its processing.[xlii] Most cotton ginning and pressing units are located in the major cotton producing states in India, such as Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra and Punjab[xliii]. There are a total of 381,043 weaving mills and 68,442 looms in India in the states of Andhra Pradesh, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal.[xliv] The cotton textile industry, which includes cotton processing and garment manufacturing, employs the highest number of people in the country after agriculture[xlv], and contributes about 4% to the country's GDP.[xlvi] In 2018-19, textile and clothing constituted 12% of

India's total exports, a large share of which was cotton yarn[xlvii]. In 2019-20, India produced 6,000 metric tonnes of cotton lint (**Figure 2**) out of which 900 metric tonnes was exported.[xlviii]

Figure 2: India's production of cotton lint. Source: ICAC 2020.

Ginning industry

The Indian cotton ginning industry is the second largest in the world.[xlix] Ginning, the process of separating fibres from cottonseed to produce lint, is a crucial link between the cotton farmer and the textile industry. During 2012-13 and 2013-14, about 36.5 and 38 million bales were ginned, respectively, using around 1,500 modern and 2,500 semi-modern ginneries.[l] While ginning is the first and most important cotton processing step as damages to cotton lint cannot be rectified further up the value chain, the Indian ginning industry continues to face multiple challenges, such as usage of outdated and primitive machinery and poor efficiency.[li] As of 2014, there were over 3,500 ginning factories in India, across nine major cotton growing states, including Gujarat, Maharashtra and Telangana. Of which, over 2,600 factories performed only ginning operations and the installed capacity of over 2,000 factories was as small as 6-12 double roller gins[lii]. Contamination of trash and excessive quantities of foreign matter due to improper ginning practices has also been an issue, hampering the quality of lint produced. Endeavours by the Ministry of Textile, Government of India, such as the Technology Mission on Cotton and the Technology Upgradation Fund, have focussed on modernising the cotton ginning and pressing space.[liii] The ginning industry also generates a substantial amount of dust, causing respiratory ailments for ginning workers.

Spinning and weaving

In cotton processing units, lint is pressed together into bales weighing 170kgs each[liv], and transported to spinning mills where the lint is spun into yarns. Weaving units manufacture fabric from yarns which are then dyed, finished and transported to garment manufacturing units. Spinning units are heavily dependent on the quality of lint produced by processing units. The Indian spinning industry has close to 50 million spindles, with an installed rotor ability of 0.8 million, across 16 states, including Tamil Nadu, Maharashtra, Gujarat, Uttar Pradesh, Karnataka, Madhya Pradesh, Rajasthan and West Bengal, with heavy concentration in the cities of Mumbai in Maharashtra, Ahmedabad in Gujarat and Coimbatore in Tamil Nadu.[lv] Over the past few years, cotton prices have increased and the international demand for cotton yarn from India has declined due to quality issues and increased competition, causing several spinning yarns to run into losses and shut down.[lvi] Unlike the spinning industry in India, which is largely organised, weaving- consisting of power loom, handloom and hosiery- is largely an unorganised and decentralised sector.[lvii] Around 95% of the weaving industry is unorganised and is dominated by small-scale enterprises. These small-scale power looms and hosieries contribute around 85% of the total fabric production[lviii]. The Indian weaving industry faces challenges, such as lack of information on latest technology, research, innovation and upgradation, and low productivity. In terms of technology India only has a share of 2% of global installed shuttle-less loom capacity.[lix]

2.4. Policy context

'National Mission for Sustainable Agriculture' is one of the eight national missions which form the core of India's National Action Plan on Climate Change (NAPCC)[lx] and is also elaborated in India's Nationally Determined Contributions to the UNFCCC.[lxi] The overarching objective of this mission is to 'devise strategies to make Indian agriculture more resilient to climate change,'[lxii] including identifying and developing varieties of crops which can withstand extreme weather patterns, dry spells and flooding. India's Economic Survey 2017-18, the guiding survey for policy formulation, dedicates a chapter to 'Climate, Climate Change, and Agriculture', which uses district-level data on temperature, rainfall and crop production to understand long-term trends in the sector.[lxiii] According to the survey, the impact of temperature and rainfall variations are felt only in cases of extreme temperature (extreme highs are considered to be greater than the 95th percentile of the grid-point specific temperature distribution), and rainfall (rainfall less than 0.1 mm/day), and the impact is significantly higher in unirrigated areas. Based on the changes in temperature and rainfall over the past 60 years, estimates of the effects of fluctuations in weather on agricultural productivity, and predicted changes in climate over the long-run, the survey projects future impacts of climate change on agricultural income. It projects that climate change could reduce annual agricultural incomes by 15-18% on average, and up to 20-25% for unirrigated areas by the end of the century based on RCP8.5 emission scenario. Furthermore, the survey estimates a 4% decline in agricultural yield of kharif crops (including cotton) due to extreme temperature shocks and an increase of 1°C in atmospheric temperatures, and a 12.8% decline in yields resulting from extreme rainfall shocks with a 100 mm reduction in rainfall. These are 7% and 14.7% respectively, for unirrigated kharif areas.[lxiv] The survey also identifies that the key challenges faced by broadly non-cereal crops, including cotton, in central, western and southern India are inadequate irrigation facilities, dependence on rainfall, ineffective procurement and insufficient investments in research and technology.[lxv]

3. Research objectives

3.1. Gaps in the current literature

An in-depth literature review reveals critical gaps in the current body of research regarding the climate impacts on the CVC in India. In general, there exists a lack of detailed studies which address climate risks to the CVC with consideration to socio-economic vulnerabilities and with a specific focus on India. Thorough assessments have been carried out in other countries, including Pakistan[lxvi], which analyses the entire CVC. While there are attempts at assessing the climate impacts on cotton cultivation at a state-level, such studies often do not quantitatively assess other stages of the CVC, nor investigate the knock-on effects climate change impacts on cotton cultivation has on cotton processing.

The majority of studies which assess cotton cultivation in India, obtain primary data through surveys with cotton farmers and, while this approach has its benefits, this approach only samples a small proportion of the population, therefore such studies are often content-specific at farm-level and do not help guide policy development at a district-level or more widely. Furthermore, there is a lack of studies which make use of the latest climate projections from an ensemble of global circulation models, with the majority of studies relying on a single, downscaled model for India, the impact of which skew the climate projections and fail to capture uncertainties in model outputs.

Studies which integrate cotton-specific climate thresholds into their analysis and simulate variables such as variability in the growing season, are even rarer. Moreover, the majority of studies only consider basic climate variables such as temperature and precipitation, and there is a lack of studies which consider other climate hazards such as wildfires, landslides and flooding.

Lastly, while numerous vulnerability assessments exist for India, not many are focused on the agriculture sector, and rarer so are studies which focus on the cotton sector.

3.2. Research objectives

Based on the gaps identified above which exists in the current literature, this Climate Risk and Vulnerability Assessment (referred to henceforth as CRVA) addresses those gaps by engaging with the following objectives:

1. Provide an in-depth analysis of physical climate risks and socio-economic vulnerabilities to the majority of the cotton value chain with specific focus on India.
2. Use the latest methodology for assessing climate risk as detailed in a methodology set out by the International Governmental Panel of Climate Change (IPCC).[lxvii]
3. Use the latest, internationally recognised climate projections from an ensemble of global circulation models to capture uncertainties in projections.
4. Integrate cotton-specific climate thresholds into the climate hazard component of the analysis.
5. Consider a plethora of climate hazards rarely considered in the literature, including the change in the growing seasons, damaging wind speed above a certain threshold, relative humidity, wildfire and many more.
6. Explore the common and different climate and socio-economic vulnerabilities on a district-level with the aim of identifying possible focus areas for the Cotton 2040 initative in terms of supporting climate resilience and adaptation.
7. Identify good-practice adaptation cases currently underway in India which help build climate resilience.

It should be appreciated that this study is a first step in assessing community-level climate risk and vulnerability. It provides results based solely on available datasets. Participatory 'community-based' engagement will be required to fully understand community vulnerabilities and to define appropriate resilience building measures, including where social adaptation-related support and interventions could be best placed. There is a strong body of literature which emphasises this important point[1].

Part B: Climate risk scores

Section 1: Results of the cotton cultivation CRVA: Farmer and field

This section focuses on the cotton cultivation aspect of the CVC, and explores at a district-level, the risks and vulnerabilities of cotton farmers and their rural communities, and risks and vulnerabilities to the cotton crop itself.

The section consists of; (1) a summary of the nature of cotton cultivation in each of the three focus states, (2) a summary of the results of the CRVA to identify the main trends in risk and vulnerabilities.

1. Cotton cultivation in the focus states

An overview of cotton cultivation in each of the three states is provided below.

1.1. Maharashtra

Maharashtra covers nearly 34% of the total cotton producing areas in India.[i] In 2018-19, the central state of Maharashtra had the highest land area under cotton cultivation (41.19 lakh[3] ha), yet its average yield (334 kg/ha) was the lowest out of all the central states.

Two species of cotton are predominantly cultivated: viz *G. Hirsutum* and *G. Arboretum*, including a range of hybrids and genetically modified species. Hybrids consist of approximately 73% of cotton grown in the state, about 11% is cultivated with *hirsutum* varieties and 16% with *arboretum* varieties. Most of the cotton varieties and hybrids grown in Maharashtra process medium and medium-long fibre.[ii] Maharashtra produces 11% of the organic cotton fibre produced in India (6735 MT).[iii] The cotton crop is grown during the kharif season and sowing is generally done with the onset of the monsoon (roughly June to the end of October).[iv] Landholdings in Maharashtra are small and fragmented with an average size of 1.44 hectares.[v]

Maharashtra receives moderate amounts of rainfall. Average rainfall over 2012-2016 was 939 mm, ranking Maharashtra as 6th in terms of highest rainfall among India's 11 cotton growing states. Maharashtra's cotton farms are predominantly rainfed, and less than 20% of Maharashtra's total cotton cultivating areas are irrigated. Maharashtra ranks last among India's core cotton growing states in terms of irrigated area, and most cotton cultivators lack the capacity to mitigate the impacts of drought events.[vi]

Cotton cultivators in Maharashtra use both chemical and biological fertilisers. Chemical fertilisers including nitrogen (N), phosphorus (P), and potassium (K) tend to be overused, exceeding the recommendations provided by the Indian Central Institute for Cotton Research (CICR). Per acre recommendations for NPK are 80:40:40, whereas rainfed farmers surveyed in Maharashtra applied a split of 100:87:30. Biological fertilisers, in particular farmland manure, are also widely used. A survey of Maharashtra cultivators showed that 54% of the sample utilised farmland manure, or another biological fertiliser, in the 2017-18 growing season. Chemical pesticides are also

[3] *A lakh is a unit in the Indian numbering system equal to one hundred thousand.*

commonly used although the number of applications varies widely. The vast majority of farmers report 3-5 applications, while a small quantity of farms report as high as 23 applications.[vii]

In Maharashtra the major risks facing cotton farmers include drought, pests (particularly the pink bollworm which has driven significant crop losses in recent years) and price volatility.[viii] In 2020, the Cotton Association of India estimated a production reduction of four lakh bales from the 360 lakh bales reported a year prior, attributed to production losses from Maharashtra where pink bollworm attacks and October rains have led to extensive crop failure.[ix]

1.2. Gujarat

The central state of Gujarat has 27.09 ha under cotton cultivation, and averages yields of 577 kg/ha.[x] Gujarat is the second largest cotton producing region by area in India. The state contributes 39% of the total cotton produced in India from 26% of cotton-cultivating areas.[xi] With regard to land holdings in Gujarat, 37% are marginal (<1 ha), 29% of parcels are small (1-2 ha), 22% of parcels are semi-medium (2-4 ha), and 10% of parcels are medium (4-10%). Only 1% of parcels is large (>10 ha).[xii]

The varieties of cotton cultivated in Gujarat include 7 varieties of *G. hirsutum*, 4 varieties of *G. arboreum* and 11 varieties of *G. herbaceum*. Beyond this, there are numerous hybrid and genetically modified varieties.[xiii] Bt cotton, genetically modified to combat bollworm, has been used widely in Gujarat since its introduction in 2002. Gujarat produces 11% of India's organic cotton (2018).[xiv] The season typically begins in the last week of June or the first week of July with the onset of the monsoon and lasts until October or November.

Gujarat receives moderate amounts of rainfall, with the majority heavily concentrated in the monsoon period.[xv] Average annual rainfall in Surat is 1188 mm, while average rainfall during the main sowing periods of cotton from June to July is 285.55 mm.[xvi]

Statistics on irrigated cotton in Gujarat are variable with the Cotton Association of India reporting that 27% of land area is irrigated (2015), an academic research study reporting that 56.7% is irrigated[xvii], and a survey of 351 organic, conventional and certified cotton cultivators reporting 89% of farms were irrigated in 2013.[xviii] Despite the variation in numbers, Gujarat has undergone large scale improvements in irrigation facilities in the last two decades and is considered to have relatively high access to irrigation.[xix]

Fertilisers are extensively applied in Gujarat which corresponds with high yields and makes Gujarat one of the lead producers of cotton in India. Fertiliser use is optimised in irrigated areas which may be linked to their high usage in Gujarat which has better irrigation than other predominantly rain-fed regions (e.g. Maharashtra).[xx] However, fertilisers can worsen predation by certain pest varieties. Surveys of cotton cultivators in Gujarat show high use of pesticides to control sucking pests, primarily the highly hazardous monocrotophous, followed by the slightly hazardous acephate. Further, the sprays generally consist of more than one chemical spray, a practise which is discouraged by entomologists, and can have health and environmental implications.[xxi]

In Gujarat the major risks facing cotton cultivators include water stress emerging from erratic or delayed monsoons[xxii] and pests (particularly the cotton mirid bug and the pink bollworm which has driven significant crop losses in recent years).[xxiii] The impacts of a delayed or weak monsoon can restrict cotton growth thereby reducing cotton outputs and cause widespread price volatility.

1.3. Telangana

The southern state of Telangana has 17.94 ha under cotton cultivation, and averages yields of 502 kg/ha.[xxiv] The varieties of cotton cultivated in Telangana include *G. hirsutum, G. arboreum, G. herbaceum, G. barbadense,* and countless numbers of hybrid and genetically modified species.[xxv] Telangana is a very small producer of organic cotton (0.3% of India's organic cotton).[xxvi] In Telangana, landholdings are predominantly marginal (62%) (<1 ha); 24% are small (1-2 ha); 11% are semi-medium (2-4 ha); 3% are medium (4-10 ha); and 0.3% are large (>10 ha).[xxvii]

The northern part of Telangana receives 900-1500 mm of annual rainfall, while the southern drier part of the state receives 700-900 mm annual rainfall.[xxviii] Nearly two-thirds of this annual precipitation occurs during the monsoon season. Approximately 54% of the agriculture is rainfed, and 46% is irrigated.[xxix] The cotton season typically brings with it the onset of the monsoon in the last week of June or the first week of July and goes until October or November.

Agrochemicals (fertilisers, herbicides and pesticides) are used widely in Telangana to maximise yields and increase pest resistance. Agrochemicals are typically used in excess of the prescribed quantity, either increasing the number of applications, and / or mixing of various types of agrochemicals, and often contain highly hazardous substances such as Monocrotophos.[xxx]

In Telangana and other cotton growing regions of India, some of the major challenges facing cotton cultivators include a high dependency on the erratic monsoon rains, and insufficient irrigation facilities; extensive use of chemical fertilisers and pesticides leading to soil imbalance and disease resistance; monocropping; multiplicity of cotton hybrids; and illegitimate seeds, fertilisers and pesticides.[xxxi]

1.4. Policy context

Maharashtra

The Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC)[xxxii] projects the impacts of climate change for key sectors in the state, including agriculture. Cotton, being one of the most important cash crops for the state, has been included in the plan. According to the MSAAPC, a temperature rise of 3.2ºC can lead to a decline of 268 kg/ha in cotton yield. While an elevated carbon dioxide level of 650 ppm and a temperature of 40ºC can improve cotton productivity, with further increase in temperature the CO_2 fertilisation effect may get nullified, leading to decline in yields. Cotton crops under enhanced temperatures are reliant upon adequate water supply to minimise the impacts of heat stress. In regions where rainfalls are projected to become increasingly more erratic, and drought conditions are projected to prevail, this will present a barrier to any potential benefits a warmer climate might present to cotton. The MSAAPC recognises climate change as a major challenge for cotton cultivation, especially as the area under cotton cultivation is increasing in the state. Agriculture Contingency Plans for Districts, including Dhule, Latur, Nagpur, Nandurbar, Wardha and Yavatmal, list contingency measures for cotton cultivation to enable sustainable production, especially during periods experiencing weather anomalies and extreme climate events.[xxxiii]

Gujarat

The Gujarat State Action Plan on Climate Change[xxxiv] identifies cotton as a thermo-insensitive and drought resistant crop, and that the state is incentivising increases in cotton production by providing technological transformation support, training and input subsidy. The document notes that across Gujarat, farmers have been shifting from crops such as groundnut, which is highly sensitive to saline water, to cotton cultivation. The plan's 'Programme of Action for Agriculture' includes research on quantifying the impact of climate change projections on cotton, and two other significant crops (wheat and groundnut) in the state. Agriculture Contingency Plans for Districts, including Rajkot, Banas Kantha and Mahesana, list contingency measures for cotton cultivation to enable sustainable production, especially during periods experiencing weather anomalies and extreme climate events.[xxxv]

Telangana

Agriculture is one of the 10 key sectors identified in the State Action Plan on Climate Change for Telangana State.[xxxvi] While cotton finds mention as an important crop, the State Action Plan does not provide specific data or interventions for the crop's production. The plan document states that the adaptation measures mentioned will be implemented in tandem with existing policies, schemes and initiatives, including the Intensive Cotton Development Programme[4]. Agriculture Contingency Plans for Districts, including Adilabad, Karimnagar, Khammam and Mahbubnagar, list contingency measures for cotton cultivation to enable sustainable production, especially during periods experiencing weather anomalies and extreme climate events.[xxxvii] Telangana has a Textiles and Apparel Policy (2017-18) in place to incentivise investment and growth in the state's textile industry.[xxxviii] The key reason for this could be to bridge gaps in the cotton value chain as the bifurcation of Andhra Pradesh and Telangana in 2014 led to most of the textile industry being in Andhra Pradesh, while majority of area under cotton cultivation became a part of the state of Telangana.[xxxix]

[4] *The Intensive Cotton Development Programme under Mini Mission – II of Technology Mission on Cotton, is a centre-based programme, in operation since 2000. The main objective of the scheme is to increase production and productivity of cotton. The sharing of fund between Central Government and State Governments is 75:25. http://djd.dacnet.nic.in/centspoassign.htm*

2. Results: Climate risk score

This section presents the climate risk score for the cotton cultivation CRVA. Results for the individual indicators of the cotton cultivation CRVA that comprise the overall risk scores for exposure, hazard and vulnerability (sensitivity and adaptive capacity) are detailed under

2.1. Climate risk score

Table 1 presents the climate risk score for cotton cultivation, calculated using **Equation 1** and normalised for each of the 13 districts, and **Figure 3** shows a cartographic representation of these scores.

Table 1: Normalised risk score for each of the 13 districts for cotton cultivation.

Climate risk score of 1 indicates the district with the highest risk score relative to other districts (red), and a climate risk score of 0 indicates the district with the lowest risk score relative to other districts (green)

	Districts	Risk score
Gujarat	Rajkot	0.45
	Banas Kantha	0.97
	Mahesana	0.59
Maharashtra	Dhule	1.00
	Nandurbar	0.86
	Latur	0.13
	Nagpur	0.00
	Wardha	0.36
	Yavatmal	0.19
Telangana	Adilabad	0.20
	Karimnagar	0.26
	Khammam	0.29
	Mahbubnagar	0.30

Table 1 and **Figure 3** show that the district with the highest risk score is Dhule, and the district with the lowest risk score is Nagpur. Overall, the risk scores appear higher for the northern district relative to the southern districts.

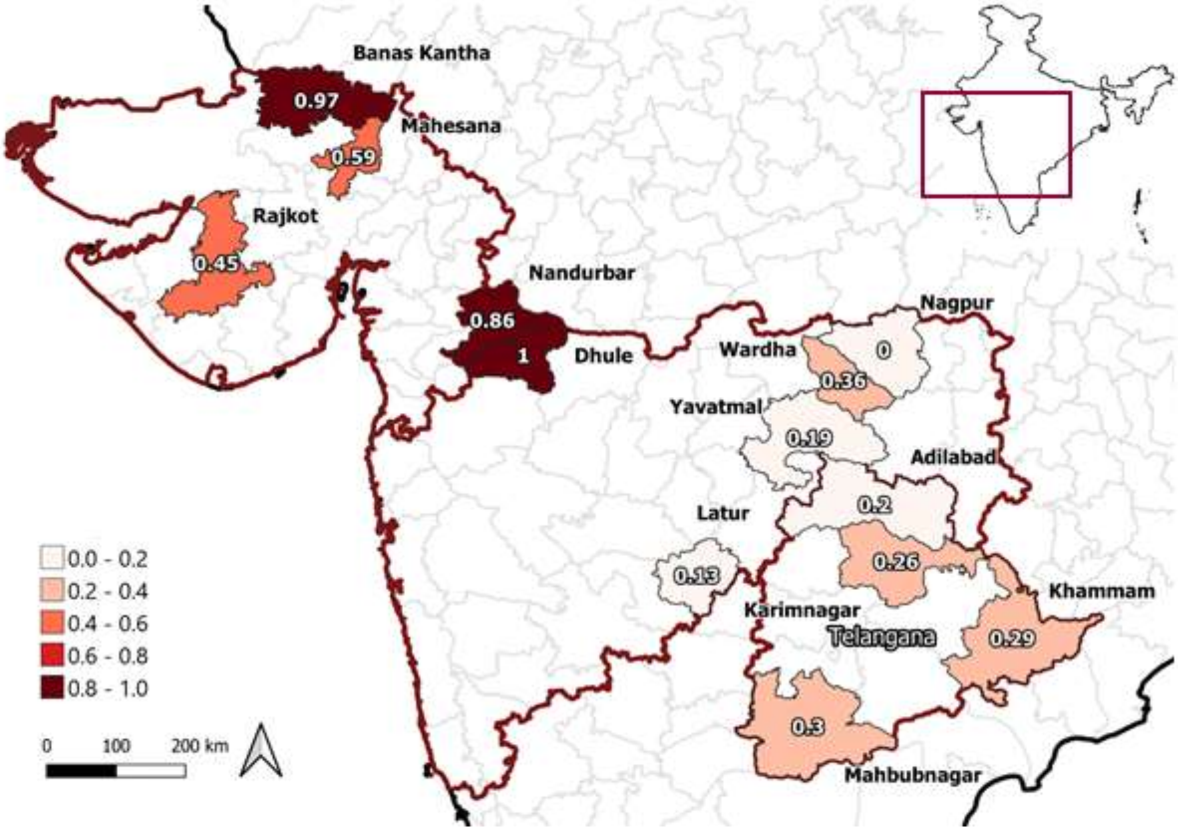

Figure 3: The climate risk score for each of the 13 districts analysed in this study.

It should be noted that the normalised risk score allows a comparison of the different districts with respect to their risk but does not report on the relative risk of each district. To do this, a detailed analysis of the factors that contribute to highest risk score will be carried out, in order to understand the underlying factors. This in turn will allow the identification of priority areas and the most relevant adaptation measures for the region.

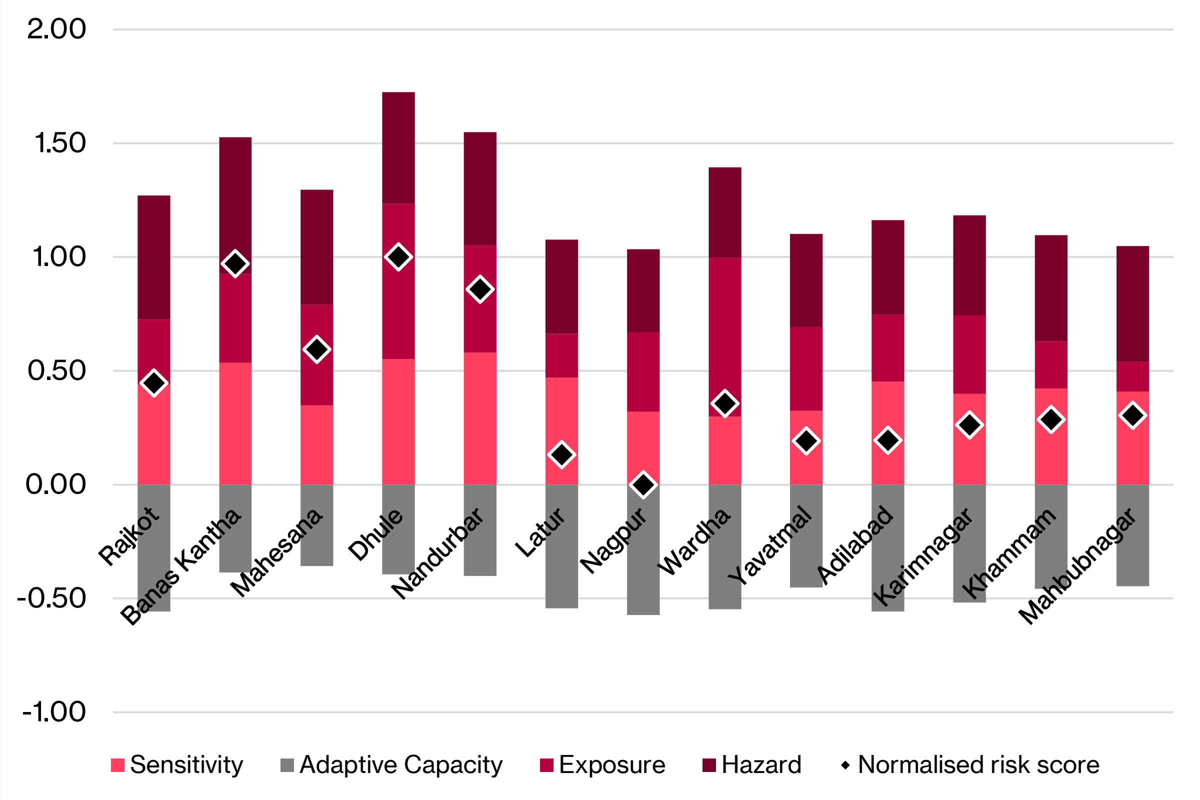

Figure 4: The contribution of each component of risk, namely exposure, hazard, sensitivity and adaptive capacity, for all 13 districts.

Figure 4 shows the relative score of each component prior to normalization. The graph shows that the high risk score for Dhule is driven by relatively high sensitivity, high exposure, high hazard score and relatively low adaptive capacity. The graph also shows that the low risk score for Nagpur is driven by high adaptive capacity, low exposure, low sensitivity and low hazard scores relatively to other districts. Key trends identified for each of the main components of risk is explored in greater detail in the sections below.

The final score and corresponding cartographic representation for each component that are used to calculate the risk score for the cotton cultivation CRVA, namely exposure, hazard and vulnerability (sensitivity and adaptive capacity) are addressed under

2.2. Results: Exposure

“Exposure” describes how much of the subject of interest is open to climate impacts.

Exposure is directly proportionate to risk.

High exposure = High risk

Low exposure = Low risk

The most exposed district is Wardha, followed closely in second place by Dhule. Both districts are located in the state of Gujarat. The least exposed district is Mahbubnagar, located in the state of Telangana.

The high exposure scoring for Wardha and Dhule is driven by a high % of net sown area, and a high number of people employed as cotton cultivators relative to other districts. The low exposure scoring for Mahbubnagar is driven by low rural population density and low net sown area relative to other districts.

Overall, the districts located in the states of Gujarat and Maharashtra are more exposed than Telangana.

2.3. Results: Hazard

Hazard is directly proportionate to risk.

High hazard = High risk

Low hazard = Low risk

The highest scoring districts are Rajkot and Banas Kantha, which are located in the state of Gujarat. The lowest scoring district is Nagpur, which is located in the state of Maharashtra.

Common hazard indicators which increase risk across all districts

The results for the following indicators are high across all, or the majority, of the districts, showing that these indicators are commonly projected hazards (2040s) for cotton cultivation across the focus regions:

- Projected increase in number of days when maximum temperature exceeds 40°C
- Projected increase in number of days when maximum temperature exceeds 34°C
- Projected increase in frequency of heatwaves
- Projected increase in number of days when wildfire risk is ‘high’
- Projected increase in number of days subject to damaging wind speeds
- Projected increase in extreme precipitation

Significant differences in hazard indicators

There exists significant difference in the results for some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations can be made.

There is a clear trend in that districts located in the state of Gujarat score higher in terms of projected hazards for the 2040s relatively to Maharashtra and Telangana. District located in the state of Gujarat are projected to experience the greatest increase in number of days when maximum temperature exceeds the temperature threshold of 40°C for cotton cultivation. They are also projected to experience the greatest increase in frequency of heatwaves. Both indicators in turn contribute to the projected decrease in the number of effective growing degree days (when temperatures are between 15-30°C), projected for the district of Rajkot. In addition, northern districts are projected to experience the greatest number of days when wildfire risk is 'high', and the greatest change in Standard Precipitation Index towards drier conditions.

Notably, for Telangana, districts are projected to experience the greatest increase in extreme precipitation relative to present day, the greatest increase in number of days when maximum temperatures exceed 34°C, and the greatest increase in the number of days when windspeeds exceed 25mph (40kmh). Districts located in Telangana are also at greatest risk from fluvial flooding during a 1 in 100 year event and greatest risk from landslides.

2.4. Results: Vulnerability

The most vulnerable district is Nandurbar, located in the state of Maharashtra. The least vulnerable district is Wardha, also located in the state of Maharashtra.

A detailed analysis of the factors that contribute to highest vulnerability score are provided in Sections 2.5 and 2.6, in order to understand the underlying factors. This in turn will allow the identification of priority areas and the most relevant adaptation measures for the region.

2.5. Results: Sensitivity

"Sensitivity" describes the degree to which a population is affected, either adversely or beneficially, by climate variability "sensitivity".

Sensitivity is directly proportionate to vulnerability.

High sensitivity = High vulnerability

Low sensitivity = Low vulnerability

Similarly, for the overall vulnerability score, the most sensitive district is Nandurbar, while the least sensitive district is Wardha. Both districts are located in the state of Maharashtra.

Common indicators which elevate sensitivity across all districts

The results for the following indicators are high across all, or the majority, of the districts, showing that these indicators are common drivers of vulnerability for cotton cultivation and rural, agricultural communities across the focus regions:

- Dependency on agriculture for rural employment
- Gender pay gap in the wages of cotton farmers
- Agricultural sector's contribution to the Gross Domestic Product (GDP)
- Multidimensional poverty.

Significant differences in sensitivity between districts

There exists significant difference in the results for some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations can be made.

Some of the indicators identified below are also identified in the section above, as common drivers of sensitivity across all focus regions, however, some of the indicators identified above also show significant disparity between districts.

- Dependency on agriculture for rural employment is high for all districts, however the results range significantly from 19% (Banas Kantha) to 70% (Mahbubnagar). Overall, the dependency is less for the districts located in the state of Gujarat relatively to the other two states.
- Difference in wages between male and females cotton growers ranges from a low of ~0% (Khammam) to a high of 63% difference (Nandurbar). While the gender pay gap in the wages of male and female cotton growers is high overall for the majority of districts, the difference is especially high for districts located in the state of Maharashtra and lower for districts located in the state of Telangana.
- While the agricultural sector's contribution to the Gross Domestic Product (GDP) is high for all districts, it is especially high for Mahbubnagar and Banas Kantha (~35-40%), while being relatively lower for Nagpur at ~2%.
- The proportion of marginal workers is relatively higher for the districts located in Gujarat (18% to 25%) and relatively lower for the districts located in Maharashtra (9% to 17%).
- Proportion of farms of less than 1 hectare is particularly high for the districts located in the state of Telangana (58% to 68%) compared to the districts located in the state of Maharashtra (10% to 38%).
- People living in multidimensional poverty ranges from 8% (Nagpur) to 60% (Nandurbar). Both districts are located in Maharashtra, which shows that significant disparity exists between districts within the same state. The district of Nandurbar is especially high considering the second highest district is Adilabad at 35%.
- Proportion of rural female head of households is higher overall for the districts located in Telangana (13% to 21%) compared to districts located in Gujarat (6% to 13%).
- Proportion of degraded and waste land is relatively higher for the districts located in Telangana (20% to 48%) compared to the districts located in Gujarat (4% to 11%). The districts with the highest proportion of degraded and waste land are Dhule at 54%, and lowest is Mahesana at 4%, both of which are located in the state of Maharashtra.

2.6. Results: Adaptive capacity

"Adaptive capacity" describes the degree to which a population has the ability to respond to a hazard and to cope with change.

Adaptive capacity is indirectly proportionate to vulnerability.

Low adaptive capacity = High vulnerability

High adaptive capacity = Low vulnerability

The district with the greatest capacity to adapt is Nagpur in the state of Maharashtra and the district with the least capacity to adapt is Mahesana in the state of Gujarat.

Common indicators which decrease adaptive capacity across all districts

The results for the following indicators are low across all, or the majority, of the districts, showing that these indicators are common drivers of vulnerability for cotton cultivation and rural, agricultural communities across the focus regions:

- All districts have a low percentage of cotton grown as irrigated cotton
- Rural female work participation rate is low for the majority of districts
- Literacy rates for both male and female are low for all districts
- Access to bank accounts is low for all districts
- Proportion of rural households with computer/laptop with Internet connection is significantly low

Significant differences in adaptive capacity between districts

There exists significant difference in the results for some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations can be made.

Some of the indicators identified below are also identified in the section above, as common drivers of vulnerability across all focus regions, however, some of these indicators identified above also show significant disparity between districts.

- Average daily wages of a male field labourer are significantly different between the different districts in the state of Gujarat, at a low of 192 Rs/day (Mahesana) to a high of 460 Rs/day (Rajkot). Compared to all other districts, the wages for Rajkot are significantly higher especially considering that the second highest wage is Banas Kantha (also located in Gujarat) at 384 Rs/day.
- Average daily wages of a female field labourer are lower for the districts located in the state of Maharashtra at 100 Rs/day to 150 Rs/day whilst wages are higher for the districts located in Gujarat and Telangana.
- While the area growing irrigated cotton is rather low for all districts, significant difference exists between districts, with the districts located in Telangana showing a relatively smaller percentage (0% to 20%), and the districts in Gujarat showing a relatively higher percentage (16% to 35%). However, the district with the greatest percentage of cotton grown as irrigated cotton is Latur in Maharashtra, at 51%.
- A significant difference exists for crop diversity, with the effective number of crops grown in a total of 4 districts being more than 10 crops (for Banas Kantha, Dhule, Nandurbar and Mahbubnagar), while a total of 4 districts grow less than 2 types of crops (Wardha, Yavatmal, Karimnagar and Khammam). There is no clear trend at a state level.
- While the rural female work participation rate is low for the majority of districts, significant difference exists with a clear trend that districts located in Gujarat have a lower female work participation rate (25% to 27%) and districts located in the state of Telangana have a higher participation rate (56% to 64%).

- There is a significant disparity between literacy rate between states and between genders. Overall, Gujarat and Maharashtra have the highest literacy rates compared to Telangana. Female literacy rates are significantly lower than male literacy rates for the districts located in Telangana (18% to 32%) compared to 41% to 50% for male literacy rate in Telangana.
- Soil organic carbon stocks are less in general for the districts located in Gujarat (24 t/ha to 29 t/ha) relative to districts located in Telangana (34 t/ha to 46 t/ha).

Section 2: Results of the cotton processing CRVA: Field to factory

This section focuses on the cotton processing aspect of the CVC and explores at a district-level the risks and vulnerabilities of manufacturers and the urban/ peri-urban community, and to the cotton processing sectors from ginning to pre-garment manufacturing. This section consists of: (1) a summary of the nature of cotton processing in each of the three focus states, and (2) a summary of the results of the CRVA to identify the main trends in risk and vulnerabilities.

3. Cotton processing in the focus states

An overview of cotton processing in each of the three states is provided below.

3.1. Maharashtra

The state of Maharashtra processes about 8 million bales of cotton lint annually[xl] with the city of Mumbai being one of the largest textile hubs in the country. Almost all the cotton is ginned on double roller (DR) gins. The cotton ginning workforce in the state consists of roughly 60,000 people and most of the state's ginning units are located in the Marathwada region.[5][xli] The state also exports cotton lint bales to countries such as Bangladesh, Vietnam and China. The state's textile industry has a share of 10.4% in the country's textile and apparel production.[xlii] The state has close to 2000 textile businesses with a fixed capital of US$ 2417 million.[xliii] Weaving is highly decentralised in the state. The handloom industry faces challenges such as lack of modern technology awareness and upgrades, and low yield.

3.2. Gujarat

Gujarat has around 800 ginning mills across the state[xliv], with more than 120 mills in Kadi, in the district of Mahesana alone[xlv], and the ginning industry is one of the state's main agro-based industries.[xlvi] Most of the ginning mills consist of mechanised raw cotton feeder machines and employ an average of 100 people in each.[xlvii] One of the biggest challenges faced by the state's cotton ginning industry is that of overcrowding due to physical proximity, causing many smaller units to shut down operation. While Gujarat has a cotton production capacity of 10 million bales, the ginning industry in the state has the capacity to process around 30 million cotton bales.[xlviii] This issue is further exacerbated by fluctuations in cotton production in the state, creating knock on implications for spinning mills and weaving in the state.

The spinning industry in Gujarat is one of the leading spurn yarn producing industries in India, with cotton accounting for around 83% of the share.[xlix] However, the industry has remained stagnant over the years[l] and has limited capacity, compared to the ginning industry in the state.[li] The state has around 11 textile hubs including activities such as spinning, weaving, yarn dyeing, knitting and garmenting. The state's textile and apparel exports were at US$ 4.79 billion in 2014-15.[lii]

3.3. Telangana

Telangana, the third largest producer of cotton and known for the cultivation of long staple cotton (>35mm), has around 320 ginning mills across the state.[liii] The state was formed in 2014, after bifurcation from Andhra Pradesh, and ever since 2014 the number of ginning facilities have increased in the state.[liv] However, the Ministry of Telangana notes that the cotton value chain in

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[5] *Marathwada region consists of the districts- Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad, Parbhani.*

the state is largely limited to cotton cultivation and ginning and pressing, with considerable gaps further along the value chain.[lv] The state had only 35 spinning mills in 2017, with a capacity of 930,000 spindles and the ability to spin 1 million bales, as opposed to the state's annual cotton production of 6 million bales.[lvi] Most of the processed cotton from Telangana is exported to the states of Gujarat, Maharashtra and Andhra Pradesh for further value addition. Weaving activities, through power looms and handlooms, are also limited in the state with about 49,000 power looms and 17,000 handlooms, mostly concentrated in the town of Sircilla.[lvii] Telangana's traditional weaves such as Pochampally, Ikat and Gadwal, are of cultural significance. However, the weaving sector in the state, as in other states, faces several challenges such as outdated technologies, absence of linkages within the value chain, dependence on middlemen, credit shortages and lack of product diversification. To address these gaps across the cotton value chain, the Government of Telangana introduced the Telangana Textiles and Apparel Policy in 2017,[lviii] aimed at encouraging both downstream and upstream investments in the processing sector, with a focus on processing, spinning, weaving, knitting and garment manufacturing.

4. Results: Climate risk score

This section presents the results of the cotton processing CRVA. Results for the individual components that are used to calculate the risk score for the cotton processing CRVA, namely exposure, hazard and vulnerability (sensitivity and adaptive capacity) are addressed in **Appendix 6: Results: Cotton processing CRVA 2.**

4.1. Climate risk score

Table 2 presents the final risk score for cotton processing, calculated using **Equation 1** and normalised for each of the 13 districts, and **Figure 5** shows a cartographic representation of these scores.

Table 2: Normalised risk score for each of the 13 districts for cotton processing.

Climate risk score of 1 indicates the district with the highest risk score relative to other districts (red), and a climate risk score of 0 indicates the district with the lowest risk score relative to other districts (green)

	Districts	Risk score
Gujarat	Rajkot	0.65
	Banas Kantha	0.53
	Mahesana	0.68
Maharashtra	Dhule	0.40
	Nandurbar	0.67
	Latur	0.20
	Nagpur	0.00
	Wardha	0.12
	Yavatmal	0.27
Telengana	Adilabad	1.00
	Karimnagar	0.33
	Khammam	0.59
	Mahbubnagar	0.48

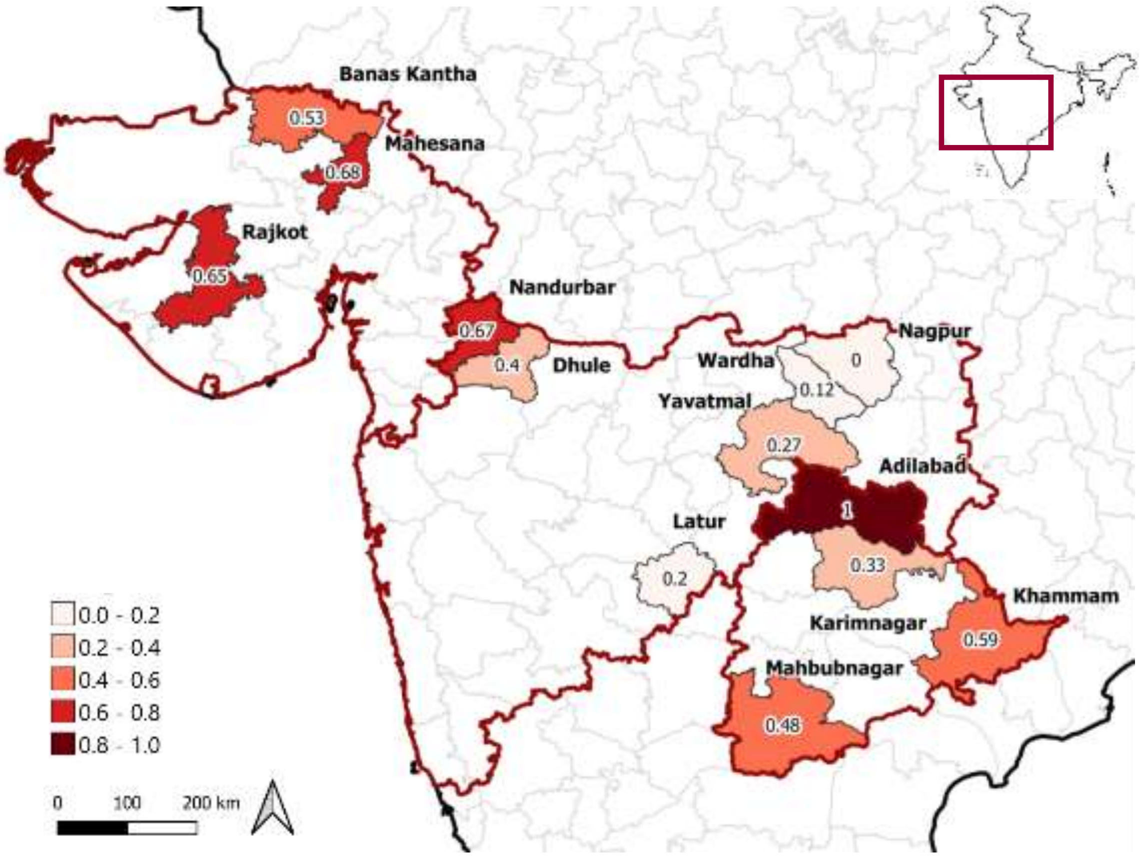


Figure 5: The climate risk score for each of the 13 districts analysed in this study.

4.2. Risk score: Main findings

Table 1 and **Figure 6** show that the district with the highest risk score is Adilabad, and the district with the lowest risk score is Nagpur. Overall, districts located in the states of Gujarat and Telangana appear to have a higher risk score relative to Maharashtra.

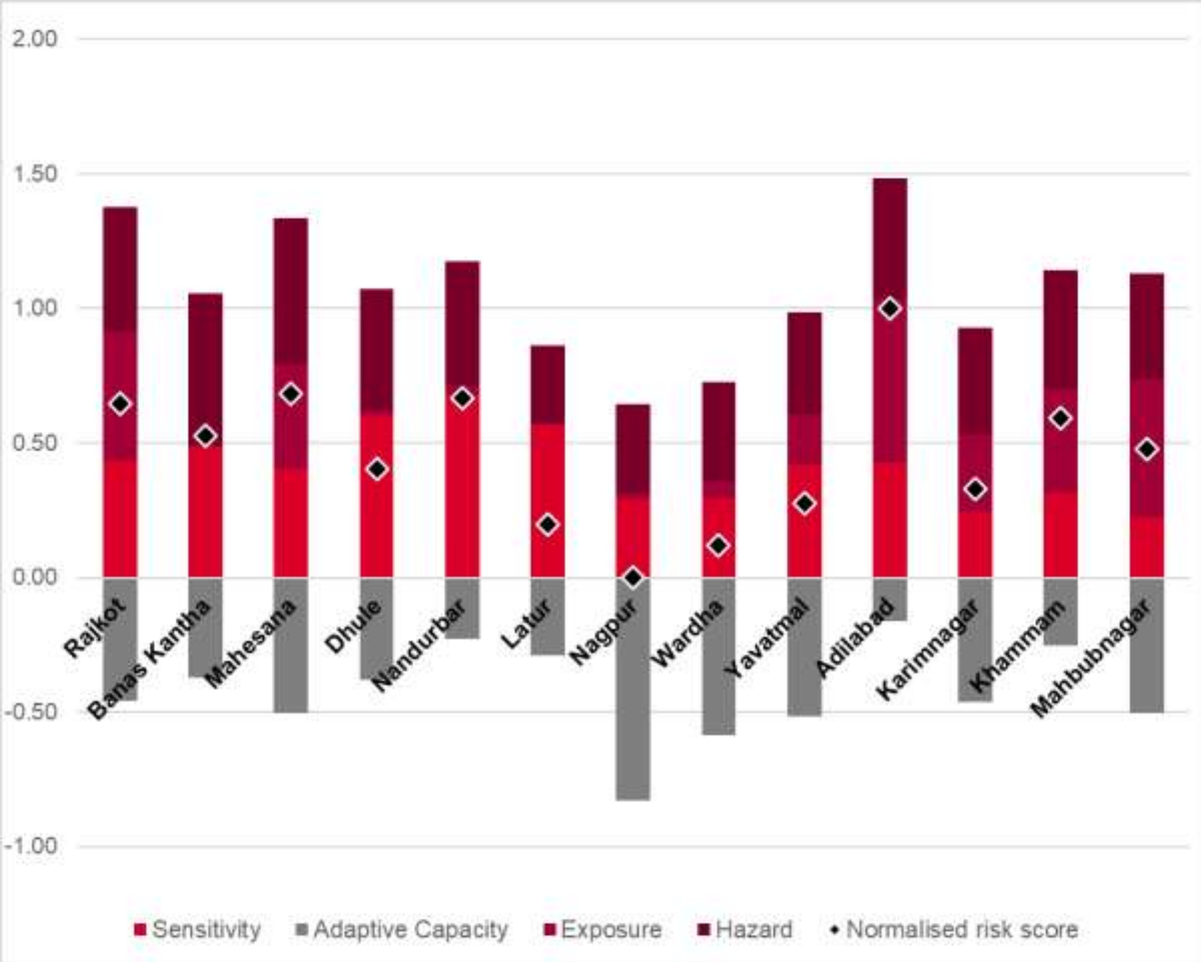


Figure 6: The contribution of each component of risk, namely exposure, hazard, sensitivity and adaptive capacity for each of the 13 districts

Figure 6 shows that the high risk score for Adilabad is driven mainly by high exposure scoring and a low adaptive capacity relative to other districts. It also shows that the low risk score for Nagpur is due to a low exposure scoring and significantly higher adaptive capacity scoring relative to other districts.

The final score and corresponding cartographic representation for each component that are used to calculate the risk score for the cotton processing CRVA, namely exposure, hazard and vulnerability (sensitivity and adaptive capacity) are addressed in **Appendix 6: Results: Cotton processing CRVA 2.**

4.3. Results: Exposure

"Exposure" describes how much of the subject of interest is open to climate impacts.

Exposure is directly proportionate to vulnerability.

High exposure = High vulnerability

Low exposure = Low vulnerability

The most exposed district is Adilabad, which is are located in the state of Telangana. Exposure is high for Adilabad as it is the district with the highest number of ginning and pressing factories. Exposure is also high for the district of Mahbubnagar, also located in Telangana, due to the district having the highest number of people working in the cotton processing sector. Overall, exposure is lower for the districts located in the state of Maharashtra and higher for the districts located in the state of Telangana.

4.4. Results: Hazard

Hazard is directly proportionate to risk.

High hazard = High risk

Low hazard = Low risk

The highest scoring district is Banas Kantha, located in the state of Gujarat, and the lowest scoring district is Latur, located in the state of Maharashtra.

Common hazard indicators which increase risk across all districts

The results for the following indicators are high across all, or the majority, of the districts, showing that these indicators are common hazards for cotton cultivation across the focus regions:

- Projected increase in number of days when maximum temperature exceeds 34 °C
- Projected increase in frequency of heatwaves
- Projected increase in number of days when wildfire risk is 'high'
- Projected increase in extreme precipitation

Significant differences in hazard indicators

There exists significant difference in the results for some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations can be made.

There is a clear trend that districts located in the state of Gujarat score higher in terms of projected hazard for the 2040s relative to Maharashtra and Telangana. Districts located in the state of Gujarat are projected to experience the greatest increase in frequency of heatwaves, the greatest number of days when wildfire risk is 'high', and the greatest change in Standard Precipitation Index.

There is also a trend whereby districts located in the state of Telangana score relatively higher in terms of the escalation of hazards from present day to the 2040s. These districts are projected to experience the greatest increase in extreme precipitation relative to present day, the greatest increase in number of days when maximum temperatures exceed 34 °C, and the greatest increase in the number of days when wind speeds exceed 25mph (40kmh). Districts located in Telangana are also at greatest risk from fluvial flooding during a 1 in 100 year event and greatest risk from landslides.

4.5. Results: Vulnerability

The most vulnerable district is Nandurbar and the least vulnerable district is Nagpur. Both districts are located in the state of Maharashtra.

A detailed analysis of the factors that contribute to highest vulnerability score will be carried out, in order to understand the underlying factors. This in turn will allow the identification of priority areas and the most relevant adaptation measures for the region.

4.6. Results: Sensitivity

“Sensitivity” describes the degree to which a population is affected, either adversely or beneficially, by climate variability “sensitivity”.

Sensitivity is directly proportionate to vulnerability.

High sensitivity = High vulnerability

Low sensitivity = Low vulnerability

The most sensitive district is Nandurbar, located in Maharashtra, and the least sensitivity district is Mahbubnagar located in Telangana.

Common indicators which elevate sensitivity across all districts

The results for the following indicators are high across all, or the majority, of the districts, showing that these indicators are common drivers of vulnerability in cotton manufacturers and urban communities across the focus regions:

- Multidimensional poverty
- Volatility in production

Significant differences in sensitivity between districts

There exists significant difference in the results of some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations are made. Some of the indicators identified below are also identified in the section above, as common drivers of sensitivity across all focus regions, however, some of the indicators identified above also show significant disparity between districts.

- There is significant volatility in the production of cotton identified for Rajkot relative to all other districts.
- People living in multidimensional poverty ranges from 8% (Nagpur) to 60% (Nandurbar). Both districts are located in Maharashtra. The district of Nandurbar is especially high at 60% considering the second highest district is Adilabad at 35%.
- The top three districts with the highest water stress are located in the state of Gujarat while the three districts with the least water stress are located in the state of Telangana.

4.7. Results: Adaptive capacity

"Adaptive capacity" the degree to which the population has the ability to respond to a hazard and to cope with change.

Adaptive capacity is indirectly proportionate to vulnerability.

Low adaptive capacity = High vulnerability

High adaptive capacity = Low vulnerability

The district with the greatest capacity to adapt is Nagpur (0.83) in the state of Maharashtra, and the district with the least capacity to adapt is Adilabad (0.16) in the state of Telangana.

Common indicators which decrease adaptive capacity across all districts

The results for the following indicators are low across all, or the majority, of the districts, showing that these indicators are common drivers of vulnerability across the focus regions:

- Across all districts, the urban work participation rate
- Urban female participation rate is significantly low
- Urban female literacy rate is low
- Proportion of households with access to bank accounts
- Proportion of urban households with computer/laptop with Internet connection

Significant differences in adaptive capacity between districts

There exists significant difference in the results of some of the indicators between individual districts, and more broadly between states. Whilst not all the districts in each state are considered in this analysis, broad approximations are made. Some of the indicators identified below are also identified in the section above, as common drivers of vulnerability across all focus regions, however, some of the indicators identified above also show significant disparity between districts.

- There is significant difference in the wages of men employed in cotton processing sector, ranging from the highest in Nagpur (769 Rs/day) to the lowest in Khammam (192 Rs/day). There are significant discrepancies between districts within the same state for all states, such as for Maharashtra where wages from 769 Rs/day (Nagpur) to 230 Rd/day (Nandurbar).

- Urban female participation rate is significantly lower for all districts, with a range of 9% to 27%. The lowest three districts are all located in Gujarat (9% to 11%). The highest three districts are located in Telangana (20% to 27%).
- While male literacy rates are higher than female literacy rates, there is a general trend in that districts located in Telangana are generally lower (85% to 87%) than the other two states.
- While the proportion of urban households with access to bank accounts is low for all districts, in general the districts located in the state of Telangana are lower (57% to 64%), while the districts located in the state of Gujarat are higher (62% to 73%).

Section 3: Summary of the main findings

Appendix 7: Summary of the main drivers of risk presents a summary of the main findings for both the cotton cultivation CRVA and the cotton processing CRVA.

The CRVAs for both cotton cultivating and cotton processing reveal common indicators that exacerbate risk across all districts.

As for the hazard indicators, these show a clear trend across all districts, in that an increase in temperature, increase in extreme weather events (including heatwaves and extreme precipitation), and increase in climate hazards (flood risk, landslides, wildfires and damaging wind speeds) is projected for the 2040s. All districts are also projected to experience an increase in the number of days at which labour productivity significantly decreases, and, furthermore, all districts are projected to experience an increase in the number of days whereby maximum temperatures are projected to exceed the threshold at which cotton can be successfully cultivated (40°C).

As for the vulnerability indicators, there are common indicators which are high across all districts, and these include multidimensional poverty, female work participation rates, male and female literacy rates, access to banking services, and access to technology and information. These are key issues facing society which need to be addressed more broadly. While the results are slightly better for urban areas compared to rural areas, the issues identified here are significant for both rural and urban.

While this analysis did not cover all districts in each of the three states, it is possible to make broad approximations based on the general trends revealed in the analysis.

For both the cotton cultivation CRVA and cotton processing CRVA, the final climate risk scores appear to be higher overall for the northern districts located in the state of Gujarat relative to southern districts located in the states of Maharashtra and Telangana. The primary component driving these higher scores across the northern districts are hazard indicators which projected absolute climate conditions for the 2040s, such as the highest total number of days above maximum temperature thresholds. Districts located in Telangana appear to have scored higher for hazard indicators which project change in climate conditions for the 2040s, including the greatest increase in the number of days when wildfire risk is 'high'.

As for the vulnerability indicators, some indicators are more pronounced in some states compared to others. For Maharashtra, the existing gender pay gap and absolute wages of cotton growers stand out as key concerns. Telangana has a low % of irrigated cotton grown, high % of small agricultural holdings, high % of rural female head of households, and significantly low male and female literacy rates. For cotton cultivation in Gujarat, 'natural capital' indicators stand out as key drivers of vulnerability, including high projected water stress, and low organic carbon stocks, however Gujarat especially stands out in terms of significantly low female work participation rates.

There are also trends in indicators which show significant differences between districts located in the same state. This is especially true of districts located in the state of Maharashtra, for example, the district with the highest (Nandurbar) and lowest (Nagpur) multidimensional poverty are both located in the state of Maharashtra, however this may be skewed due to the number of districts sampled for Maharashtra (5 districts) being higher than for Gujarat (3 districts) and Telangana (4 districts).

Part C: Discussion: Paving the way forward

The climate vulnerability and risk assessment carried out for the cotton cultivation and cotton processing aspect of the CVC has revealed key indicators which exacerbate physical climate risk for the 13 districts considered in this study. Identifying these drivers of risk is a crucial first step in the adaptation story, as it can be used to guide action and drive interventions towards increasing resilience to climate change.

The following section discusses the main indicators relating to the increasing physical climate risks across the various districts located in Gujarat, Maharashtra and Telangana, and identifies examples of various programmes, practical activities and research efforts which have helped to tackle these challenges and build climate resilience.

Each of the components used to calculate climate risks, namely hazard, exposure, sensitivity and adaptive capacity, have been used to structure the discussion and example solutions provided below. Moreover, the focus areas are identified i.e. with one, some or all districts would benefit from the proposed adaptation action. It is also specified whether a solution is applicable for cotton cultivation and the rural communities, or for the cotton processing and the urban communities i.e. the actors in the CVC. These solutions are intended to demonstrate initial examples of good-practice adaptation cases currently underway in India which help build climate resilience going forward.

1. Hazards and exposure: Reducing direct impacts

The following present hazard and exposure indicator led solutions to build climate resilience.

1.1. Challenge 1: Heatwaves and heat stress: Reducing the impacts of heat stress on labour productivity (cultivators and manufacturers)

Heat stress during work is an occupational health risk as it restricts workers' physical functions and capabilities, work capacity and productivity, and in extreme cases, can lead to heatstroke and fatality. In India, a study by the International Labour Organization (ILO) shows that working hours lost to heat stress across the agriculture sector in India is projected to increase from 5.87% in 1995 to 9.04% in 2030, while working hours lost to heat stress across the manufacturing sector is projected to increase from 2.95% in 1995 to 5.29% by 2030.[i] Heat stress impacts both aspects of the CVC. Not only does heat stress impact cotton cultivators who are directly exposed to heat in fields, but studies show that it also impacts manufacturers working in factories in densely populated urban areas, as small industries, such as cloth-weaving units, cannot afford air-conditioning.[ii]

Across all 13 districts analysed in this CRVA, the number of days when temperature exceeds a threshold of 34°C is projected to increase for the 2040s – a temperature threshold at which, according to the ILO, reduced labour productivity by 50%.[iii] The top three districts which are projected to experience the greatest increase are located in the state of Telangana, namely the districts of Khammam, Karimnagar and Adilabad, which are projected to experience an increase above present day (2000-2019) of +41 days, +39 days and +37 days respectively. This is echoed by the findings of the ILO report, which projects that populated areas in southern India will be one of the regions of the world to suffer greatest from heat stress.

Currently in Telangana, maximum temperature during the summer months can reach up to 47°C across Khammam and Karimnagar. In 2015, the country witnessed the fifth deadliest heat wave in history which killed 2,500 people across Andhra Pradesh and Telangana.[iv] Heatwaves across India are becoming more intense and frequent.[v]

While swift action is required to address heat stress across all districts, immediate action is required across the state of Telangana, and especially targeting the districts of Khammam, Karimnagar and Adilabad, to implement measures to reduce the impact of heat stress on both cotton cultivators and textile manufacturers.

1.1.1. Adaptation actions for the cotton cultivation sector

Aim: *Prepare contingency plans for dealing with heatwaves, to incorporate the recommendations as stated in the state action plan such as rescheduling of working hours of cotton cultivators.* **Target area:** *All districts, but especially Khammam, Karimnagar and Adilabad [Telangana].*

Following the 2015 heatwave, the state of Telangana took the initiative to develop a comprehensive Heatwaves Action Plan (2020)[vi] for extreme heat events, which identifies prevention and mitigation measures to minimise the effects of heatwaves and build capacity. Preparedness measures identified in the report for agriculture and outdoor working include shifting the outdoor workers schedules away from peak afternoon hours (1PM to 4 PM), ensuring adequate drinking water facilities is provided, and ensuring adequate shade is provided from direct sunlight. Given that the greatest increase in heatwaves and heat stress is projected for the district of Khammam, Karimnagar and Adilabad, it is vitally important that employers and landowners of cotton fields in these districts ensure that similar measures to those recommended in the Heatwaves Action Plan are incorporated into their practices as these address the health and safety of cotton cultivators, and ensure that the cotton farm maintains good levels of productivity.

Supporting initiatives which aim to help employers and cotton farmers to prepare contingency plans for dealing with heatwaves and heat stress would be significantly beneficial to all districts, but especially for the districts of Khammam, Karimnagar and Adilabad, to help build resilience across rural communities.

1.1.2. Adaptation actions for the cotton processing sector

Aim: *Support the implementation of cool roofs in urban areas, with a focus on cotton processing factories and textile manufacturing factories.* **Target area:** *All districts, but especially Khammam, Karimnagar and Adilabad [Telangana]*

The Heatwaves Action Plan incorporates a cool roof initiative into its action plan. The Telangana Cool Roofs Program[vii] aims to improve 150,000 sq. km of roof area by 2030, by turning the roofs of slum dwellings into cool roofs, improve the reflectivity of roofs on government buildings and schools, and raise public awareness. Studies have shown that cool roofs can be up to 30°C cooler than conventional roofs and can bring the indoor temperatures down by 3-5°C.[viii] Cool roofs reflect sunlight and absorb less heat, reducing the urban heat island effect. They can comprise a coating of a material or paint with high reflectivity on top of a conventional roof material; pre-fabricated materials such as membranes or sheeting to cover an existing roof; the application of high albedo, china mosaic tiles or shingles on top of an existing roof; or make use of vegetation to help the roof absorb less solar energy. Telangana is at the forefront of initiating measures for implementing the cool roofs programme, however further funding and resources are required to implement cool roofs programmes.

Providing funding to initiatives which implement the Telangana Cool Roofs Program, and especially by targeting cotton processing factories and textile manufacturing factories in densely populated urban areas, would highly benefit the districts of Khammam, Karimnagar and Adilabad, to help build climate resilience across the urban manufacturing community.

1.2. Challenge 2: Drought and water stress: Reducing the impact of water stress on cotton cultivation

Optimum temperature for cotton cultivation ranges from 20-30°C, and yields in general are greatly reduced above 38°C.[ix] Despite this, cotton has been known to grow at temperatures of 41.8°C and higher in regions in northern India, far exceeding expected thresholds, however heat stress is a big constraint to increasing yields.[x] This study utilised a threshold of 40°C as the number of days in a given year when temperatures exceed this threshold pose a significant risk to yields.

High temperature accelerates water losses from the soil and plant through increased rates of evaporation and transpiration, placing the crop under water stress in dry regions and/or during dry spells. The FAO states that cotton requires adequate water supply during critical phases of development.[xi] Abrupt changes in water supply and severe water deficits will adversely affect growth and cause flower and boll shedding. This shows that not only is the timing of rainfall crucial for rainfed cotton, but interannual variability in rainfall will also impact on the quantity of water available for irrigated cotton.

This CRVA shows that the districts of Rajkot, Banas Kantha and Mahesana, all located in the state of Gujarat, are projected to experience a significant increase of up to +25 days in the number of days the temperature exceeds a threshold of 40°C – a critical temperature threshold for cotton. This increase in temperature and increase in exposure to heat stress is a key driver for the notable lower effective growing degree days projected for the 2040s across these northern districts relative to other districts. This is especially true for the district of Rajkot which is projected to experience a decrease in Effective Growing Degree Days (EGDD) due to the upper temperature limit being exceeded far more frequently than during present day conditions (2000-2019). Furthermore, the CRVA shows that while overall total rainfall during the growing season is projected to remain high and adequate for cotton cultivation, climate change will increase rainfall variability, and thus water availability. The analysis shows that water stress is projected to be significantly higher for all the districts located in the northern state of Gujarat, namely Rajkot, Banas Kantha and Mahesana, relative to the other districts. These districts also show a tendency towards drier conditions for the 2040s according to the projected SPI index, with the greatest decrease and lowest absolute SPI projected for the district of Mahesana.

The cotton cultivation CRVA also identifies that districts in Gujarat have amongst the lowest soil water holding capacity, and by far the lowest soil organic carbon stocks. Again, both of these are especially low for the district of Mahesana. Both soil water holding capacity and soil organic carbon are crucial drivers of land productivity and water security, as good quality soil can retain water during dry spells and avoid water stress. A series of interventions are necessary across the districts of Gujarat, and especially for Mahesana, to mitigate water stress across cotton growing areas.

1.2.1. Adaptation actions for the cotton cultivation sector

Aim: *Support programmes which implement irrigation channels, micro-irrigation devices and training on good water practice.* **Target area**: *Rajkot, Banas Kantha, Mahesana, Dhule, Khammam, Mahbubnagar, Yavatmal and Adilabad*

Irrigated cotton, versus rain-fed cotton, has higher resilience to periods of low-rainfall, drought, delayed or erratic monsoons, as cultivators have access to water during periods of low rainfall. Regions with irrigated cotton have greater adaptive capacity than rain-fed cotton during times of water stress, improving cultivators yields and incomes.

As is identified in the CRVA, while districts located in Gujarat have a higher percentage of total cotton grown as irrigated cotton relative to other districts considered in this study, a range of 16-35% is still low considering the projected increase in water stress and extreme rainfall events facing these districts with future climate change.

The CRVA also shows that the district of Dhule in the state of Maharashtra is both high in exposure and high in hazard scoring and has only 3% of its cotton grown as irrigated cotton. While districts including Khammam, Mahbubnagar, Yavatmal and Adilabad have the lowest % of irrigated cotton, these districts are projected to receive adequate rainfall during the growing period, therefore implementing measures to mitigate water stress is not as much of a priority. Nonetheless, given the increasingly delayed and erratic monsoons rainfall observed over the last few decades[xii], these districts would benefit from implementing measures to mitigate water stress at some point in the future.

Maharashtra has implemented numerous government-led and international-led projects supporting the implementation of irrigation systems over the last few years. One example is from the Jalna district in central Maharashtra, where a project led by the Sustainable Trade initiative (IDH) and Watershed Organisation Trust (WOTR)[xiii] is securing smallholder farmers' livelihoods by through coordinated solutions promoting water security and integrated livelihood opportunities. Solutions have been implemented which target cotton smallholder farmers, and these include improving access to water by constructing check dams and micro-irrigation devices (water absorption trenches, water impounding and harvesting structure) to conserve rainfall. Over 6,300 small-holder farmers have engaged with the initiative, and increased water infrastructure facilities have resulted in a 9% increase in water access thus far. In parallel, cultivators receive training on water management, good agricultural practices, training on female empowerment through the mainstreaming women's roles, and training on how to utilise meteorological advisories to inform on farm decision-making. Cultivator have also reported a 20% reduction in production costs and over a third of cultivators have added a second crop into production. Furthermore, the cost of cotton cultivation has reduced from Rs. 9,338 per acre in 2018 to Rs. 7,488 per acre.[xiv]

As shown by the success of the programme in Jalna, supporting initiatives which encourage the implementation of measures which promote sustainable water management, cognisant of future water scarcity conditions, through the building of irrigation channels and the holistic training on water management, could increase water security of smallholder farmers. Around ~38% of farms across Mahesana and ~34% of farms across Dhule are less than 1 hectare and thus, supporting similar initiatives in these districts would help build climate resilience in the face of increasing water stress.

1.2.2. Adaptation actions for the cotton processing sector

Aim: *Conduct water risk assessments for the cotton textile value chain for present and the future climate conditions, to develop context specific strategies for efficient water use and secure livelihoods of people engaged in the sector.* **Target area:** *Rajkot, Banas Kantha and especially Mahesana and Dhule*

Urban spaces in India experience high levels of water stress due to various demographic, geographical and climatic reasons. Rural-urban migration to search for employment opportunities, rapid and often unplanned urbanisation, and concentration of production hubs in cities cause significant increases in water demand.[xv] Deterioration in water quality, reduction in groundwater levels, inequitable distribution of water resources and an intermittent water supply[xvi] further impact the availability of, and access to, clean water. The state of Gujarat is drought-prone and has been facing significant water shortages. More than 20 districts in the state were severely affected in 2019, with water supply being limited to twice a week in towns and villages.[xvii] The city of Rajkot faced water shortages in 2020, as its water demand has increased from about 260 million litres per day in 2019, to 280 million litres per day in 2020.[xviii] The cotton processing and textile industry is heavily dependent on water. A textile unit producing around 9,000 kgs of fabric per day, consumes around 36,000 litres of water.[xix]

Columbia Water Centre, in partnership with Federation of Indian Chambers of Commerce and Industry, undertook a national level assessment[xx] to understand water risk perceptions and responses across 27 industrial sectors in India, including the textile industry. The study identified primary sources of water, impact of water availability on businesses at present and in the future, and initiatives undertaken for wastewater treatment and recycling. Industrial sectors such as textiles are highly vulnerable to water insecurity as they do not just rely on water availability for their operations but are also reliant on agricultural produce. A lack of data and assessments have been identified as a major gap in addressing inefficient water usage and water scarcity. Corporate water-related reporting has largely been qualitative, with descriptions of water stewardship initiatives, policies and programmes aimed at reducing internal water usage. However, most of these policies and programmes are not based on comprehensive quantitative assessments of present and future climate and water risks. The study states the importance of preparing climate and water risk and sustainability frameworks within the industry for quantification and analysis of water risks for the industry in different geographies, based on which context specific decision-making frameworks can be prepared for water risk reduction, sustainability reporting and disclosure.

The Institute for Sustainable Communities (ISC) has been working towards enabling adoption of water stewardship practices across the textile value chain in India.[xxi] This initiative is a part of the Women + Water Alliance, a public-private partnership led by the United States Agency for International Development (USAID) and Gap Inc., aimed at improving the health and wellbeing of women and communities directly or indirectly involved in the textile value chain. Based on research, stakeholder engagement and assessment of water stewardship practices, guidelines and tools across the CVC, ISC formulated a comprehensive list of best practices and categorised them according to their potential impact and costs. The study states that while most industrial units across the CVC are aware of water stewardship initiatives, there is no regulatory mechanism in place to drive them in a systematic manner. For example, due to specific environmental regulations in the state of Tamil Nadu, many processing units have internalised costs of environmental compliance through use of technologies such as zero liquid discharge.[6] In other parts of India with more relaxed regulations, such initiatives are not adopted. **Figure 7** presents examples of best practises in the processing sector for improving water use efficiency. Supporting textile businesses to implement regulations and measures to improve water stress, such as the implementation of a zero liquid discharge, the use of sustainable dyeing technology to reduce water consumption, or the reusing of waste water, would significantly help build resilience to water stress across the northern districts of Rajkot, Banas Kantha, and especially targeting Mahasena and Dhule.

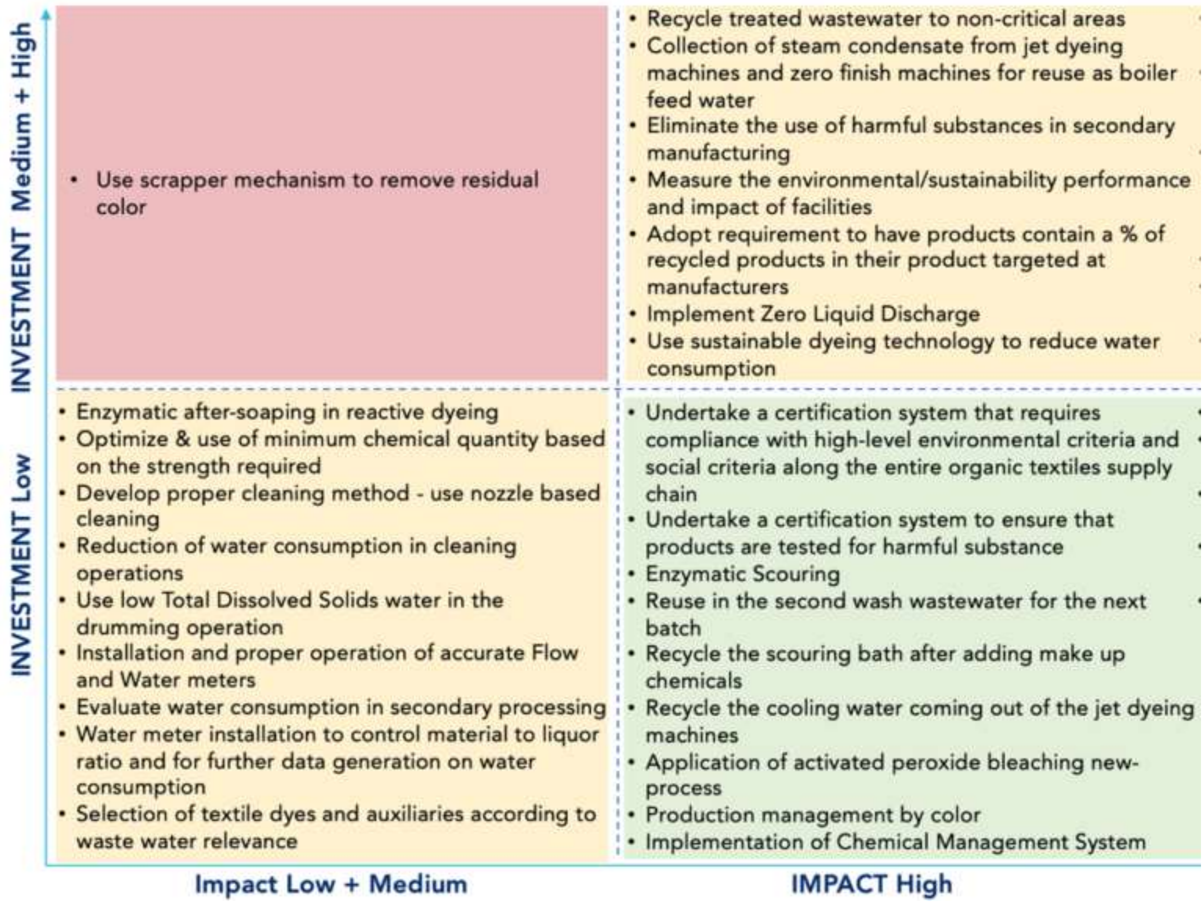


Figure 7: Examples of secondary processing best practices for water use efficiency. Source: Institute for Sustainable Communities (2020)

1.3. Challenge 3: Heavy rains, flooding and precipitation-induced landslides: Integrated watershed management and implementing adaptation measure to reduce the impact of flooding and the risk of landslides

With cotton cultivation across India predominantly rainfed cotton, the intensity, frequency and duration of rainfall is a key factor influencing production. Exposure to excess water, especially early in the growing period, will restrict root and crop development, while waterlogged conditions can result in complete loss of crop. For smallholder farmers, this can have a significant effect on livelihood outcomes.

[6] *Zero Liquid Discharge (ZLD) is a treatment process designed to remove all the liquid waste from a system.*

The CRVA shows that while Rajkot, Banas Kantha and Mahesana (Gujarat) are projected to be exposed to increasing water stress for the 2040s, these districts will continue to experience periods of extreme precipitation; significantly higher compared to the other districts considered in this study. As previously described, the soils in Gujarat are poor quality with less water holding capacity and soil organic carbon content, limiting permeability. Moreover, dried out soil following periods of drought, increases the risk of surface water flooding and soil erosion, following periods of heavy rain.

The CRVA identifies that the percentage of district exposure to projected flood risk during both a 1 in 10, and 1 in 100 year event is highest for Wardha in the state of Maharashtra, and Adilabad and Khammam, in the state of Telangana state. Extreme precipitation is projected to increase across these three districts. Furthermore, the absolute total rainfall received during the growing period is projected to be significantly higher for the districts of Wardha, Adilabad and Khammam relative to other districts, further increasing the risk of flooding. An additional hazard impacting these southern districts, is that the districts of Adilabad and Khammam are also projected to experience the greatest exposure to precipitation-induced landslides, with a coverage of 28% of total district area exposed to landslide risk across Khammam.

Extreme precipitation, flooding and landslides pose a threat to both agricultural crops and to buildings and infrastructure, hence is a risk to both the cotton cultivation and cotton processing aspect of the CVC.

1.3.1 Adaptation actions for the cotton cultivation sector

Aim: *Supporting the implementation of integrated watershed management.* **Target area:** *Rajkot, Banas Kantha, Mahesana, Dhule, Wardha, Adilabad and Khammam*

In rainfed areas, integrated watershed management can contribute significantly to the improvement of livelihoods and towards building climate resilience, as projects have shown that appropriate soil and water conservation practices can not only reduce surface water runoff, prevent soil erosion and land degradation, and reduce flood and landslide risk, but can also increase crop yield. Many organisations have attempted to promote improved land use and uptake of soil-water conservation (SWC) technologies at the community level to improve agriculture, improve livelihoods and prevent further erosion.[xxii] Government-led investments in the Adarsha watershed in Telangana implemented various SWC technologies and techniques. The project showed that the uptake of SWC practices significantly improved agricultural practices, and farmers realised returns amounting to US$720/ha from cotton.[xxiii] The SWC technologies and techniques implemented to reduce surface water runoff, to reduce soil erosion and to reduce the risk from flooding and precipitation-induced landslides included the construction of contour and graded bunds in the fields to minimise the velocity of runoff and allow more water to percolate into the soil to protect it from erosion, the removal of silt from river channels, the management of impoundment structures (e.g. sluice gates) to reduce peak discharge, and the control of runoff into soakaways to increases groundwater recharge. Other SWC practices to improve water and soil conservation included techniques such as balanced fertiliser application, use of improved seeds, supplementary irrigation and crop diversification. Before the above SWC project was implemented, the baseline average yield for cotton was 1050 kg/ha, however this increased to 1300 kg/ha after the watershed intervention, representing a 24% increase in yield.

As shown here, SWC approaches can reduce the risk of flooding from surface water runoff or fluvial flooding and can reduce soil erosion and protect soils from degradation, increasing crop yield, and reducing climate sensitivity by making degraded lands more suitable for cotton cultivation. Supporting and implementing projects which employ soil-water conservation practices across the districts of Rajkot, Banas Kantha, Mahesana, Wardha, Adilabad and Khammam could provide significant climate resilience benefits.

1.3.2. Adaptation actions for the cotton processing sector

Aim: *Implement adaptation measures such as early warning systems, real-time weather forecasting, and evacuation plans to reduce the impacts of flooding on urban areas.* **Target area:** *Rajkot, Banas Kantha, Mahesana, Wardha, Adilabad and Khammam*

As part of the Asian Cities Climate Resilience Network's working paper series, a study was conducted to assess the 'Flood-induced economic loss and damage to the textile industry in Surat City, Gujarat'[xxiv], following a significant flood event in 2006 that killed 150 people. The study aimed to estimate the extent of direct and indirect loss and damage to the textile and weaving industry in Surat and understand the measures adopted by the weavers and textile associations to build their resilience to flooding. The study found that businesses in the city were severely impacted by the 2006 floods, with each business assessed requiring 49 days to return to normal operation. Most workers left the city, causing a shortage of labour. The mean loss and damage for each business was assessed to be approximately US$ 20,400. The surveyed textile businesses were unable to access insurance, due to the reluctance of insurers to cover businesses located in flood risk areas. Prior to the 2006 flood, the study showed that around 63% of textile business owners had insurance. Despite the increase in insurance coverage, up to around 78% in 2014, the majority of respondents interviewed for the study clarified that the ground floor of their business premises are not typically covered by insurance. The study states that textile businesses are keen to buy insurance to reduce the potential impacts of floods, however, most insurance companies are not willing to insure their businesses, particularly the ground floor.

The study emphasises the overall urgency to implement measures to reduce the loss and damage to the textile industry following flood events, and proposes a set of infrastructure- and policy-based measures to help the textile industry become more resilient to climate change induced disasters. Infrastructure measures include the installation of permanent pumps within the industrial areas to help drain the flood waters, increasing the storm water drainage system, improving solid-waste management systems to increase the workers' health, incorporating tax waivers for businesses post-floods so that businesses can collectively invest in infrastructure facilities. Furthermore, many of the business owners interviewed for the study cited the availability of good quality and trustworthy insurance products as a measure to strengthen business continuity.

In 2011, the Surat Municipal Corporation developed its City Resilience Strategy to address the challenges of climate change in general, and flood vulnerability. This work was done in partnership with the Rockefeller Foundation's Asian Cities Climate Change Resilience Network and local experts such as TARU Leading Edge, an Indian urban development consultancy. A major objective of the strategy is to safely rehabilitate the poor and most vulnerable populations living in low-lying, flood-prone parts of the city. The first major accomplishment by the strategy was an early warning system that uses satellite data and hydrological models to forecast weather conditions. Mobile phone messages are sent to citizens 48 hours in advance of the release of water, which gives them time to react and evacuate, if necessary. The early warning system was critical in preventing large-scale devastation by a flood in 2013. Another important development was the setting up of the Urban Health and Climate Resilience Center (UHCRC) in 2013 to monitor the impact of extreme health events. Industrial units at Hazira also partly financed the building of a weir.[xxv]

Measures to prepare for and reduce the impacts of extreme precipitation and reduce the risk of flooding across Rajkot, Banas Kantha, Mahesana, Wardha, Adilabad and Khammam, are required to build climate resilience in these districts. To reduce the impacts on flooding, the support and implementation of measures, in collaboration with local and regional governments, such as early warning systems, real-time weather forecasting, and evacuation plans, are recommended. Other measures may include producing a detailed city-level flood risk assessment, the formation of designated overflow areas such as parks etc, and the implementation of improved upstream watershed management. To prepare for extreme hazards, facilitating access to insurance for textile business owners is recommended.

2. Sensitivity: How socio-economic improvements can help reduce vulnerability

The following present sensitivity indicator led solutions to help build climate resilience.

2.1. Challenge 4: Gender inequality: How encouraging women to engage in sustainable farming and other economic activities can reduce vulnerability

Women play a major role in the cotton value chain. As for the cotton cultivation sector, tasks undertaken by female farmers have a direct impact on the quality and quantity of cotton produced. The choices that women make in the field related to sowing, weeding, fertiliser application and pest management can be optimised with proper information and resources, allowing them to respond adequately to changing weather regimes and improve crop resilience in the wake of climate shocks and stressors. Yet females often do not have equal access to education, training, decision-making, skill development, finance and land-ownership, which limits their potential to improve cotton-productivity and break out of low-wage positions.[xxvi]

The CRVA shows that the district of Mahesana has the lowest percentage of rural females in the workforce (25%), followed closely by Rajkot, Nandurbar and Banas Kanthas (27%), Dhule (32%) and Yavatmal (33%). The other districts record a range of 41% to 64% which is still generally low.

As for urban female work participation, again these are predominantly low in the districts located in the northern regions, namely Banas Kantha (9%), Rajkot (10%), Mahesana (11%) and Dhule (14%) and Latur (15%). All other districts fall within a range of 17% to 27%, which shows that urban female work participation rate is significantly low across all districts.

Access to education and overall literacy is positively correlated with climate resilience, as it allows access to information and knowledge, and increases the possibilities of accessing jobs of higher pay. Rural female literacy rates amongst cultivators are very low at 18% in Mahbubnagar, Adilabad (25%), Karimnagar (28%) and Khammam (33%). Urban female literacy rates amongst manufacturers are slightly higher, but still low, especially in Adilabad (51%), Khammam (58%) and Karimnagar (61%).

The CRVA shows that gender inequality is an issue across all districts. This is a compound issue which varies in root cause across districts, from gender pay gap across the districts located in Maharashtra, female participation in the workforce across districts located in Gujarat to literacy rates across districts located in Telangana. Moreover, these discrepancies are higher for rural cultivators relative to urban manufacturers, however discrepancies are still high for urban manufacturer communities.

2.1.1. Adaptation actions for the cotton cultivation sector

Aim: *Supporting educational and training programs which aim to empower female cotton farmers and encourage rural women to participate in economic activities.* **Target area:** *Rajkot, Banas Kantha, Mahesana, Mahbubnagar, Adilabad, Karimnagar, and Khammam*

Encouragingly, initiatives focused on reducing gender disparity and female empowerment are taking place across India. Irish retailer Primark and CottonConnect, in collaboration with a local NGO partner, established a sustainable cotton programme in Gujarat which focused on supporting female farmers to learn sustainable farming methods, improve cotton yields and increase incomes. Women were trained in the most appropriate farming techniques for their land, and decision-making with regard to seed selection, water use, pest management and pesticide use, fibre quality and grading, and proper storage of harvested cotton. Over 1,250 female smallholders were trained through classroom sessions, in-field training and learning groups. The results of the initiative resulted in average small-holder profit improvements of 211%, and an increase in household incomes.[xxvii]

Furthermore, a 'Business case for gender mainstreaming in cotton in Maharashtra'[xxviii] commissioned by IDH, The Sustainable Trade Initiative, analysed gender-related division of labour and responsibilities on cotton farms, women's participation in decision making processes and their access to resources and constraints that limit women's role in cotton production. The study also assessed existing farm practices, women farmer's access to support through schemes, training, subsidies, finances and extension services. The business case builds on the assessment's findings and suggests strategies such as building knowledge and skills of women farmers in agronomic practices, and digital and financial literacy, improving access to credit linkages, government schemes and extension services, forming women farmers' cooperatives (Self Help Groups) and sensitising communities and addressing gendered social norms.

A series of similar interventions to encourage women to participate in agricultural economic activities would be especially beneficial in Rajkot, Banas Kantha and Mahesana to build resilience across rural communities. Furthermore, supporting programmes which educate women around sustainable farming, and enable women to access training and education, would also highly benefit climate resilience-building effort in these districts in addition to Mahbubnagar, Adilabad, Karimnagar, and Khammam.

2.1.2. Adaptation actions for the cotton processing sector

Aim: *Create an enabling policy environment to empower women engaged in the CVC and ensure effective implementation and reach. Build capacity and enhance skills of women engaged in cotton cultivation and across the textile value chain.* **Target area:** *Rajkot, Banas Kantha, Mahesana, Dhule, Latur, Adilabad, Karimnagar, and Khammam*

The majority of the unskilled and semi-skilled workforce within the textile value chain constitute women.[xxix] Gender pay gap, lack of wage security and benefits, and poor working conditions subject women workers to exploitation and discrimination in the textile and garment industry.[xxx] The handloom sector, which is largely unorganised and consists of small scale household based units, engages about 3.5 million handloom workers, out of which 2.3 million workers (over 70%) are women, mostly within the age bracket of 18-35 years.[xxxi] The demand on women in the handloom sector is high, as in addition to handloom activities, they are also responsible for household chores and family care work.[xxxii] Most women in the handloom sector are involved in allied activities such as pre-loom and post loom activities[xxxiii], which constitutes around 24% of the handloom workforce.[xxxiv] A higher proportion of women handloom workers are self-employed compared to men engaged in the sector, making them particularly vulnerable.[xxxv] Most handloom workers belong to socio-economically marginalised groups, with about 67% of weaver households earning less than US$ 70 per month.[xxxvi]

To empower women engaged in the sector, the Ministry of Textiles has introduced multiple schemes such as the National Handloom Development Programme, the Handloom Weavers' Comprehensive Welfare Scheme, the Yarn Supply Scheme and the Comprehensive Handloom Cluster Development Scheme.[xxxvii] As part of the National Handloom Development Programme, a 100% subsidy is given to women belonging to Scheduled Castes, Scheduled Tribes and who are living Below Poverty Line (BPL) for construction of workspaces, and are provided 75% subsidy for enrolling under Indira Gandhi National Open University (IGNOU) and National Institute of Open Schooling (NIOS). Under the Ministry's Integrated Skill Development Scheme, women were trained to bridge the skill gap in the textile sector.[xxxviii] The Stand-up India scheme provides subsidies and financial assistance to women entrepreneurs from marginalised communities to purchase power-looms and other machinery.

Alongside the introduction of schemes for women workers in the textile sector, it is imperative to increase awareness amongst females living in urban communities about government schemes, eligibility and how to access benefits available for them. Supporting initiatives which aim to empower women to engage with economic activities, especially textile and cotton processing activities, would highly benefit the districts of Rajkot, Banas Kantha, Mahesana, Dhule, Latur, Adilabad, Karimnagar and Khammam to build resilience amongst their urban communities.

2.2. Challenge 5: Small-holder farmers forming co-operatives to reduce vulnerability

Marginal and small landholders are often non-viable for commercial production, are resource-constrained, lack access to technology and information to boost productivity.[xxxix] They lack the capacity to manage and respond to climatic events (e.g. access to irrigation during periods of water stress) and therefore tend to have higher vulnerability to climate change, as compared to larger farms with better access to resources. The CRVA shows that a key driver of climatic sensitivity is the proportion of marginal landholdings (<1 ha), which is significantly high in Karimnagar (67%), Khammam (62%), Mahbubnagar (58%) and Adilabad (50%), all of which are located in Telangana.

2.2.1. Adaptation actions for the cotton cultivation sector

Aim: *Supporting initiatives which encourage cotton farmers to create group farms or co-operatives.*
Target area: *Karimnagar, Khammam, Mahbubnagar and Adilabad*

The pooling of land and labour into group farming, or farming cooperatives, can offer farmers economies of scale; reduced expenses for farm inputs, shared labour and skills, and greater access to markets and government support. These advantages are particularly beneficial for women cultivators. In Telangana, research shows that group farming results in savings on purchased inputs, in particular hired labour, while matching annual productivity of individual farms.

A recently published paper evaluates the success of a project by the United Nations Development Programme (UNDP) and the Government of India which supported 500 group farms across Telangana between 2001-2005.[xl] Under the project, the UNDP-GoI provided small-scale farms, which were solely managed by women, with a seed grant of Rs. 35,000 as a start-up revolving fund, agricultural implements, training in specialised agricultural practices, and financial literacy. The research has shown that group farming can provide an effective alternative, subject to specified conditions and tailoring of the model to the local context. Group farming could provide them a dependable labour force, more investible funds and skills, and greater bargaining power with governments and markets. These potential advantages could prove especially important for women farmers who face production constraints over and above those faced by cultivators in general.

The CRVA results reveal that not only do districts located in Telangana score highest with regards to percentage of marginal and smallholder farmers, especially Karimnagar (67%), but they also score highest in terms of rural female head of household, at up to 20% in Khammam. Considering the benefits of group farming in terms of economic security for female farmers, supporting the implementation of group farming or farming co-operatives would help build climate resilience in Mahbubnagar, Adilabad and especially Karimnagar and Khammam.

2.3. Challenge 6: Combatting land degradation and soil erosion

Unsustainable land management practices and soil erosion increases the vulnerability of a district to climate change as soil erosion is a major threat to cotton cultivation, particularly in rain-fed areas, where continuous soil erosion reduces land productivity and harms livelihoods. Soil erosion, by wind and water, strips topsoil of its organic content as well as acidity, salinity and alkalinity, making soils unsuitable for agricultural activities.[xli] Particularly in rain-fed areas, continuous erosion reduces land productivity and poses a major threat to cotton cultivation. Growing cotton on degraded soils increases climate vulnerability as the soil has limited capacity to sustain the crop, and no capacity to mitigate climatic hazards (e.g. waterlogging and drought).

Approximately 90% of cotton grown in India today is Bt cotton.[xlii] This variety was first developed in the 1970's as a cotton variety resistant to bollworm. While it was initially effective and temporarily reduced pesticide use, secondary pests emerged with high pest resistance. The over-reliance on Bt cotton and lack of seed diversification has resulted in high input costs through pesticide overuse and lower profit margins.[xliii] Furthermore, Bt-cotton has resulted in widespread monocropping, a lack of seed variety, and extensive fertiliser and pesticide use, which greatly deteriorates soils and eventually makes land unsuitable for further cultivation. Areas with a high ratio of Bt-cultivated cotton are more climatically sensitive due to poor soil health from extensive chemical inputs, and poor performance under water-stressed conditions.

Bt cotton is grown extensively across all the districts analysed in this study, however the CRVA shows that the proportion of degraded and waste land is highest for Dhule (53%) and Adilabad (48%). Furthermore, Dhule ranks second place in terms of hazard risk due to projected increase in drought conditions, wildfire risk and increase in damaging wind speeds – all of which contribute to increasing land degradation and soil erosion.

2.3.1. Adaptation actions for the cotton cultivation sector

Aim: *Supporting initiatives which provide education and training to cotton farmers on cultivation methods that prioritise soil health.* **Target area:** *Dhule and Adilabad*

A range of initiatives have successfully supported the training of farmers in sustainable land management practices, improving soil health and achieving more secure livelihoods. For example, the Laudes Foundation has supported 23,000 cotton farmers to convert to organic cultivation practices, of which 16,000 of these will be organic certified and will receive a premium for their cotton.[xliv] Ecological and organic cotton farming, that utilise diverse seeds, integrates crop rotation, and require minimal or no chemical inputs, can improve cotton productivity while improving soil health, and land quality.

CottonConnect's Organic Cotton Farmer Training Programme prioritises soil health as a key component in supporting farmers to develop skills and knowledge to transition to organic. Farmers learn a range of skills including how to intercrop cotton with peas or beans to support nutrient fixation and ultimately improve cotton quality; how to compost and organically add nutrients to the soil; and how to produce organic fertiliser, greatly reducing input costs. Improved soil management through composting also increase water filtration in the soils, making soils less prone to waterlogging during wet periods, and helping soils to retain moisture during dry periods.[xlv] Cotton cultivation practices that prioritise soil health (organic, ecological) can greatly improve productivity while enhancing the health and resilience of the land.

An initiative by the International Cotton Advisory Committee (ICAC) has developed a mobile phone application named the 'Soil and Plant Health App', which uses the GPS location of a particular field to enable a cotton farmer to receive information about the specific field of interest directly to the phone.[xlvi] The mobile phone application provides a complete diagnosis for soil health and plant health, soil nutrient deficiencies, insect pests and beneficial insects, diseases and nematodes, agrochemical toxicities and extreme weather changes. Furthermore, the application has a unique voice over feature for illiterate farmers and is available in four Indian languages.

Supporting and implementing initiatives similar to Laudes Foundation and CottonConnect's organic cotton training programmes, and ICAC's mobile phone application, which provide education and training to cotton farmers on cultivation methods that prioritise soil health, would benefit the districts of Dhule and Adilabad, and increase the climate resilience of rural communities.

2.4. Challenge 7: Creating an enabling a policy environment for boosting growth and investments across the cotton value chain

The CVC in India is complex, with small landholdings, small scale and fragmented processing units, as well as large sized organised textile mills and enterprises.[xlvii] This makes it challenging to strengthen cotton value chain linkages. However, over the past decade, the sector's expanded considerably with new enterprises and integrated manufactures and technology upgradation[xlviii], providing more employment opportunities. Many of these have been a result of schemes and incentives introduced by the Ministry of Textiles. The CRVA shows that the districts with the lowest number of cotton processing factories are Nagpur, Nandurbar, Dhule and Mahbubnagar.

2.4.1. Adaptation actions for the cotton processing sector

Aim: *Create an enabling policy environment for the cotton value chain through schemes and incentives for boosting investments and engagement in cotton processing and the textile value chain. This will help build synergy and improve linkages across the CVC and address existing gaps.*
Target area: *Nagpur, Nandurbar, Dhule and especially Mahbubnagar*

Telangana implemented a set of schemes as part of the Telangana Textiles and Apparel Policy (2017), to boost downstream investments and generate employment opportunities in the textile sector, with a focus on processing, spinning, weaving, knitting and garment manufacturing. While the state produces one of the finest long staple cotton varieties, the CVC is largely limited to cotton cultivation and ginning and pressing. While the state produces roughly 6 million bales of cotton, spinning units in the state, as of 2017, had the capacity to spin only a million bales, annually.[xlix] Due to lack of spinning and weaving units in the state, processed cotton is exported to neighbouring states such as Andhra Pradesh, Gujarat and Maharashtra, for further value addition. To address these gaps in the value chain, the policy introduces schemes for capital assistance for new and existing units, operational assistance including power tariffs, interest and tax subsidies, assistance for energy, water and environmental compliance to existing units and incentives for adopting environmental protection measures, assistance for purchase of new technology and capacity building, among others. The 'Fibre to Fabric' incentive provides additional subsidies for entities that establish production chains from production of fibre to fabric. The policy also includes support provisions for the largely unorganised small-scale weaving sector. Along with a focus on encouraging investments and generating employment opportunities for the local population, the policy emphasises on providing 'fair and decent wage to the workforce'.[l,li]

Support in implementing a similar incentive to the 'Fibre to Fabric' to encourage the establishment of cotton processing units in order to add value to raw cotton, would not only increase financial security and decrease the dependency on agriculture, but would increase the adaptive capacity and build climate resilience across the districts of Nagpur, Nandurbar, Dhule and Mahbubnagar.

2.5. Challenge 8: Reducing volatility in cotton yield and production to reduce vulnerability along the cotton value chain

Volatility in cotton prices may be due to several factors such as fluctuation in global market prices, national regulation, subsidies and stockpiling. Crop failures due to various production constraints such as small land holdings, rainfed cotton cultivation, weather-related natural hazards and a lack of irrigation resources are a major challenge for cotton farmers. This creates an uncertain market for farmers and has knock-on effects across the CVC. For example, increase in cotton prices and market competitions have heavily impacted ginning and spinning mills in India.[lii] While minimum support price (MSP) and procurement regulations introduced by the government and the Cotton Corporation of India provides a certain degree of income security to cotton farmers[liii], enterprises across the cotton value chain have struggled with fluctuation in market prices. In 2018, the Government of India increased the minimum support price for cotton by 28%, to ensure that cotton farmers receive a minimum of 50% profit on their production costs.[liv] While this has boosted cotton production, the textile industry, especially small spinning and weaving units, faces the challenge of purchasing raw cotton at higher prices. In 2019, the difference between prices of yarn and cotton (cotton price spread) fell as low as US$ 1/kg, leading to low profit margins for the spinning industry.[lv] The price of yarn, being an intermediary product, is dependent both on cotton prices as well as the demand in the fabric market.[lvi] Raw cotton exports have been increasing since 2004, leading to the domestic textile industry competing with the international market.[lvii] In the domestic market, price differences in different states is also a major challenge.[lviii]

The CRVA shows that cotton yield volatility between 1998 and 2007 was highest for Rajkot, Latur, Banas Kantha and Nagpur, while the districts with the highest production volatility were Rajkot, Yavatmal and Adilabad. While the volatility in yields is a greater driver of vulnerability across the cotton cultivation sector and thus rural cotton farmers, volatility in production has a greater impact on the vulnerability of urban, textile manufacturers.

2.5.1. Adaptation actions for the cotton cultivation sector

Aim: *Identify financial bottlenecks which limit fair price realisation for farmers. Equip farmers with price and market information, introduce regulatory mechanisms to connect farmers to the market,* *identify effective measures to improve price transparency and empower farmers through formation of cooperatives to better control local markets.* **Target area:** *Rajkot, Latur, Banas Kantha and Nagpur*

IDH, in collaboration with Technoserve, studied the status of cotton cultivation in Maharashtra to understand existing challenges which inhibit cotton farmers' incomes and outline a strategy for improving farmers' livelihoods and incomes.[lix] One of the major challenges identified by the study is cotton farmers are often not adequately compensated for high quality cotton, with aggregators and local middlemen often capturing the bulk of profits. The assessment finds considerable differences in cotton prices in different districts, based on access to government's minimum support prices and Agricultural Produce Market Committee (APMC)[7] as opposed to markets dominated by aggregators and local middlemen. For example, in the district of Yavatmal, only 2 percent of raw cotton was sold by farmers to local aggregators, while in the district of Jalna, about 98 percent of cotton was sold to middlemen. Districts with better competition, could sell their produce at a higher rate, while those dominated by aggregators negatively impact farmer price realisation. The other financial challenge recognised is that farmers' access to finance remains limited to crop loans. To address price realisation challenges, the strategy suggests a variety of measures such as better market linkages and information, formation of cotton farmers' cooperatives for farmers to better control the market through collective selling and purchasing, improving access to crop insurance and lint-based marketing to avoid opaque pricing, among others.

Supporting initiatives which aim to improve cotton farmers' access to financial compensation and crop insurance would mitigate the impacts of yield volatility on rural farming communities, especially across the districts of Rajkot, Latur, Banas Kantha and Nagpur, decrease vulnerability and help build climate resilience.

2.5.2. Adaptation actions for the cotton processing sector

Aim: *Assess cotton price volatility along the CVC to understand existing bottlenecks and economic and political drivers for different CVC interest groups. Introduce measures to improve access to information and technology and empower farmers, weavers and decentralised units to be able to make more informed market decisions. Provide financial safety nets for farmers, cooperatives and spinning and weaving units to reduce market risks associated with price volatility and demand supply gaps.* **Target area:** *Rajkot, Yavatmal and Adilabad*

The International Institute for Sustainable Development (IISD) conducted an assessment of price volatility in the cotton yarn industry[lx] to understand how price volatility of cotton and cotton yarn impacts different rungs of the CVC, and national and local interventions implemented to address price volatility challenges and provides recommendations to address these. The study notes that most efforts made in the sector have been disjointed and there is need for a more integrated and systematic approach to tackling price volatility across the CVC. The study's recommendations include institutional corrections such as maintaining yarn stocks, cooperatives creating reserve funds for periods of high price volatility, regulation of cotton trade through licensing and price caps, enabling cotton farmers and weavers to take control of cooperative mills, and integrating spinning and weaving activities. Furthermore, the study also recommends improving technology access to encourage scaling up of small units in cotton growing areas, make price information available to farmers, spinners and weavers through rural kiosks, radio, etc. and encourage; strengthening

[7] *Agriculture markets are regulated under the Agricultural Produce Market Committee (APMC) Act and enacted by State governments.*

supply and trading processes through effective procurement mechanisms, market based risk instruments to manage price fluctuations caused by unforeseen issues such as weather variability and market price fluctuations, improving access to exchange markets and infrastructure, and more research to strengthen risk insurance for farmers and all actors across the CVC; enhancing capacity and knowledge of farmers and weavers to access and read trends; and expansion of financial and technological support and funding from the mill sector to farmers and weavers. Overall, the study emphasises the need to base interventions on social, economic and political drivers for decision making among different interest groups along the CVC.

The plethora of recommendations stated in the study would highly benefit the districts of Rajkot, Yavatmal and Adilabad, thus supporting projects and programs which aim to implement such measures, including the formation of cooperatives to create reserve funds for periods of high price volatility, improving technology access to make price information available through rural kiosks and radios, and encouraging more research to strengthen risk insurance for all actors across the CVC.

3. Adaptive capacity: Supporting communities through skills, training etc and buildings capacity

3.1. Challenge 9: Fair wages: Improving social compliance and empowering workers

Adaptive capacity is poor among low-wage earners, and the impacts of climatic events are disproportionately felt by those with poor access to resources. Low wages among cotton farmers result in less resources for savings, less ability to make investments into better agricultural practices or diversity income, and less ability to rebound after shocks and stress, for example floods, droughts or pest outbreaks. Low wages among workers in the processing sector likewise results in less resources for savings, more working hours to meet basic needs, and less ability to rebound after market volatility / price spikes.

The CRVA shows that the average daily wages for male cotton labourers are variable ranging from a low of 192 Rs/day (Mahesana) to a high of 460 Rs/day (Rajkot). The districts with the lowest male wages are Mahesana (192 Rs/day), Dhule (200 Rs/day) and Latur (200 Rs/day) in Gujarat, Yavatmal (192 Rs/day) in Maharashtra, and Khammam (192 Rs/day) in Telangana. Average daily wages for female cotton labourers are lower than male wages, ranging from a low of 100 Rs/day to a high of 300 Rs/day. The districts with the lowest female wages are Dhule (100 Rs/day), Latur (100 Rs/day), and Nandurbar (115 Rs/day) in Maharashtra. The CRVA shows that the gender pay gap is high in the majority of districts in this study (between 20-60%) and is illustrative of gender inequality among cotton farmers. In Maharashtra women cultivators are typically paid 150 Rs/day (£1.5) while men are paid 200-300 Rs/day (£2-3). Difference in wages between male and female cotton growers is highest for all districts located in Maharashtra – namely Nandurbar, Nagpur, Latur, Wardha, Yavatmal, Dhule. Additionally, according to a 2019 study in Maharashtra, only a third of women cultivators had received any training in the last two years.[lxi]

The CRVA shows that average daily wages for males engaged in cotton processing activities range from a low of 192 Rs/day to a high of 769 Rs/day (Nagpur). The district with the lowest wages is Khammam, Telangana (192 Rs/day), followed by Nandurbar (231 Rs/day) in Maharashtra. Wages are also low in Mahbubnagar (300 Rs/day), Wardha (300 Rs/day) and Latur (346 Rs/day). Data was unavailable for the wages of females in the cotton processing sector. Thus, a comparison was not possible.

3.1.1. Adaptation actions for the cotton cultivation sector

Aim: *Support initiatives which encourage farmers to produce cotton in a sustainable manner to be rewarded with a Fairtrade minimum price and a Fairtrade premium.* **Target area:** *Mahesana, Dhule, Latur, Yavatmal and Khammam*

Initiatives that minimise production costs (e.g. fertilisers), and standards that fetch a higher price for cotton (e.g. organic, Fairtrade) serve as a means to improve the livelihoods of cotton farmers and minimise harmful environmental practices. Chetna Organics, based in Maharashtra, is India's largest organic and Fairtrade producer. They supported 15,279 cotton-cultivating families organised into 13 cooperatives since its inception in 1994. Organic farming provides farmers with the opportunity to obtain yields on par with conventional cotton while drastically minimising the high production costs associated with pesticides and chemical fertilisers. Farmers that produce cotton in a sustainable manner are rewarded with a Fairtrade minimum price and a Fairtrade premium. The Fairtrade premium is an additional sum of money that is pooled into a communal fund for farmers and cultivators to use as deemed necessary. This could entail providing payments to farmers to otherwise prevent them from selling cotton when prices are low or investing in technological investments or infrastructure that build climate resilience. Additionally, investments have included constructing warehouses for cotton storage so that communities can store cotton and sell it when the price is high.[lxii,lxiii]

As identified in the CRVA, cotton farmers in the districts of Mahesana, Dhule, Latur, Yavatmal and Khammam would highly benefit from being engaged in Fairtrade initiatives to not only improve the wages for cotton farmers in general, but to also eliminate the significant gender disparity in wages.

3.1.2. Adaptation actions for the cotton processing sector

Aim: *Support the implementation of programs such as the Fairtrade Textile Programmes which supports supply chain actors in changing their approach to tackling social compliance.* **Target area:** *Khammam, Nandurbar, Mahbubnagar, Wardha and Latur*

As for people employed in the textile industry and the cotton processing aspect of the CVC, Fairtrade International, an ethical marketing organisation, has introduced the Fairtrade Textile Standard as part of the Fairtrade Textile Programme, aimed at facilitating change in textile supply chains and associated businesses. Recognising the existing challenges in the textile industry such as lack of safety in workspaces, low wages, forced labour and gender-based violence in the largely unorganised sector, the organisation launched the Fairtrade Textile Programme to support supply chain actors in changing their approach to tackling social compliance. The Fairtrade Textile Standard sets requirements for participation in the Fairtrade system for workers across the textile supply chain, focusing on improving living standards of workers, and empowering them socially and economically. As part of this initiative, the organisation supports management of production sites through preparing action plans and providing specialised training .

The CRVA results point to the districts of Khammam, Nandurbar, Mahbubnagar, Wardha and Latur as potential important beneficiaries of the Fairtrade Textile Programme, as all these districts record low average wages for males engaged in cotton processing activities.

3.2. Challenge 10: Increasing access to banking services to increase financial security.

Access to banking services provides a form of security in the face of disaster. Banking facilities are an important indicator of wealth and provide information related to the adaptive capacity of the region in response to extreme events or climate related shocks. The higher the proportion of urban and rural population with access to banking services, the higher the adaptive capacity.

The cotton cultivation CRVA shows that access to banking services is low for rural communities across all districts ranging from 30% to 67%. It is particularly low in Khammam, Telangana (42%), Dhule, Maharashtra (38%) and especially in Nandurbar, Maharashtra where the proportion of households availing banking services out of the total rural population is as low as 30%. Maharashtra has the districts with the lowest access to bank accounts Nandurbar (30%) and Dhule (38%).

Access to banking services is comparatively higher in urban communities, ranging from 56% to 73.3. Access to bank accounts is low in Telangana; Khammam (57%), Mahbubnagar (58%), and Maharashtra; Dhule (58 %) and as with rural areas, is the lowest in Nandurbar (56%). The proportion of urban households with access to banking services is lowest in Telangana, followed by Maharashtra.

Access to banking services is greater in urban areas than rural areas across all districts, with the exception of Latur, Maharashtra where it is equal. For example, in rural Nandurbar 30% of households have access to banking services, compared to urban Nandurbar where 56% of households have access.

3.2.1. Adaptation actions for the cotton cultivation sector

Aim: *Support initiatives which help set up 'banking kiosks' in rural communities*. **Target area:** *Khammam, Dhule and especially Nandurbar*

Access to banking facilities are low to moderate for rural communities, and particularly low for rural women who seldom have opportunities for land ownership and decision-making in farming practices. Rural women tend to lack experience in commercial transactions and have limited knowledge of private and public financial products and services. Yet research shows that when women cultivators have access to decision-making, it can result in a profit increase of 40%.[lxiv]

Technoserve in partnership with Visa Inc and Gap Inc piloted a project in 60 villages in the state of Madhya Pradesh to advance women's decision-making and create access to finance. One of the programme's initiatives involved bringing a banking representative to a local residence at a time whereby a group of women could convene and set up their own bank accounts. A bank account would allow women to save formally, grow investments, withdraw funds as needed, and enable digital payments for business transactions. The initiative also set up 'banking kiosks' located in rural areas as bank branches are often concentrated in populous areas and reaching a bank for a transaction can take a full day. These initiatives increase women's income and decision-making power on the farm, making them more resilient and better equipped to manage climate stressors.[lxv]

Launched by the International Fund for Agricultural Development (IFAD) in 2012, the Adaptation for Smallholder Agriculture Programme (ASAP) is the world's largest climate change adaptation programme for smallholder farmers.[lxvi] The aim of the trust fund is to channel climate finance to smallholder farmers so they can access the tools and technologies that help build their resilience to climate change, reaching millions of smallholders worldwide, including across India. ASAP empowers community-based organizations to make use of new climate risk management skills, information and technologies and combine them with tried and tested approaches to sustainable land and water management. For example, improved weather station networks are providing farmers with more reliable seasonal forecasts while mapping technologies are helping farmers to better understand and monitor landscape use in a changing environment. India is the largest borrower from the IFAD Fund, and IFAD has invested US$2.8 billion, including US$1 billion of IFAD's own financing, through 28 projects, directly benefiting some 4.6 million households. In partnership with the government, these IFAD-supported projects have delivered significant results in various areas including the commercialization of smallholder agriculture, grass-roots institution building to enable communities to manage their own development, the empowerment of women, and the improvement of livelihoods in tribal and other communities.[lxvii]

While this pilot project occurred in Madhya Pradesh, it could be applied to Khammam, Dhule and especially Nandurbar to increase access to bank accounts for rural women, men, and households, and thus help build resilience across rural communities.

3.2.2. Adaptation actions for the cotton processing sector

Aim: *Support initiatives which encourage training in financial literacy and improve access to and invest in technologies such as ATMs, telephone and internet banking.* **Target area:** Khammam, Mahbubnagar, Dhule and especially Nandurbar

Access to banking services is comparatively higher in urban than rural communities, ranging from 56% to 73.3%, yet there is still a large proportion of the population without a bank account. In recent years, the Indian government undertook an ambitious strategy to enhance financial inclusion (both in rural and urban areas) to achieve development objectives. Government sponsored programmes promoted access to no-frills savings accounts for low-income groups that required zero balance to set up and offered very low maintenance fees. Additionally, expanding technologies such as ATMs[8], telephone and Internet banking and biometric point of transaction terminals have been very successful in enhancing access in a region like India, where telecommunications, particularly in urban areas, are strong. Yet surveys show that accessibility still remains an issue with low-income workers needing to pay a substantial portion of their wages to travel to a bank, wait in long queues at the bank to be served and thereby foregoing a working day as a result.[lxviii] While efforts to enhance banking access have been broadly successful across India, the urban and rural working poor still tend to channel savings into informal saving mechanisms.[lxix]

Efforts to enhance financial literacy and bank accessibility; potentially through longer operating hours, more locations, information on how to use telephone/wireless options, may help facilitate greater uptake among urban cotton processors in the districts of Khammam, Mahbubnagar, Dhule and especially Nandurbar.

3.3. Challenge 11: Increasing access to technology/Internet access to increase access to information.

Access to technology and to the internet enables households to receive emergency warnings prior to disasters, increasing their ability to respond to warnings and take preventative measures. The

[8] *In recent years there has been an enormous growth in ATMs in India; between 2014 to 2017 ATMs grew by 28% across India.*

higher the proportion of the rural population with access to the Internet, the greater their adaptive capacity.

The cotton cultivation CRVA shows that access to technology and Internet for rural communities is extremely low, ranging from 0.3% to 0.9%. The districts with the lowest access are Karimnagar (0.4%) and Mahbubnagar (0.3%) in Telangana, Nandurbar (0.4%) in Maharashtra and Banas Kantha (0.3%) in Gujarat.

Access to technology and Internet is comparatively higher in urban communities, whilst still low, ranging from 0.7% to 8%. The districts with the lowest access are Adilabad (0.7%), Karimnagar (2.6%) and Mahbubnagar (3%) in Telangana, and Banas Kantha (2.5%) in Gujarat.

3.3.1. Adaptation actions for the cotton cultivation sector

Aim: *Support programmes which help rural cotton farmers access web-based Decision Support System (DSS).* **Target area:** *Adilabad, Karimnagar, Mahbubnagar and Banas Kantha*

To help cotton farmers access real-time data to help make informed decisions, WWF-India's Sustainable Agriculture Programme (SAP) in collaboration with Swedish multinational IKEA, introduced in 2017 the 'Cotton Doctor' mobile app, an Android and web-based decision support system.[lxx] The app delivers alerts about extreme weather events, pest forecasts and irrigation advice straight to the farmers' smartphones – this information assists them in making effective farming decisions. While not all farmers have access to a smartphone, WWF-India has launched a physical 'farmer kiosk' in the Jalna district of Mahrashtra, which allows farmers from the district to access the app via a tablet computer situated inside the kiosk. WWF-India expects around 30,000 farmers to benefit from access to the kiosk.

Supporting programmes which help rural cotton farmers access web-based Decision Support System (DSS), such as the 'Cotton Doctor' mobile app would highly benefit all districts addressed in this study, but would especially help build climate resilience in Adilabad, Karimnagar, Mahbubnagar and Banas Kantha.

3.3.2. Adaptation actions for the cotton processing sector

Aim: *Help textile businesses to access government funds to facilitate the adoption of ICT.* **Target area:** *Adilabad, Karimnagar, Mahbubnagar and Banas Kantha*

A study[lxxi] published in 2007 assessed the level of technology adoption within the context of the Indian garment industry. Access to technology and access to the Internet generally helps to reduce production cost and time, enables manufacturers to market their products online, and ensures that the Indian garment manufacturers remain competitive and grow relative to global markets. The study, which has a number of important translatable messages for the pre-garment manufacturing CVC (the subject of our study), showed that small firms have less access to technology compared to larger firms, and that small sized firms may be constrained by available resources that could otherwise be allocated to the adoption of advanced technologies, and thus are limited in responding to global competition. Moreover, this potential lack of ICT may hinder access to information that can help companies take action on weather- and climate-related risks. Smaller firms therefore require support from government initiatives and industry programmes to remain competitive and access the resources that support their businesses.

The Government of India is making investments under the Credit Linked Capital Subsidy and Technology Upgradation Scheme (CLCS-TUS) to encourage private investment in the Indian textile and apparel industry, to facilitate modernisation / technology upgradation of textiles mills, to make available funds to the domestic textile industry for existing units as well as to set up new units with state-of-the-art technology, and to facilitate the upgrade existing technology to a substantially higher tech level. Specifically, the Promotion of Information and Communication Technology in MSME Sector[lxxii] scheme was set up to encourage and assist small businesses in adopting ICT applications to achieve competitiveness in national and international markets. The broad activities planned under the scheme include identifying target cluster for ICT intervention, setting up of e-readiness infrastructure, developing web portals for clusters, skill development of MSME staff in ICT applications, preparation of local software solution for MSMEs to enhance their competitiveness, construction of e-catalogues and e-commerce etc., and networking MSMEs on a national portal in order to outreach MSMEs into global markets. It is possible that schemes, like the above, could be used to disseminate and create business to business dialogue around managing physical climate risks, including the sharing of good practices and guidelines covering many of the issues described in this section.

Helping textile businesses to access the fund in order to implement measures to facilitate the adoption of ICT would not only ensure that textile businesses remain competitive on a national and global stage, but also help them indirectly build resilience, particularly across the districts of Adilabad, Karimnagar, Mahbubnagar and Banas Kantha.

Next steps

How should this report be used?

The India Analysis, and the broader Global Analysis, were both generated by Cotton 2040 in response to the lack of comprehensive, readily available information about how the climate crisis is likely to impact cotton production, its supply chain, and the nature of the industry over the coming decades. The reports and supporting resources are aimed at apparel brands and retailers, cotton producers or those working with them, sustainable cotton standards and industry associations, the climate finance community, civil society organisations working on climate justice and adaptation, and other actors across the cotton value chain.

The information presented in these resources is designed to help users prioritise supporting and implementing adaptation actions to help build climate resilience across the cotton value chain. Users can identify in which districts cotton cultivation or cotton processing aspects of the cotton value chain are at greatest risk from climate change projected for the 2040s. Most importantly, resources allow individuals and organisations to explore the vital drivers which exacerbate risks in these districts, and, utilise this information to address the question:

"How can I, as a stakeholder in the cotton value chain, take action to help address climate risks and work towards increasing climate resilience in my district?"

Addressing this question forms the core objective of Cotton 2040. Identifying these drivers of risk is a crucial first step in the cotton value chain adaptation story, as it can be used to guide responsible action and drive interventions towards increasing resilience of the CVC to climate change. What is clear, however, is that investing in climate justice and socio-economic resilience IS investing in climate resilience.

The section *'Discussion: Paving the way forward'* in the full report makes a first attempt at identifying examples of various programmes, practical activities and research efforts which have been successful in tackling these challenges and building climate resilience of the CVC across India. Each of the components used to calculate climate risks – namely hazard, exposure, sensitivity and adaptive capacity – have been used to structure the discussion. The focus areas are identified i.e., one, some or all districts that will benefit from the proposed adaptation actions. It is also specified whether a solution is applicable for cotton cultivation and the rural communities, or for cotton processing and urban communities. These solutions are intended to demonstrate initial examples of good-practice adaptation cases currently underway in India which help build climate resilience going forward.

The Cotton 2040 Climate Adaptation workstream will further build on this work through 2021-22 and beyond. The focus will be on supporting the sector to further understand the report findings; explore the implications for individual organisations and the cotton value chain; create a more exhaustive pool of adaptation actions and solutions to build resilience; and – critically – identify and act collectively on systemic solutions. We hope you will join us!

To access the reports, the Climate Risk Explorer tool and supporting resources visit *www.acclimatise.uk.com/collaborations/cotton-2040/*. For more information, please contact: Erin.Owain@willistowerswatson.com.

To learn more and explore how your organisation can help create a resilient cotton sector, please contact Hannah Cunneen at h.cunneen@forumforthefuture.org.

To find out more about Cotton 2040 visit *www.forumforthefuture.org/cotton2040*.

Glossary

Adaptive capacity- The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.[lxxiii] Building adaptive capacity involves undertaking research, monitoring data and relevant information sources, awareness raising, capacity building and creating a supportive institutional framework.[lxxiv]

Baseline scenario- Scenario without the project, or scenario that is based on the assumption that no mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. Baseline scenarios are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further effort. "Baseline Scenario" is used synonymously with "Reference Scenario", but also sometimes with "Business-as-Usual (BAU) Scenario" although the use of the term BAU has fallen out of favour due to uncertainties in very long-term projections.[lxxv]

Climate change- A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.[lxxvi]

Climate change adaptation- Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[lxxvii]

Climate variability- Climate variability refers to variations in the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).[lxxviii] The term is often used to denote deviations of climatic statistics over a given period of time (e.g. a month, season or year) when compared to long-term statistics for the same calendar period. Climate variability is measured by these deviations, which are usually termed anomalies.[lxxix]

Exposure- The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.[lxxx]

Extreme weather event- Refers to weather phenomena that are at the extremes of the historical distribution and are infrequent for a particular place and/or time, especially severe or unseasonal weather. Such extremes include flooding, hurricanes, and high winds, and heat waves.[lxxxi] When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).[lxxxii]

Hazard- The potential occurrence of a natural or human-induced physical event, or trend or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In the context of climate change, the term hazard usually refers to climate-related physical events or trends or their physical impacts.[lxxxiii]

Representative concentration pathways (RCPs)- Understanding the relationship between GHG emissions of today and its long-term impacts over the next years or decades requires standardised basis. RCPs are scenarios that describe alternative trajectories for CO_2 emissions and its resulting concentration in the atmosphere from 2000 to 2100. RCPs provide common standard scenarios for climate researchers and modellers to work on. Four RCP trajectories are commonly used, and each RCP projects a different degree of warming by the end of the century. Projected change in temperature by 2081-2100 relative to 1850-2100 under a RCP 2.6 is +1.6°C, +2.4°C for RCP 4.5, +2.8°C for RCP 6.0. and +4.3°C for RCP 8.5.

Resilience- The capacity of social, economic, and environmental systems to cope with climate change induced hazardous events or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.[lxxxiv]

Risk- The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard. The Intergovernmental Panel on Climate Change (IPCC) primarily use the term risk to mostly refer to the physical risks of climate change impacts.[lxxxv]

Sensitivity- This is the degree to which 'a system' is affected, either adversely or beneficially, by climate variability or change. It is 'typically shaped by natural and/or physical attributes of the system' but also 'refers to human activities which affect the physical constitution of a system'.[9]

Vulnerability- The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[lxxxvi]

Acronyms

CVC- Cotton Value Chain

CRVA- Climate Risk and Vulnerability Assessment

EGDD- Effective Growing Degree Days

GCM- Global Circulation Models

GDP- Gross Domestic Product

IPCC- Intergovernmental Panel on Climate Change

ILO- International Labour Organisation

RCP- Representative Concentration Pathway

UNFCCC- United Nations Framework Convention on Climate Change

VA- Vulnerability Assessment

[9] *GIZ. 2014. The Vulnerability Sourcebook. Concepts and guidelines for standardised vulnerability assessments. GIZ, Bonn and Eschborn, Germany.*

Appendix 1: Methodology

This chapter presents the methodology used in this analysis, which takes a four-step systemic approach.

Step 1: Identifying the focus along the cotton value chain

This study essentially carries out two separate analyses, each of which focuses on two separate components of the CVC: **cotton cultivation** and **cotton processing** up until the pre-garment manufacturing stage.

The cotton cultivation Climate Risk and Vulnerability Assessment (CRVA), the subject of this report, will predominantly assess physical climate risks to cotton growing areas, people employed as cotton growers, cultivators and agricultural workers, and to rural communities more broadly. The cotton processing CRVA will predominantly assess physical climate risks to cotton processing factories and units, people employed as manufacturers, and to urban/ peri-urban communities more broadly.

Step 2: Identifying focus regions

In order to identify which districts in India should be the focus of the study, the analysis makes use of a 'location quotient (LQ)' methodology. A LQ is used to quantify the concentration of a particular economic activity/industry in a specific region relative to the national average (**Equation 1**).

District-scale employment data was obtained for 2018-2019 for various industry codes specific to the CVC in India using the following sector sub-classes of the CVC as per India Standard Industry Codes[10]:

Cotton cultivation

A. 01161 - Growing of cotton

Cotton processing

B. 01632 - Cotton ginning, cleaning and bailing

C. 13111 - Preparation and spinning of cotton fibre

D. 13121 - Weaving, manufacture of cotton and cotton mixture fabrics

E. 13131 - Finishing of cotton and blended cotton textiles

F. 13911 - Manufacture of knitted and crocheted cotton fabric

[10] *Data derived from: Unit level Periodic Labour Force Survey Data 2018-2019, Government of India. Edited by: Dr. Paaritosh Nath*

The equation to find the LQ is:

$$LQ = \frac{\frac{e_i}{e}}{\frac{E_i}{E}}$$

Equation 1

where, e_i is sector local employment, e is total local employment, E_i is sector national employment and E is total national employment.

The equation was used to identify districts with strong clusters of economic activity for both cotton cultivation and cotton processing (**Figure 8**). Based on the results of the LQ, the analysis in this study focuses on 3 states, namely, **Maharashtra**, **Gujarat** and **Telangana**.

A total of 13 districts were identified as the focus of both the cotton cultivation and the cotton processing CRVAs. These districts are:

Maharashtra	**Telangana**	**Gujarat**
Dhule	Adilabad	Rajkot
Nandurbar	Karimnagar	Banas Kantha
Latur	Khammam	Mahesana
Nagpur	Mahbubnagar	
Wardha		
Yavatmal		

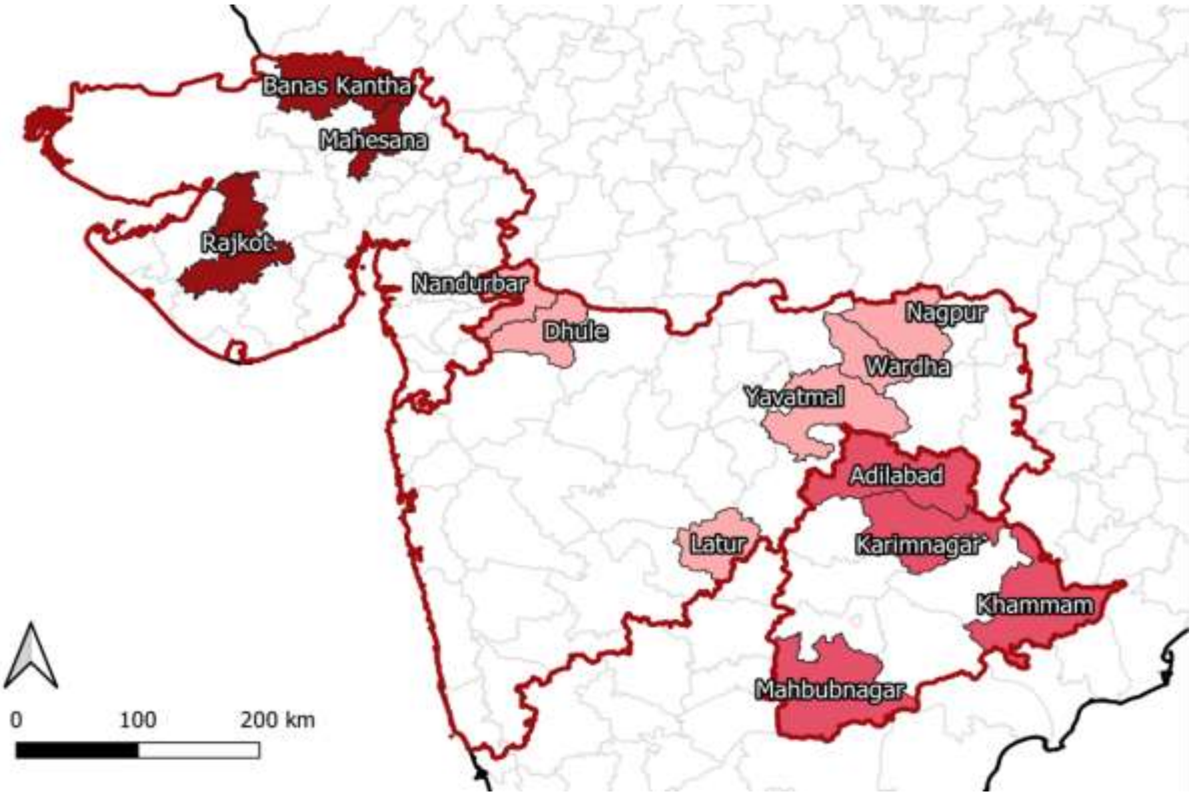


Figure 8: Focus states and focus districts.

Step 3: Defining the CRVA framework

Aim of the CRVA

The purpose of both CRVAs is to formalise and quantify concepts of risk to climate change in order to provide a measure of the vulnerability to both stages of the CVC;

- CRVA 1: Cotton cultivation
- CRVA 2: Cotton processing

Selection of the CRVA approach

A literature review of existing CRVA approaches was carried out to inform the CRVA methodology. A framework has been created to provide a powerful tool for assessing the issues contributing to physical climate risk and vulnerability for the CVC. Many frameworks and guidance documents on vulnerability assessments specifically for India were reviewed, including:

- UNFCCC Resource Guide for Preparing the National Communications of Non-Annex I Parties – Module 2: Vulnerability and Adaptation to Climate Change [i]
- GIZ: A Framework for Climate Change Vulnerability Assessments [ii]
- The Toolkit for Vulnerability and Adaptation Training by the Stockholm Environment Institute [iii]
- Gender and Climate Change Research in Agriculture and Food Security for Rural Development by the Food and Agriculture Organization [iv]
- CARE Climate Vulnerability and Capacity Analysis Handbook [v]
- Handbook on Vulnerability and Adaptation Assessment [vi]

In line with the mandate for this study, a CRVA methodology was developed on the basis of the latest internationally accepted definitions and approach to CRVA as presented by the Intergovernmental Panel on Climate Change (IPCC) report, the 2014 Fifth Assessment Report (AR5).

Defining the main component of a Climate Vulnerability and Risk Index

Hazards, exposure, vulnerability and impacts are central to the concept of "risk" as defined in the IPCC's Fifth Assessment report. As shown in **Figure 9,** changes in both the climate system (left hand side) and socioeconomic processes including adaptation and mitigation (right hand side) are drivers of hazards, exposure, and vulnerability. As such, risk is "the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems" that results in the risk of climate-related impacts.

A CRVA informed by the IPCC's tripartite concept of risk can help form the evidence base for a structured assessment of future possible climate risks, as well as the prioritisation of risk management / adaptation options at a range of spatial scales. The CRVA can bring together a suite of hazard, sensitivity, exposure and adaptive capacity indicators that can be normalised to a common scale, enabling a rich picture to be formed of climate risk and vulnerability hotspots, and the drivers behind these hotspots. As such, the CRVA helps to ensure that adaptation options are linked to specific risks and vulnerabilities, and that these options are tailored to specific regions. Probing more deeply, the development of individual indicators that describe the separate components of the CRVA (e.g. capacity to adapt) can allow the identification of the drivers of risk and vulnerability at any given location. Data for each of these individual indicators may be obtained at a range of spatial scales e.g. at the district level (or relevant administrative area), and then aggregated to create a combined score for e.g. ‘exposure’ or ‘sensitivity’. These scores may then in turn be combined to produce an overall climate vulnerability index (CVI) score. These scores can be represented graphically, allowing one to easily visualise the key contributors (i.e. exposure, sensitivity, or adaptive capacity) to physical climate risk and vulnerability by region.

For this analysis, data for each indicator was received through stakeholder engagement and through making use of publicly available information sources from India and elsewhere.

A glossary of IPCC AR5 definitions, which are also applied to the project CRVA method, is provided in the Glossary section.

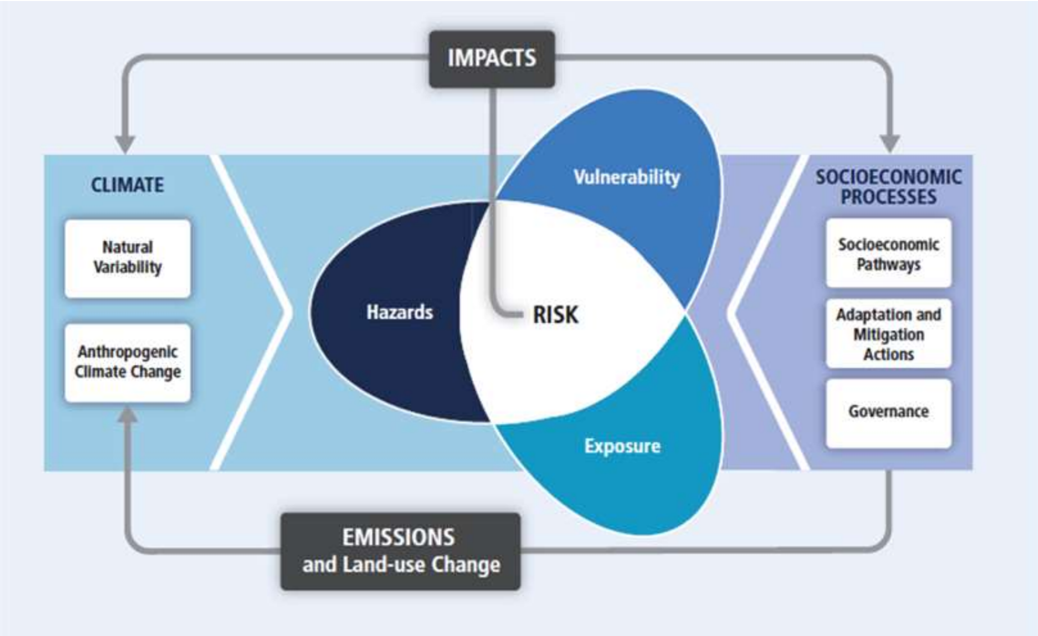


Figure 9: Core concepts of IPCC AR5 report, and framework for their interaction.

Step 4: Constructing the CRVA

Indicators and data selection process

The term ‘indicator’ is widely used in the context of vulnerability assessments. It is a means of attempting to quantify a particular state. Selecting the indicators is one of the most important steps in a CRVA. A ‘selection control plan’ was established to determine the most suitable indicators and corresponding datasets for the CRVA. The process used an indicative and normative approach, based on current knowledge about the system, and expert knowledge from WTW, key experts and the working group.

The process of selecting the indicators for the CRVA was as follows:

Step 1: Literature review

An exhaustive literature review was carried out which included the review of national adaptation plans, national communications, academic research papers and articles, vulnerability assessments, frameworks for vulnerability assessments, and technical papers in order to identify cotton's key climate sensitivities and specific thresholds, and key socio-economic factors underpinning social vulnerabilities along the cotton value chain. The initial sweep of the literature aimed at identifying materials which had a predominant focus on the cotton industry and climate resilience. This proved to be limited, thus the search was broadened to include literature which had a predominant focus of agriculture and climate resilience. Finally, a wider net was cast to identify India specific vulnerability assessments that did not pertain to agriculture but other social settings, such as urban areas, businesses, etc.

An exhaustive list of indicators was gathered and filtered according to specific selection criteria.

Step 2: Data availability

Each indicator was reviewed to determine whether good quality data was available. Good quality data was defined as being (1) at a district-level resolution, (2) available for all or the majority of districts, (3) within a timeframe of 10 years in order to capture the current situation as best as possible, (4) from a credible, reliable source such as Government census, and (5) freely available.

Indicators which did not satisfy the above criteria were discarded.

Step 3: Selection criteria for indicators

The remaining indicators were subjected to a second selection process and scored in terms of suitability as follows:

"**High**" – The literature specifically focused on cotton and physical climate risk and resilience, and/or with a focus on India.

"**Medium**" – The literature specifically focused on agriculture and climate resilience and had a focus on India. The literature was a vulnerability assessment which focused on India.

"**Low**" – Any vulnerability assessments or research papers with an agriculture and climate resilience focus, which were not specific to India.

See **Appendix 1: Methodology** for the full list of indicators reviewed for this analysis.

Step 4: Consultation with expert stakeholders and the working group
Individual stakeholders with expertise in the cotton industry were contacted and asked to review the list of indicators. Furthermore, the working group were also approached on two occasions to review the indicators and provide feedback. All feedback was considered and integrated, where possible. If the feedback is not suitable, a reason was provided.

Final list of indicators

Appendix 2: Full list of indicators reviewed presents the full list of indicators, corresponding rationale with regards to climate resilience and corresponding datasets. Indicators cover various dimensions including demographic datasets, economic datasets, technology-related datasets, and equity-datasets. The CRVA should be viewed as a 'living-framework' to which indicators can be added (as new data becomes available) and others taken out.

The final list of hazard indicators used in the cotton cultivating analysis (CRVA 1) and cotton processing analysis (CRVA 2) are detailed in **Table 3**. See **Appendix 3**: Metadata table: Cotton cultivation CRVA 1 for metadata table.

Table 3: Final list of hazard indicators used in the cotton cultivating analysis (CRVA 1) and cotton processing analysis (CRVA 2). The symbol '✔' indicates that an indicator is included in the analysis, while '×' indicates that an indicator is not included.

Indicators	Description	CRVA 1	CRVA 2
Effective growing degree days (EGDD)	Annual sum of the number of degrees Celsius that each day's mean temperature is above a specified base temperature. Often used to determine conditions favourable to growth of plants and insects and to estimate the growing season duration. A threshold of 15-30 °C is applied in this study.	✔	×
Maximum temperature	Projected number of days in a given year when maximum daily temperature exceeds a specific threshold. The number of days in a given year when temperatures over 40 °C pose a significant risk to yields. A threshold of 34 °C is set as a threshold for labour productivity in this study.	✔	✔
Heatwaves	Annual sum of the number of days when daily maximum temperature of air at 2m above the surface of land, sea, or in-land waters exceeds > 95%ile.	✔	✔
Total growing season rainfall	Daily liquid and frozen water, including rain and snow, that falls to the Earth's surface. The sum of large-scale precipitation (generated by large-scale weather patterns, such as cold fronts) and convective precipitation (air at lower levels in the atmosphere which rises because it is warmer and less dense than the colder air above). Threshold for total annual precipitation is set at >500mm for rainfed cotton.	✔	×
Extreme precipitation	Percentage of total annual rainfall falling on 5% heaviest rainfall days.	✔	✔
Meteorological drought	Characterises meteorological drought in a range of time scales. Calculated as the number of standard deviations that observed cumulative precipitation deviates from the climatological average. A 3-month SPI is used to characterise droughts at a monthly time scale.	✔	×
Hydrological drought	Characterises meteorological drought in a range of time scales. Calculated as the number of standard deviations that observed cumulative precipitation deviates from the climatological average. A 18-month SPI is used to characterise droughts at a monthly time scale.	✔	×
Fluvial flooding	Represents the depth of water across a floodplain which arises when flow in a given river breaches its banks and overflows. A 1-in-10 year flood return period is considered in the cotton cultivation CRVA. A 1-in-100 year flood return period is considered in the cotton processing CRVA.	✔	✔
Damaging wind speeds	The number of days in a given year when wind gust exceeds a threshold of 55 mph. This is the threshold for damaging wind speeds according to the Beaufort scale[11], as such wind speed can uproot trees and cause considerable structural damage.	✔	×
Wildfire	The number of days when the Fire Weather Index is greater than 30, with 30 being considered as the start of 'High' risk	✔	✔
Landslide	Projected precipitation induced landslides.	✔	✔

[11] *The Beaufort wind force scale is an empirical measure that relates wind speed to observed conditions at sea or on land. https://www.weather.gov/jetstream/beaufort_max*

The final list of exposure, sensitivity and adaptive capacity indicators for cotton cultivation (CRVA 2) are detailed in **Table 4**. The metadata table is detailed in **Appendix 3**: Metadata table: Cotton cultivation CRVA 1.

Table 4: Final list of exposure, sensitivity and adaptive capacity indicators used in the cotton cultivation CRVA

Exposure		Sensitivity		Adaptive capacity	
No.	**Indicator**	**No.**	**Indicator**	**No.**	**Indicator**
1	Net sown area of cotton	**1**	Primary sector share of total GDP	**1**	Wages of male cotton grower labourer
2	Rural population density	**2**	Employment in agriculture as cultivators or agricultural labourers	**2**	Wages of female cotton grower labourer
3	Number of people employed as cotton farmers and cultivators	**3**	Marginal cultivators or agricultural labourers	**3**	Rural work participation rate
		4	Gender pay gap in the wages of male and female cotton farmers	**4**	Rural female work participation rate
		5	Multidimensional Poverty Index	**5**	Male literacy rate (cultivators)
		6	Rural female head of household	**6**	Female literacy rate (cultivators)
		7	Rural dependent population	**7**	Area under irrigated cotton
		8	Rural mean household size	**8**	Crop diversity
		9	Size of agricultural land holdings	**9**	Rural households with access to bank accounts
		10	Cotton yield volatility	**10**	Road density
		11	Degraded land	**11**	Rural households with access to technology and information
		12	Water stress	**12**	Soil organic carbon stocks
				13	Soil water holding capacity

The final list of exposure, sensitivity and adaptive capacity indicators for cotton processing (CRVA 2) are detailed in **Table 5**. The full metadata table is detailed in **Appendix 4**: Metadata table: Cotton processing CRVA 2.

Table 5: Final list of exposure, sensitivity and adaptive capacity indicators use in the cotton processing CRVA

Exposure		Sensitivity		Adaptive capacity	
No.	**Indicator**	**No.**	**Indicator**	**No.**	**Indicator**
1	Number of cotton processing factories	**1**	Production volatility	**1**	Wages of male engaged in cotton processing activities.
2	Number of people employed in cotton processing activities	**2**	Marginal manufacturers	**2**	Urban work participation rate
		3	Multidimensional Poverty Index	**3**	Urban female work participation rate
		4	Urban female head of household	**4**	Male literacy rate (manufacturers)
		5	Urban dependent population	**5**	Female literacy rate (manufacturers)
		6	Urban age of head of household	**6**	Urban households with access to bank accounts
		7	Urban mean household size	**7**	Urban households with access to technology and information
		8	Water stress		

Defining climate boundaries and acknowledging uncertainty in climate models

Time horizons

Time horizons of interest were discussed and agreed with the Working Group. For the latest climate projections, a 20-year period, centred around any one future time horizon of interest, is considered appropriate for this analysis. The aim is to smooth out single or multi-year modelling anomalies where under/over estimations can be present and to account for decade-to-decade climate variability. The analysis is therefore centred on 2040, analysing across a 20-year climatology from 2031 to 2050.

The Working Group also have an interest in present day conditions as well as the relative change between present day and 2040s. Based on the most recent available observed data, present-day has been defined as a 20-year climatology from 2000 to 2019. The data sources for present day are derived from the ERA5 and ERA5-Land reanalysis data sets (both part of the ECMWF dataset[12]).

Percentiles

To account for uncertainties in the climate models, two percentiles have been used for each of the hazard indicators:

1. the mean of the ensemble model distribution (also referred to as the 50th percentile, or P50), and
2. either the 75th percentile or the 25th percentile (also referred to as the P75 or P25 respectively) in order to capture the extremes of the ensemble model distribution.

Representative Concentration Pathway (RCP) selection

In 2014, the IPCC (Intergovernmental Panel on Climate Change) published its fifth assessment report (AR5). AR5 provides a comprehensive assessment of literature on the three inter-related aspects of climate change science: the physical science; impacts, vulnerability and adaptation; and mitigation. The literature underpinning AR5 is, to a large extent, associated with climate projections from the 5th phase of the Coupled Model Inter-comparison Project (CMIP5), for the first time using RCPs. RCPs describe the evolution of future atmospheric greenhouse gas (GHG) concentrations without any assumptions on mitigation actions, thus RCPs are possible future GHG emissions and concentration scenarios that give rise to a given radiative forcing.

Four RCPs (RCP8.5, RCP6.0, RCP4.5 and RCP2.6) have been widely used in climate modelling as well as adaptation and mitigation analyses. Each RCP number represents the projected radiative forcing at 2100, for example, 2.6Wm^2 of radiative forcing by 2100 is represented by RCP2.6.

In addition, all RCPs show a broadly similar warming pathway up to mid to late 2030s, with no significant difference. As shown in **Figure 10,** RCPs begin to diverge after the 2030s. Current warming trends exceed that projected by all RCPs except RCP8.5.

GHG emission reductions are essential to avoid the worst effects of climate change being experienced over the longer term. However, regardless of future action on reducing emissions, society and ecosystems are already faced with inevitable changes in climate that will impact over the coming decades. In terms of the CVC, every stakeholder will be affected, from individual farmers and cooperatives and their communities, to large corporates and major brands.

Despite the ambitious goal as set out by the Paris Agreement to keep global warming “under 2°C by 2050”, to date, even the ambitious pledges and targets of countries around the world will only limit warming to between 2.2-3.4°C.[vii] As it stands, current policies are being missed by the majority of countries around the world, meaning that warming of more than 3°C is probable by the end of this century. This will limit changes in our climate, but some change will inevitably continue to occur. However successful we are with decarbonisation, we are faced with decades of unavoidable climate change and changes for our oceans and cryosphere that are expected to be irreversible on timescales relevant to human societies and ecosystems.[viii] As such, it is essential we explore the more profound changes in the climate and the impacts that this will have on the CVC. This approach will enable us to identify robust adaptation actions that are relevant to all climate futures

[12] *ECMWF is the European Centre for Medium-Range Weather Forecasts. https://www.ecmwf.int/en/about*

and which actors in the supply chains and other interested groups can implement. Therefore, for this study, we have selected the highest emission scenario available from the IPCC, namely the RCP8.5, as this will show the significant challenges that the sector could face in the future.

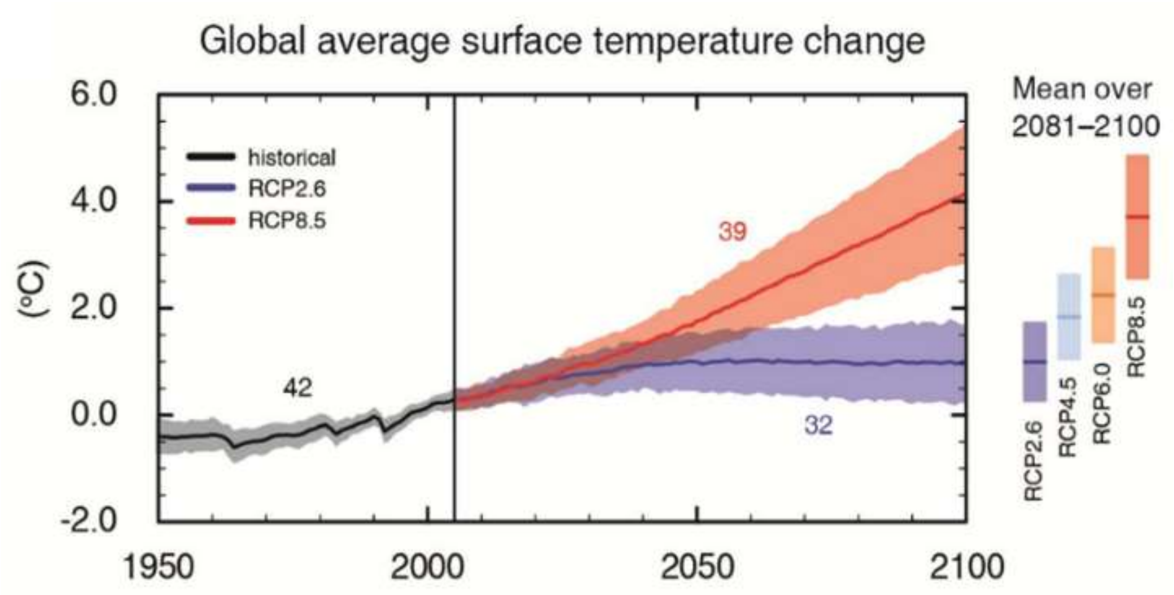


Figure 10: Multi-model simulated change in global annual mean surface temperature from 1950 to 2100 relative to 1986–2005.

Uncertainties

Uncertainty in climate information stems from a number of key areas including:

- Natural climate variability resulting from natural processes within the climate system which cause changes in climate over relatively short time scales.
- Future emissions of greenhouse gases arising from uncertainty over the scale of future global emissions of greenhouse gases.
- Modelling uncertainty arising from incomplete understanding of earth system processes and incomplete representation of these processes in climate models.

It is important to recognise these uncertainties in terms of this study and the methods deployed to reduce uncertainties as far as possible. Uncertainties do not decrease the validity or the credibility of the results, but they increase the range of possible outcomes.

Methodology behind the Climate Vulnerability and Risk Index

Having defined that 'risk' is the interaction between various components, namely hazard, exposure and vulnerability (including sensitivity and adaptive capacity), this section presents the mathematical equations used to construct the index.

Raw data and Normalisation

The raw data for each indicator are cleaned and processed for each 13 districts. The raw data are then normalised to the dimensionless scale from 0 to 1 through conversion that is used, for instance, by the Human Development Index (HDI) and similar studies on climate change vulnerability.

The normalisation equation for the indicators which make up the components 'exposure', 'hazard' and 'sensitivity' is described as:

$$N' = \frac{S - Mx}{M - Mx}$$

Equation 2

Where N' is the normalised value for the indicator, S is the raw datum, Mx is the maximum value of the raw datum and M is minimum value of the raw datum. The normalisation procedure is denoted by an apostrophe (').

The normalisation equation for the indicators which make up the component 'adaptive capacity' is described as:

$$N' = \frac{S - M}{Mx - M}$$

Equation 3

Where N' is the normalised value for the indicator, S is the raw datum, M is the minimum value of the raw datum and Mx is maximum value of the raw datum. The normalisation procedure is denoted by an apostrophe (').

Component 1: Vulnerability

Vulnerability is composed of two elements; 'sensitivity' and 'adaptive capacity'.

Once each indicator has been normalised, the indicators are summed up. The two components of vulnerability are calculated separately as follows:

$$Y = \frac{(N'_1 + \cdots + N'_n)}{n}$$

Equation 4

*Where Y is either the sum of the sensitivity or adaptive capacity indicators, N is either normalised sensitivity or normalised adaptive capacity indicators (from **Equation 2** or **Equation 3**), and n donates the total number of indicators for the specific component. The (') denotes that the components have been normalised.*

Both components are bought together to create the 'vulnerability' component of the CRVA, as follows:

$$V = \frac{S}{AC}$$

Equation 5

whereby V is vulnerability, S is sensitivity and AC is adaptive capacity.

Component 2 and 3: Hazard and Exposure

The hazard (H) and exposure (E) component of the CRVI are separately calculated as follows;

$$X = \frac{(N'_1 + \cdots + N'_n)}{n}$$

Equation 6

*where X is either the hazard (H) or exposure (E) component, N is either normalised hazard or exposure indicators (from **Equation 2**), and n donates the total number of indicators for the specific component. The (') denotes that the components have been normalised.*

Risk

Figure 9 shows that "risk" is a function of hazard, exposure and vulnerability, and it is mathematically described as the sum of all components:

$$R = H' + E' + V'$$

Where R is Risk, H is Hazard, E is Exposure and V is Vulnerability. The (') denotes that the components have been normalised.

The final risk score is then itself normalised.

Building the index

Each individual component of the CRVI was constructed separately, and a Geographical Information System (GIS) database was setup to act as a platform to merge the components. The GIS data layers are subsequently used as an input to an index model, allowing like-for-like comparisons of locational scores to be undertaken as an indicator of their overall vulnerability / resilience.

Appendix 2: Full list of indicators reviewed

Sub-group	Variable	Source	Type of literature Cotton CRVA (C), Agriculture CRVA (A), General CRVA (G), Vulnerability Assessment (VA)	India specific	Good quality data available	Level 1	Level 2	Included
SENSITIVITY								
Population	Rate of urbanisation	GIZ Framework for Vulnerability Assessment (2014)	C	Yes	1	Retain	High	
	Population density	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Rural population density"
	Dependency ratio	Senapati (2020)	A	Yes	1	Retain	Medium	Covered by "Dependency ratio"
	Mean family size	Senapati (2020)	A	Yes	1	Retain	Medium	Covered by "Mean household size"
	Life expectancy of the household head	Senapati (2020)	A	Yes	0	Discard	Discard	
	Dependency ratio	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Dependency ratio"
	Population density	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Rural population density"
	Life expectancy	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
	Human Development Index	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
	Dependency ratio	Below et al., (2012)	A	No	1	Retain	Low	
	Household is female headed	Below et al., (2012)	A	No	1	Retain	Low	
	Rural population density	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Rural population density"

	Rural population density	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Rural population density"
	Female Population	Sherly et al. (2015)	VA	No	1	Retain	Low	
	Total Population	Sherly et al. (2015)	VA	No	1	Retain	Low	
	Rural Population	Sherly et al. (2015)	VA	No	1	Retain	Low	
	SC and ST population	Sherly et al. (2015)	VA	No	1	Retain	Low	
	Rural poor (%)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by the multidimensional poverty index
	SC/ST population (%)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Discarded following further consultation.
	Dependency Ratio *	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by "Dependency ratio"
	Degree of gender equity in a district	O'Brien et al (2004)	G	YES	1	Retain	Low	
	Density of population (persons per sq. km)	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Rural population density"
	% of female	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Female work participation rate"
	Growth of Population	Sridevi et al. (2014)	A	Yes	0	Discard	Discard	Included
	% of SC Population	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Discarded following further consultation.
	% of ST Population	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Discarded following further consultation.
	Gender gap	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Gender gap in work participation rate"
	Sex ratio	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Gender gap in work participation rate"
	Child population (< 6 years)	Guillard-Gonçalves et al. (2015); Kotzee and Reyers (2016)	VA	No	1	Retain	Low	

	Population density	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Rural population density"
Labour	Percentage share of agricultural and cultivator main workers	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Covered by "Employment in agriculture"
	Number / Percentage of male and female labourers involved in agricultural activities	Batool and Saeed (2018)	C	No	1	Retain	High	
	The percentage of landless laborers in the agricultural workforce	O'Brien et al (2004)	G	YES	1	Retain	Low	
	Marginal workers (including cultivators, agricultural labourers, household industry, and others)	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by "Marginal cultivators/agricultural labourers"
	Non-workers	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered under the indicator "Work participation rate"
	Main agricultural and cultivator's population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by "Employment in agriculture"
	Working population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by "Work participation rate"
	Female working population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by "Female work participation rate"
	Workforce in agriculture (%)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Employment in agriculture"
	% of Marginal workers	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Marginal cultivators/agricultural labourers"
	% of Non Workers	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered under the indicator "Work participation rate"
	% of cultivators	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Employment in agriculture"
	% of agricultural workers	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Employment in agriculture"
	Number of male and female labourers in agricultural lands	Batool and Saeed (2018)	C	NO	1	Retain	High	
Migration	Percent of households with a family member working in a different community/migration in some time	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	

Health	Percent of households where a family member had to miss work or school due the illness in the past yea	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Percent of households have reductions in nutrition in bad times	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	HIV prevalence	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Population served per health centre (community, primary and sub health centres)	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Protein consumption per capita	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
	Percentage of households with family member suffering from chronic illness	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Average number of households receiving treatment in hospitals	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Average number of households receiving proper facilities for child delivery and immunisation	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
Education / Literacy	% of households are illiterate due to lack of education facilities in their villages	Senapati (2020)	A	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Average in studies while in school	Senapati (2020)	A	Yes	0	Discard	Discard	
	Illiterate population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Illiterate female population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Percent of households where the head of household has not attended school, are illiterate	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
Households	Percentage of female-headed households	Madhuri et al., (2014)	G	Yes	1	Retain	Low	
	Percentage of households where head of the household had not attended school	Madhuri et al., (2014)	G	Yes	1	Retain	Low	
	Percentage of households with family members working outside the community	Madhuri et al., (2014)	G	Yes	1	Retain	Low	
	Household size	Below et al., (2012)	A	No	1	Retain	Low	

	Number of household	Sherly et al. (2015)	VA	No	1	Retain	Low	
	Percent of female-headed households	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by "Female head of household"
	Average age of head of household	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Average family member in household	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by "Mean household size"
	Average of household head farming experience	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Average HH Size	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Mean household size"
Water	Water use	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
	Percentage of households that utilise natural water source	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Percentage of households that do not have consistent water supply	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Percentage of households that have to go far to fetch water	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Percentage of households that store water	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Percentage of households reported conflicts over water	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Distance to drinking water	Below et al., (2012)	A	No	0	Discard	Discard	
	Population without access to clean water	Sehgal et al (2013)	A	Yes	0	Discard	Discard	
	Infrastructure index	Ravindranath et al (2011)	A	Yes	0	Discard	Discard	
	Fertilizer use/cropland area	Sehgal et al (2013)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Irrigation	Weldesilassie et al (2015)	C	No	0	Discard	Discard	

	Distance to market for inputs	Below et al., (2012)	A	No	0	Discard	Discard	
	Travel time in hours to urban areas.	Vittal (2020)	G	Yes	0	Discard	Discard	
	Household with (without) electricity	Vittal (2020)	G	Yes	1	Retain	Low	
	Accessibility to markets	Sehgal et al (2013)	A	Yes	0	Discard	Discard	
	Number of population dependent of canal water for irrigation	Batool and Saeed (2018)	C	NO	0	Discard	Discard	
	% of sample household have regular access to water	Senapati (2020)	A	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Households that do not have toilet facilities	Madhuri et al., (2014)	G	Yes	1	Retain	Low	
	Percentage of households using only forest-based energy for cooking purposes	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Degree of gender equity	O'Brien et al. (2004)	A	Yes	1	Retain	Medium	Covered by "Gender pay gap"
Cooperative	Membership of one or more family members in an agricultural social group	Below et al., (2012)	A	No	0	Discard	Discard	
Livelihood strategies	% of sample households where any member is already migrated	Senapati (2020)	A	Yes	0	Discard	Discard	
	% of sample households managing their family with crop cultivation	Senapati (2020)	A	Yes	0	Discard	Discard	
	% of sample households could not able to fetch expected price after harvesting their crop	Senapati (2020)	A	Yes	0	Discard	Discard	
	% of sample households staying in kutcha houses	Senapati (2020)	A	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Average area of land used for cultivation from the total land possessed	Senapati (2020)	A	Yes	1	Retain	Medium	Covered by "Net area sown"
Wealth	% of sample households spent more than current income	Senapati (2020)	A	Yes	0	Discard	Discard	

	GINI index	Vittal (2020)	G	Yes	0	Discard	Discard	
	Annual per capita household income from most important livelihood activities (proxy for wealth)	Below et al., (2012)	A	No	0	Discard	Discard	
	Percentage of households solely dependent on agriculture as source of income	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Human poverty index	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Income equity	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Gender pay gap"
	Primary Source of Income	Weldesilassie et al (2015)	C	No	0	Discard	Discard	
	% of sample household already borrowed money from the bank	Senapati (2020)	A	Yes	0	Discard	Discard	
	% of sample household with outstanding debt	Senapati (2020)	A	Yes	0	Discard	Discard	
	Average number of households who have burden of loan	Madhuri et al., (2014)	G	Yes	0	Discard	Discard	
	Poverty incidence	Yusuf and Francisco (2009)	G	No	0	Discard	Discard	
	Income inequality	Yusuf and Francisco (2009)	G	No	1	Retain	Low	
Size of farm	Average landholding	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".
	Area owned by small and marginal farmers (%))	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".
	Average landholding	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".
	Percent small-scale holdings	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Area of farm (hectare);	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".
	Proportion of farm holdings less than 2 ha	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".

	% less than 1 hectare	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Covered by "Size of agricultural land holdings".
	Land holding	Weldesilassie et al (2015)	C	No	1	Retain	High	
Land	Financial capital asset index	Below et al., (2012)	A	No	0	Discard	Discard	
	Number and working status of productive assets:	Below et al., (2012)	A	No	0	Discard	Discard	
Assets	Ownership of farm equipment	Weldesilassie et al (2015)	C	No	1	Retain	High	
	Ownership to Livestock	Weldesilassie et al (2015)	C	No	1	Retain	High	
	Access to Finance	Weldesilassie et al (2015)	C	No	1	Retain	High	
	Livestock density	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
ADAPTVE CAPACITY								
Income / Wealth / GDP	Wealth status	Batool and Saeed (2018)	C	No	1	Retain	High	Covered by "Wages of male/female cotton grower labourer"
	Wealth status	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Wealth status	Batool and Saeed (2019)	C	NO	1	Retain	High	Covered by "Wages of male/female cotton grower labourer"
	Farm income	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Income	Weldesilassie et al (2015)	C	No	1	Retain	High	Covered by "Wages of male/female cotton grower labourer"
	GDP per capita	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Wages of male/female cotton grower labourer"
	Percentage of people below the poverty line;	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Share of agricultural GDP	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	

	Share of agriculture in district domestic product	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Primary sector share of total GDP"
Access to finances	Access to financial services	Batool and Saeed (2018)	C	No	1	Retain	High	
	Access to financial services	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Access to financial resources	Batool and Saeed (2019)	C	NO	1	Retain	High	
	Access to credit	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Percent of households with investment risk	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Percent of households with a money loan	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
Livelihood diversification	Crop diversity (number of crops grown)	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	0	Discard	Discard	
	Livelihood diversification	Batool and Saeed (2018)	C	No	1	Retain	High	
	Livelihood diversification	Batool and Saeed (2019)	C	NO	1	Retain	High	
	Average crop diversity index	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Included as indicator "Crop diversification"
	Presence of alternative economic activities is measured by the percentage of the district workforce that is employed in agriculture	O'Brien et al (2004)	G	YES	1	Retain	Low	
	Average agricultural livelihood diversification index	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Percent of households dependent solely on agriculture as a source of income	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	Crop diversification index:	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Average agricultural livelihood diversification	Madhuri et al., (2014)	G	YES	1	Retain	Low	

	Average Crop Diversity Index	Madhuri et al., (2014)	G	YES	1	Retain	Low	
Other	Density of livestock population	Rao et al., (2016)	A	Yes	0	Discard	Discard	
Education / Literacy	Level of education	Batool and Saeed (2018)	C	No	1	Retain	High	
	Number of years in school completed by household head	Below et al., (2012)	A	No	1	Retain	Low	
	Literacy rate	Sehgal et al (2013)	A	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Literate Population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Female literate population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Number of primary, middle, high and higher secondary educational institutions per 100,000 population	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	0	Discard	Discard	
	Literacy rate	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Female literate population	Sherly et al. (2015)	VA	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Level of education of the respondents	Batool and Saeed (2018)	C	NO	0	Discard	Discard	
	Highest level of education at the household level	Batool and Saeed (2018)	C	NO	1	Retain	High	
	Literacy (%)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Human capital is represented by literacy rate	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Average years in education	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
	Percent of households have more expenditures than income	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
	adult literacy rates	O'Brien et al (2004)	G	YES	1	Retain	Low	

	% Literacy	Sridevi et al. (2014)	A	YES	1	Retain	Medium	Covered by the indicator "Male/female literacy rate"
Age	Life expectancy	Botero and Salinas (2013)	A	Yes	0	Discard	Discard	
Infrastructure / Technology	Access to critical infrastructure	Batool and Saeed (2018)	C	No	0	Discard	Discard	
	Road density	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Included.
	Infrastructure Development Index	TERI (2003) and O'Brien et al. (2004)	A	Yes	1	Retain	Medium	Covered by "Road density" indicator which is used as a proxy for infrastructure.
	% of households with access to electricity	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	% of households owning radio, television and telephones	Batool and Saeed (2018)	C	No	1	Retain	High	Covered by "Technology and information" indicator.
	Electrified pump sets per thousand hectares of gross cropped area	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	0	Discard	Discard	
	Electrified pump sets per thousand hectares of gross cropped area	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	0	Discard	Discard	
	Access to weather updates	Batool and Saeed (2018)	C	NO	0	Discard	Discard	
	Early warning systems	Batool and Saeed (2018)	C	NO	0	Discard	Discard	
	Paved roads (% villages)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Road density" indicator which is used as a proxy for infrastructure.
	Rural electrification (% villages)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Average time to market	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by "Road density" indicator which is used as a proxy for infrastructure.
	Infrastructure and access to markets	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	Covered by "Road density" indicator which is used as a proxy for infrastructure.

	Quality of infrastructure	O'Brien et al (2004)	G	YES	1	Retain	Low	Covered by "Road density" indicator which is used as a proxy for infrastructure.
	Fertilizer consumption	Rao et al., (2016)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	NPK fertilizer use	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Amount of fertilizers consumed	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Distance to market for inputs	Below et al., (2012)	A	No	1	Retain	Low	
	Amount of fertilizer consumed	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Fertiliser consumption	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Amount of manure used	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Discarded following consultation with stakeholders.
	Percent of households with access to water source	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Incorporated into the multidimensional poverty index.
	Use of electricity	Yusuf and Francisco (2009)	G	No	1	Retain	Low	
	Irrigation	Yusuf and Francisco (2009)	G	No	1	Retain	Low	
	Road density	Yusuf and Francisco (2009)	G	No	1	Retain	Low	
	Communication	Yusuf and Francisco (2009)	G	No	1	Retain	Low	
Potable water / groundwater	Groundwater availability	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by the indicator "Meteorological drought".
	Groundwater availability	O'Brien et al (2004)	G	YES	1	Retain	Low	
	Net annual groundwater availability	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Covered by the indicator "Meteorological drought".

	Water availability	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Covered by the indicator "Water stress".
Crops	Cropping intensity	Sridevi et al. (2014)	A	Yes	0	Discard	Discard	
	% of irrigation area	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by indicator "Area under irrigated cotton"
	% of net sown area	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Net irrigated area (%)	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by indicator "Area under irrigated cotton"
	Average of total Land cultivated	Botero and Salinas (2013)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Severity of soil degradation	O'brien et al (2004)	G	YES	1	Retain	Low	
	Productivity	Vulnerability of Agriculture to Climate Change: District Level Assessment in the Indo-Gangetic Plains (2013)	A	Yes	1	Retain	Medium	Covered by "soil organic carbon stocks"
	Net sown area to gross sown area	Vulnerability of Agriculture to Climate Change: District Level Assessment in the Indo-Gangetic Plains (2013)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Percentage of households with fertile land	Adapted from Thorpe et al. (2007)	GR	No	1	Retain	Low	
	Mean rainfed crop yield	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Inversely covered by indicator "Area under irrigated cotton"
	% irrigated areas	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by indicator "Area under irrigated cotton"
	Land degradation index:	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Cropping intensity	Sehgal et al. (2013)	A	Yes	0	Discard	Discard	
	Available water holding capacity of soil	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "soil water holding capacity"

	Net sown area as % geographical area	Rao et al., (2016)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Cereal production/crop land area	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Net sown areas to gross sown area	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Productivity	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Land degradation" and "soil organic carbon stocks"
	Suitability for crop production	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Included
	Soil degradation	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "Land degradation" and "soil organic carbon stocks"
	Net sown area	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Covered by "Net sown area"
	Area of irrigated cotton	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Covered by indicator "Area under irrigated cotton"
	Area of rainfed cotton	Ravindranath et al (2011)	A	Yes	1	Retain	Medium	Inversely covered by indicator "Area under irrigated cotton"
	Area under high-yielding varieties	Ravindranath et al (2011)	A	Yes	0	Discard	Discard	
	Harvested area data for the crop	Vittal (2020)	G	Yes	1	Retain	Low	
	Proportion of productive soil	TERI 2003 and O'Brien et al. (2004)	G	Yes	1	Retain	Low	
	Area under high yielding varieties	Ravindranath et al (2011)	A	Yes	0	Discard	Discard	
Soil	Depth of the soil cover	O'Brien et al (2004)	G	YES	0	Discard	Discard	
	Organic carbon content	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "soil organic carbon stock" as a proxy for soil quality
	Water holding capacity	Sehgal et al. (2013)	A	Yes	1	Retain	Medium	Covered by "soil water holding capacity"
	Water holding capacity	Sridevi et al. (2014)	A	Yes	1	Retain	Medium	

	Combined soil and vegetation degradation	Gbetibouo and Ringler (2009)	A	No	1	Retain	Low	
	Soil conditions (quality and depth)	O'Brien et al. (2004)	A	Yes	1	Retain	Medium	Covered by "soil organic carbon stock" as a proxy for soil quality
Water	Surface water availability	GIZ Framework for Vulnerability Assessment (2014)	VA	Yes	1	Retain	Medium	Covered by "Meteorological drought" as a proxy for groundwater
	Groundwater availability	TERI 2003 and O'Brien et al. (2004)	A	Yes	1	Retain	Medium	Covered by " Meteorological drought" as a proxy for groundwater
	Ground water availability	O'Brien et al. (2004)	A	Yes	1	Retain	Medium	Covered by " Meteorological drought" as a proxy for groundwater
Markets / Co-operatives	Number of markets per 1 lakh holdings	Rao et al., (2016)	A	Yes	0	Discard	Discard	
	The number of farmers in organized agriculture	Gbetibouo and Ringler (2009)	A	No	0	Discard	Discard	

Appendix 3: Metadata table: Cotton cultivation CRVA 1

No.	Indicator	Measure	Relationship with vulnerability or risk	Rationale	Examples of studies which use the indicators	Data source
Sensitivity						
1	Primary sector share of total GDP	Proportion of the primary sector GDP relative to the total GDP of the district.	Directly proportional	This indicator is a proxy for the district's financial dependency on the primary sector (which includes the agricultural sector). Agriculture is directly impacted by climatic change and therefore the greater the economic dependency on agriculture and the primary sector, the greater the vulnerability to climate change.	Gbetibouo and Ringler (2009); BASIC Project (2007); Rao et al., (2016)	ICRISAT (2015-2016). Available from: https://www.icrisat.org/
2	Employment in agriculture	Proportion of people employed as rural cultivators or agricultural labourers relative to the total rural population of working age (15-60 years old).	Directly proportional	This indicates the importance of agriculture in the livelihoods of the population compared to other sectors. The higher the percentage of the population who are dependent on agriculture as their main source of income, the greater the economic impact on a household	O'Brien et al (2004); GIZ Framework for Vulnerability Assessment (2014); Madhuri et al., (2014); Sherly et al. (2015); Rao et al., (2016); Sridevi et al. (2014); INRM Consultants Pvt. Ltd (2016); Batool and Saeed (2018)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

				level of any decline in agricultural productivity from climate change.		
3	Marginal cultivators/agricultural labourers	Proportion of rural cultivators/agricultural labourers who are marginal workers relative to total rural population employed as cultivators/agricultural labourers.	Directly proportional	Marginal workers are defined as not having been in employment for 6 months or more. Marginal workers are a proxy for daily/temporary/seasonal workers, contract-less workers, and are generally landless labourers. They are often paid on a per-acre basis. Any loss in agricultural productivity associated with climate change would result in decreased employment opportunities resulting in lost wages and unemployment for marginal workers. The greater the proportion of marginal workers, the higher the vulnerability.	Sherly et al. (2015); PRISE (2018); Vittal et al (2020); Sridevi et al. (2014)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
4	Gender pay gap	Percentage difference in the wages between male and females cotton growers.	Directly proportional	Lower incomes make people less resilient in the face of adverse climate shocks. The greater the wage inequality between males and female, the greater the dependency on one income, and the lesser the overall household income. A higher wage gap indicates gender inequity. Agricultural shocks arising from climate change will exacerbate inequalities between men and	Lahiri (2020); Chanana-Nag et al (2020)	Unit level Periodic Labour Force Survey Data. Government of India. (2018-2019)

				women, therefore the greater the gender pay gap, the higher the vulnerability.		
5	Poverty	Proportion of both urban and rural people living in poverty according to the Multidimensional Poverty Index (MPI)	Directly proportional	A higher index value indicates low household income, poor nutrition, high child mortality, lack of preventive health care, low education, poor sanitation, low access to clean drinking water, and low access to electricity. The higher the proportion of people living below poverty line, the higher the vulnerability level and the greater the impact of adverse climate change shocks.	Thornton et al. (2006); Gbetibouo and Ringler (2009); Oxfam (2009); INRM Consultants Pvt. Ltd (2016); PRISE (2018); Batool and Saaed (2018), Senapai (2020); Manglem (2020)	Alkire, S., Oldiges, C. and Kanagaratnam, U. (2018). 'Multidimensional poverty reduction in India 2005/6–2015/16: still a long way to go but the poorest are catching up', OPHI Research in Progress 54a, University of Oxford Available from: https://ophi.org.uk/rp54b/
6	Female head of household	Proportion of rural female head of households relative to total rural head of households.	Directly proportional	This indicator is a proxy for males who have left the household and migrated elsewhere, possibly in search of work. This increases the responsibility of the female head of the household, increases difficulties in hazard-evacuations due to added responsibilities as a single adult, and increases the vulnerability to the impacts of climatic shocks. The greater the proportion of female head of	DHS (2006); Hahn et al. (2009); Botero and Salinas (2013)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

				households, the higher the vulnerability.		
7	Dependent population	Proportion of rural population <14 y/o or >60 y/o relative to total rural population	Directly proportional	The higher the indicator, the higher the burden on the productive part of the population to maintain the pensions of the economically dependent. Any economic shocks arising from climate change impacts will increase the burden of the productive populations. The greater the value, the higher the vulnerability.	Sherly et al. (2015); Rao et al., (2016); Sridevi et al. (2014) ; INRM Consultants Pvt. Ltd (2016); Senapati 2020; Sehgal et al (2013); Below et al. (2012); Botero and Salinas (2013)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
8	Mean household size	Average number of people in one household (rural population)	Directly proportional	The higher the number of members in a given household, the greater the caring and economic responsibility on the productive part of the household. The larger a household, the greater the vulnerability.	Below et al., (2012); Sherly et al. (2015); Sridevi et al. (2014)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
9	Size of agricultural land holdings	Proportion of land holdings which are less than 1 hectare (marginal).	Directly proportional	Marginal sized landholders are limited in their ability to produce a marketable surplus and lack opportunity to diversify cropping patterns. The low investment capacity of farmers makes agriculture more sensitive to	Ravindranath et al., (2011); Gbetibouo and Ringler (2009); Rao et al., (2016); Sehgal et al (2013); GIZ Framework for Vulnerability Assessment (2014); Weldesilassie, et al	Agriculture census. Government of India (2015-2016)

				climate change. The greater the proportion of marginal sized landholdings, the higher the vulnerability.	2015; INRM Consultants Pvt. Ltd (2016)	www.agricoop.nic.in/
11	Cotton yield volatility	Standard deviation in yield between years (1998-2017)	Directly proportional	The higher the average annual change in cotton yield, the greater the economic uncertainty to cotton farmers and the greater the vulnerability in the face to adverse climatic events.		The Cotton Corporation of India (2019) Available from: https://cotcorp.org.in/
12	Degraded land	Percentage of degraded and waste land relative to total district area.	Directly proportional	This index considers soil loss due to water erosion, soil loss due to wind erosion, acidic soils, salt-affected soils, forest cover, and physical degradation (barren rock, waterlogged, snow-covered area, mining and industrial activity). This indicator is a proxy for potential productive lands. Productivity levels would be low if crops are grown on degraded land. The greater the proportion of degraded lands, the higher the vulnerability.	O'Brien et al (2004); Gbetibouo and Ringler (2009); Sehgal et al (2013)	Maji, A.K., Reddy, G.O. and Sarkar, D., 2010. Degraded and wastelands of India: status and spatial distribution. Indian Council of Agricultural Research (ICAR), New Delhi, p.167. Available from: https://icar.org.in/files/Degraded-and-Wastelands.pdf

13	Water stress	Area of cotton production located within water stress zone measured as projected water stress (2040s).	Directly proportional	This indicator demonstrates water availability per unit area (mm). Lower availability due to increase in demands for agricultural, domestic and industrial use, indicates higher vulnerability to climate change.	Vittal (2020) uses SPI-3 months. Other literature that considers various drought indicators: O'Brien et al., (2004); Gbetibouo and Ringler (2009); Ravindranath et al., (2011); Sridevi et al (2014); Aggarwal et al (2016); Baatol and Saeed (2018); Senapati (2020).	WRI Aqueduct Water Risk Atlas (2020) Available from: https://www.wri.org
Adaptive capacity						
1	Wages of male cotton grower labourer	Average wages of a male cotton grower.	Inversely proportional	Higher household incomes create greater financial security and ability to withstand climate shocks and stresses. Higher male wages decrease vulnerability.	Gbetibouo and Ringler (2009); Weldesilassie, et al (2015)	Unit level Periodic Labour Force Survey Data. Government of India. (2018-2019)
2	Wages of female cotton grower labourer	Average wages of a female cotton grower.	Inversely proportional	Higher household incomes create greater the financial security and ability to withstand climate shocks and stresses. Higher female wages decrease vulnerability.	Gbetibouo and Ringler (2009); Weldesilassie, et al (2015); Chanana-Nag et al (2020); Lahiri (2020).	Unit level Periodic Labour Force Survey Data. Government of India. (2018-2019)
3	Work participation rate	Percentage of total rural workers (main and marginal) relative to the total rural potential population within	Inversely proportional	A higher proportion of work participation leads to the economic growth of a region, greater income to sustain livelihoods and thus higher	INRM Consultants Pvt. Ltd (2016); Chanana-Nag et al (2020); Lahiri (2020).	Census of India, Government of India (2011)

		working age (15-60 years old).		adaptive capacity to climate stressors. Higher work participation rates are associated with decreased vulnerability.		Available from: www.censusindia.gov.in
4	Female work participation rate	Percentage of total rural female workers (main and marginal) relative to the total rural potential female population within working age (15-60 years old).	Inversely proportional	A family's coping capacity will be higher if the proportion of females in the workforce in a community is high as it increases economic independence and the proportion of the population engaged in economic activity. A high proportion of employed rural females decreases vulnerability in the face of climate shocks and stress.	Wood et al. (2010); Sherly et al. (2015); Vitall (2020); Chanana-Nag et al (2020); Lahiri (2020).	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
5	Male literacy rate	Proportion of literate rural male cultivators/agricultural labourers relative to total rural male cultivators/agricultural labourers.	Inversely proportional	Higher literacy rates increase workers capabilities and access to information, thereby enhancing their ability to cope with adversities. Literacy also enhances their ability to diversify livelihoods in the face of long-term climate change.	Leichenko and O'brien (2002); Eriksen et al. (2007); Wongbusarakum and Loper (2011); Sherly et al. (2015); Vittal (2020); Dumenu and Obeng (2016); Senapati (2020), PRISE (2018); Gbetibouo and Ringler (2009); Botero and Salinas (2013); Aggarwal et al (2016); Sridevi et al., (2014); O'Brien et al., (2004); INRM Consultants Pvt. Ltd (2016).	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

6	Female literacy rate	Proportion of literate rural female cultivators/agricultural labourers relative to total rural female cultivators/agricultural labourers.	Inversely proportional	Higher literacy rates increase workers capabilities and access to information, thereby enhancing their ability to cope with adversities. Literacy also enhances their ability to diversify livelihoods in the face of long-term climate change.	Leichenko and O'brien (2002); Eriksen et al. (2007); Wongbusarakum and Loper (2011); Sherly et al. (2015); Vittal (2020); Dumenu and Obeng (2016); Senapati (2020), PRISE (2018); Gbetibouo and Ringler (2009); Botero and Salinas (2013); Aggarwal et al (2016); Sridevi et al., (2014); O'Brien et al., (2004); INRM Consultants Pvt. Ltd (2016).	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
7	Area under irrigated cotton	Proportion of area growing irrigated cotton relative to total area growing cotton.	Inversely proportional	Irrigation, the application of water to the land or soil, is an important adaptation-enabler as it allows farmers to sustain crops during periods of inadequate rainfall. The higher the proportion of area under irrigated cotton (versus rainfed cotton), the greater the capacity to mitigate dry spells and droughts and reduce vulnerability. Climate change is projected to increase the intensity and frequency of dry spells in regions of India.	O'Brien et al (2004); Gbetibouo and Ringler (2009); Ravindranath et al., (2011); Aggarwal (2016); Sehgal et al (2013); INRM Consultants Pvt. Ltd (2016)	International Food Policy Research Institute, 2019, "Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 2.0". Available from: https://doi.org/10.7910/DVN/PRFF8V

8	Crop diversity	Diversity is expressed as the "effective number of species".	Inversely proportional	Lower crop diversity may negatively affect the sustainability of agro-ecosystems, whereas increased biodiversity in agroecosystems may improve productivity and resiliency, and buffer against crop failure. Higher crops numbers correspond with higher adaptive capacity.	Botero and Salinas (2013); Gbetibouo and Ringler (2009); Madhuri et al., (2014); GIZ Framework for Vulnerability Assessment (2014)	FAOSTAT (2017). Available from: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0225555#pone.0225555.ref023
9	Bank accounts	Proportion of rural households availing banking services out of the total rural population.	Inversely proportional	Access to financial services provides a form of security in the face of disaster. Banking facilities are an important indicator of wealth and provide information related to the adaptive capacity of the region in response to extreme events or climate related shocks. The higher the proportion of rural population with access to banking services, the lesser the vulnerability.	PRISE (2018); Senapati (2020); Batool and Saeed (2018); Gbetibouo and Ringler (2009); INRM Consultants Pvt. Ltd (2016)	Household census, Government of India (2015) Available from: https://www.niti.gov.in
10	Road density	Proportion of district area covered by primary or secondary road relative to total district area.	Inversely proportional	This is used as a proxy for infrastructure quality and access to markets. A better transport infrastructure enables an improved integration of the rural economy within the broader economy. The higher the road	Vittal (2020); Gbetibouo and Ringler (2009); INRM Consultants Pvt. Ltd (2016)	Digital Charts of the World (2020) Available from: https://freegeographytools.com/2007/digita

				density the lesser the vulnerability.		l-chart-of-the-world-server
11	Technology and information	Proportion of rural households with computer/laptop with internet connection relative to total rural population.	Inversely proportional	Access to technology and to the internet enables households to received emergency warnings prior to disasters increasing their ability to respond to warnings and take preventative measures. The higher the proportion of the rural population with access to the internet, the lesser the vulnerability.	GIZ (2014); Batool and Saeed (2018); Yusuf and Francisco (2009)	Household census, Government of India (2015) Available from: https://www.niti.gov.in
12	Soil organic carbon stocks	Total soil organic carbon stocks averaged across the district.	Inversely proportional	This indicator is a proxy for the potential soil quality for agricultural practices. A higher soil organic carbon content indicates greater physical structure, good soil aeration, and good water drainage, reducing the potential for soil erosion and nutrient leaching. The higher the index, the lesser the vulnerability.	O'Brien et al., 2004; Sehgal et al 2013; Below et al., (2012); Jans et al., (2020)	Soil Grids (2020) Available from: https://www.soilgrids.org/
13	Soil water holding capacity	Potential water holding capacity of soils.	Inversely proportional	The higher the index, the greater the capacity of the soil to hold high volumes of water, which can sustain crops between rainfall and periods of irrigation and save crops during dry spells. The higher the soil water holding	Sehgal et al (2013); Sridevi et al., (2014); Aggarwal et al (2016); Rao et al., (2016)	Computed by Rao et al., (2013) using texture and depth of soil taken from NBSSLUP and Dunne and Wilmott (2000).

				capacity, the lesser the vulnerability.		
Exposure						
1	Net sown area	Net sown area of cotton relative to total geographical area of the district	Inversely proportional	This variable determines the 'extent' of the problem. This variable determines the proportion of the district that is covered by cotton growing, and therefore is exposed to climate impacts. The higher the area under cultivation the higher the relative importance of agriculture in the district. The total land area on which crops are grown in a region is called the 'net sown area'. A high net sown area implies a higher productivity of agriculture crops in a region and decreased vulnerability.	Ravindranath et al., 2011; Aggarwal eta l., (2016); Senepati (2020); Sehgal et al (2013); Rao et al., (2016); INRM Consultants Pvt. Ltd (2016)	International Food Policy Research Institute, 2019, "Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 2.0". Available from: https://doi.org/10.7910/DVN/PRFF8V
2	Rural population density	Rural population relative to total district area (km^2)	Directly proportional	This variable determines the 'extent' of the problem. Higher density is an indicator of population pressures on land resources. As the livelihoods of rural populations are agriculture-dependant it means greater exposure to climate impacts. Districts experiencing rapid growth lack available housing and social services to	Aggarwal eta l., (2016); World Bank (2002); Shewmake (2008); Fekete (2009); Vittal (2020)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

				accommodate rapid population influx which increase vulnerability. High density leads to more problems related with poverty, security, global warming, water, natural resources, etc.		
3	Number of people employed in cotton cultivation activities	Number of people employed in all cotton cultivation activities	Directly proportional	The higher the number of people working in the sector, the more exposure to climate impacts.		Unit level Periodic Labour Force Survey Data 2018-2019, Government of India. Edited by: Dr. Paaritosh Nath
Hazard						
1	Effective Growing Degree Days (EGDD) - Delta *(Change in the length of the growing season)*	Projected number of EGDD (<30°C) during growing season. Growing season is the internal between when daily average temperature first exceeds >14°C for >6 consecutive days and when daily average temperature first <15°C for >6 consecutive days.	Negative change = Directly proportionate Positive change = Inversely proportionate	The temperature range for optimal growth of cotton is between 14-30°C according to the FAO. Thus, this range is used to define the threshold for the growing season. A positive change in the length of the growing season, provides an opportunity to cotton cultivation. However, a negative change in growing season length, possibly due to an exceedance of temperature above optimal threshold of 30°C, will present a risk to cotton cultivation.	Zhou et al., (2017); Sawan et al (2009); Iksian (2020); FAO (2020).	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

2	Maximum threshold for cotton growing	Projected number of days when temperature exceeds >40°C	Directly proportionat e	Cotton crop is negatively impacted if temperature increases above a threshold of 40°C. A projected increase in the number of times the temperature exceeds this threshold, will present a risk to cotton crop.	Sawan et al., 2018	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
3	Temperature threshold for labour productivity	Projected number of days when temperature exceeds >34°C	Directly proportionat e	According to the International Labour Organization, excessive heat during work creates occupational health risks; it restricts a worker's physical functions and capabilities, work capacity and productivity. Temperatures above 24–26°C are associated with reduced labour productivity. At 33–34°C, a worker operating at moderate work intensity loses 50 per cent of his or her work capacity.	ILO (2019)	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

4	Heatwave	Projected number of days when daily maximum temperature exceeds baseline average for at least 3 consecutive days	Directly proportionate	According to the WMO, a heatwave is defined a 1 period of marked unusual hot weather (maximum, minimum and daily average temperature) over a region persisting for at least three consecutive days during the warm period of the year based on local (station-based) climatological conditions, with thermal conditions recorded above given thresholds. An increase in number of heatwaves present a risk to the crop and to the cotton cultivators.	WMO (2020)	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
5	Total growing season rainfall	Precipitation >500mm during growing season (rainfed cotton growing regions).	Directly proportionate	Cotton requires total rainfall throughout the growing season in excess of >500mm. If total rainfall is <500mm, the crop can be negatively impacted.	Ikisan (2020); Sehgal et al (2013); Batool and Saeed (2018); Rao et al., (2016)	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

6	Extreme precipitation (pluvial flood)	Percentage of total annual rainfall falling on 5% heaviest rainfall days	Directly proportionate	Extreme rainfall events can lead to waterlogged conditions, which can cause inundate cotton plantations. An Increase in intensity and frequency of extreme rainfall events, increases the risk of waterlogging and crop damage.	Sehgal et al (2013); Vittall et al., (2020)	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
7	Damaging wind speeds	Projected wind gust above baseline wind speeds. We use 25 mph -- based on Beaufort scale	Directly proportionate	Combines both wind and cyclone. There was no exact threshold identified although FAO states that strong winds can affect the delicate young seedlings as wind can blow fibre away from opened bolls and soil the fibre with dust.	FAO (2020).	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

8	Flood fluvial	Area of district in a flood zone for the projected in 1-in-10 year flood extent as a proportion of total area of district	Directly proportional	Extreme rainfall events which lead to flooding can cause widespread damage to agricultural crops. For example, in 2010, flooding caused significant damage to cotton production across Pakistan, causing a significant reduction in the crop area for cotton production. The IPCC projects that climate change will increase the intensity and frequency of extreme weather events across India. The higher the percentage of cotton growing areas located in fluvial flood zones, the higher the vulnerability.	PRISE (2018); Gbetibouo and Ringler (2009); Ravindranath et al., (2011); Senapati (2020), Aggarwal et al (2016); Batool and Saeed (2018); Oxfam Discussion Papers (2012).	WRI Aqueduct Floods (2020) Available from: https://www.wri.org/
9	Wildfire	Projected number of days when fire weather index is greater than 20 – "Medium-high"	Directly proportional	Wildfires cause significant damage to agricultural crops. This literature review did not find an example of a study which has previously considered the impacts of changes in wildfire on cotton cultivation. However past events clearly demonstrate that wildfires are a risk to cotton such as the recent Australian wildfires. The IPCC projects that climate change will increase the intensity and frequency of wildfires across India. The higher the percentage of cotton growing areas located in wildfire zones, the higher the vulnerability.	No literature found which directly uses exposure to "wildfire" as an indicator in a cotton specific CRVA.	CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

10	Wildfire	Projected number of days when fire weather index is greater than 30 – "High"	Directly proportional	As above	As above	As above
11	Landslides	Precipitation induced landslides.	Directly proportional	Landslides cause significant damage to agricultural crops. The IPCC projects that climate change will increase the intensity and frequency of landslides across India. The higher the percentage of cotton growing areas located in landslide zones, the higher the vulnerability.	No literature found which directly uses exposure to "landslides" as an indicator in a cotton specific CRVA.	CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
12	Meteorological drought	Projected change in annual average 3-month standard precipitation index (SPI).	Directly proportional	The Standardized Precipitation Index (SPI) is a drought index based on precipitation and calculated as the average of the last 3 month for each month (SPI12). "Very wet" to "Extremely wet" are denoted by SPI >1.5.	Vittall et al., (2020)	CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
14	Hydrological drought	Projected annual average 18-month standard precipitation index (SPI). Projected annual average 3-month standard precipitation index (SPI). The Standardized Precipitation Index (SPI) is a drought index based on precipitation and calculated as the average of the last 3 month for each month (SPI12). "Very wet" to	Directly proportional	As above	As above	As above

		“Extremely wet” are denoted by SPI >1.5.				

Appendix 4: Metadata table: Cotton processing CRVA 2

No.	Indicator	Measure	Relationship with vulnerability	Rationale	Other studies which use this indicator	Data source
Sensitivity						
1	Production volatility	Standard deviation in cotton production.	Directly proportional	Agricultural impact on cotton production will have a knock-on effect on the quantity of high-quality cotton ginning facilities receive. Climate change may lead to decline in cotton productivity, leading to lesser profits for the ginning industry due to the need to import cotton from elsewhere. The greater the volatility of cotton production, the higher the vulnerability.	Batool and Saeed (2017)	The Cotton Corporation of India (2019) Available from: https://cotcorp.org.in/
2	Marginal manufacturers	Proportion of urban manufacturers who are marginal workers relative to total urban population employed as manufacturers.	Directly proportional	Marginal workers are defined as not having been in employment for 6 months and more. Marginal workers are a proxy for daily or seasonal workers, contract-less workers and workers who hold temporary jobs. Any decrease in cotton production arising from climate change, result in	Sherly et al. (2015); PRISE (2018); Vittal et al (2020); Sridevi et al. (2014)	Census of India, Government of India (2011) Available from:

				decreased wages and unemployment for marginal manufacturers. The greater the proportion of marginal workers, the higher the vulnerability.		www.censusindia.gov.in
3	Poverty	Proportion of both urban and urban people living in Multidimensional Poverty Index (MPI)	Directly proportional	A higher index value indicates lower household income, poor nutrition, higher child mortality, lack of preventive health care, lower education, lower sanitation, less access to clean drinking water, and less access to electricity. The higher the proportion of people below poverty line, the higher the vulnerability level and the greater the impact of adverse climate change shocks.	Thornton et al. (2006); Gbetibouo and Ringler (2009); Oxfam (2009); INRM Consultants Pvt. Ltd (2016); PRISE (2018); Batool and Saaed (2018), Senapai (2020); Manglem (2020);	Alkire, S., Oldiges, C. and Kanagaratnam, U. (2018). 'Multidimensional poverty reduction in India 2005/6–2015/16: still a long way to go but the poorest are catching up', OPHI Research in Progress 54a, University of Oxford Available from: https://ophi.org.uk/rp54b/
4	Female head of household	Proportion of urban female head of households relative to total urban head of households.	Directly proportional	This indicator is a proxy for males who have left the household and migrated elsewhere, possibly in search of work. It can also be used as a proxy for male head of households who are deceased or who are not in capacity to work. These factors increase the caring responsibility on the	Adapted from DHS (2006); Hahn et al. (2009); Botero and Salinas (2013)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

				female head of the household, increases difficulties in evacuation during hazards, reduces incoming wages and increases the vulnerability to the impacts of climatic shocks. The greater the proportion of female head of households, the higher the vulnerability.		
5	Dependent population	Proportion of urban population <14 y/o or >60 y/o relative to total urban population	Directly proportional	The higher the indicator, the higher the burden on the productive part of the population to maintain the pensions of the economically dependent. Any economic shocks arising from climate change impacts will increase the burden of the productive populations. The greater the value, the higher the vulnerability.	Sherly et al. (2015); Rao et al., (2016); Sridevi et al. (2014) ; INRM Consultants Pvt. Ltd (2016) ; Senapati 2020 ; Below et al., 2012 ; Botero and Salinas (2013)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
6	Water stress	Proportion of ginning factories located within water stress zone measured as projected water stress (2040s).	Directly proportional	This indicator demonstrates the amount of water available per unit area (mm). Lower availability due to increase in demands for agricultural, domestic and industrial use, indicates higher vulnerability to climate change.	Vittal (2020) uses SPI-3 months. Other literature that considers various drought indicators: O'Brien et al., (2004); Gbetibouo and Ringler (2009); Ravindranath et al., (2011); Sridevi et al (2014); Aggarwal et	WRI Aqueduct Water Risk Atlas (2020) Available from: https://www.wri.org

					al (2016); Baatol and Saeed (2018); Senapati (2020);	
Adaptive capacity						
1	Wages of male engaged in cotton processing activities.	Average wages of a male cotton processing activities.	Inversely proportional	The more income a household receives, the more resilient they are in the face of adverse climate change. The higher the average male wages of a cotton manufacturer, the lesser the vulnerability.	Gbetibouo and Ringler (2009); Weldesilassie, et al 2015	Unit level Periodic Labour Force Survey Data. Government of India. (2018-2019)
2	Work participation rate	Percentage of total urban workers (main and marginal) relative to the total urban potential population within working age (15-60 years old).	Inversely proportional	Higher proportion of work participation rate leads to economic growth of a region and greater income to sustain livelihood, and thus higher adaptive capacity to adapt to climatic stresses. The higher the work participation rates, the lesser the vulnerability.	INRM Consultants Pvt. Ltd (2016)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
3	Female work participation rate	Percentage of total urban female workers (main and marginal) relative to the total urban potential female population within working age (15-60 years old).	Inversely proportional	The coping capacity of a family will be higher if the female working population is higher in a community as it increases economic independence and increases the proportion of the population engaged in economic activity. The more urban females	Wood et al. (2010); Sherly et al. (2015); Vitall (2020); Chanana-Nag et al (2020) ; Lahiri (2020).	Census of India, Government of India (2011) Available from:

				in employment, the less vulnerable in the face of climate shocks and stress.		www.censusindia.gov.in
4	Male literacy rate	Proportion of literate urban male manufacturers relative to total urban male manufacturers.	Inversely proportional	Higher literacy level decreases vulnerability by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities. It also enhances their ability to diversify livelihoods in the face of long-term climate change.	Leichenko and O'brien (2002); Eriksen et al. (2007); Wongbusarakum and Loper (2011); Sherly et al. (2015); Vittal (2020); Dumenu and Obeng (2016); Senapati (2020), PRISE (2018); Gbetibouo and Ringler (2009); Botero and Salinas (2013); Aggarwal et al (2016); Sridevi et al., (2014); O'Brien et al., (2004); INRM Consultants Pvt. Ltd (2016)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in
5	Female literacy rate	Proportion of literate urban female manufacturers relative to total urban female manufacturers.	Inversely proportional	Higher literacy level decreases vulnerability by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities. It also enhances their ability to diversify livelihoods in the face of long-term climate change.	Leichenko and O'brien (2002); Eriksen et al. (2007); Wongbusarakum and Loper (2011); Sherly et al. (2015); Vittal (2020); Dumenu and Obeng (2016); Senapati (2020), PRISE (2018); Gbetibouo and Ringler (2009); Botero and Salinas (2013); Aggarwal et al (2016); Sridevi et al., (2014); O'Brien et al., (2004); INRM Consultants Pvt. Ltd (2016)	Census of India, Government of India (2011) Available from: www.censusindia.gov.in

6	Bank accounts	Proportion of urban households availing banking services out of the total urban population.	Inversely proportional	Access to financial services provides a form of security/safety net in the face of disaster. Banking Facilities are an important indicator of wealth and provide information related to the adaptive capacity of the region in of extent of extreme events or climate related shocks. The higher the proportion of urban population with access to banking services, the lesser the vulnerability.	PRISE (2018); Senapati (2020); Batool and Saeed (2018); Gbetibouo and Ringler (2009); INRM Consultants Pvt. Ltd (2016)	Household census, Government of India (2015) Available from: https://www.niti.gov.in
7	Technology and information	Proportion of urban households with computer/laptop with internet connection relative to total urban population.	Inversely proportional	Access to technology and to the internet enables households to received emergency warnings when a disaster is about to strike, increasing their ability to respond to warning and take preventative measures. The higher the proportion of the urban population with access to the internet, the lesser the vulnerability.	GIZ (2014); Batool and Saeed (2018); Yusuf and Francisco (2009)	Household census, Government of India (2015) Available from: https://www.niti.gov.in
Exposure						
1	Number of factories	Number of ginning and pressing factories	Directly proportional	The higher the number of factories, the greater the exposure to climatic impacts. Impact of climate change on cotton production may have	Crichton (2006); GIZ (2013); Batool and Saeed (2018)	Ministry of Textiles Available from: http://texmin.nic.in/sites/default/files/List_of_Rated_877_units_tex

				knock on impacts on factories, especially small enterprises.		tiles_committee_2013 0911_0.pdf

2	Number of people employed in cotton processing	Number of people employed in all cotton processing activities	Directly proportional	The higher the number of people working in the sector, the more exposure to climate impacts.		Unit level Periodic Labour Force Survey Data 2018-2019, Government of India. Edited by: Dr. Paaritosh Nath
Hazard						
1	Temperature threshold for labour productivity	Project change in the number of days when temp >34°C	Directly proportionate	According to the International Labour Organization, excessive heat during work creates occupational health risks; it restricts a worker's physical functions and capabilities, work capacity and productivity. Temperatures above 24–26°C are associated with reduced labour productivity. At 33–34°C, a worker operating at moderate work intensity loses 50 per cent of his or her work capacity.	ILO (2019)	Baseline: ERA5 Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
2	Heatwave	Projected change in the number of days daily maximum temperature exceeds baseline average	Directly proportionate	According to the WMO, 1 period of marked unusual hot weather (maximum, minimum and daily average temperature) over a	WMO (2020)	Baseline: ERA5

		for at least 3 consecutive days		region persisting at least three consecutive days during the warm period of the year based on local (station-based) climatological conditions, with thermal conditions recorded above given thresholds. An increase in number of heatwaves present a risk to the health and safety of cotton manufacturers.		Available from: https://www.ecmwf.int/ Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
3	Wildfire	Projected number of days when fire weather index is greater than 20 – "Medium-high"	Directly proportional	Wildfires cause significant damage to agricultural crops. This literature review did not find an example of a study which has previously considered the impacts of changes in wildfire on cotton cultivation. However past events clearly demonstrate that wildfires are a risk to cotton such as the recent Australian wildfires. The IPCC projects that climate change will increase the intensity and frequency of wildfires across India. The higher the percentage of cotton growing areas located in wildfire zones, the higher the vulnerability.	No literature found which directly uses exposure to "wildfire" as an indicator in a cotton specific CRVA.	CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
4	Wildfire	Projected number of days when fire weather index is greater than 30 – "High"	Directly proportional	As above	As above	As above

5	Flood fluvial	Area of district in a flood zone for the projected in 1-in-100 year flood extent as a proportion of total area of district	Directly proportional	Extreme rainfall events which lead to flooding can cause widespread damage to agricultural crops. For example, in 2010, flooding caused significant damage to cotton production across Pakistan, causing a significant reduction in the crop area for cotton production. The IPCC projects that climate change will increase the intensity and frequency of extreme weather events across India. The higher the percentage of cotton growing areas located in fluvial flood zones, the higher the vulnerability.	PRISE (2018); Gbetibouo and Ringler (2009); Ravindranath et al., (2011); Senapati (2020), Aggarwal et al (2016); Batool and Saeed (2018); Oxfam Discussion Papers (2012).	WRI Aqueduct Floods (2020) Available from: https://www.wri.org/
6	Landslides	Precipitation induced landslides.	Directly proportional	Landslides cause significant damage to agricultural crops. The IPCC projects that climate change will increase the intensity and frequency of landslides across India. The higher the percentage of cotton growing areas located in landslide zones, the higher the vulnerability.	No literature found which directly uses exposure to "landslides" as an indicator in a cotton specific CRVA.	CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5
7	Extreme precipitation (pluvial flood)	Percentage of total annual rainfall falling on 5% heaviest rainfall days	Directly proportionate	Extreme rainfall events can lead to waterlogged conditions, which can cause inundate cotton plantations. An Increase in intensity and frequency of extreme rainfall events,	Sehgal et al (2013); Vittall et al., (2020)	Baseline: ERA5 Available from: https://www.ecmwf.int/

				increases the risk of waterlogging and crop damage.		Projected: CMIP5 Available from: https://pcmdi.llnl.gov/mips/cmip5

Appendix 5: Results: Cotton cultivation CRVA 1

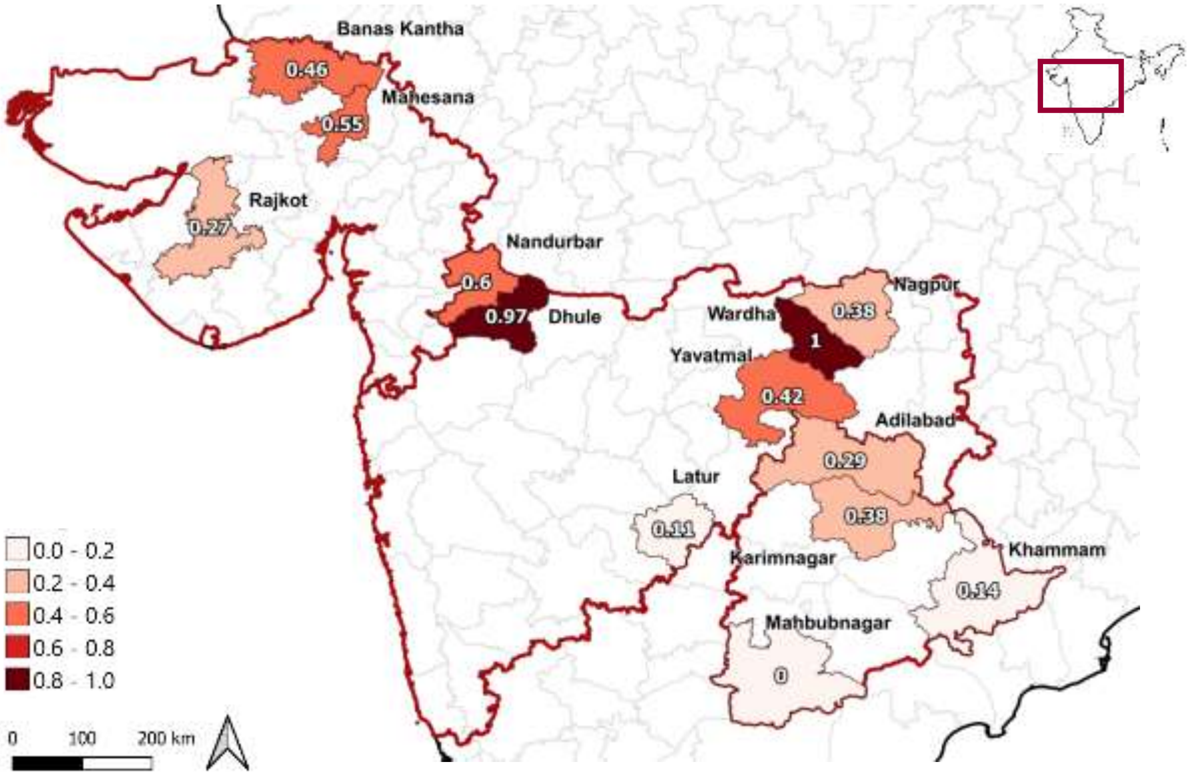
This section presents the results of the individual components that are used to calculate the risk score for the cotton cultivation CRVA, namely exposure, hazard and vulnerability.

Cotton cultivation CRVA: Exposure and Hazard Index

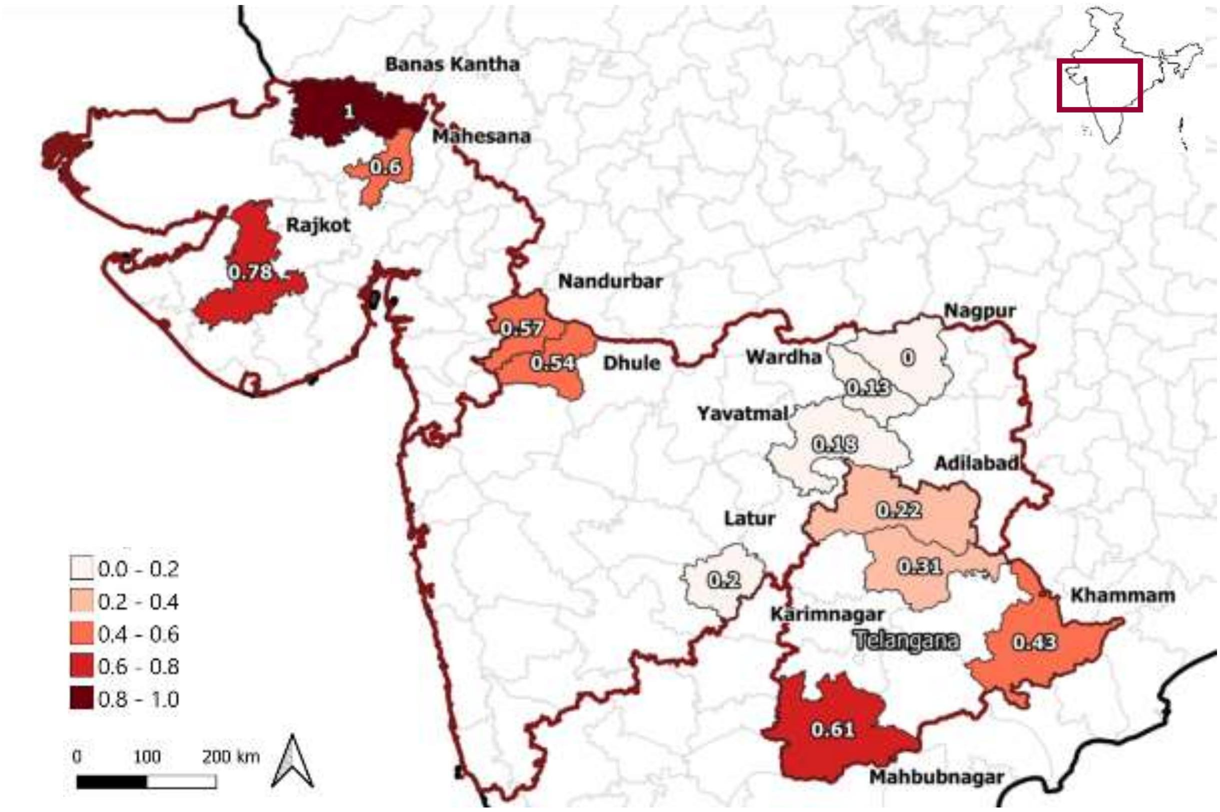
Normalised scores for exposure and hazard:

	Districts	Exposure	Hazard
Gujarat	Rajkot	0.27	0.78
	Banas Kantha	0.46	1.00
	Mahesana	0.55	0.60
Maharashtra	Dhule	0.97	0.54
	Nandurbar	0.60	0.57
	Latur	0.11	0.20
	Nagpur	0.38	0.00
	Wardha	1.00	0.13
	Yavatmal	0.42	0.18
Telangana	Adilabad	0.29	0.22
	Karimnagar	0.38	0.31
	Khammam	0.14	0.43
	Mahbubnagar	0.00	0.61

The following figure shows a cartographic representation of the exposure index:



The following figure shows a cartographic representation of the hazard index:

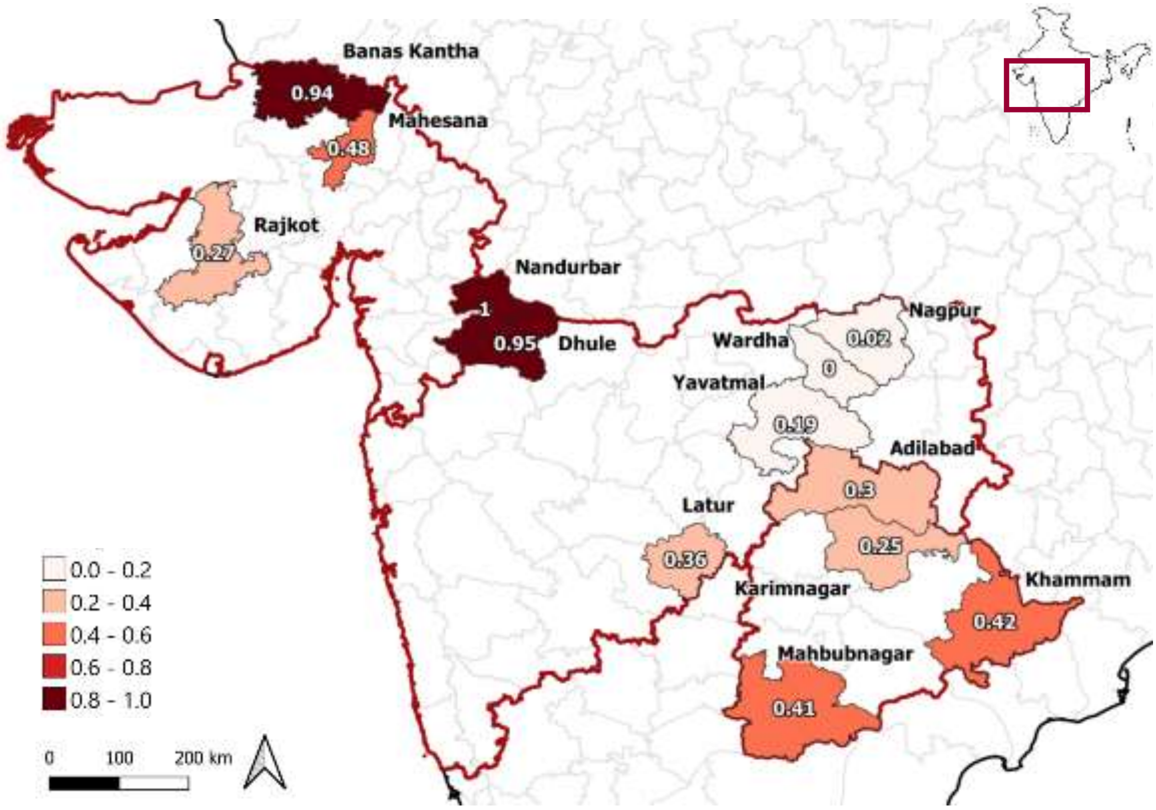


Cotton cultivation CRVA: Vulnerability Index

Normalised scores for sensitivity, adaptive capacity and vulnerability:

	Districts	Sensitivity	Adaptive Capacity	Vulnerability	Normalised Vulnerability
Gujarat	Rajkot	0.44	0.56	0.79	0.27
	Banas Kantha	0.54	0.39	1.39	0.94
	Mahesana	0.35	0.36	0.97	0.48
Maharashtra	Dhule	0.55	0.39	1.40	0.95
	Nandurbar	0.58	0.40	1.45	1.00
	Latur	0.47	0.54	0.87	0.36
	Nagpur	0.32	0.57	0.56	0.02
	Wardha	0.30	0.55	0.55	0.00
	Yavatmal	0.32	0.45	0.72	0.19
Telangana	Adilabad	0.45	0.56	0.81	0.30
	Karimnagar	0.40	0.52	0.77	0.25
	Khammam	0.42	0.46	0.93	0.42
	Mahbubnagar	0.41	0.45	0.92	0.41

The following figure shows a cartographic representation of the normalised vulnerability index.



Appendix 6: Results: Cotton processing CRVA 2

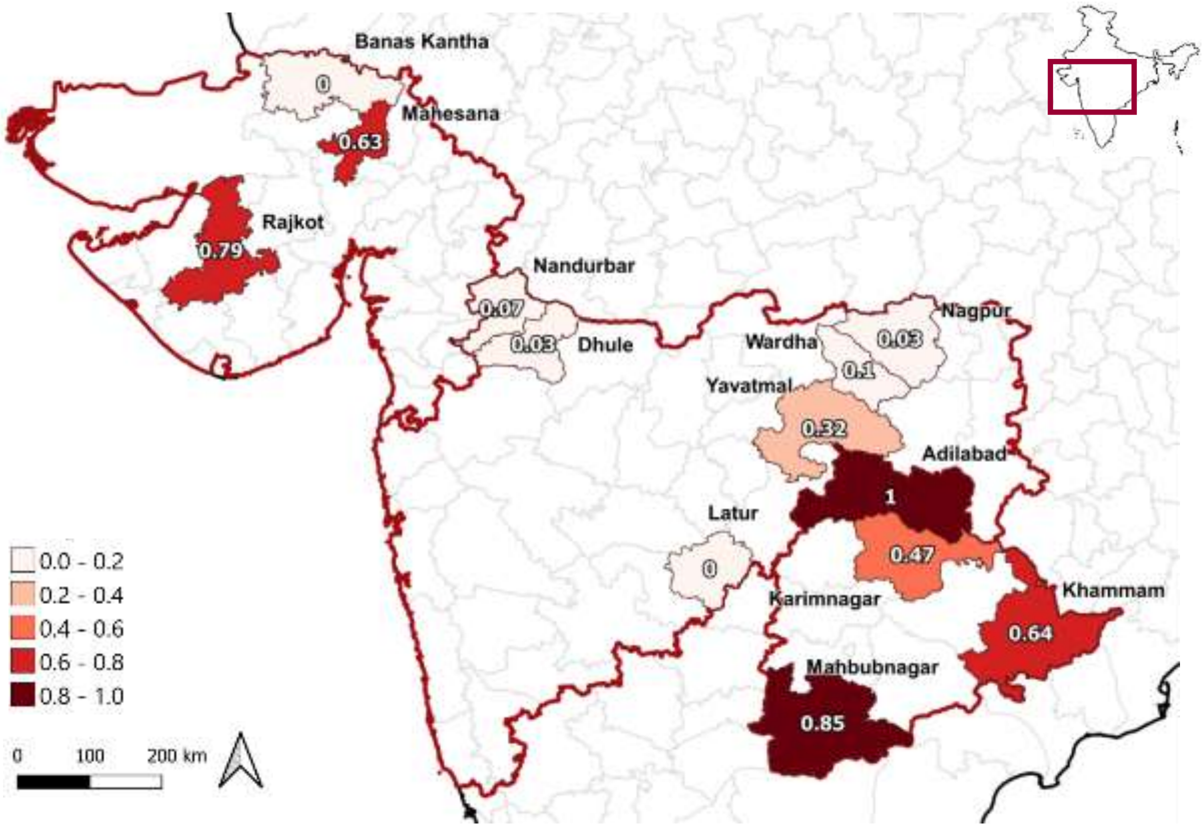
This section presents the results of the individual components that are used to calculate the risk score for the cotton processing CRVA, namely exposure, hazard and vulnerability (sensitivity and adaptive capacity).

Cotton processing CRVA: Exposure and Hazard Index

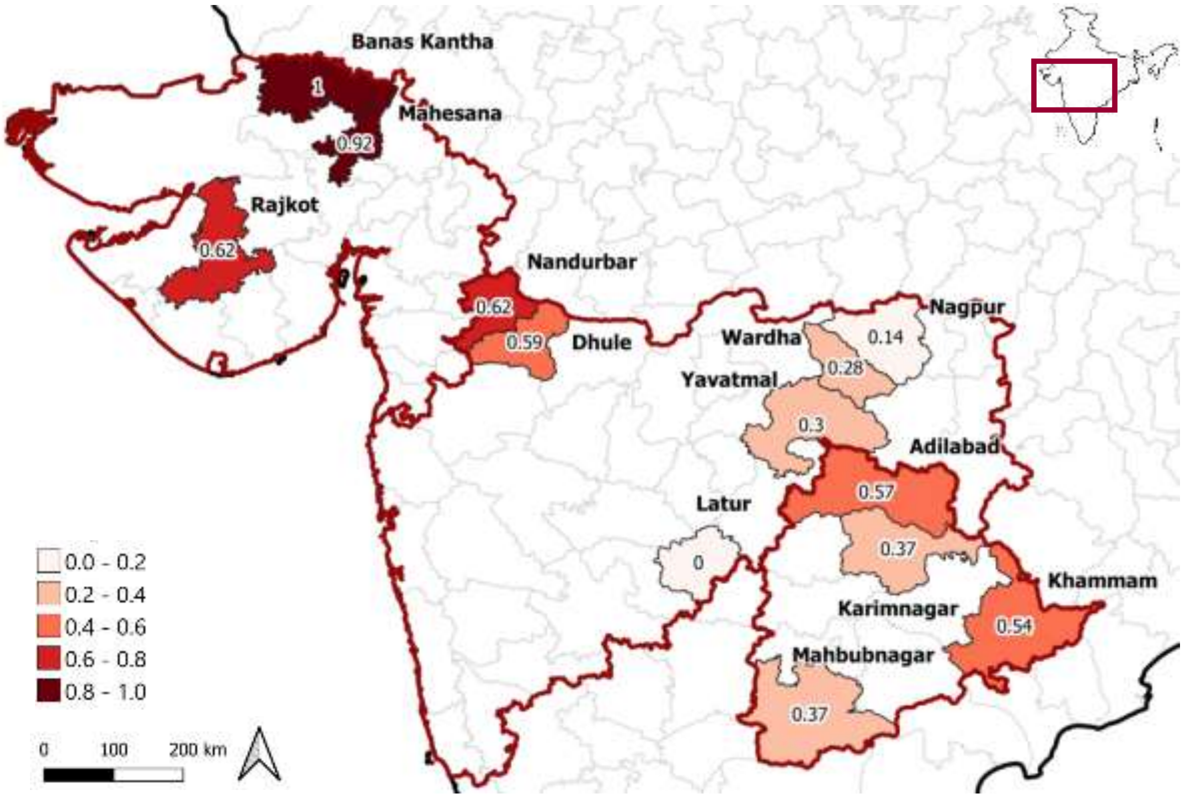
Normalised scores for exposure and hazard:

	Districts	Exposure	Hazard
Gujarat	Rajkot	0.79	0.62
	Banas Kantha	0.00	1.00
	Mahesana	0.63	0.92
Maharashtra	Dhule	0.03	0.59
	Nandurbar	0.07	0.62
	Latur	0.00	0.00
	Nagpur	0.03	0.14
	Wardha	0.10	0.28
	Yavatmal	0.32	0.30
Telangana	Adilabad	1.00	0.57
	Karimnagar	0.47	0.37
	Khammam	0.64	0.54
	Mahbubnagar	0.85	0.37

The following figure shows a cartographic representation of the exposure index:



The following figure shows a cartographic representation of the hazard index:

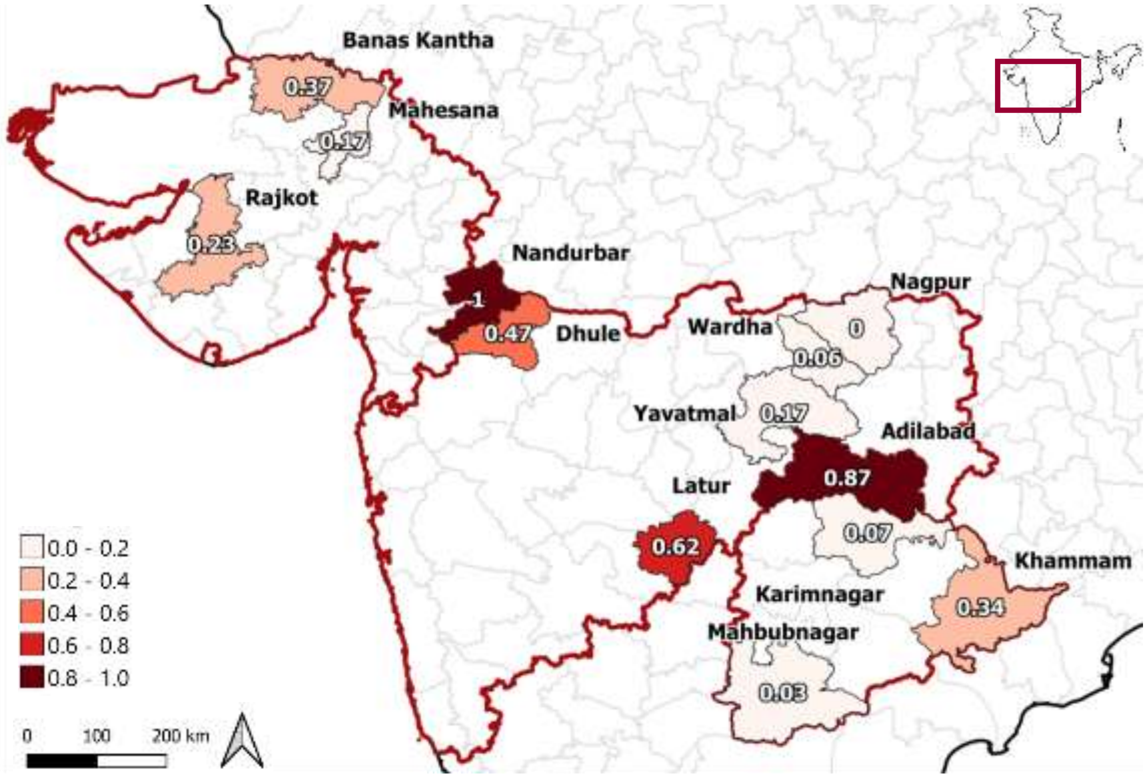


Cotton processing CRVA: Vulnerability Index

Normalised scores for sensitivity, adaptive capacity and vulnerability:

	Districts	Sensitivity	Adaptive Capacity	Vulnerability	Normalised Vulnerability
Gujarat	Rajkot	0.43	0.46	0.95	0.23
	Banas Kantha	0.49	0.37	1.32	0.37
	Mahesana	0.41	0.50	0.81	0.17
Maharashtra	Dhule	0.60	0.38	1.58	0.47
	Nandurbar	0.67	0.23	2.96	1.00
	Latur	0.57	0.29	1.97	0.62
	Nagpur	0.30	0.83	0.36	0.00
	Wardha	0.29	0.59	0.50	0.06
	Yavatmal	0.42	0.51	0.81	0.17
Telangana	Adilabad	0.43	0.16	2.63	0.87
	Karimnagar	0.25	0.46	0.53	0.07
	Khammam	0.32	0.25	1.25	0.34
	Mahbubnagar	0.22	0.50	0.44	0.03

The following figure shows a cartographic representation of the normalised vulnerability index:



Appendix 7: Summary of the main drivers of risk

Summary of the main drivers of risk (a) across all districts, (b) apparent state-level trends, (c) and apparent hotspots on for individual districts for the cotton cultivation CRVA (top) and cotton processing CRVA (bottom).

Exposed	Hazard	Sensitivity	Adaptive capacity
Cotton Cultivation			
Common indicators which elevate risk across all districts			
	High projected increase in number of days subject to damaging wind speeds	High dependency on agriculture for rural employment	Low percentage of cotton grown as irrigated cotton
	High projected increase in number of days when maximum temperature exceeds 34 °C	High gender pay gap in the wages of cotton farmers	Low rate of rural female work participation
	High projected increase in number of days when maximum temperature exceeds 40 °C	High % of GDP reliant on the agricultural sector	Low % of rural household with access to bank accounts
	High projected increase in frequency of heatwaves	High multidimensional poverty	Low % of rural households with computer/laptop with internet connection
	High projected increase in number of days when wildfire risk is 'high'		Low male literacy rate (agricultural worker)
			Low female literacy rate (agricultural worker)

				Low urban household with access to banking services
State-level trends in indicators which elevate risk				
Gujarat		High projected increase in number of days when maximum temperature exceeds 40 °C	High % of rural, agricultural marginal workers	Low rural work participation rate
		High projected increase in days receiving extreme precipitation.	High projected water stress	Low rural female work participation rate
		High projected increase in frequency of heatwaves		Low organic carbon stocks
		High projected increase in number of days when wildfire risk is ‘high’		
		High projected decrease in SPI-3 months		
		High projected increase in extreme precipitation		
Maharashtra			High gender pay gap	Low wages of female cotton labourers
Telangana	High fluvial flood risk	High projected increase in number of days subject to damaging wind speeds	High % of farms less than 1 hectare	Low % of irrigated cotton
		High projected increase in number of days when maximum temperature exceeds 34 °C	High % of rural female head of household	Low rural male literacy rate (agricultural worker)

		High projected decrease in effective growing degree days High projected flood risk. High projected landslide risk.		Low rural female literacy rate (agricultural worker)
Specific district whereby indicator is highest/lowest				
Gujarat	District with highest rural population density (Mahesana)	District with the greatest increase in number of days above temperature threshold of 40 °C (Banas Kantha and Mahesana)	District with highest % of rural, agricultural marginal workers (Banas Kantha)	District with lowest wages of male cotton labourers (Mahesana)
		District with the lowest effective growing degree days (Banas Kantha)	District with highest % of dependant rural population (<14 y/o & >65 y/o) (Banas Kantha)	District with lowest road density (Banas Kantha)
		District with the greatest decrease in effective growing degree days (Rajkot)	District with highest rural mean household size (Banas Kantha)	District with lowest female work participation rate (Mahesana)
		District with the highest number of days with extreme precipitation (Rajkot)	District with highest rural mean household size (Rajkot)	District with lowest % of rural household with access to technology and internet connection (Banas Kantha)
		District with the highest number of heatwaves (Mahesana)	District with highest yield volatility (Rajkot)	District with lowest soil organic carbon stock (Rajkot)

		District with the greatest increase in the frequency of heatwaves (Mahesana)		District with lowest soil water holding capacity (Mahesana)
		District with the highest number of days when wildfire risk is 'high'		District with highest projected water stress (Mahesana)
		District with the greatest change in SPI (Mahesana)		
Maharashtra	District with highest net sown area (Wardha)	District with the greatest increase in number of days subject to damaging wind speeds (Dhule)	District with highest gender pay gap (Nandurbar)	District with lowest wages of female cotton labourers (Dhule)
	District with highest number of people working in the cotton processing sector (Wardha)	District with the greatest increase in the number of days when wildfire risk us 'high'	District with highest % of people living in poverty (Nandurbar)	District with the lowest % of rural households availing banking services (Nandurbar)
			District with highest % of degraded lands (Dhule)	Districts with lowest soil water holding capacity (Mahesana and Nagpur)
Telangana	District with highest fluvial flood risk (Adilabad)	District with the highest number of days subject to damaging windspeeds (Mahbubnagar)	District with highest % of rural population dependant on agriculture for employment (Mahbubnagar)	District with lowest female literacy rate (agricultural worker) (Mahbubnagar)
		District with the greatest increase in number of days	District with highest % of farms less than 1 hectare (Karimmnagar)	District with lowest % of irrigated cotton (Mahbubnagar)

	above temperature threshold of 34 °C (Mahbubnagar)		
	District with the highest % of district exposed to flood risk (Khammam)	District with highest % of rural female head of household (Khammam)	District with lowest male literacy rate (agricultural worker) (Mahbubnagar)
	District with the highest % of district exposed to landslide risk (Khammam)	District with highest % of GDP reliant on the agricultural sector (Mahbubungar)	

	Exposed	Hazard	Sensitivity	Adaptive capacity
Cotton Processing				
Common indicators which elevate risk across all districts				
		High number of days when temperature exceed 34 °C	High multidimensional poverty	Low urban work participation rate
		High projected increase in frequency of heatwaves		Low urban female work participation rate
		High projected increase in extreme precipitation		Low urban female literacy rate (manufacturers)
				Low urban household with access to banking services
				Low urban household with computer/laptop with internet connection
State-level trends in indicators which elevate risk				
Gujarat	High number of ginning factories		High projected water stress	Low urban female participation rate
Maharashtra				

Telangana	High number of people employed in cotton processing	High number of days when temperature exceed 34 °C		
			High % of marginal manufacturers	Low wages of men employed in the processing sector
				Low literacy rate amongst male urban manufacturer
				Low literacy rate amongst female urban manufacturer
Specific district whereby indicator is highest/lowest				
Gujarat		District with highest % of area exposed to flood risk (Rajkot)	District with the highest production volatility (Rajkot)	District with the lowest female work participation rate (Banas Kantha)
		District with highest increase in frequency of heatwaves (Mahesana)		
		District with highest number of days when wildfire risk is 'high' (Banas Kantha)		
		District with highest number of days subject to extreme rainfall (Rajkot)		
		District with greatest increase in number of days subject to extreme rainfall (Banas Kantha)		

		District with highest % of district subject to flood risk (Rajkot)		
Maharashtra		District with greatest increase in number of days when wildfire risk is 'high' (Nagpur) District with highest landslide risk (Nandurbar)	District with highest mean household size (Latur) District with the highest mean household size (Latur) District with the highest multidimensional poverty (Nandurbar)	District with the lowest % of urban household with access to banking services (Nandurbar)
Telangana	District with the highest number of ginning factories (Adilabad) District with the highest number of people employed in cotton processing (Mahbubnagar)	District with the highest number of days when temperature exceed 34 °C (Khammam) District with highest % of district area subject to landslide risk (Khammam)	District with the highest % of marginal manufacturers (Adilabad) District with the highest urban female head of households (Khammam)	District with lowest wages of men employed in the processing sector (Khammam) literacy rate amongst female urban manufacturers (Adilabad) District with the lowest literacy rate amongst male urban manufacturers (Adilabad) District with the lowest % of urban households with computer/laptop with internet connection (Adilabad)

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