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Climate Risk Case Study

Bulleh Shah Paper Mills – Packages, Ltd.
Kasur, PAKISTAN

International Finance Corporation
World Bank Group

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The authors wish to thank Packages, Ltd. for its valuable contributions to the study.

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Foreword

It is increasingly recognized that a changing climate is creating risks and opportunities for the performance of private sector investments. Yet, to date, the evidence base on the significance of these issues is poorly defined. Most climate change assessments have focused on large-scale impacts on natural and social systems, and on end of century timescales which appear to be of little relevance to business.

Recognizing this important knowledge gap, the International Finance Corporation (IFC) commissioned Acclimatise to undertake three pilot studies during 2008 to 2009, based on IFC investments in developing countries. The main aim of these studies was to test and develop methodologies for evaluating climate risks to the private sector and identifying appropriate adaptation responses.

The first three pilot studies are:

Khimti 1 hydro-power scheme, Nepal: A 60 MW run-of-river hydro-power facility, generating 350 GWh of electricity per year, located in Dolakha District, about 100 km east of Kathmandu. The facility utilizes a drop from 1,270 to 586 meters above sea level from the Khimti River, a tributary of the Tama Koshi River. Khimti 1 was built, and is owned and operated by Himal Power Ltd (HPL) and, as a Public Private Partnership project, will be transferred to the Nepalese Government in the future.

Ghana Oil Palm Development Company Ltd (GOPDC), Ghana: GOPDC is an integrated agro-industrial company with two oil palm plantations at Kwae and Okumaning, in Ghana's Eastern Region. GOPDC also operate a mill at Kwae, where oil palm fresh fruit bunches are processed into crude palm oil (CPO) and palm kernel oil (PKO). Also at Kwae, a refinery and fractionation plant processes up to 150 metric tonnes per day of CPO into olein and stearin products.

Packages Bulleh Shah Paper Mills, Pakistan: Packages Ltd is Pakistan's premier pulp and paper packaging company, and has been an IFC client since 1964. The company produces paper and paper board, writing and printing paper, tissue products and flexible packaging products. It uses wheat straw, recycled and waste paper, and imported pulp in its production lines. The newly-established Bulleh Shah Paper Mills (BSPM), near Kasur, has allowed the company to relocate existing pulp and paper production facilities from its headquarters in Lahore to larger premises, to enable it to increase its production capacity from 100,000 to 300,000 tpa.

This report presents the outcomes of the Packages pilot study.

Overview of the approach to the pilot studies

Potentially, the performance of a private sector investment – measured in financial, environmental and social terms – can be affected by changing climatic conditions, particularly when the investment relies on long-lived fixed assets or has complex supply chains. To evaluate potential climate impacts for the three pilot studies, we utilized a climate risk assessment and management framework originally developed in the UK. Applying the framework involves understanding the linkages between various aspects of business performance and climatic conditions. In some cases, these relationships were developed from data recorded at the study site, and where no site-specific data were available, we drew on the scientific literature. The impacts of future climate change scenarios (based on global climate models) were then evaluated. To analyze financial impacts, we perturbed elements of the clients' financial models. Recommendations were made for adaptation actions that could be considered by the companies, reflecting on the level of confidence in the assessments of risk.

In practical terms, the pilot studies involved:

- A site visit (except in the case of Packages),
- Meetings with the IFC client, to discuss climatic sensitivities and vulnerabilities, obtain data, reports etc,
- Meetings with in-country sector experts and c limate change experts – from the public sector, research institutions, universities and NGOs,
- Literature reviews and qualitative analysis of impacts,
- Quantitative modeling of impacts where possible.

There are challenges and uncertainties in undertaking these assessments, which have been revealed through the pilot studies, including:

- Gaps in understanding of the relationships between climate and various aspects of business performance.
- Uncertainties in baseline climate data and in scenarios of future climate change on timescales and spatial scales relevant to individual business. These uncertainties are particularly apparent in relation to changes in extreme climatic events, which may hold the most significant consequences.
- On the shorter timescales of relevance to business, natural climatic variability often dominates the 'signal' of climate change.

However, despite these constraints, the studies have been able to generate new information about climate risks to the private sector. They have also demonstrated some of the practical approaches that can be applied to understand these risks better, and to reduce uncertainty about the future.

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1. Executive Summary

This report assesses the risks posed by climate change to IFC's investment in Packages' new Bulleh Shah Paper Mills (BSPM) at Kasur, Pakistan, and identifies potential adaptation (risk management) measures that can be used to 'climate-proof' the investment. A number of conclusions can now be drawn regarding climate risks at BSPM.

Packages Limited is Pakistan's premier pulp and paper packaging company, and has been an IFC client since 1964. The company produces paper and paper board, writing and printing paper, tissue products, and flexible packaging products. It uses wheat straw, recycled and waste paper, and imported pulp in its production lines. The newly-established Bulleh Shah Paper Mills (BSPM), near Kasur, has allowed the company to relocate existing pulp and paper production facilities from its headquarters in Lahore to the new plant. This has enabled the company to increase production of higher margin products at Kasur, and to upgrade and expand production lines at the existing plant.

Temperatures over Pakistan as a whole have increased by 0.35°C over the period 1970–99, and projections of future temperature show strong warming with high confidence. Annual average temperatures in this region are projected to increase by 1.0°C to 2.25°C by 2025 (based on a multi-model ensemble of 21 GCMs), and from 2.0°C to 3.5°C by 2050, using a medium emissions scenario for the future. There is little agreement, however, among models of future precipitation across the region, making projections of future changes in rainfall highly uncertain. The region around Kasur already experiences very large year-to-year variability in seasonal rainfall; this range is far larger than the changes in precipitation projected as a result of climate change by the end of this century.

Packages employs a wide range of feedstock at BSPM. This diversity minimizes the impact of supply chain disruptions, price fluctuations, and any climate-related risks to raw materials such as wheat straw. Though agricultural modeling studies project future decreases in wheat yields in the region, these are largely the result of changes in precipitation and increased risk of crop stress due to droughts. Because farms around BSPM are groundwater-irrigated they are not as susceptible to problems associated with projected changed in precipitation, *provided that* climate change does not result in reduced groundwater recharge rates or increasingly unsustainable extraction.

This report presents a groundwater recharge analysis (using two different modeling methods) showing that a majority of climate models suggest an increase in natural recharge in the future. These modeled changes to future recharge indicate that it is unlikely that *supply* of groundwater resources will be depleted as a result of climate change over the lifetime of BSPM. For this analysis, however, it was not possible to estimate the abstraction rates of other users (if any), or whether these rates might change in future. Recent research in nearby locations shows unsustainable groundwater depletion levels in recent years, and climate change is likely to increase *demand* for freshwater resources, particularly in semi-arid areas. Other studies indicate that small changes in precipitation as a result of climate change can be magnified into larger changes in groundwater recharge levels. The uncertainty associated with current availability and future projections of groundwater underlines the need for investment in integrated groundwater resources research.

The engineering analysis for this study indicates that climate change will have a slight negative impact on steam turbine output (as a result of higher cooling water temperatures), which is partially offset by an increase in boiler efficiency. The savings in reduced natural gas requirement for fuel are exceeded by an increase in the cost of generating power, which effectively reduces the amount of power the company is able to export to the grid.

For this desk-based study, it was possible to obtain technical data for a limited number of new engineering assets (a 200TPH boiler and a 41MW steam turbine/generator with double extraction). A full engineering analysis would require many months of on-site observation. Quantification of the impact of climate change on these new power assets revealed a relatively small financial impact, however there are potentially more significant risks involved that we cannot quantify, and a more detailed system-level engineering-level risk assessment may be beneficial.

A site visit was not possible for this case study, and all analysis was undertaken as a desk-based study, drawing on the climate change impacts and adaptation literature, an engineering risk assessment, and a groundwater modeling analysis. The desk-based analysis also involved making enquiries of the company and of local and provincial organizations, however this allowed only limited knowledge of the company's operations in the context of the surrounding area, and made it challenging to do further quantitative analysis. A site visit would have allowed close examination of both the company's operations and the surrounding area that simply cannot be done remotely. It is possible that this would have uncovered additional climate risks that are not apparent from a remote analysis. Closer contact with the company and local stakeholders would also have facilitated follow-up discussion.

Because this study relied heavily on climate impacts literature and data sets, it revealed specific subject areas where improved information about climate changes could help guide further research. For example, a significant amount of research has already been done on regional wheat yield and food security issues (particularly in developing countries), but very little information is available on the climate impacts on the pulp and paper industry; in order to analyze these risks we worked with the company and with engineers to understand what the sensitivities are. There is also limited information available on groundwater (whether observed changes or projections of future change), and what little exists tends to have a local focus, with results that are not necessarily transferrable to other locations. In general, research on natural systems is much farther advanced than research on business impacts, which have not yet been explored for many sectors. One of the benefits of this study is that it has investigated impacts on engineering issues. This engineering analysis found that, in general, turbine output is not very sensitive to a changing climate (at least in the short term), but it underlined the need for individual case studies with in-situ observations in order to identify system constraints and bottlenecks which may be exacerbated by a changing climate.

In terms of climate change information and data, this study relied mainly on general circulation models (GCMs), which provide global projections of climate change variables. There is good agreement among GCMs on future temperature trends, however projections of future precipitation across South Asia differ widely. This uncertainty means that the benefits of downscaling (which is often recommended as a way to identify specific local impacts) are irrelevant. A focused modeling effort on improving understanding of monsoon processes would certainly be beneficial for combating divergent GCM results in this part of the world.

This assessment has looked at how climate change could affect Packages' operations in the near- to medium-term (the 2020s through 2050s). Though these shorter timescales are more relevant to the private sector, much of the standard climate change projections concentrate on end-of-century changes. For example, most of the regional climate projections presented by the Intergovernmental Panel on Climate Change (IPCC) are for the 2080–2099 time period. By contrast, private sector investment is generally made on relatively short time horizons for which climate changes and associated impacts are relatively small. On these timescales of this study the financial impact of climate change, though uncertain, may not be critical to the company. Over the long term, however, these impacts may be far more significant.

2. Introduction

This report presents a climate risk assessment for IFC's investment in Bulleh Shah Paper Mills (BSPM) in Kasur, Pakistan. This facility is owned by Packages Limited, the leading integrated paper products manufacturer in Pakistan. Starting in 2005, Packages began to relocate its paper manufacturing facilities from Lahore (which has limited capacity for expansion), to Kasur. This has allowed the company to increase paper and paperboard production at the new site, while continuing to operate a packaging production plant at Lahore.

BSPM processes wheat straw in a mechanical pulping process. The company also pulps old corrugated containers and mixed office waste on separate pulping lines at the same facility. There are two generators on site (one steam turbine and one gas turbine) and the facility has substantial waste water processing. All water used in the operation is from groundwater.

This study explores the potential climate risks to the company's operational/engineering plant, to wheat straw input yields, to groundwater resources, and to the local community. In the absence of detailed information on the company's sensitivity to climate variability (a site visit was not possible for this case study) this report also presents a general overview of the climate risks faced by the pulp and paper sector worldwide.

2.1. Project Background

Packages Ltd is the leading integrated paper products manufacturer in Pakistan, and has been an IFC client since 1964 (the client relationship is one of IFC's longest). It is widely acknowledged as the country's market leader in production of high quality packaging products.

Packages undertook an investment program during the period 2005–2008, involving:

- establishing a new pulp and paper plant in Kasur,
- relocating existing pulp and paper production facilities from Lahore to the new plant in Kasur,
- increasing production of higher margin printing and writing paper products, and
- upgrading and expanding the converting lines and tissues lines at the existing plant.

Packages' first paper mill was installed in 1968 on the outskirts of Lahore. With time, the city of Lahore has encroached upon the company's existing facilities and there is no further room for expansion. The present processing facility in Lahore has become a limiting factor for future expansions, especially as a considerable amount of wheat straw has to be stored at site to secure a continuous production of straw pulp.

Moreover, collecting and transporting the straw in loose form in truck/tractor loads makes the straw transport very hazardous, particularly during the daytime.

Packages has relocated a major part of the company's pulp and paper operations to a 42ha site at Kasur, approximately 70 km away from the city of Lahore. The project site is in a rural area, reducing the time and distance required to source wheat straw, one of the operation's main raw materials. The site has access to good groundwater resources, and about 30,000m^3/day of fresh water is supplied from four deep well pumps. A public drainage canal runs along the plant site, which is close to the public grid and the public substation. The natural gas main supply line is 12km away, and site is accessible from the main road network.

With the new and relocated facilities, the company's production capacity will increase from 100,000 tonnes to 300,000 tonnes per year. At the conclusion of the project, all pulp and paper-making facilities at Packages' existing plant in Lahore will cease, with the exception of the manufacture of de-inked pulp and tissue paper (which will also ultimately shift to Kasur Site). Other operations at Lahore will, however, continue. Commercial production of the expansion project commenced in three phases starting 2006 onwards. Annual production at the Kasur site comprises the following:

- Carton board: 101,000 tonnes
- Container board: 88,000 tonnes
- Printing and writing paper: 115,000–127,000 tonnes
- Straw based pulp: 80,000 tonnes
- Waste paper based pulp: 1,53,000 tonnes
- Other pulp (imported): 40,000 tonnes

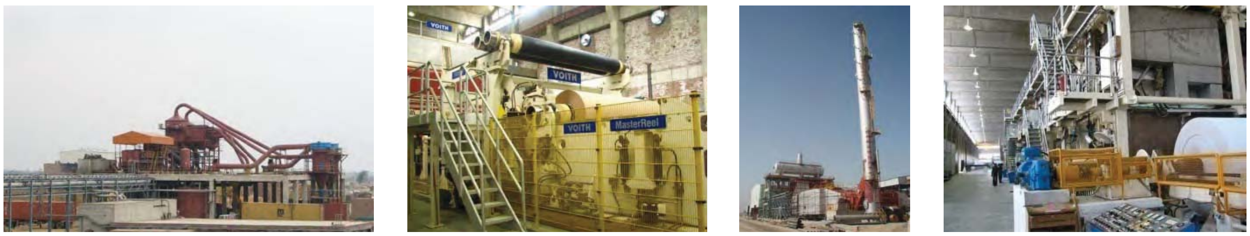

Figure 1. Photos taken at Bulleh Shah Paper Mills, from left: straw cleaning operations, winding reels, boiler stack, unwinders [Source: Shahid Hafeez, Packages Ltd].

2.2. Project Objectives

The investment in BSPM is intended to provide multiple benefits. The financial, environmental, engineering and social objectives are listed below.

Financial objectives underlying investment in a new facility at Kasur:

- Strengthened competitive position, strengthened long-term sustainability of the company's operations;
- Increased market share of growing national paper market;
- Increased overall production;
- Improved product quality and production efficiencies, through higher utilization of waste paper in the fiber mix in substitution of chemical pulp ;
- Reduced logistics costs and freshwater requirements.

Environmental objectives underlying investment in a new facility at Kasur:

- Installation of Secondary Stage Treatment Plant;
- Improved pulping process which reduces water pollution at source, and improved effluent treatment;
- Improved operational efficiencies, with reduced specific consumption of heat, power and water.

Engineering and technical objectives underlying investment in a new facility at Kasur:

- Increased production: with the new and relocated facilities, production capacity will increase from 100,000 metric tons/year to 500,000 metric tons/year;
- Improved quality of pulp and paper / paper-board production and sufficient supply of quality paperboard at reasonable prices for the company's growing converting operations;
- Higher production efficiencies (consumption of heat, power and water will be reduced) through reduced operating costs;

- Higher utilization of waste paper in the fiber mix in substitution of chemical pulp will bring cost efficiencies to the company.

Social objectives underlying investment in a new facility at Kasur:

- Continued good community relations through support for local events and educational institutions, and through reductions in traffic congestion, noise associated with regular industrial activity, and odor from straw storage and pulping.

If project objectives are met IFC, the company and its shareholders will benefit from the investment. The project will also benefit members of the local community by providing employment (particularly during construction), a new market for wheat straw, which would otherwise be burned, and a new source of income for local farmers. In addition, the investment will contribute to the upgrading of local basic services. Treated discharged water from the plant will be available for irrigating surrounding farms, and the company provides advice and support to local farmers on wheat growing.

The following sections explore the potential impacts of a changing climate on the project objectives.

3. Climate Analysis

3.1. Introduction

This chapter presents an overview of historical and present day (baseline) climate data for the area around Kasur, as well as the best currently available information and data on future climate change, focusing on the near and medium terms. Where possible, the time horizons of future climate change have been chosen to match the timescales of the project financial model, and to reflect projected climate change over the life of the project itself. The projected future changes in climate identified here are used in later chapters to identify and assess the risks that climate change poses to BSPM.

This chapter makes reference to several freely accessible data sets, methodologies and tools for climate change risk assessment. More detailed guidance and links to documentation and further information are provided in Annex A1 – Climate Analysis.

3.2. Approach

The information presented in this chapter is divided into three categories:

1. The observed regional climate, averaged over a thirty year (1961–90) period – this provides a ‘snapshot’ of the average conditions over a large geographical area centred on the case study location. Images of baseline regional climate were created using the data visualisation tool available through the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre. The data presented are part of the ‘CRU Global Climate Dataset’, which was developed to show mean monthly climate (‘climatology’) for 1961–90. The data are presented as grid cells of approximately $55km^2$ across the globe.

2. An observed timeseries of climatic conditions recorded monthly at an individual meteorological station over more than 140 years (1861–2008) – this provides a picture of year-to-year climatic variability and trends over a very long time period, at a geographical point very close to BSPM. The nearest weather station for which complete meteorological data has been recorded over a long time period is located at Lahore City, some 50km from Kasur. These long-term data records were obtained through the Climate Explorer tool developed by KNMI (Royal Netherlands Meteorological Institute), and presented using graphs developed in Excel.

3. Future climatic conditions for Pakistan, as projected by an ensemble of 15 global climate models. Given the lack of agreement among global climate models (GCMs) on the direction of change in precipitation in this part of the world, downscaling was not judged to be beneficial for this study. Although GCMs are unable to adequately represent local detail (and downscaling is recommended to combat this), the additional information provided by downscaling would only add detail to the uncertainty in the GCM projections in this case. The ensemble of 15 GCM projections used in this study was drawn from the UNDP’s ‘Climate Change Country Profiles’ for Pakistan. The profiles were funded jointly by the National Communications Support Program (NCSP) and the UK Department for International Development (DfID), and were developed to address the climate change information gap in many developing countries by making use of existing climate data to generate country-level data plots from the most up-to-date multi-model projections. These use a consistent approach for 52 countries to produce an ‘off the shelf’ analysis of climate data, and also make available the underlying data for each country for use in further research.

3.3. Key Messages

- The region around Kasur is characterized by three climatic seasons:
    - Winter (Dec –Mar), typified by mild temperatures and very few rain days,
    - Summer (Apr–Jun), a dry period during which the hottest temperatures are experienced,
    - and a rainy season (Jul–Sep), during which it typically rains on up to half of the days.
- The IPCC Fourth Assessment Report describes a future warming trend in each season for the sub-continental region which covers Kasur, with the strongest warming occurring during June, July and September. The multi-model climate projections presented in the Fourth Assessment show a slight increase in Jun/Jul/Aug precipitation and a slight decrease in Dec/Jan/Feb precipitation by the end of the century, under a medium emissions scenario. However, there is little agreement among these models over much of this region, making changes in precipitation highly uncertain. Because of the complex topography in this part of the world and the associated weather systems, global climate models typically perform poorly when representing current climate in this region.
- Over Pakistan as a whole, mean annual temperature has increased by 0.35°C over the period 1970–99. Extremes of hot weather have increased significantly since 1960, while extremes of cold weather have decreased over the same period.
- Projections of future temperature show strong warming. Annual average temperatures in this region are projected to increase by 1.0°C to 2.25°C by 2025 (based on a multi-model ensemble of 21 GCMs), and from 2.0°C to 3.5°C by 2050, using a medium emissions scenario for the future. As outlined above, we have not used downscaled projections because the lack of agreement among global climate models (GCMs) on the direction of change in rainfall in this part of the world means that downscaling would only serve to add detail to uncertainty. This annual average presents a smoothed picture that masks higher (and lower) changes in daily and monthly temperatures. Higher temperatures (combined with changes in precipitation) will have an impact on agricultural productivity in the region; this is assessed in Chapter 4. Higher temperatures (particularly sustained periods of extreme heat) may also affect the efficiency of assets and operations at BSPM; this is explored in Chapter 3.
- The region around Kasur already copes with very large year-to-year variability in seasonal rainfall. This range is far larger than the change in precipitation projected as a result of climate change by the end of the century. No long-term trend towards increased or decreased precipitation has been observed over the historical record near Kasur.
- There is little agreement among models of future precipitation across this region, making projections of future changes in rainfall highly uncertain. While the range of projections is large, the global climate model ensembles tend to project decreases in rainfall in winter and summer, and increases in the rainy season. There is greater consistency across models for future extremes of precipitation; the proportion of total rainfall that falls as heavy events is projected to increase, particularly during the rainy season. Changes in rainfall will affect the rate of groundwater recharge, which may have consequences for groundwater resources in the area; this is explored further in Chapter 5.

3.4. Results

The following five figures provide an overview of the long-term average (1961–90) monthly temperature and precipitation for the region around Kasur. They were created using the data visualization tool available through the IPCC's Data Distribution Centre (please see Annex A1 – Climate Analysis for details on how to access this tool). Figure 2 shows national and civic boundaries and rivers for the area surrounding Kasur, and serves as a legend for the remaining four figures.

Observed Regional Climate: Baseline Temperature and Precipitation

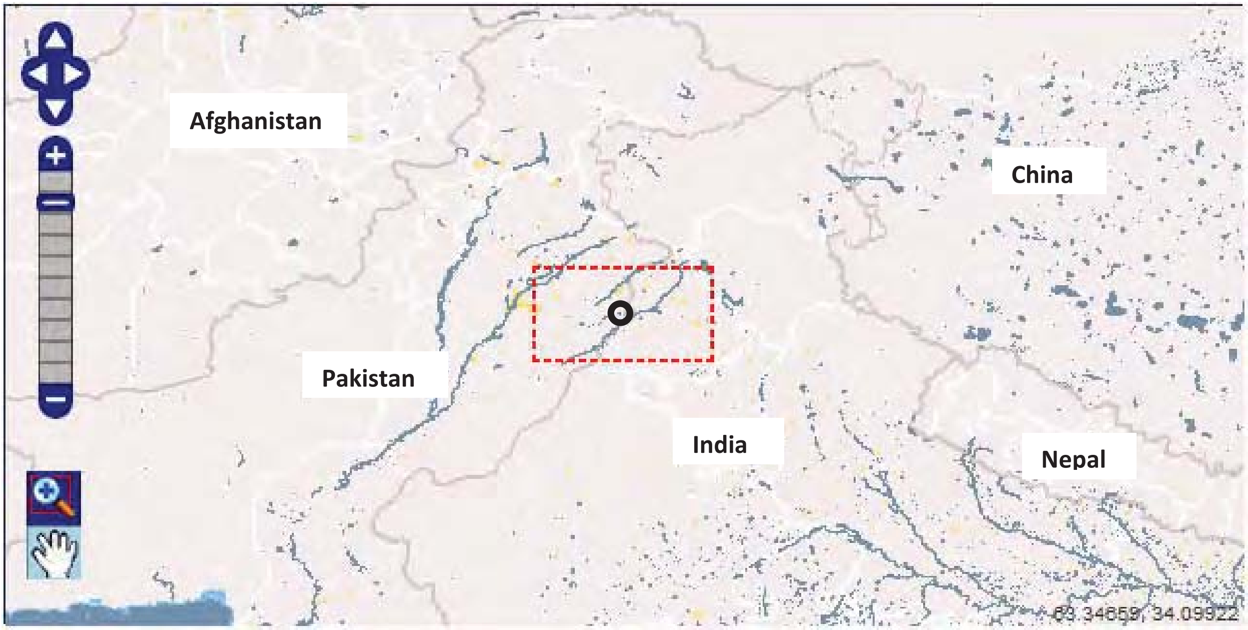

Figure 2. Overlay map showing national boundaries and water courses for the area surrounding Kasur. The approximate location of BSPM is given by a black circle at the centre of the map. The dashed red rectangle encloses an area approximately 490x210km^2 around BSPM. This same rectangular area is visible in Figure 3 and Figure 5, which show temperature and rainfall across a broad region. A zoomed-in view of the data *within* the rectangular area is provided in Figure 4 and Figure 6 [Source: IPCC Data Distribution Centre].

The approximate location of BSPM is indicated by a black circle at the centre of this map. The dashed red rectangle shows an area (roughly 490x210km^2) surrounding BSPM. The same rectangular area is visible in Figure 3 and Figure 5, which show average temperatures and rainfall, respectively, across the region. Larger-scale images (Figure 4 and Figure 6) show a zoomed-in view of the same data *within* the area bounded by the red rectangle.

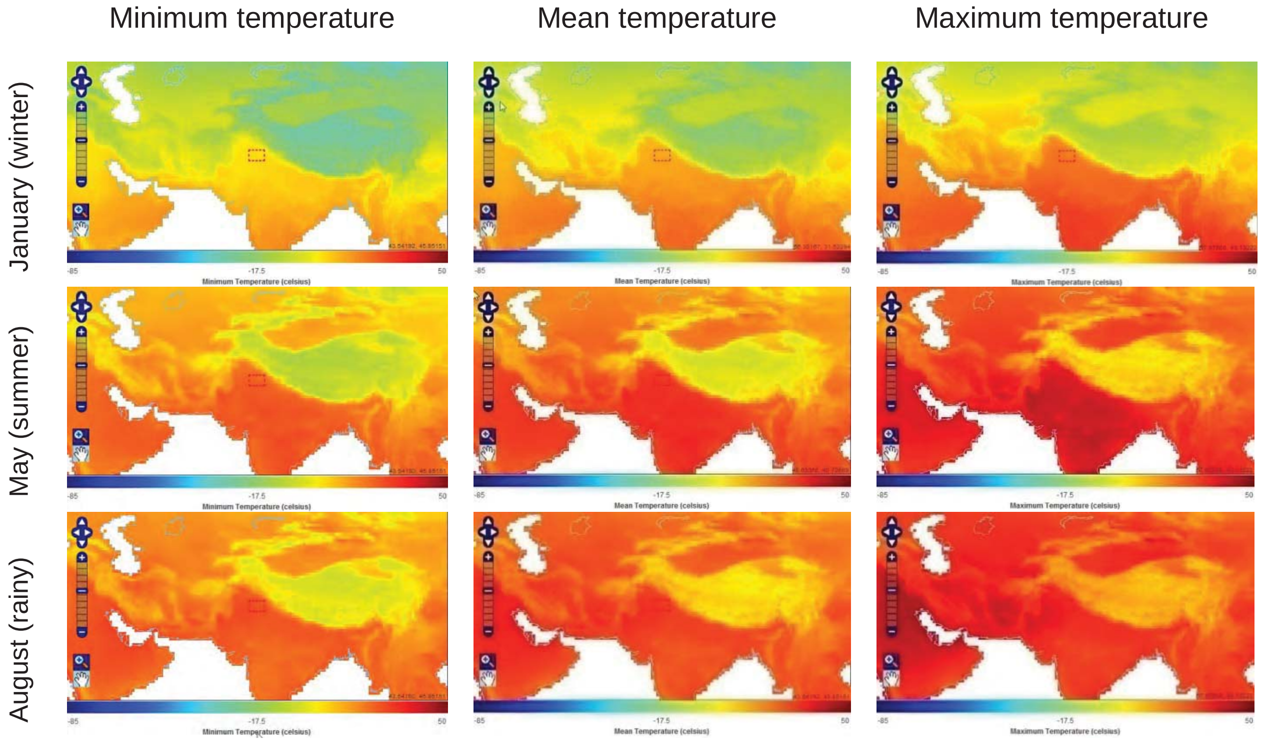

Figure 3. Long-term average (1961–90) monthly minimum, mean and maximum temperatures in degrees Celsius for January (top row), May (middle row) and August (bottom row). These images show average conditions in the Kasur area within the context of the wider climatic region. For a zoomed-in view of the area outlined in red above, please see Figure 4. [Source: IPCC Data Distribution Centre].

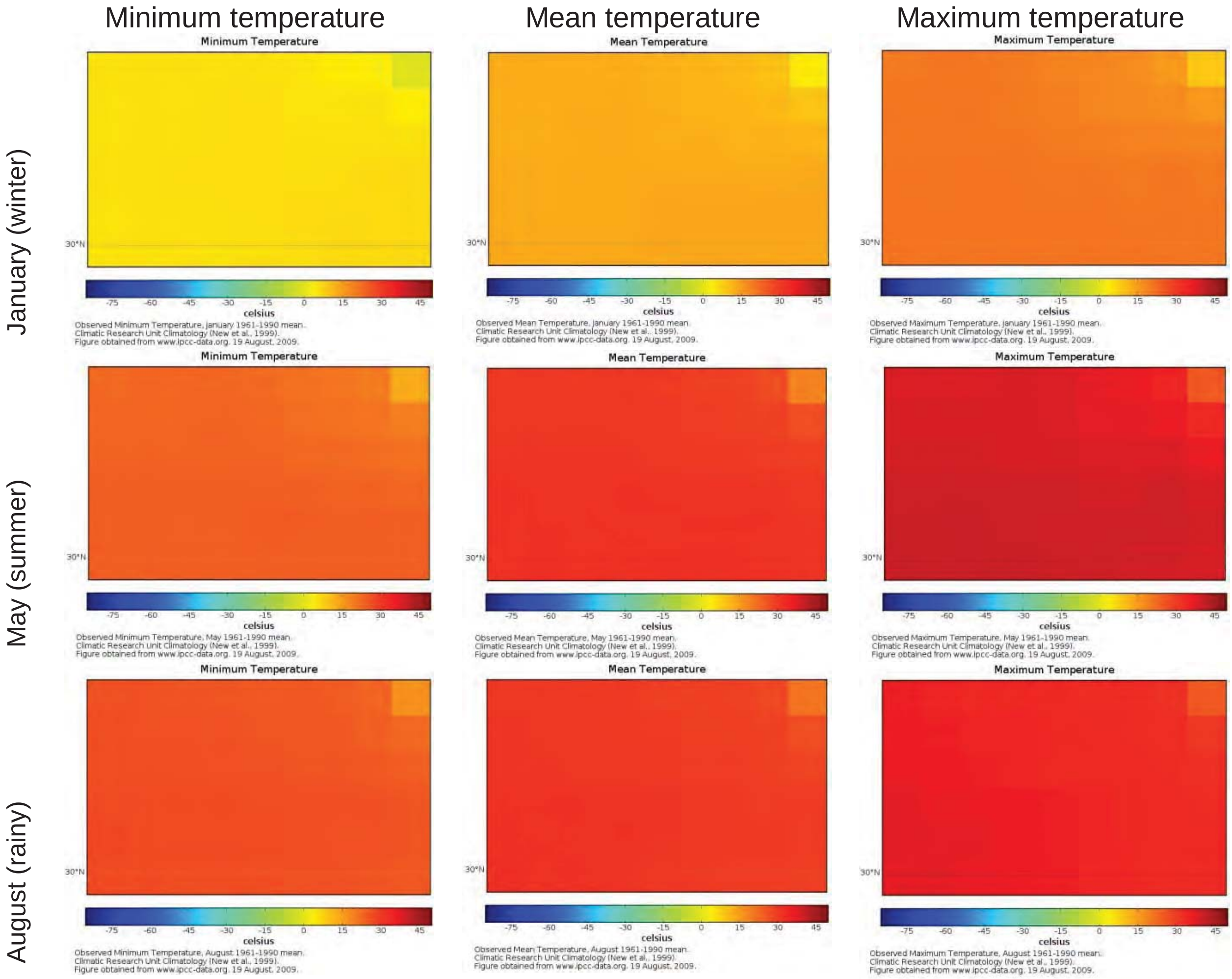

Figure 4. Long-term average (1961–90) monthly minimum, mean and maximum temperatures in degrees Celsius for January (top row), May (middle row) and August (bottom row). The geographic area shown is the same as that outlined in red in Figure 3, above. [Source: IPCC Data Distribution Centre].

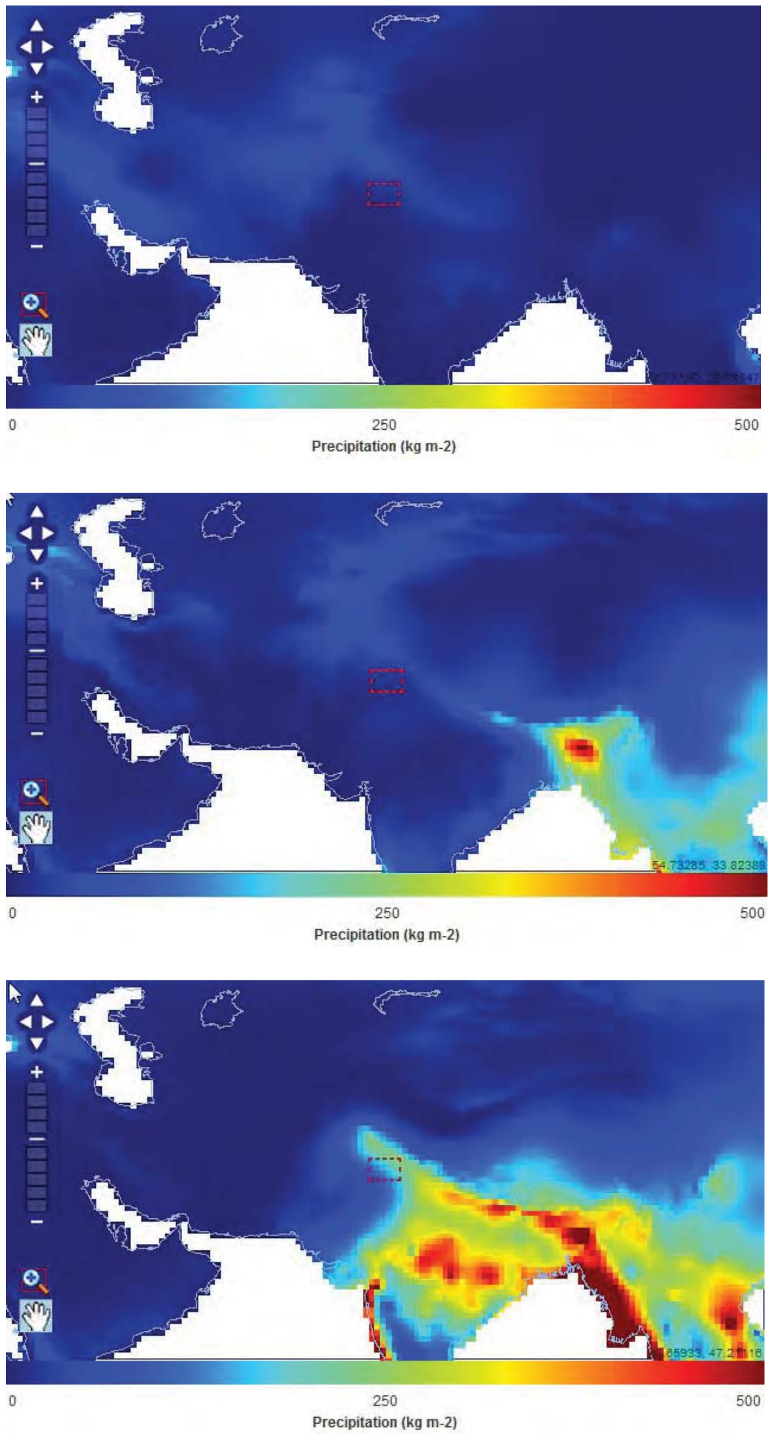

Figure 5. Long-term (1961–90) average monthly precipitation in kg/m^2, which is equivalent to mm/month, for January (top), May (middle) and August (bottom). These images show average conditions in the Kasur area within the context of the wider climatic region. For a zoomed-in view of the area outlined in red above, please see Figure 6. [Source: IPCC Data Distribution Centre].

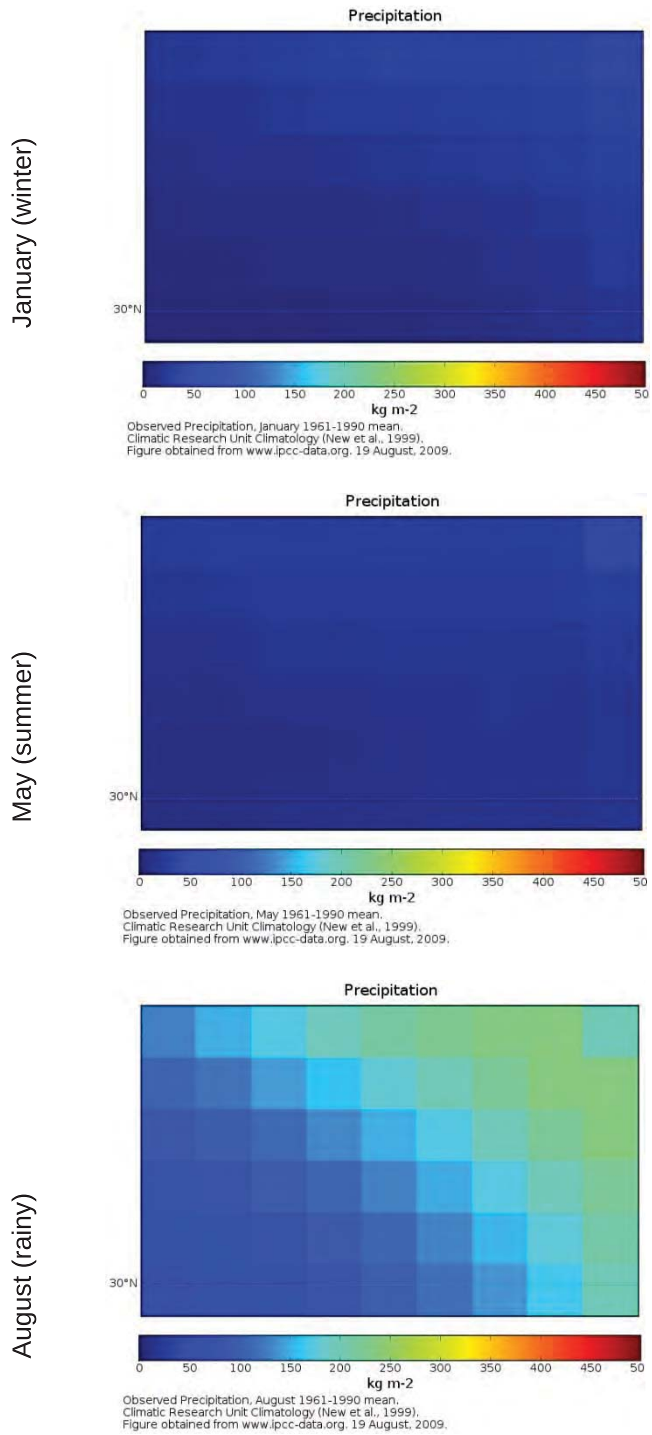

Figure 6. Long-term (1961–90) average monthly precipitation in kg/m^2, which is equivalent to mm/month, for January (top), May (middle) and August (bottom). The geographic area shown is the same as that outlined in red in Figure 5, above. [Source: IPCC Data Distribution Centre].

Figure 3 clearly shows that the region around Kasur experiences the hottest temperatures at the end of the summer, just before the rainy season begins. The region is characterized by very low rainfall until July, normally the start of the rainy season. Please note that green, yellow and red colors indicate *wetter* conditions in the maps shown in Figure 5, while blue colors indicate *drier* conditions. During the winter (top) and summer (middle) there are very few rain days on average. During the rainy season (in August, bottom) it rains on up to half the days in the month.

Recent Trends in Precipitation and Temperature

For Pakistan as a whole, long term meteorological records of mean annual rainfall have not shown any discernible trend since 1960. There is also no consistent trend in the indices for observed daily rainfall. In other words, there is no trend in the frequency or severity of extreme rainfall events (McSweeney et al., 2008). Figure 7 shows the mean rainfall recorded monthly at Lahore over a 150 year period, together with the 10th and 90th percentile rainfall amounts for each month over the same period. The records at this observing station show a marked monsoon season starting in June and ending in September. The wide range between 10th and 90th percentile amounts illustrates the very large year-to-year variability in precipitation in the region. Though the average peak monthly monsoon rainfall is about 130mm/month, amounts can vary year-on-year from as little as 25mm to as much as 280mm/month. This region is also vulnerable to dry spells. For 10 months of the year the station experiences no monthly rainfall 10% of the time on average. This region is already dealing with a huge amount of variability in seasonal precipitation; this range is far larger than the median change in precipitation projected as a result of climate change by the end of the century. When combined with long-term climate change, these natural variations in rainfall increase the potential for extreme events in the region (e.g., dry spells leading to increased drought risk and wet periods leading to increased flood risk).

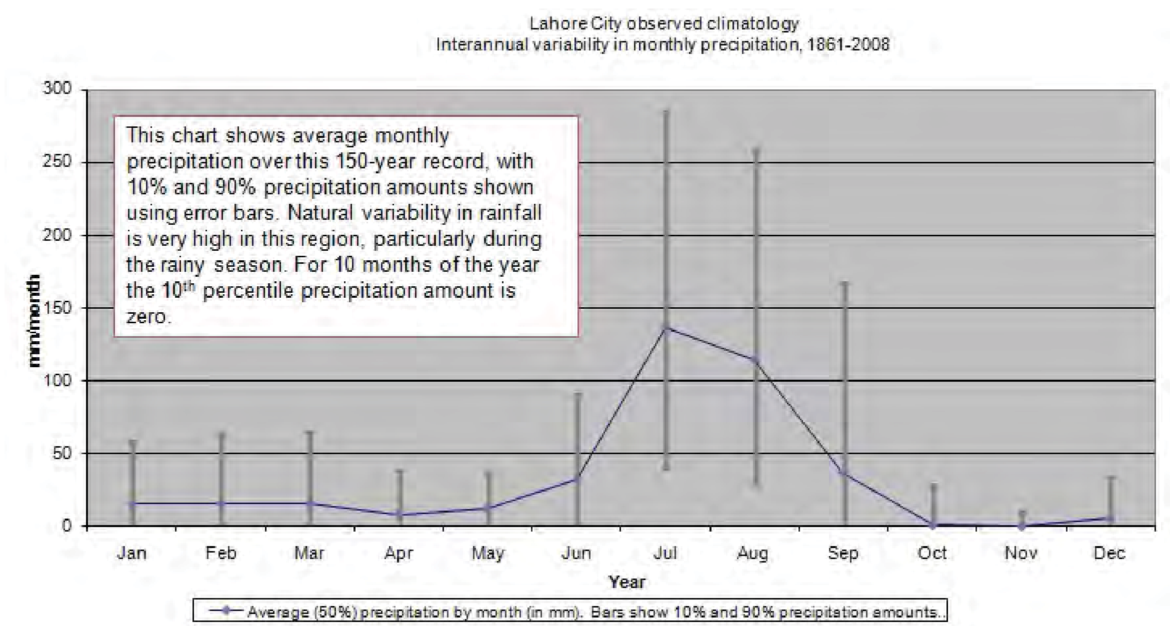

Figure 7. Observed monthly precipitation at Lahore 1861–2008 [Source: KNMI].

The timeseries in Figure 8 shows total winter precipitation amounts for each year from 1861–2008 at Lahore meteorological station. The interannual variability is very clear from this timeseries, and no long-term trend towards increased or decreased precipitation is evident. The data for the summer and rainy seasons show a very slight upward trend in precipitation over the same time period, but this trend is not statistically significant.

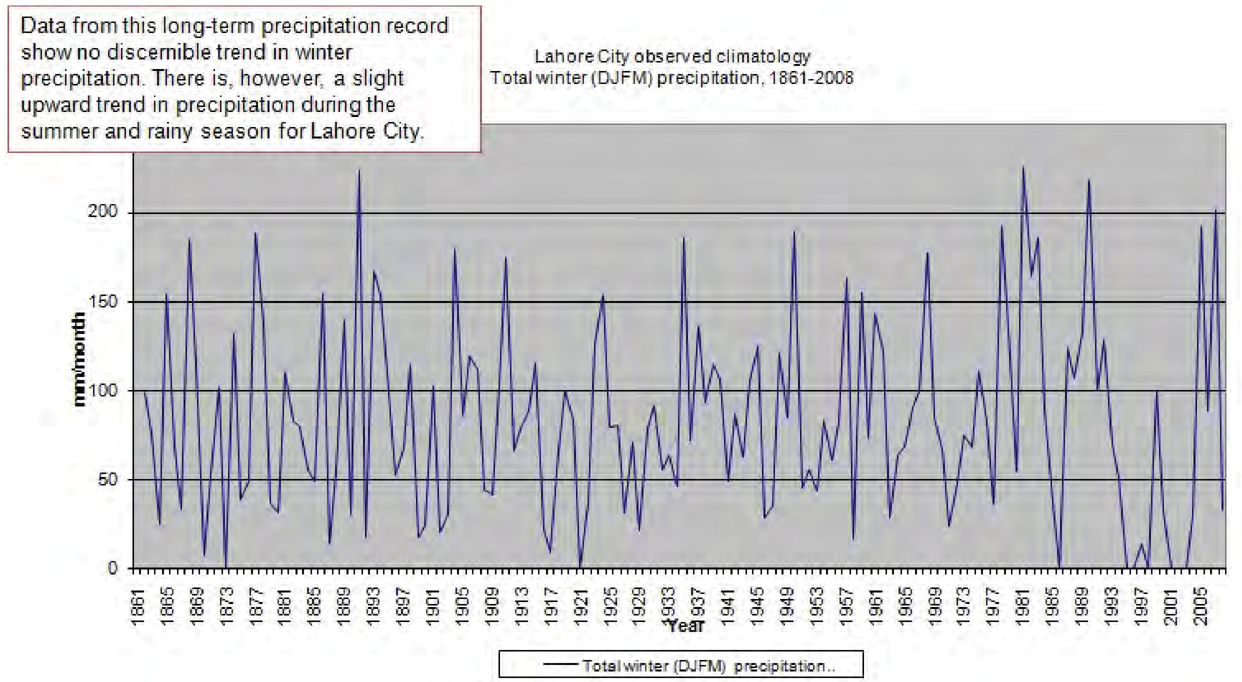

Figure 8. Timeseries of winter precipitation at Lahore 1861–2008 [Source: KNMI].

In comparison with precipitation, seasonal temperatures are far less variable. Figure 9 shows long term seasonal average temperatures at Lahore recording station for winter, summer and rainy seasons. Although year-to-year fluctuations are evident, monthly average temperatures are fairly stable over the 135 year recording period. Over Pakistan as a whole, however, mean annual temperature has increased by 0.35°C over the period 1970–99, an average rate of 0.08°C per decade. This increase has been most rapid in the shoulder season from October through December, while there is no evidence of a warming trend in the rainy season (typically the warmest season). The frequency of hot days and hot nights (the temperature exceeded on 10% of days or nights) has increased significantly since 1960. The average number of 'hot' days per year has risen by 20 in Pakistan between 1960 and 2003. The rate of increase is seen most strongly in the shoulder season after the rains. The average number of 'hot' nights per year increased by 23 over the same period. This is seen most strongly at the end of winter and the beginning of summer. The frequency of cold days and nights (the temperature below which 10% of days or nights are observed) has decreased significantly over the period 1970–99. The average number of 'cold' days per year has decreased by about 10 between 1960 and 2003. The average number of 'cold' nights per year has decreased by 13 over the same time period. This rate of decrease is most rapid in the winter (McSweeney et al., 2008)

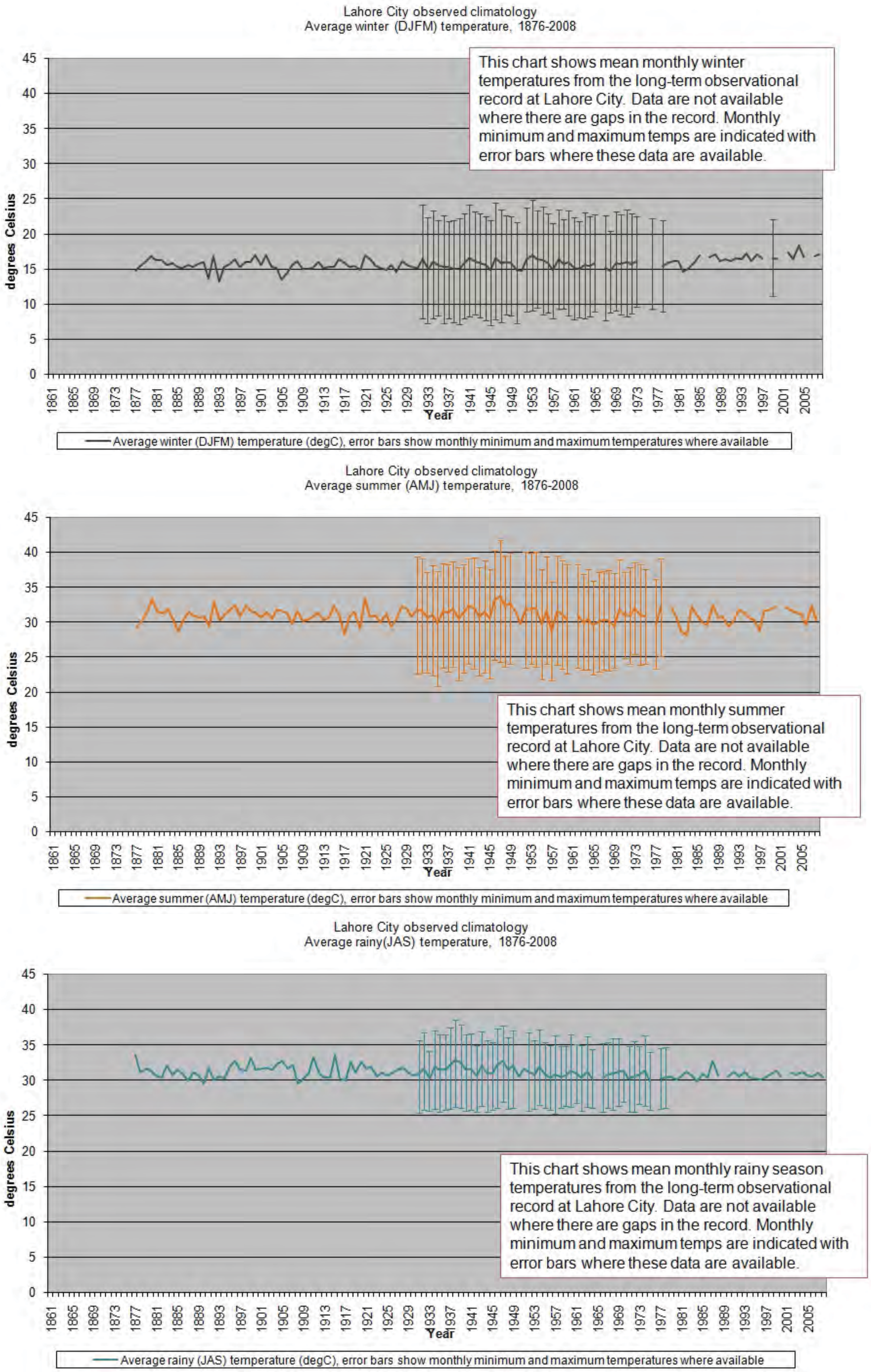

Figure 9. Seasonal average observed temperatures at Lahore during the winter (top), summer (middle) and rainy (bottom) seasons over the period 1876–2008 [Source: KNMI].

Projected Climate Change: Temperature and Precipitation

In presenting the following projections of climate change we have drawn together the readily available information for the emissions scenarios that are available. The emissions scenarios are based on the 'Special Report on Emissions Scenarios' – or SRES – scenarios, which provide a basis for estimating future climate change (Nakićenović and Swart, 2000). At the moment global emissions are following a trajectory near the highest of the SRES scenarios. Please refer to Annex A1 – Climate Analysis for more detail on the SRES emissions scenarios.

Figure 10 shows the projected rise in annual average temperature, with respect to the 1901–1950 long term average. The black line shows observed (recorded) temperatures from 1906 to 2005, while the red envelope shows temperatures over this 1906–2006 baseline period as modeled by a coordinated set of 21 climate model simulations (called the multi-model data set, or MMD). The orange envelope shows the range of temperature change as projected for 2001 to 2100 by the MMD for the A1B emissions scenario. Because the extent of future climate change is dependent on current and future greenhouse gas emissions, this chart presents results for two further emissions scenarios: the bars at the right hand side show the range of projected changes for 2091 to 2100 for the B1 (blue) and A2 (red) emissions scenarios.

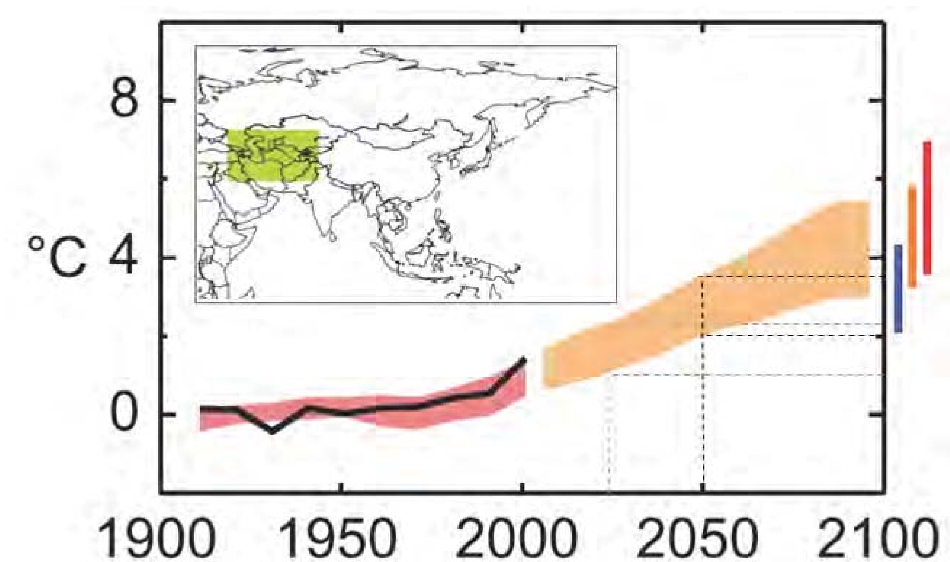

Figure 10. Projected rise in annual average temperature for the area shown in green on the map, with respect to the 1901–1950 long term average [Source: IPCC, 2007].

The chart shows strong warming: annual average temperatures in this region are projected to increase by 1.0°C to 2.25°C by 2025, and from 2.0°C to 3.5°C by 2050, using a medium emissions scenario for the future. This annual average presents a smoothed picture that masks higher (and lower) changes in daily and monthly temperatures.

A seasonal analysis, using the UNDP's Climate Change Country Profiles (please see Annex A1 – Climate Analysis for details on how to access this information), shows that maximum warming occurs during Jun/Jul/Aug. This is in contrast to most other Asian regions, where seasonal modeling shows greatest warming during Dec/Jan/Feb. In Pakistan as a whole, the mean annual temperature is projected to increase by 0.8 to 2.8°C by the 2030s, by 1.4 to 3.7°C by the 2060s, and 1.9 to 6.0°C by the 2090s, depending on the emissions scenario and climate model used. The range of projections by the 2090s under any one emissions scenario is 1.5- 2°C.

All projections within the UNDP dataset indicate large increases in the frequency of days and nights that are considered ‘hot’ in current climate. Annually, projections indicate that ‘hot’ days (The temperature threshold for a ‘hot day’ is defined by the daily maximum temperature which is exceeded on the 10% warmest of days in the 1970–99 climate period) will occur on 16-25% of days by the 2060s, and 18-38% of days by the 2090s. Days considered ‘hot’ by current climate standards for their season are projected to increase most rapidly during the rainy season (Jul/Aug/Sep), occurring on 27-74% of days of the season by the 2090s. Nights that are considered ‘hot’ (these include the warmest 10% of daily *minimum*, or nighttime, temperatures) for the climate of 1970-99 are projected to occur on 18-30% of nights by the 2060s and 20-42% of nights by the 2090s. Nights that are considered ‘hot’ for each season by 1970-99 standards are projected to occur on 32-81% of nights in every season by the 2090s, increasing most rapidly in Jul/Aug/Sep. All projections indicate decreases in the frequency of days and nights that are considered ‘cold’ (the coolest 10% of maximum and minimum temperatures) in the current climate. In much of the country by the end of this century ‘cold‘ days and nights will not occur at all.

The UNDP’s Climate Change Country profiles can be used to gather more detailed information of multi-model projections of climate change across Pakistan (please refer to Annex A1 – Climate Analysis for additional figures and graphics). Table 1 provides projections of average temperature rise (relative to the mean climate of 1970–99) for the climate model grid cell representing the area around Kasur (the models have a spatial resolution of roughly 275km^2 at this latitude). The temperature rise given here reflects the A2, or ‘medium’, greenhouse gas emissions scenario, though other scenario results are available. The values for each future time period represent the minimum, median and maximum temperature rise projected by the ensemble of 15 climate models.

Winter (JFM)	Summer (AMJ)	Rainy (JAS)
2030s: 1.1, 1.7, 2.8°C 2060s: 2.0, 3.1, 5.2°C	2030s: 0.8, 1.7, 2.4°C 2060s: 0.8, 3.0, 4.5°C	2030s: ***, 1.4, 2.3°C 2060s: 1.7, 3.1, 5.6°C

Table 1. Increase in average temperature for the Kasur area by the 2030s and 2060s, projected by an ensemble of 15 climate models under the A2 emissions scenario. The ensemble minimum, median and maximum values are given for two different future time periods, where available (‘*’ indicates missing or unavailable data) [Source: McSweeney et al., 2008].**

Using the same format, Table 2 provides projections of the change in extremes of high temperatures by the 2060s for winter (top), summer (middle) and rainy (bottom) seasons for the grid cell representing the area around Kasur. The left column shows the projected change in the number of ‘hot’ days (days when maximum temperatures exceed the current 10th percentile) and ‘hot’ nights (when minimum, or night time, temperatures exceed the current 10th percentile) by the 2060s. The values represent the projected rise (by an ensemble of climate models under the A2 scenario) in the number of days relative to the mean climate of 1970–99. The ensemble minimum, median and maximum values are given.

Increase in ‘hot’ days	Increase in ‘hot’ nights
Winter (JFM) 2060s: 17, 24, 45	Winter (JFM) 2060s: 2, 24, 31
Summer (AMJ) 2060s: 22, 28, 60	Summer (AMJ) 2060s: 1, 30, 41
Rainy (JAS) 2060s: 13, 32, 75	Rainy (JAS) 2060s: 2, 39, 54

Table 2. Increase in extremes of high temperature for the Kasur area by the 2060s, projected by an ensemble of 15 climate models under the A2 emissions scenario. The ensemble minimum, median and maximum values for increase in ‘hot’ days and ‘hot’ nights are given [Source: McSweeney et al., 2008].

Figure 11 shows projected percentage change in annual (left), Dec/Jan/Feb (middle) and Jun/Jul/Aug (right) precipitation over Asia. The top row shows mean percentage changes between 1980–1999 and 2080–2099, averaged over the suite of 21 MMD models. The bottom row shows the number of models out of the 21 that project increases in precipitation. This provides an indication of the agreement among models.

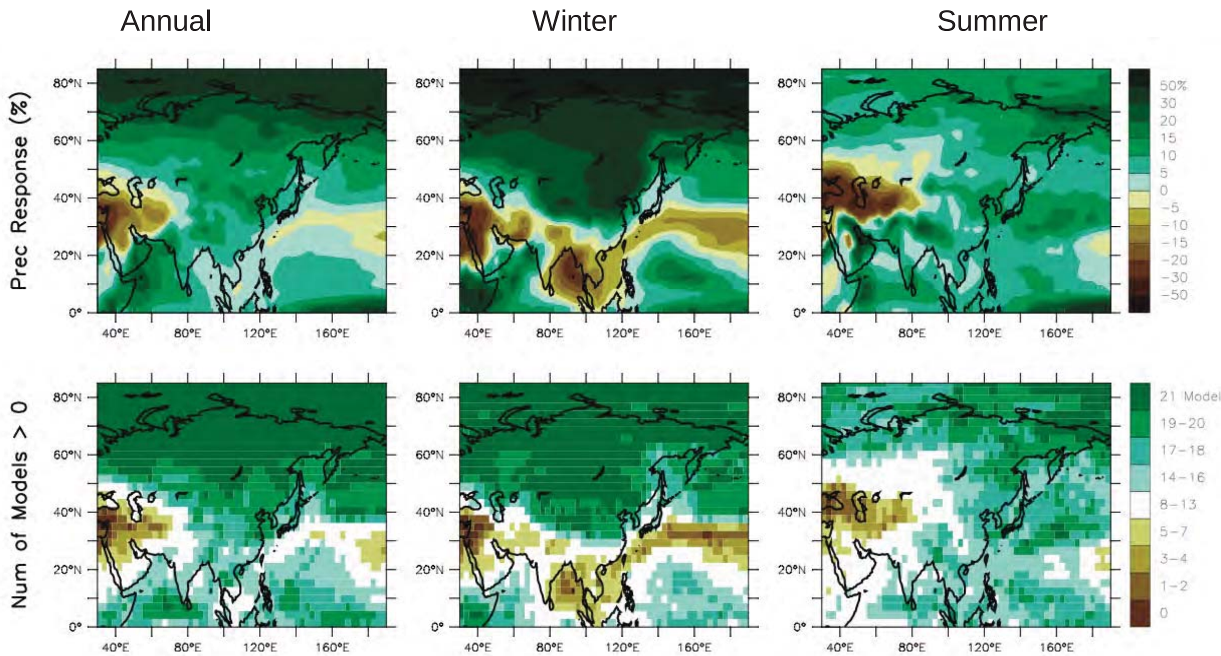

Figure 11. Projected percentage change, by the end of this century, in annual (left), winter (middle) and summer (right) precipitation over Asia, as projected by a suite of 21 GCMs under a range of emissions scenarios [Source: IPCC, 2007].

The MMD models seem to show a slight increase in Jun/Jul/Aug precipitation and a slight decrease in Dec/Jan/Feb precipitation by the end of the century, under a medium emissions scenario. However, there is little agreement among these models over much of this region, making changes in precipitation highly uncertain. Because of the complex topography in this part of the world and the associated weather systems, global climate models typically perform poorly when representing current climate in this region. Simulations of observed baseline climate tend to overestimate precipitation for this region, particularly in semi-arid areas of Pakistan (IPCC, 2007). According to the IPCC's Fourth Assessment Report: "There are substantial inter-model differences in representing monsoon processes, and a lack of clarity over changes in ENSO [El Nino Southern Oscillation] further contributes to uncertainty about future regional monsoon and tropical cyclone behavior. Consequently, quantitative estimates of projected precipitation change are difficult to obtain."Global climate models tend to show weakened monsoonal flows in a changing climate. However, there is an emerging scientific consensus that the effect of enhanced moisture-holding capacity of a warmer atmosphere dominates over any such weakening of the circulation, resulting in overall increased monsoonal precipitation (IPCC, 2007).

Over Pakistan as a whole, projections of mean annual rainfall from the UNDP's Climate Change Country profile show a wide range of both positive and negative changes in precipitation (please refer to Annex A1 – Climate Analysis for additional figures and graphics). Projected changes range from -5 to +9mm per month (-18 to +23%) by the 2030s, with ensemble means close to zero. Whilst the range of projections across the model ensemble is large, the model ensembles tend to project decreases in rainfall in winter and summer, and increases in the rainy season.

Even though there is very little agreement between models as to changes in mean rainfall amount, there is greater consistency for the rainfall extremes. The proportion of total rainfall that falls in heavy events shows mixed positive and negative changes in projections from different models. These changes do, however, tend towards increases in the annual average and particularly during the rainy season. Maximum 1- and 5-day rainfalls also tend to increase in projections (particularly in the rainy season), although some models do project decreases. Changes range from -3 to +9 mm by the 2060s in 1-day maxima (data are not available for nearer time periods), and -9 to +19mm in 5-day maxima (McSweeney et. al., 2008).

Table 3 shows the projected change in monthly precipitation for two 10-year periods in the future (left column: 2030s, middle column: 2060s). The right-hand column shows projected change in the proportion of precipitation falling in 'heavy' (10th percentile) events by the 2060s. As with previous results, values are the projected percentage changes (by an ensemble of climate models under the A2 scenario) in precipitation relative to the mean climate of 1970–99, for the model grid cell representing the area around Kasur. The ensemble minimum, median and maximum values for the Kasur gridcell are given.

Projected change in seasonal precipitation		Change in heavy precipitation events
Winter (JFM) 2030s: -66, -30, +54 %	Winter (JFM) 2060s: -57, -13, +147 %	Winter (JFM) 2060s: -30, -7, +17 %
Summer (AMJ) 2030s: -51, 0, +47 %	Summer (AMJ) 2060s: -52, +18, +69 %	Summer (AMJ) 2060s: -33, +4, +35 %
Rainy (JAS) 2030s: -19, +5, +215 %	Rainy (JAS) 2060s: -47, +20, +304 %	Rainy (JAS) 2060s: -8, +6, +13 %

Table 3. Change in seasonal and heavy precipitation events by the 2030s and 2060s, projected by an ensemble of 15 climate models under the A2 emissions scenario. The ensemble minimum, median and maximum values are given [Source: McSweeney et al., 2008].

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4. Operational/Engineering Issues

4.1. Introduction

This section assesses the performance impacts of a range of warmer weather scenarios on new power plant assets at BSPM (41MW steam turbine, 200PTH boiler and water treatment plant). Climate change will mean minor changes to operational performance of these assets, resulting in a small financial impact (this is covered in Chapter 8). It is important to note that this desk-based study takes account of the new assets only; existing system pressures, equipment limitations, and production bottlenecks (which are unknown) may have a much larger impact and could be exacerbated by climate change. The company may find it beneficial to 'keep a watching brief' in order to monitor climate-related operational impacts. In future, if equipment design data were obtained to show full operational input and output process temperatures, this analysis could be repeated to provide a more robust engineering climate risk assessment.

4.2. Approach

This study analyses the potential impact of higher ambient temperature on the site's power generation system and waste water treatment, as these systems are most likely to be affected by an increase in ambient temperature. Three different temperature rises were considered as the basis for the evaluations: 1.1°C, 1.26°C, and 1.88°C. These values were obtained from the Kasur-area gridcell of the UNDP's Climate Change Country Profiles for Pakistan. Because there is not much variation in temperature increases among the different emissions scenarios by the 2020s (i.e., most climate change is already 'built in' to the system as a result of historical emissions), only two emissions scenarios were chosen. In order to provide a representative range of potential temperature increases, both median and maximum values of the 15-member GCM ensemble were selected, as detailed in Table 4.

Time period	Emissions scenario	15-member GCM ensemble value	Temperature increase
2020s	B2	Ensemble median	1.1°C
2020s	A2	Ensemble median	1.26°C
2020s	A2	Ensemble maximum	1.88°C

Table 4. Temperature increases used in engineering analysis

The observed baseline (1876–2008) annual average temperature for the area is 24°C (winter average over the same period = 15.7°C; summer average = 30.9°C; rainy season average = 31.1°C). These data are from the meteorological station at Lahore, some 50km north of BSPM.

In the absence of equipment design data, it was necessary to make a number of assumptions about the engineering system at BSPM. These are listed below:

- 17.85 MW are available for export and that the grid connection is able to handle this. [(41.0 MW - 20.0 MW) * Power factor 0.85)];
- The boiler is run on 100% on natural gas and is normally fully loaded;
- In the absence of more information on the boiler combustion air preheater, we assume that the impact of combustion air preheater is not significant and combustion air increases by the same amount as the ambient air temperature increases;
- Temperature increases of ambient air and cooling water are the same;

- The cooling water step off temperature is 32^{o}C;
- Boiler combustion air fans have enough spare capacity to maintain combustion air flow (lbs/hr) as air temperature rises and air density decreases;
- We can use the same % changes in the unit costs of steam ($/ton) and electricity ($/KW-HR) as well as power cost per unit ($/ton of production);
- In the absence of more information, we can use generic boiler data to calculate the impact of ambient air temperature increases on boiler output/ efficiency;
- In the absence of more information, we can use generic turbine characteristic data to calculate the impact of cooling water temperature increases on power output/ efficiency;
- Base electrical costs – the company's financial model specifies a drop in unit cost of electricity from 3.10 in 2004/2005 period to 1.60 for 2006 onwards (this may be due to the move from Lahore to BSPM) We assume that a unit cost of 1.60 is realistic;
- The unit cost numbers for electricity and steam in the financial model are for the variable portion of the cost of generating electricity/steam. Though the 'fixed costs' number in the financial model is not broken down in any detail, it is assumed that this includes the fixed costs for the boiler/steam.

4.3. Key Messages

Over the range of winter/summer temperatures, the findings of this study are summarized as follows:

- The impact of air temperature increases on boiler efficiency is positive but minor.

- Power output of the steam turbine with double extraction decreases slightly with an increase in the cooling water temperature. It is estimated that the projected temperature increases of 1.1^{o}C, 1.26^{o}C, and 1.88^{o}C would result in a decrease in steam turbine power output of 0.07MW, 0.08MW and 0.12MW (or 0.20%, 0.23% and 0.35%) respectively.

- An increase in cooling water temperatures of 1.1°C, 1.26°C and 1.88°oC increases the variable portion of the cost of electricity generation (unit cost) from 1.600 to 1.603, 1.604 and 1.606 (ignoring reduction in natural gas costs), because the amount of power (surplus) for export decreases from 17.85 MW to 17.78, 17.77 and 17.73 MW. The decrease in cost of steam generated as a result of increases in boiler efficiency is minor.

- The slight increase of the cost of generating power is offset to a small degree by the increase in efficiency of the boiler which will result in a reduction of natural gas requirement for fuel.

- In an aerobic sludge activated water treatment plant, the impact of increase in water temperature would be positive provided wastewaters do not surpass 38^{o}C at the feed entry point.

- Various adaptation measures could be investigated for managing temperature-related changes in assets over time (reduction in available (surplus) power for export), such as:
    - Maintain the cooling water temperature from the cooling tower (expand the cooling tower).
    - Increase the condenser heat transfer area and/or increase the cooling water flow to compensate for higher cooling water temperatures.

4.4. Results

Packages have stated that the efficiency of the company's gas turbine decreases as air temperature increases: **"*Our gas turbine generates about 5 MW at around 15°C Celsius ambient temperature in winter but only 3.5 MW at around 45°C Celsius ambient in summer.*"** This will have implications for energy costs, particularly during the summer and rainy seasons in the future. On the other hand, the company's boiler efficiency benefits from warmer temperatures: **"*As a rule of thumb with every 10°C rise of combustion air temperature there is a rise of 1% combustion efficiency.*"** Though these statements refer to the previous engineering setup (i.e., before the new 41MW turbine was installed), they nonetheless illustrate current climate impacts on operations.

This study focuses on the potential impact of a warmer whether scenarios on new power plant assets (i.e., the 200TPH boiler and 41MW steam turbine with double extraction). The basis for the evaluations are:

- Observed baseline (1876–2008) annual average temperature = 24^{o}C (winter average over the same period = 15.7^{o}C; summer average = 30.9^{o}C; rainy season average = 31.1^{o}C). These data are from the meteorological station at Lahore, some 50km north of BSPM.
- Projected temperature increases: low = 1.1^{o}C, medium = 1.26^{o}C, high = 1.88^{o}C

Steam Turbine

The table below gives the technical data for 41 MW Siemens condensing steam turbine with double extraction. These data are used to estimate the power outputs (Figure 12) using the assumptions that the increases in temperature of ambient air and cooling water are the same (low = 1.1°C, medium = 1.26°C, high = 1.88°C), the baseline cooling water temperature is 32°C and the condensing pressure is 0.0677bara (2inHg).

	Flow, t/h	Pressure, bar(a)	Temperature, °C
Inlet steam	195.6	95	525
Extraction No. 1	65.31	14.5	-
Extraction No. 2	78.46	6.2	-
Bleed	7.22	0.767	-
Cooling water	2485.9	-	32

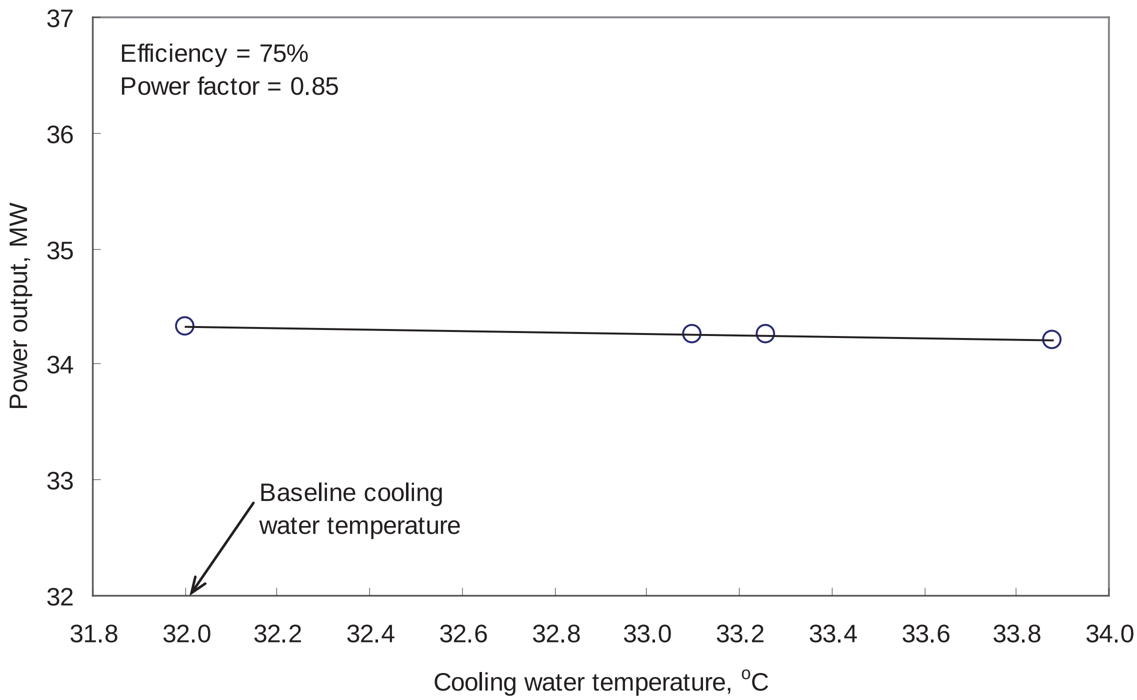

Figure 12. Power output of double extraction steam turbine vs. cooling water temperature.

Figure 12 shows that increasing cooling water temperature in the range of +1.1 to +1.86°C results in a very slight decrease in power output of the steam turbine.

Figure 13 shows the power output decrease as a function of cooling water temperature. It is estimated that the projected temperature increases: low = 1.1°C, medium = 1.26°C, high = 1.88°C decrease power output of the steam turbine 0.07, 0.08, 0.12 MW i.e., negligible and the reduction in revenue from reduced sales amounts to $57,000, $65,000 and $98,000/year (based on an assumed 10¢/kW-HR & 340 days/year) respectively. These costs are discussed in more detail in Chapter 8. The slope of the line is very similar whether the step off temperature is 15.7°C (winter average) or 31.1°C (rainy average).

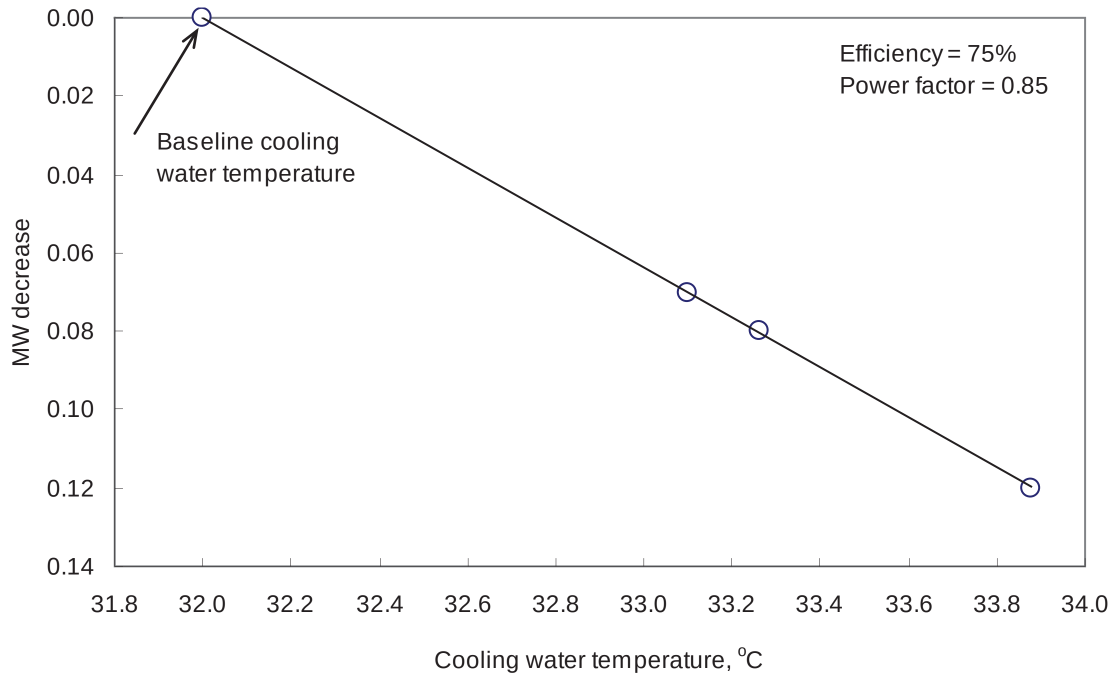

Figure 13. Decrease in double extraction turbine power output vs. cooling water temperature.

The table below shows that increasing the cooling water temperature increases slightly the variable portion of the cost of generating power (unit cost). The same % changes are assumed in the unit cost of electricity ($/kW-HR) and power cost per unit ($/ton of paper production). Therefore, there will be only a slight reduction in revenue from electricity sales. Cost of electricity (consumed plus export) goes up and there is less available power for export.

Temperature increase, °C	Cost of power generated (base 1.600)
1.1	1.603
1.26	1.604
1.88	1.606

Boiler

The American Society of Mechanical Engineers (ASME) heat balance method calculates boiler efficiency by accounting for all the stack losses and radiation and convection losses.

Boiler efficiency % = 100 – (heat losses / HHV of fuel)

The heat losses are dry flue gas loss, loss due to moisture from combustion of hydrogen, air moisture loss and radiation and convection losses. Higher Heating Value (HHV) is the quantity of heat liberated by the complete combustion of a unit weight of a fuel assuming that the product water vapor is completely condensed and the heat is recovered.

The key factors in calculating the heat losses and hence boiler efficiency are flue gas temperature, fuel specification, excess air and ambient (combustion) air temperature. The boiler uses 100% natural gas. The excess air is assumed to be 20%. The baseline (1876–2008) annual average temperature is 24°C. It is assumed that the impact of combustion air preheater is not significant and combustion air temperature increases by the same amount as the ambient air increases.

Figure 14 shows that increases in ambient air temperature in the range of 1.1 to 1.88°C has a minor positive effect on the boiler efficiency. It is estimated that the projected temperature increases: low= 1.1°C, medium = 1.26°C, high = 1.88°C increase boiler efficiency 0.072, 0.084 and 0.12% respectively. The slope of the line is similar across the seasons from a winter average of 15.7°C to a rainy season average of 31.1°C.

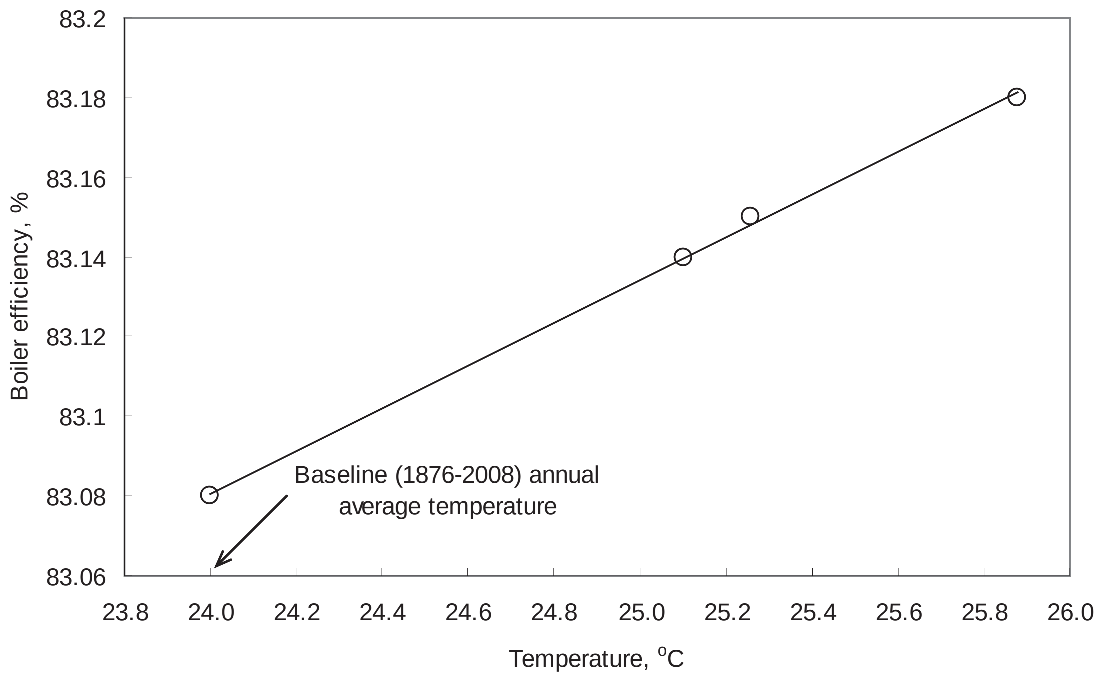

Figure 14. Boiler efficiency vs. ambient (combustion) air temperature.

Water Treatment Plant

The pulp and paper industry's effluents cause considerable damage to the receiving waters if discharged untreated since they have a high biochemical oxygen demand (BOD), chemical oxygen demand (COD) and contain chlorinated compounds, suspended solids (mainly fibers), fatty acids, lignin, and sulphur compounds.

The total designed generation of liquid effluents at BSPM, from various streams of processing plants, is estimated at about 30,000 m^3/day. The Company has installed a waste water treatment plant with capacity to treat the above mentioned waste water to meet NEQS." [Pakistan Environmental Protection Act-1997, Pakistan National Environment Quality Standard (NEQS)]

The major sources of effluents discharge from the project include:

Source of effluent	Effluent discharge volume M^3/day
1- Chemical Pulping (CP)+ Bleaching	14430(5830+8600)
2- Semi Chemical Pulping (SCP)	3730
3- Deinking Plant (DP)	1900
4- Mixed Office Waste Paper Plant (MOWPP)	1760
5- OCC Waste Water Plant (OCC WWP)	2385
6- White Board Machine (WBM)	612
7- Brown Board Machine (BBM)	740
8- White Paper Machine (WPM)	6180
9- Other	2000
Total	33737

A schematic diagram of the BSPM effluent treatment process is shown in Figure 15. Waste water from various areas of the mills is directed to a central collection sump and its pH is adjusted to maintain a range of about 6.5–7.5. From the collection sump, effluent is pumped to a primary clarifier to allow the diversion of mill effluent spill conditions. Primary clarified effluent then flows through an equalization basin and cools to 35–37°C. After the equalization basin the effluent is put through an activated sludge treatment, and biological solids generated are settled in the clarifier. Solids are returned as activated sludge and remainder is directed to a sludge blend tank. Sludge from the primary and secondary clarifier is pumped to pre-thickeners and twin wire presses. The filtrate from the dewatering process is returned to the equalization basin for further treatment.

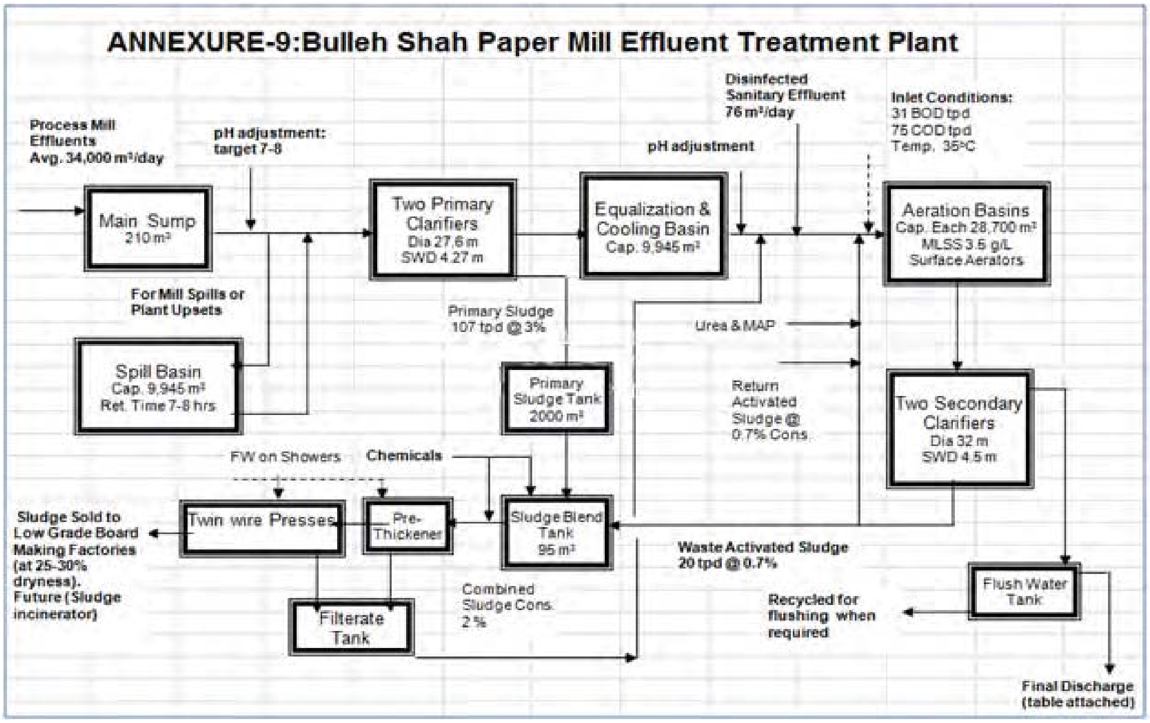

Figure 15. Process block diagram showing BSPM effluent treatment plant [Source : BSPM, 2006. Annexure 9 K-ETP Block Diagram].

Once treated effluent is mixed with canal water/ground water it is available for irrigation. This provides an additional source of water for irrigation for the farmers around the project area and onsite the project to be used partly for vegetation, trees, and sprinkling on road sides within the plant to reduce dust. Some quantity of water is also recycled in the plant operations (BSPM, 2006a).

In an aerobic sludge activated plant, the impact of increase in water temperature would be positive (greater reduction of BOD, greater treating capability) provided wastewaters do not surpass 38^oC at feed entry point. BOD stands for biochemical oxygen demand. This is the amount of dissolved oxygen consumed by microbial activity when a sample of effluent is incubated at 20^oC.

The temperature of the water being fed to the aeration basins is currently 35^oC. If this figure is accurate, there are some 3 degrees to spare before a reduction in treating capacity would be seen. If the temperature of the effluent water increases above this limit, cooling would have to be considered. The rest of the plant would remain as is.

Conclusions

- The impact of increases in air temperature (climate change) on the boiler efficiency is positive but minor.
- Power output of the double extraction steam turbine with double extraction decreases slightly with increase in the cooling water temperature.
- An increase in cooling water temperatures increases the variable portion of the cost of electricity generation, and a reduction in revenue from reduced sales amounts.

- The slight increase of the cost of generating power is offset to a small degree by the increase in efficiency of the boiler which will result in a reduction of natural gas requirement for fuel.
- The financial implications of the net effect (higher boiler efficiency/reduced natural gas purchases and reduction in revenue from reduced electrical exports) will be assessed in more detail in Chapter 8.
- If a more detailed future study is deemed beneficial, it should consider all major equipment systems (beyond the limited number of systems considered in this preliminary evaluation). In addition to original equipment specific design data it will be necessary to take account of current equipment systems that are most likely to limit production capacity first.

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5. Wheat Yields

5.1. Introduction

Packages uses wheat straw – the stem and stalk waste product of grain farming – as a feedstock for paper making. Wheat straw is processed through two pulping lines (chemical and semi-chemical, total capacity of 330 tons/day), then combined with other pulps (mixed office waste, old corrugated carton waste, and imported pulp, total capacity of 845 tons/day) for paper making. Straw-fed lines make up about 35% of total pulping capacity at BSPM, and Packages is interested in increasing this proportion.

As an agricultural waste product, wheat straw is perennially renewable as long as wheat farms are sustainable. This chapter looks at the potential climate change impacts on wheat yields in the region, and the knock-on consequences for production at BSPM.

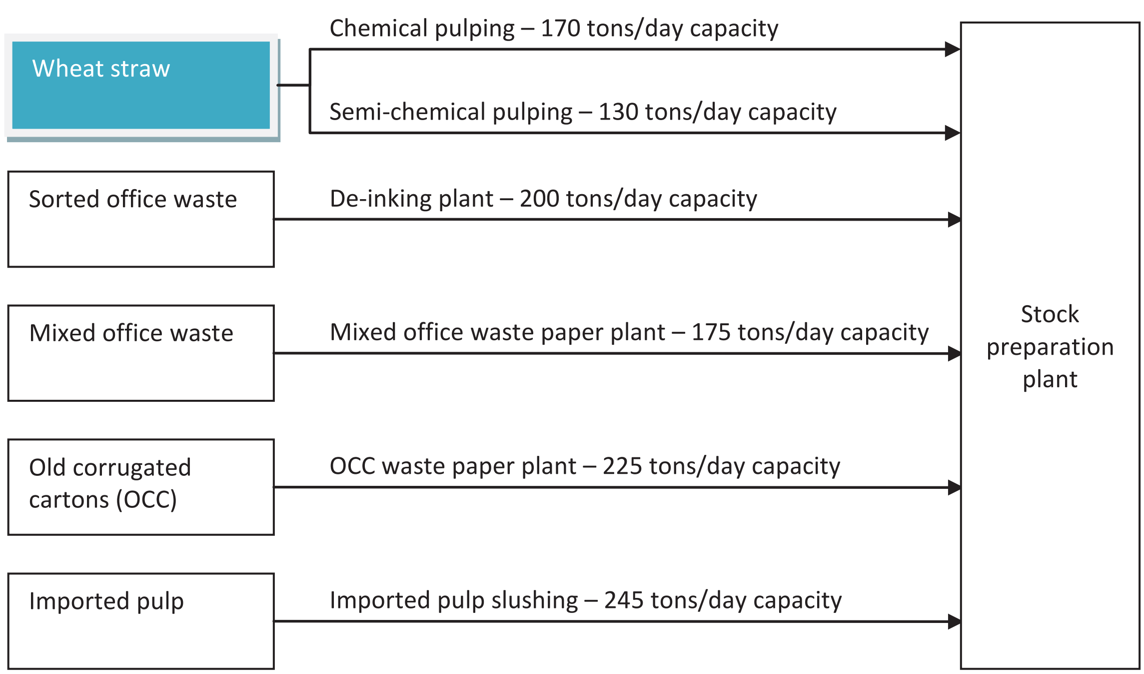

Figure 16. Feedstock and pulping lines at BSPM [Source: Packages].

5.2. Approach

The results reported in this chapter are drawn from a review of the scientific literature (see section 4.5). Because the focus is on farming, this chapter also draws on the results of the groundwater modelling in Chapter 5, and the analysis of social interactions in Chapter 6.

5.3. Key Messages

- Climate-related impacts on wheat yield are not likely to negatively affect the company during the first half of this century, for two reasons:
  - Though some agricultural modeling shows projected decreases in wheat yields in the region, these impacts are the result of changes in precipitation and increased risk of

drought. Farms around BSPM are groundwater irrigated, and not as susceptible to problems associated with projected changes in precipitation. The groundwater modeling reported in Chapter 5 indicates that groundwater recharge rates, which peak during the monsoon season, are likely to *increase*, rather than *decrease* in future.

    - Packages uses a wide range of feedstock at BSPM. Maintaining this diversity of inputs is beneficial for minimizing currency and price fluctuations (some feedstocks are domestic, others imported), supply chain disruptions, and any climate-related risks to input supplies.

- In the medium-term (toward the middle of this century and beyond) it is likely that increased temperatures will cause a decrease in crop yields in seasonally dry and low-latitude regions. An IPCC synthesis of crop yield studies shows projected wheat yield *decreases* in low latitude regions of 10–30% for mid-century temperature changes. When adaptation options (e.g., heat-tolerant species, improved pest management techniques, etc.) are factored into the analysis, crop yield projections are improved (ranging from +5% to -10%). These changes will particularly affect rain-fed crops.

5.4. Results

Wheat is the most important cereal in Pakistan. Wheat yields are critical to food security, providing 67% of the country's total cereal production (FAO/WFP Special Report 2000). In recent years Pakistan has experienced deficits in wheat production, with the exception of a bumper crop in 2006–2007 (UN WFP Pakistan Food Security, 2009). Since wheat is a key contributor to daily caloric intake in the country, wheat yield deficits can lead to caloric shortfalls and heightened food insecurity.

Several climatic variables (e.g., temperature, radiation, precipitation, and wind speed) affect the processes that drive productivity of wheat crops. The crop generally grows better when CO_2 concentrations are higher. However, growth, development and yield can all be affected by climatic thresholds (e.g., lower than average rainfall). Short-term extreme events, like exceptionally strong winds or floods, can also have negative impacts on crop productivity. In addition, compound climatic stressors (e.g., high temperatures combined with decreased rainfall) can increase vulnerability in the agricultural sector as a whole.

Farmers with smallholdings are likely to be disproportionately sensitive to extreme events, and vulnerable to an additional range of socio-economic pressures, including demographic shifts, urban sprawl, and pollution.

The IPCC's Fourth Assessment Report makes the following broad statement about crop yields in future:

"While moderate warming benefits crop and pasture yields in mid- to high-latitude regions, even slight warming decreases yields in seasonally dry and low-latitude regions (medium confidence)." [Note that Kasur is located at latitude 31°N, where the mid- and low-latitudes meet].

Several crop simulations have been carried out recently, making it possible to produce synthesis charts which summarise the results of individual, independent studies. Figure 17 shows percentage change in wheat crop yield against temperature increases ranging from about 1–2°C (projected for the next several decades), up to 4–5°C (projected for the end of this century). Though the results are highly uncertain (because of the large range of climate model projections for precipitation, and insufficient representation of extreme events) they indicate that in mid- to high-latitude regions, moderate to medium increases in temperature (1°C to 3°C) can have small positive impacts on the wheat yield. Additional warming has increasingly negative consequences for yield. In low-latitude regions, these crop simulations indicate that even moderate increases in temperature are likely to result in decreased crop yields.

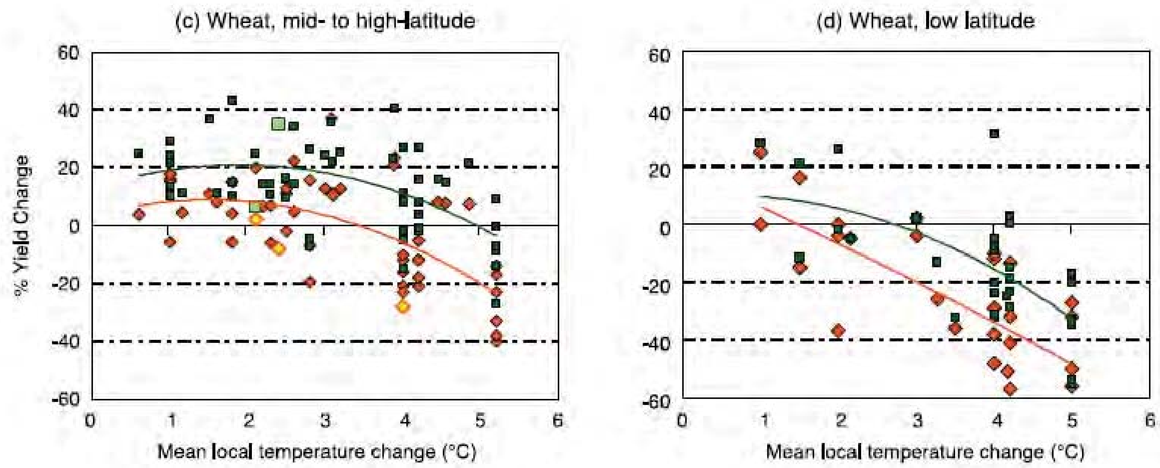

Figure 17. Synthesis of crop yield study results, showing percentage change in wheat yield for projected temperature increases. Orange lines and markers show impacts without adaptation, while green lines and markers show effects of adaptation [Source: IPCC, 2007].

Kasur is located at the boundary between the mid- and low-latitudes. From Figure 17 it is not possible to say whether wheat yields in the area are likely to decrease or remain steady in the near-future, though existing regional water stress might mean that crops are more likely to suffer during hotter, drier seasons. The fact that the region relies heavily on groundwater and irrigation (i.e., crops are not rain-fed) will insulate wheat yields somewhat from some of the effects of drier seasons. Both charts, however, indicate that wheat crops are likely to decrease in the latter half of this century, even if adaptive measures are taken. Crop management can be adapted to cope with projected changes in climate, in the following ways:

- Monthly and seasonal climate forecasting can be used to help farmers prepare for drought/wet events;
- Technology to help farmers use water more effectively and conserve soil moisture (e.g., crop residue retention) can help in areas with rainfall decreases;
- The timing and/or location of cropping activities can be altered;
- Fertilizer doses can be adjusted to maintain grain quality that is consistent with the climate;
- The amount and timing of irrigation can also be altered;
- New varieties and/or species that are more appropriate to warmer and longer growing seasons can be introduced; these can also be more robust to drought, extremes of heat, or pests and diseases;
- Pest, disease and weed management practices can be strengthened and maintained;
- Farming income can be supplemented by diversifying into other farming activities (e.g., livestock raising);

The wheat straw used at BSPM is groundwater-fed. Though the groundwater recharge modeling presented in Chapter 5 indicates that recharge rates are likely to increase rather than decrease as a result of climate change, there is considerable uncertainty associated with this finding. If the region experiences problems with groundwater resources in the future this will have an impact on wheat yields, with negative consequences for Packages' operations. Because of the diversification of its feedstock the company would not be significantly exposed in the event of a decrease in wheat crop production. The most sensible course of action for the company is to keep a watching brief and monitor the situation closely, so that the plant can source alternative feedstock if crop quality/quantity declines in future.

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6. Groundwater Resources

6.1. Introduction

Human activity (including man-made climate change) affects fresh water quality, quantity, and demand in complex ways, as shown diagrammatically in Figure 18. Climate change is just one of the many interconnected pressures on fresh water resources, and shifts in one area can bring about significant changes in the system overall. For example, deforestation can cause changes in moisture recycling which can contribute to decreased precipitation during some seasons. Conversely, drier seasons (as a result of a changing climate) are very likely to lead to increased demand for fresh water for cooling and irrigation. Water demand is also strongly influenced by socioeconomic changes, such as growing populations, increasingly affluent lifestyles and the mechanization that accompanies technological advances. It is vital that climate risk management strategies for water resources take account of the potential changes across all components of the fresh water system.

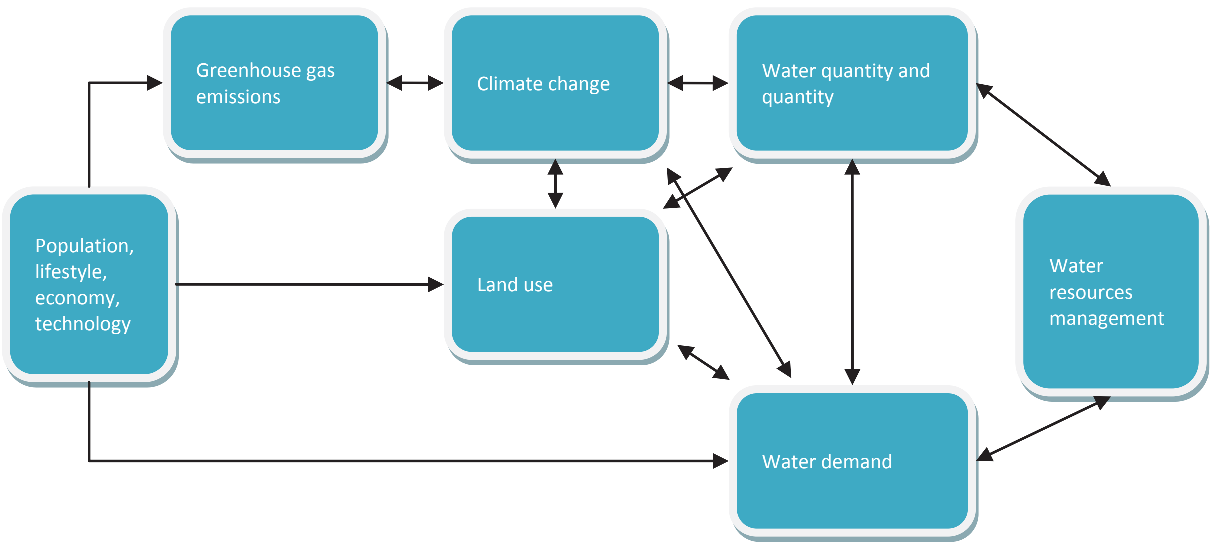


Figure 18. Climate change is one of many factors that affect the way human activities impact on freshwater resources and their management [Source: modified from Oki, 2005].

BSPM uses groundwater for all operations, and the area around Kasur is strongly reliant on groundwater resources (92% of the groundwater tubewells within Pakistan's Indus Basin Irrigation System are found in Punjab province). Clearly any decrease in groundwater resources would have serious consequences for the company itself and for the region around BSPM. This chapter investigates the potential impact of climate change on groundwater resources around Kasur, including a quantitative analysis of the impact of changing patterns of precipitation on groundwater resources for BSPM.

6.2. Approach

Given that there has been very little research on the climate change impacts on global ground water resources, this chapter begins by presenting an overview of the few studies which have examined observed or modeled future response of groundwater systems over a specific geographic area or aquifer. It should be noted that climate impacts on groundwater will likely differ from place to place (depending on vegetation, soil structure, aquifer type, etc.), and that location-specific study results are not necessarily transferrable to other areas.

Though Packages' Report on Groundwater Studies (2005) for the proposed BSPM site concluded that groundwater resources are sufficient to meet operational needs in the current climate, we have developed a groundwater model for the area and perturbing it using projections of future climate change, to generate data on projected future groundwater yields. The detailed methodology for this modeling is given in Section 5.4.

6.3. Key Messages

- Packages' Report on Groundwater Studies (2005) for the proposed BSPM site concluded that groundwater resources are sufficient to meet operational needs in the current climate.
- In arid and semi-arid central and west Asia (which contain some of the most vulnerable basins on the globe with respect to water stress) changes in climate and climate variability are already having an effect on fresh water demand, supply and quality. Climate change impacts have the potential to exacerbate existing pressures on water resources caused by population growth, industrialization, steady urbanization, and inefficiencies in water use.
- Packages' Report on Groundwater Studies (commissioned in 2005) recommended the drilling of tubewells to a depth of 225–245m, in order to provide 150% designed capacity for operations. This report was based on historical and observed conditions; the analysis presented in this chapter takes account of the potential impact of future climate change on groundwater supply (recharge).
- Despite uncertainty in projections of future precipitation for the region, our analysis using two different groundwater recharge modeling methods shows that a majority of climate models (at least 70% for the 2020s, and more by the 2040s) indicate an increase in natural recharge in the future. These modeled changes to future recharge indicate that it is unlikely that *supply* of groundwater resources will be depleted as a result of climate change over the lifetime of the project. It is not possible to estimate, however, how current *demand* from other users (if any) is depleting the groundwater aquifer.
- Recent research in nearby locations shows unsustainable groundwater abstraction levels in recent years (i.e., increasing demand). Climate change is likely to increase demand for freshwater in the future, putting pressure on groundwater resources. Farmers may need to extract more water in the future due to higher evaporation rates with increased temperatures, and the needs of other users (including industrial users) may increase.
- Given the uncertainty associated with current availability and future projections of groundwater, it would be very beneficial to perform an integrated assessment of groundwater resources which takes account of the needs of agricultural and other industrial users.

6.4. Results

Recent water resource assessments at different spatial scales indicate that semiarid and arid areas are the most vulnerable basins on the globe with respect to water stress (IPCC, 2007). Figure 19 shows current levels of water stress for different areas of the world. The indicator, which compares water withdrawal with water availability, shows high to very high levels of water stress across Pakistan.

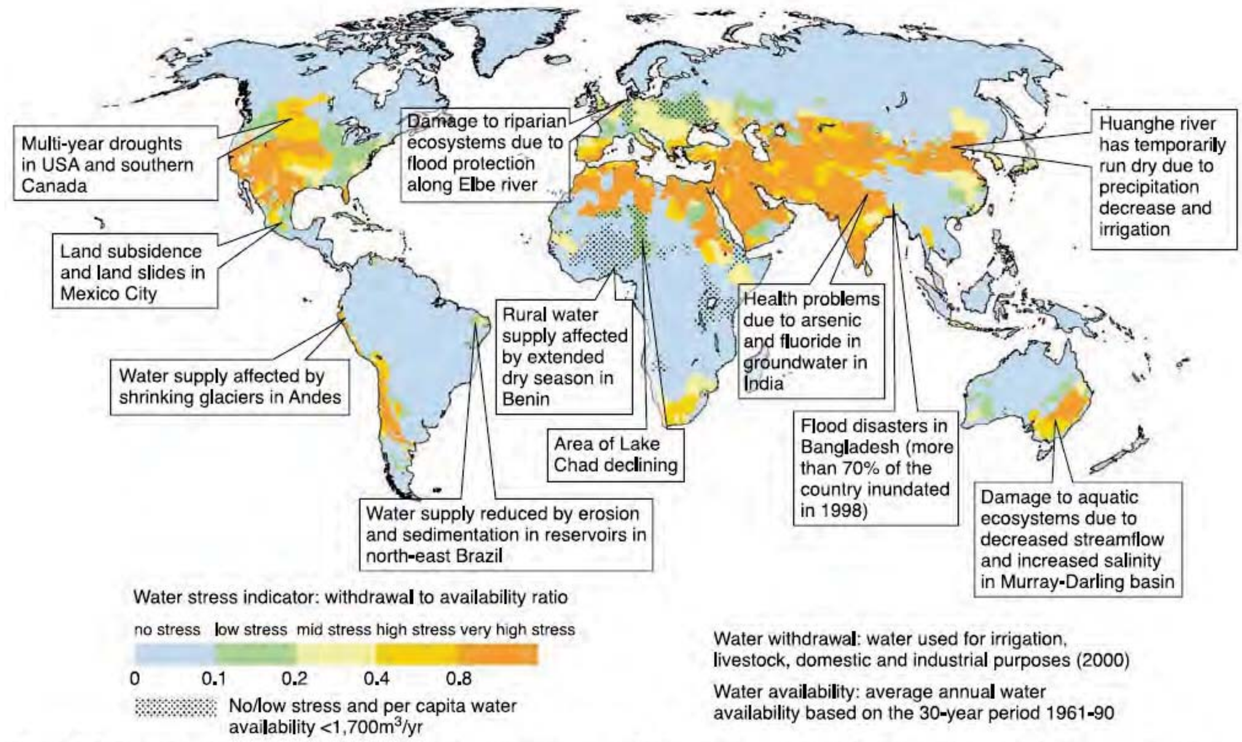


Figure 19. Some examples of observed climatic impacts and adaptation in the fresh water system; map colours show levels of current water stress [Source: IPCC 4th Assessment Report, WGII, diagram based on Alcamo et al. (2003)]

Though broad-scale indicators of water stress are useful for giving a general picture, the comparison of water availability and withdrawals at the country level are difficult to interpret and often misleading because they sum together all river basins within a country (Alcamo, 2003). In countries where basins range from densely to sparsely populated, and where climate varies significantly, country averages are less meaningful. National boundary issues present another drawback to gauging water resources at the country level. In Pakistan, the availability of water supplied by some rivers greatly depends on the inflow from other countries upstream.

Though Pakistan's National Communication on Climate Change recognizes that "the effect of climate change on water resources is expected to be significant", the report does not provide further detail. Information on current groundwater recharge and levels in most countries is poor, and this lack of data often makes it impossible to determine whether groundwater states have changed in the recent past due to climate change. There has been very little research on the future impact of climate change on global groundwater resources. Given the importance of groundwater systems for many regions, the IPCC has identified lack of data and knowledge about groundwater as a key research gap (Bates et al., 2008). There are a few notable exceptions, however, where studies have examined the observed or modeled future response of groundwater systems to a changing climate. One recent study uses terrestrial water storage-change observations from NASA Gravity Recovery and Climate Experiment (GRACE) satellites to show that groundwater is being depleted at unsustainable rates across the Indian states of Rajasthan, Punjab (just across the border from Kasur) and Haryana (Rodell, 2009). Over the study period (Aug 2002–Oct 2008), groundwater depletion was equivalent to a net loss which is double the capacity of India's largest surface-water reservoir. The study concludes that unsustainable consumption of groundwater for irrigation and other human use is likely to be the cause of depletion, and that unless groundwater usage is made more sustainable, residents of the region may experience a reduction in agricultural output and shortages of potable water, leading to considerable socioeconomic stress.

Other studies have provided very site-specific results regarding aquifers in other parts of the world, though it is difficult to gauge the relevance of these to the semi-arid region around Kasur. Please see key results of these groundwater studies discussed in Annex A3 – Groundwater Resources.

Because it is difficult to draw conclusions for BSPM from country-level assessments or from studies of specific aquifers elsewhere, our analysis focuses on modeled groundwater recharge response to climate change using meteorological data from a very small area near Kasur.

Groundwater Recharge Modeling Methodology

The groundwater recharge modeling presented in this chapter was carried out in three steps:

- processing of climate data (precipitation and temperature) to represent
    a) the baseline period of 1970–99, which is consistent with the observed baseline presented in Chapter 2,
    b) the future climate (2000 to 2100)
- translating monthly/seasonal climate data to daily precipitation and temperature
- feeding the climate information into a groundwater recharge model which calculates recharge from daily precipitation and potential evaporation (PE).

Each of these steps is described in greater detail below.

Climate Data

Climate data at a daily resolution is required to model groundwater recharge as described below. Daily observed meteorological data is available for Lahore City and Lahore Airport meteorological stations, however the quality of the data is rather patchy with a lot of missing data. Although mean monthly observed meteorological data are available for Lahore City (50km north) over the period 1861–2008, and for Ferozepur City, India (30km southeast) over the period 1901–1970 (via the Global Historical Climatology Network), no information is readily available to disaggregate these monthly values to daily amounts.

To overcome this, monthly average climate data from the Climate Research Unit (CRU), University of East Anglia (Mitchell et al., 2003) were extracted for the grid cell (0.5° by 0.5°) representing Kasur at 31.1N 74.3E. The CRU dataset has been used in numerous studies and is the standard dataset used in IPCC Assessment Reports to represent global observed climate. Three climate variables were extracted for the period 1970–99: mean monthly precipitation, temperature, and number of wet days per month.

Potential evaporation was then calculated using the following equation by Oudin *et al.* (2005):

$$PE = \begin{cases} \dfrac{R_e}{\lambda\rho}\dfrac{T+5}{100} & \text{if } T+5>5, \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

where T is the surface air temperature in degrees Celsius, R_e is the extraterrestrial radiation (J/m^2/s) which is dependent on the latitude and Julian day, λ is the latent heat flux (2.45× 10^{6}J/kg) and ρ_w is the density of water (1000kg/m^3) and *PE* is given in m/day.

The groundwater recharge model, described in greater detail below, requires daily climate data as an input. In order to disaggregate monthly precipitation to daily resolution, an algorithm was used to distribute monthly precipitation across the appropriate number of wet days for each month. The potential evaporation is distributed uniformly across each month, i.e., each day of the month has the same value for potential evaporation.

Projections of future climate were extracted from UNDP Climate Change Country profiles database (McSweeney et al., 2008), which is consistent with the information presented in Chapter 2. This database provides projected future changes in mean climate for Pakistan (and 51 other countries), compared to a baseline climate for the period 1970–99. Decadal mean changes (i.e., 2010s, 2020s, etc.) are available in a gridded format. Grid cell values for the area representing Kasur were extracted for three climate scenarios (SRES A2, SRES A1B and SRES B2), as projected by the 13 global climate model results available for this region. Values were obtained for each of the decades up to 2090–2099.

The UNDP Climate Change Country profiles provide future temperature changes in degrees Celsius, and precipitation changes as a percentage (i.e., 'change factors' rather than absolute future values). These factors were applied to the 30-year baseline climate for temperature and precipitation, to provide series of future climate representing each of the decades of the 21st century. The generated temperature series was then fed into equation (1) to calculate future PE.

More sophisticated methods are available to downscale GCM climate data to specific sites. However, given the limited time and resources to conduct this modeling, and the relative lack of good quality daily data in the vicinity of the site, the change factor methodology used was deemed the most appropriate as a first approximation. Should the results prompt further investigation, a more detailed procedure should be employed if more detailed observed climate data are available.

Groundwater Recharge

As there is little published information on the characteristics of the aquifer that serves the area around Kasur, two methods were employed to calculate the natural recharge (the recharge contributed by rainfall):

- (i) an empirical equation method using the Amritsar Formula; and
- (ii) A water balance method using CATCHMOD.

These are just two of several models which are used to calculate groundwater recharge. CATCHMOD is a simple water balance model which has been widely used for a large number of catchments, including those that are dominated by groundwater processes. It is a conceptual model that divides the catchment into different units according to the soil and land-use type.

The Amritsar formula was developed specifically for the local area in 1973 by Sehgal for the Irrigation and Power Research Institute, Punjab, to estimate the annual natural recharge. For further information and references on both of these methods, please see Annex A3 – Groundwater Resources.

It must be noted that the analysis of natural recharge presented in this chapter does not extend to providing information on how the natural recharge then percolates to each of the aquifers in the region (i.e., there is no information whether the deep aquifer beneath BSPM is recharged by precipitation in or outside of the region, nor how long it takes to recharge the aquifer). There are also other sources of recharge including the large network of irrigation canals, small storage lakes, groundwater flow into the region and rivers. In order to determine the effects of these external factors on the aquifer, a more detailed hydrogeological survey of the area (at depth) would be required.

Groundwater Recharge Modeling - Baseline Period

A comparison of baseline groundwater recharge calculated using the two different methods (CatchMOD and Amritsar) is given in Figure 20. The two methods produce consistent results; the mean annual recharge for 1970–99 is 141 mm/year for CATCHMOD and 140 mm/year for the Amritsar method. Please note that the Amritsar calculation includes a threshold precipitation amount of 16inches (approximately 400mm), which explains the null recharge amounts for particularly dry years (e.g., 1970, 1972, 1974, etc).

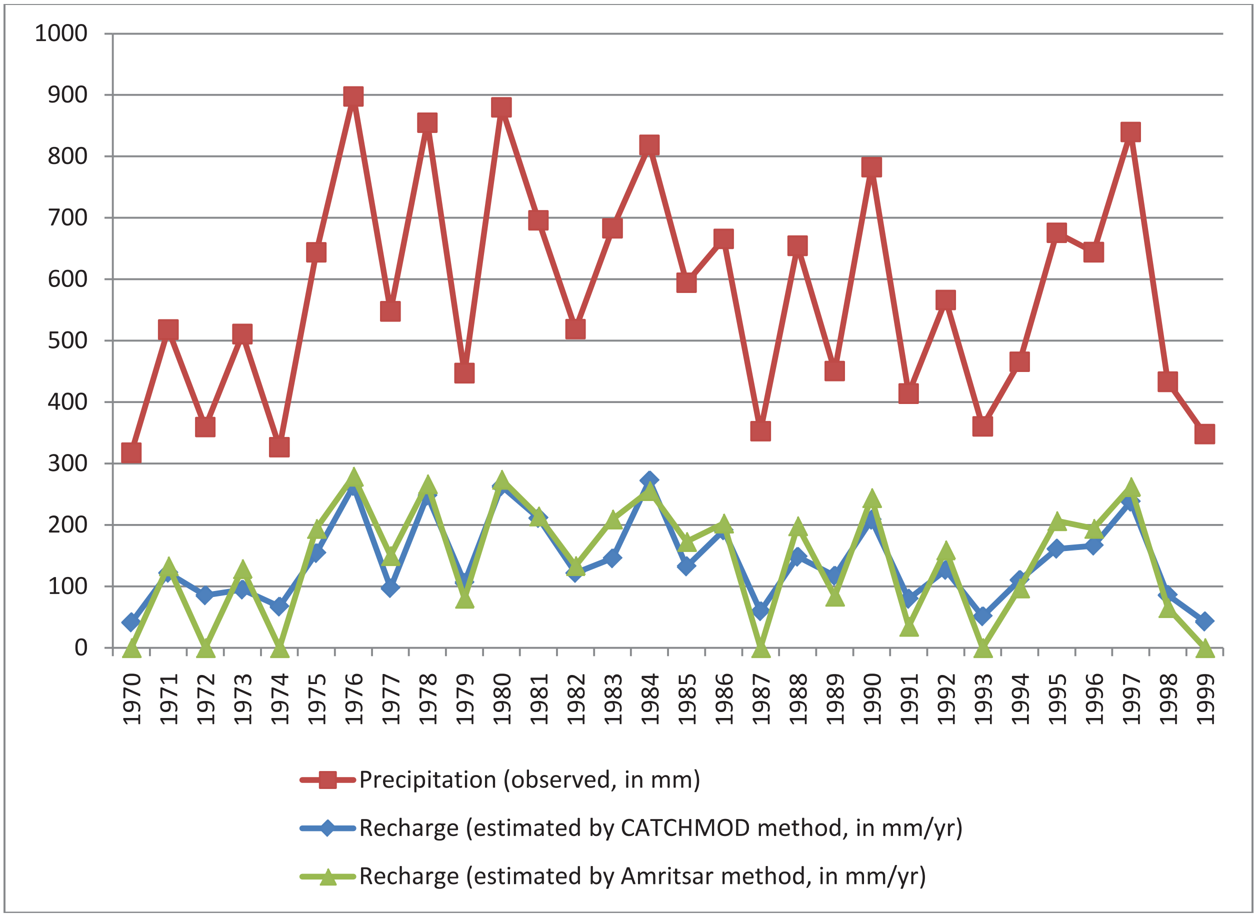
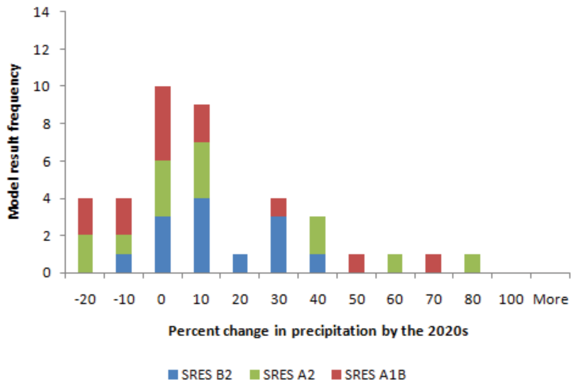


Figure 20. Observed rainfall during the 1970–99 baseline period, and recharge rates calculated using two different methods.

As the current tubewells at BSPM pump out 46,000m^3/day (BSPM, 2006), if the aquifer is supplying water solely for the paper mill operations, the catchment area required to recharge the groundwater aquifer by rainfall would have to be at least 119km^2 (or a radius of approximately 6.2km around the site). This area will either increase or decrease in the future should recharge decrease or increase respectively.

Groundwater Recharge Modeling – Future Scenarios

The percentage change in future precipitation for the 2020s and the 2040s (as compared to the 1970–99 baseline) is shown in Figure 21. The results show projections for 13 global climate models (GCMs). These GCMs are run for three different scenarios, each of which represents a different future greenhouse gas emissions profile. Of the three scenarios, SRES A1B reflects the highest future emissions profile (and consequently the most warming), followed by SRES A2 and then SRES B2. Whereas all GCMs showed an increase in potential evaporation (which is to be expected given the high confidence in future temperature increases) projections for annual precipitation are more uncertain. Both time periods show a rough clustering of projected values, though there is no clear projected increase or decrease in annual precipitation. The clustering is more evident around zero or small changes, and results are skewed towards showing fewer, but higher, projections of increased rainfall. For the 2020s, 46% of modeled results indicate a reduction in precipitation in the area while 54% indicate an increase. By the 2040s, there is a shift towards increased precipitation, with 62% of projections indicating higher rainfall. This uncertainty is consistent with the IPCC 4th Assessment Report, which states that there is little agreement between modeled results for future precipitation across South Asia (see Chapter 2 for more detail). This uncertainty is mainly due to the difficulty of modeling the Asian monsoon.



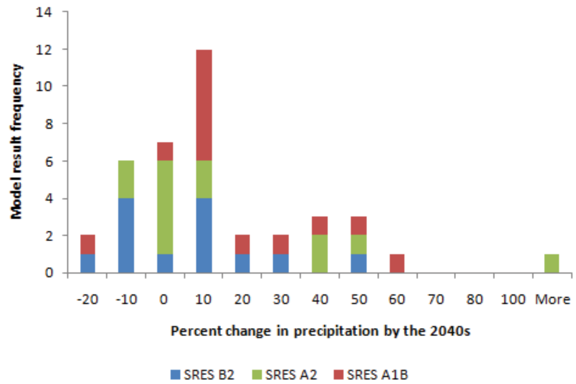


Figure 21. Histograms showing the frequency of projected change in annual precipitation, as projected by 13 global climate models run for three different emissions scenarios, for the 2020s (left) and the 2040s (right).

Figure 22 shows model result frequency for projections of percentage change in natural recharge, compared to the 1970–99 baseline. Recharge is calculated using both the Amritsar (top row) and the CATCHMOD (bottom row) methods, described above. Two of the GCMs project very low values for precipitation during the normal monsoon period (July-August-September) for the observed period 1970–99 (0.12mm/month and 0.52mm/month respectively). These projected values differ by a factor of ten or more from the model ensemble, and by a factor of 100 from the observed dataset (67mm/month). Though absolute change factors for precipitation are very small for these two models, they represent extremely large relative changes (a 1300% and 240% change respectively). When these relative changes are applied to the baseline dataset, very large absolute changes ensue, which skew results for the CATCHMOD calculation. Because of this, these two models are omitted from the CATCHMOD analysis.

Using the Amritsar approach, climate model projections indicate an increase in groundwater recharge: 77% of the model results show a positive change in recharge for the 2020s and a 67% show this for the 2040s, as compared to the baseline. The CATCHMOD method also shows strong positive changes for groundwater, despite the two unrealistically high precipitation projections being removed from the analysis. For both timeperiods, CATCHMOD shows approximately 88% of model projections with increased groundwater recharge.

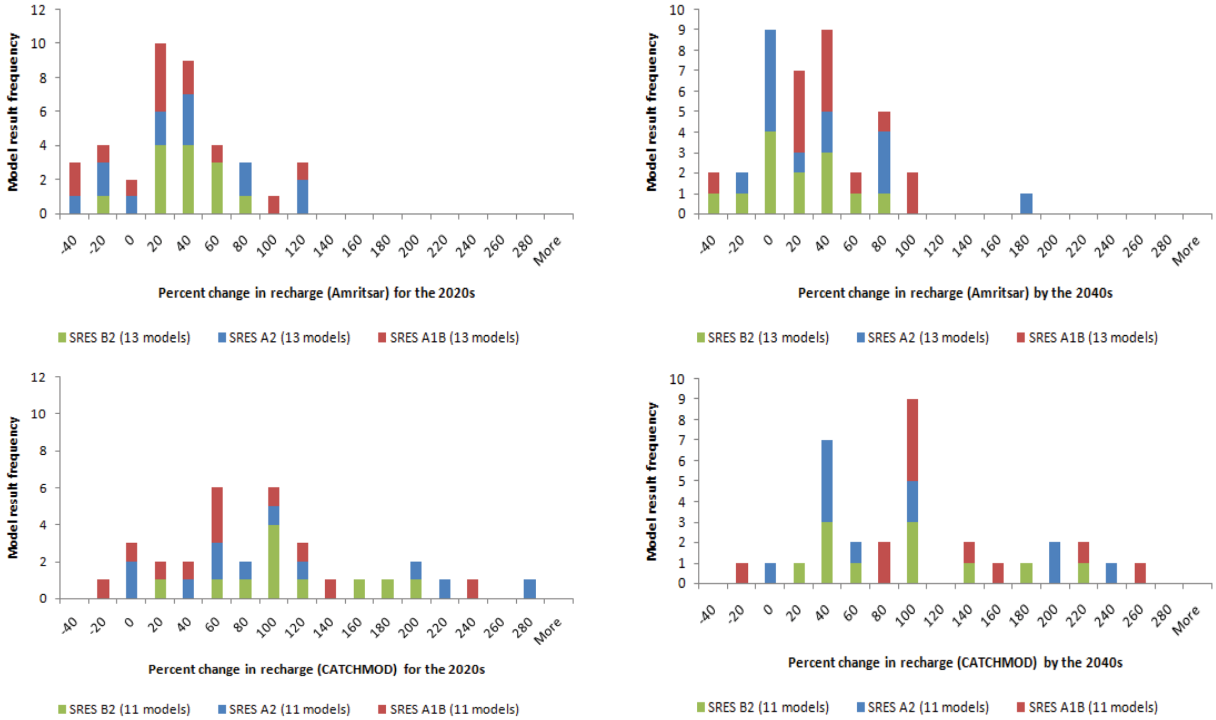


Figure 22. Histograms showing the frequency of projected groundwater recharge, as calculated using two separate methods. Both analyses use global climate model projections. Projections using the Amritsar method (13 GCM results analyzed) are shown in the top row. Projections using the CATCHMOD model (11 GCM results analyzed) are shown in the bottom row. Results for the 2020s are at left and for the 2040s at right.

There are a several reasons why rainfall projections from nearly all the GCMs result in a an increase in annual recharge despite the inconsistent signal for changes in annual precipitation during the 21st century. The first is that nearly 75% of precipitation in the region falls during the monsoon season (IWMI, 2009) and this is when most of the natural recharge occurs rather than being evaporated. Most GCMs project an increase in precipitation during the monsoon season. Some of these changes are very large in absolute terms (i.e., mm/day) as even small percentage changes in precipitation during the monsoon season translate into significant amounts in mm/day, and therefore large changes in recharge.

Recommended Adaptation Options

These modeled changes to future recharge indicate that groundwater resources are unlikely to be depleted due to climate change over the lifetime of the project. It should be noted however that this modeling was undertaken as a desk-based approach, in the absence of detailed information on the underlying soil, geology, and aquifer characteristics. This analysis was also unable to take into account the other users of the groundwater aquifer and how their needs for water may change due to climate change. The company should continue to monitor groundwater levels and well drawdown. Should very large abstractions occur in future that outstrip the projected increases in groundwater recharge the company should undertake a more detailed analysis in order to ensure a sustainable groundwater yield throughout the lifetime of the project.

Given the uncertainty associated with current groundwater resource levels and projected rates of recharge, future investments would benefit from robust integrated assessments of the impact of climate change on groundwater resource supply and demand, taking account of the water needs of all users.

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7. Community and Social Issues

7.1. Introduction

Pakistan is a developing country with an economy strongly reliant on agriculture and with high levels of poverty, particularly in rural areas. The rural poor are particularly vulnerable to climate change because their livelihoods are rooted in the productivity of ecosystems, which are already being altered by rising temperatures and changing levels of precipitation (WRI, 2009). Despite a long history of coping with climate challenges, such as periodic droughts and floods, the rural poor also have limited capacity for adaptation to climate change. While BSPM may not be directly affected by climate change and therefore may not need to implement adaptation measures at its operations, the company may feel the effects of climate change on the surrounding communities.

7.2. Approach

The information presented in this section has been gathered from a variety of secondary sources, including published papers, documents and press articles. Primary information is limited to questionnaire responses received from Packages. A site visit was not conducted as part of this case study. In 2006 a social baseline study was conducted as part of the Environmental and Social Impact Assessment for the construction of BSPM. The social baseline information provided in the ESIA forms the basis of the project level analysis presented here.

7.3. Key Messages

Climate change has the potential to exacerbate and compound existing problems for the communities around BSPM. These are complex and interlinked, stemming from many factors both natural and political. In the absence of adaptation efforts, existing issues of poverty, nutrition, health, and political stability could worsen. As a significant and responsible enterprise in the area BSPM can benefit and minimize risk to its operations by working with others to address these issues.

Key risks include:

- Risk of perception that BSPM contributes to local water resource pressures;
- Risk of general instability if local communities suffer as a result of climate change impacts;
- Risk of poor and worsening health of staff;
- Risk of migration of staff away to cities.

7.4. Results

The communities around BSPM will be impacted by a changing climate whether or not the company is there. Those most likely to be negatively impacted are the local communities as they are already the most vulnerable and have least capacity to adapt.

Climate change has the potential to result in increased risks of:

- soil erosion;
- dryland degradation from overgrazing;
- over-extraction of the shallow groundwater resources accessed by farming communities (Packages' draws groundwater from much deeper wells);
- forest fires;
- loss of biodiversity;
- vulnerability to new agricultural diseases and pests.

Although climate change may not result in significant impacts for BSPM, the local community could experience negative impacts arising from climate change unless adaptation is undertaken.

Socioeconomic impacts are most likely to be derived from impacts on sectors such as agriculture, livestock and forestry. Some direct socioeconomic impacts are also likely to occur, primarily in the form of health impacts. The rural poor, which often depends on natural systems for a sources of revenue, is especially vulnerable to the impacts of climate change because they have very limited adaptative capacity. Current pressures on farmers in the project area that may be exacerbated by climate change include:

- Fragmentation of land;
- Ill defined property rights and land held by few;
- Population growth putting greater pressure on the land;
- International food and fuel prices;
- Competition for water for irrigation;
- Limited access to clean water and sanitation;
- Poor health conditions;
- Poorly maintained irrigation system;
- Migration from other areas of Pakistan and to urban centres;
- Low levels of education and skills among rural populations.

All these existing factors combine to make the population vulnerable to any additional pressures on their survival.

BSPM has developed good relations with the local communities and it would be beneficial to maintain and to strengthen these. The company supports the local community and is generally well regarded: there were very few negative comments expressed about the company during consultation for the ESIA.

BSPM abstracts groundwater from wells that are much deeper than those used by the local farming community, and the large quantities extracted by the paper mill do not currently impact groundwater availability for local farmers. However, local communities may not be aware of the different depths and aquifers. If, in future, the community experiences problems with groundwater quality or quantity, there is a possibility that the paper mill will be held responsible when in fact the problem is climate change-related.

Much of the rural population around the BSPM lives close to the poverty line (please see Annex A4 – Community and Social Issues for a socioeconomic breakdown of the project area). It is unlikely, but possible that worsening conditions would result in greater local tensions and competition for resources.

The company has demonstrated its commitment to providing local employment and should therefore be aware of the potential climate risks to its staff, including exposure to new diseases and the increased need to provide for other family members unable to support themselves.

It is not within the scope of this report to discuss adaptation measures appropriate to addressing such a large and complex challenge. However, below are a number of actions that could be beneficial in increasing the adaptive capacity of the local community:

- Continue to support local wheat farmers with advice and technical support, particularly with regard to managing the potential impacts of a changing climate (e.g., information on heat- and drought-resistant crop strains);
- Work with local communities and government to plan for and manage the additional pressures that climate change will place on water resources and infrastructure;
- Take climate change impacts into account when designing company health care plans and facilities available to the wider public;

- Include in the community engagement strategy plans for community response in the event of lower wheat yields. As discussed in Chapter 4, the groundwater-fed crops around Kasur are less vulnerable to climate-related impacts on wheat yields; however the future availability of groundwater resources is uncertain and a decrease in crop production would have significant impacts on farmers and would need careful management;
- Continue to engage with local stakeholders

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8. Climate Risks for the Broader Pulp and Paper Industry

8.1. Introduction

This section looks beyond the BSPM, and provides an overview of the broader pulp and paper sector, including discussion of the key issues (non-climate related) currently facing the industry. It then looks at the impacts of climate change on the industry as a whole, including risks to forest management, transport of raw materials, storage and handling of chemicals, and heat and power plants.

Pulp and papermaking is a multifaceted sector that involves a wide range of raw materials, diverse process stages and many different products. Pulp may be created from virgin fiber (e.g., wood pulp or wheat straw pulp) by mechanical or chemical means, or it may be produced by the re-pulping of recycled paper. Paper is effectively a sheet of fibers with a number of added chemicals which affect the properties and qualities of the sheet. Besides fibers and chemicals, manufacturing of pulp and paper requires a large amount of process water and energy in the form of steam and electric power. Consequently, the main environmental issues associated with pulp and paper production are emissions to water, emissions to air, and energy consumption (IPPC, 2001). A paper mill may simply purchase pulp made elsewhere, but in integrated pulp and paper mills the activities of pulp and papermaking are undertaken on the same site.

8.2. Approach

The results reported in this chapter are drawn from a review of the relevant literature (please see Section 7.5 for a full list of references).

8.3. Key Messages

- The forestry, paper and packaging (FPP) sector currently faces several key stressors which could potentially be exacerbated by a changing climate, including:
    - Increasing fiber costs, particularly in markets where fiber sources are in demand as renewable fuels;
    - Increasing energy costs, especially as FPP companies are high energy users;
    - Rising transport costs, as the FPP sector is heavily dependent on road, rail and shipping for supply chain and distribution of products.
- A changing climate is likely to affect the pulp and paper sector in a variety of ways, including the physical risk to fixed assets arising from storm damage or flood, impacts on natural resources like fiber sources and water, impacts on the supply chain arising from transport system disruption, as well as knock-on impacts affecting communities that depend on the FFP industry. All of these impacts present economic risks to the sector as a whole. However, opportunities to develop renewable energy sources and climate resilient management practices will evolve to help manage these risks.

8.4. Results

Current Climate-Related Sensitivities

Pulp and paper industries are concentrated mainly in North America, northern Europe (particularly Finland and Sweden) and East Asian countries (Japan). Australasia and Latin America also have large pulp and paper industries. In recent years industry growth rates have declined in North America, Europe and Japan. Emerging markets have been more resilient (due in part to strong domestic demand), however, and India and China are emerging as leaders key to the industry's growth over the next few years (PwC, 2008).

In PricewaterhouseCoopers' annual overview of the key issues shaping the pulp and paper sector, climate change is mentioned as a significant factor affecting the industry, but only from a greenhouse gas emissions/climate change mitigation point of view. Though not often associated with contributing to climate change, the pulp and paper industry is the third or fourth largest source of industrial greenhouse gas emissions in most developing countries (Environmental Paper Network, 2007). The industry is responsible for emissions related to sourcing (i.e., deforestation and the reduced carbon storage that is associated with it), emissions relating to production (i.e., manufacturing) and emissions related to disposal (i.e., the large proportion of landfill given over to paper, which contributes to methane release).

The PwC report, summarized from publicly available financial information of the largest 100 forestry, paper and packaging (FPP) companies globally, stresses the importance of sustainable forest management in reducing greenhouse gas emissions, as well as the early-mover advantages that FPP companies have to develop biomass products in response to rapidly growing demand for renewable energy. Climate impacts are not mentioned in the report, though the reality of climate change means that forest management must take account of the potential risks posed by a changing climate in order to be truly sustainable. The report identifies several other key issues which could potentially be exacerbated by a changing climate, including:

1. Fiber costs:

   Rapidly-growing emerging markets with fiber deficits (particularly in Asia) are purchasing both virgin and recovered fiber sources in regions in surplus, putting pressure on price. For example, Asia Pulp and Paper (China) has just acquired its first Canadian pulp mill in Saskatchewan (PwC, 2008).

   The same fiber sources are in demand as renewable fuels. Competition for renewable resources often stems from government policy designed to encourage alternatives to fossil fuels as a response to climate change.

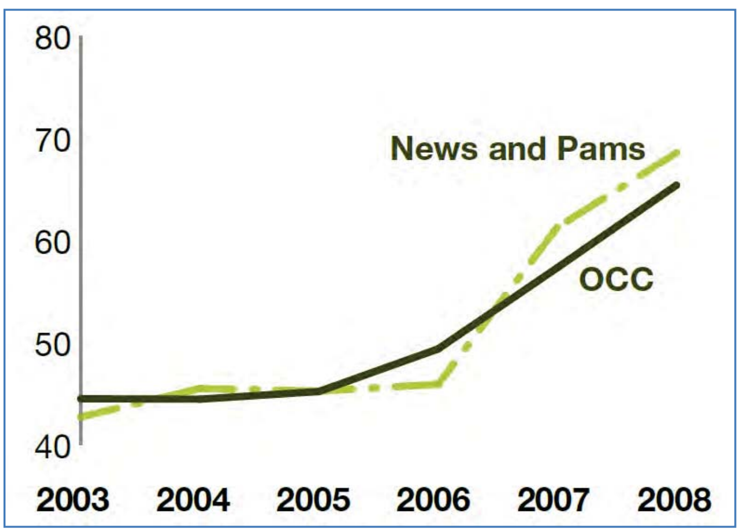

Figure 23. Cost of recovered UK domestic fiber in £/ton. 'News and Pams' refers to mixed newspapers and magazines, while 'OCC' refers to old corrugated containers or cardboard. (Source: Global Forest, Paper and Packaging Industry Survey, 2008, Pricewaterhouse Coopers)

   These two factors have combined to produce localized fiber supply problems and general increases in fiber costs worldwide. Figure 23 shows the rapid recent rise in the cost of recovered domestic fiber in the UK. The FPP sector will continue to face challenges securing sustainable and affordable fiber so long as economic growth is strong in emerging pulp and paper markets. The discussion on climate risks, below, will outline some of the ways that a changing climate can further exacerbate raw material access problems and costs.

2. Increased energy costs:

   FPP companies are high energy users, hard hit by the rapid global growth in energy demand and recent price increases, though impacts are not consistent across the industry. Modern pulp and integrated paper makers that are already reducing energy consumption and switching to renewable energy sources are able to lessen the impact of rising energy costs. Any climate-related risks to energy supplies will likely increase energy costs for the FPP sector.

3. Higher transportation costs:

   Because the FPP sector is heavily dependent on road, rail and shipping for supply chain and distribution of products, rising oil prices have increased transportation costs throughout the industry. Transport problems have been exacerbated by port capacity shortfalls globally, leading to significantly increased shipping costs. Again, any climate-related risks to supply chain, distribution networks and transportation logistics will further exacerbate transport costs.

Sensitivities Due to Projected Changes in Climate

A changing climate will affect the pulp and paper sector in a variety of ways, including the physical risk to fixed assets arising from storm damage or flood, impacts on the supply chain arising from transport system disruption, and shifting patterns in demand for different products. Changing weather patterns may impact asset values; they may increase costs as raw materials or other inputs become less plentiful, or as maintenance regimes or working practices need to change. All of these impacts present economic risks to sector as a whole. However, opportunities to develop renewable energy sources and climate resilient management practices will evolve.

Raw Materials

1. Fiber supply

Changing atmospheric CO_2 concentrations, increases in temperature and changes in seasonal precipitation can alter physiological processes in soils, trees, and other fiber species, with direct consequences for yield and growth of commercial species in the future (Alig et al., 2002). The most favorable climatic conditions for individual species often exist over a relatively small area. As a result, though species may continue to grow in current locations, they may face competition from other species better suited to the new climate conditions. Competition, as well as changing climatic conditions, can also alter growth rates of existing species (Walker and Sidneysmith, 2008). In addition, climate change will cause migration of new pests and diseases which affect individual fiber sources. Please see Box 1 for a detailed discussion of the recent mountain pine beetle epidemic in British Columbia, Canada.

A changing climate is also expected to have a direct effect on tree and other fiber species in the following ways:

- Increasing temperature alone will lead to an increase in forest fire activity. Depending on the region, however, changes in precipitation frequency and intensity may counteract this effect, possibly even leading to a decrease in fire activity (Bergeron, 2004). A recent study, using a single global climate model (under the A2 emissions scenario), finds that regional increases in probability of fire by the 2030s may be offset by decreases at other geographic locations, due to the interplay of temperature and precipitation variables (Krawchuk et al., 2009). The fire model used in this study predicts substantial invasion and retreat of fire across large portions of the globe, as shown in Figure 24. Firefighting capacity can be increased through enhanced fire detection and monitoring programs, effective initial response procedures, and increased use of firebreaks through landscape fragmentation and road system development.
- Forests in drier areas may experience yield, fire or regeneration problems due to an increase in summer droughts. Though fewer than 7% of the world's forests are in strongly water-limited systems (Boisvenue, 2006), these forests are often commercially significant within the region.

The European heat wave and drought during the summer of 2003 had enormous social, economic and environmental adverse effects, including the destruction of large areas of forests by fire in Portugal, Spain, France and Italy. The direct damage as a result of forest fires in Portugal was estimated at €1.03 billion (COPA COGECA, 2003).

- Coastal forests will likely see an increase in the number and intensity of storms, thereby increasing windthrow damage.

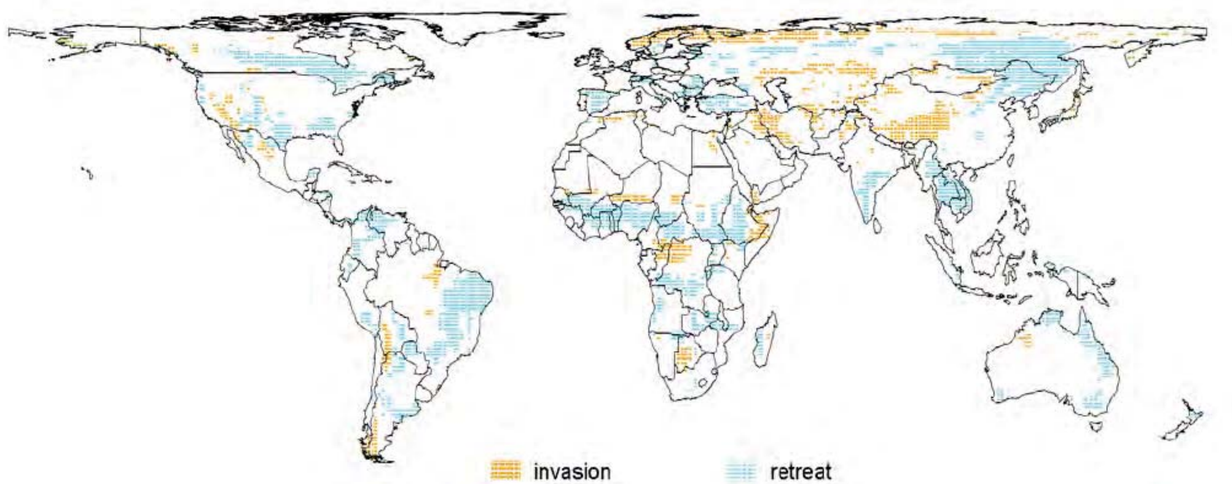

Figure 24. Potential invasion (orange) and retreat (blue) of fire projected by 2010–2039 under the A2 emissions scenario and based on a single global climate model. Invasion results are limited to places with existing vegetation. [Source: Krawchuk et al., 2009].

The demand for fiber products is relatively inelastic (i.e., not price-sensitive), meaning that small percentage decreases in yield lead to larger percentage increases in prices, and vice versa (Alig et al., 2002). Any climate-related increases in fiber costs are likely to be met by consumers – through shifts in consumption patterns towards alternative fiber sources – and by producers – through changes in planting, thinning, rotation and other management practices.

2. Water

Many pulp and paper facilities depend on large, uninterrupted supplies of water as an input to manufacturing processes, and climate change is expected to lead to reductions in river flows in many regions. Although less is known about the impact of climate change on groundwater supplies, warmer temperatures and changing patterns of precipitation have the potential to reduce the rate of recharge to aquifers, with knock-on consequences for industries that rely heavily on groundwater. During periods of drought (which are projected to increase in severity and intensity in some regions), demand for water resources from third parties will also increase, leading to heightened competition for an already scarce resource. If climate change exacerbates water shortages, and/or water quality issues, industrial pulp and paper facilities may be held responsible, increasing reputational risks.

Supply Chains and Logistics

The supply chains and transport links on which the pulp and paper sector depends are vulnerable to climate related disruptions, including flood, fire and storm events, heat waves and/or landslip caused by heavy rainfall. Changes in the intensity and frequency of heavy rainfall events can lead to increased erosion or downslope debris, necessitating changes to the construction and maintenance of logging roads. Access to forests may be constrained during winter as a result of warmer and wetter conditions, and during summer as a result of forest fire activity. The design and maintenance of logging roads will also be affected by extreme precipitation events. Heat waves can cause buckling of railway lines and melting of tarmac road surfaces. Industries that are dependent on government-owned transport infrastructure over which the private companies have no control are particularly vulnerable to climatic risks, if the infrastructure is not designed to cope with climate change risks. Disruptions and delays to ‘just-in-time’ distribution systems can also lead to pulping plant closures and production delays.

Assets and Site Conditions:

Sea level rise, storm surges, higher rainfall and increased river flows can heighten flood and coastal erosion risks, leading to asset damage, inability to operate, and downtime during clean up operations. Existing flood management systems will be compromised by sea level rise, storm surges, increased seasonal precipitation, and increased risk of river and flash floods. This may lead to higher insurance premiums, wider exclusion clauses and removal of cover, which will in turn have an impact on asset value and availability of finance. Areas currently at risk from flooding may become uninsurable in the future.

There is some evidence that climate change will lead to an increase in cyclone activity and intensity and monsoon intensity. Large fixed assets at pulp and paper facilities may be vulnerable to extremes of wind and driving rain.

Workforce:

The comfort and productivity of pulp and paper production line and factory workers can be compromised by warmer working conditions. Dangerous conditions can arise if building temperatures exceed certain thresholds during heat waves. The need to cool buildings, processes and workplaces may lead to increased use of energy and increased greenhouse gas emissions, and emissions reductions targets may be compromised.

Maximum workplace temperatures may be imposed (if not already in effect), which could result in significant capital and revenue costs.

Climate change may compromise each sector’s ability to provide health and safety protection for its large workforce, for the following reasons:

- Outdoor workers may be increasingly susceptible to heat stress during sustained periods of hot weather;
- Climate change will introduce new pests and diseases into previously unaffected areas and could create new health risks for workers;
- The local workforce is also vulnerable in the vicinity of high flood risk pulp and paper sites.

Operations

1. Equipment and processes

During sustained periods of high temperatures, pulp and paper-making equipment may perform sub-optimally and processes may be less efficient. For example:

- Air coolers cope less effectively during heat waves, leading to reduced production.
- Compressor efficiency is reduced during periods of higher temperatures.
- Output from many forms of energy generation, particularly gas- or steam-fired turbines, is lower in hot weather.
- Electricity supplies are at risk during sustained high temperatures as generators struggle to meet increased peak demands and distribution systems fail under loading.

These impacts can result in reduced output, and in some cases may lead to downtime and outages, with knock-on consequences for lost revenue and reputational damage.

Climate impacts on forest yields will also have direct impacts on forestry operations, as wood quality, wood volume and log sizes shift. In Canada, for example, climate-related increases in forest damage (due to fire and pests) have resulted in increased proportions of salvaged wood being harvested (Walker and Sydneysmith, 2008). Because timber stands can remain in the ground for over 50 years, forest planning must take into account the projected climate over the lifetime of the stand. Species choice, planting regimes and management practices should address the future climate, rather than historical climatological conditions.

2. Water abstraction and discharge

Low river flows during hot, dry summers can lead to restrictions on water abstractions, with consequences for cooling and industrial processes when the need for cooling is highest. Hotter temperatures and decreased river flows due to climate change also increase the risk that river water will be insufficient to dilute cooling water effluent and pollutant discharges. As a result, pulp and paper facilities may be forced to reduce output or shut down in order to meet abstraction/extraction and discharge consents, designed to protect the environment and other water users, e.g., local communities dependent on fisheries.

3. Chemicals

Higher temperatures and heat waves can compromise chemical processes and affect corrosion rates, physical properties of end products and storage times. This has knock-on impacts on performance conditions and quality standards for production processes. Chemical shelf life or expiry dates are also temperature sensitive. With rising temperatures and increased risk of heat wave events, some chemicals in storage or in transit may lose efficacy or begin to degrade, with consequences for business continuity and liability. Safety thresholds may also be compromised by higher temperatures, leading to an increased risk of plant failure (explosion, fire, loss of life) or pollution.

4. Downtime and safety

Over short time scales, impacts on operations and processes tend to be associated with extreme weather events (e.g., floods and heat waves). These events can lead to local (i.e., limited in damage and disruption) or system (i.e., widespread) failures. Operating risks include downtime, outages and impaired access for supplies and/or workforce.

Over the longer term incremental climatic changes will have a significant impact on a system's operating and safety thresholds, as well as the deterioration of raw materials and products. These are not as apparent as extreme failures and can easily be overlooked if not actively evaluated. Existing assets may require continuous repair and maintenance, with associated costs. Regulatory risks must be considered if handling, transmission and storage safety standards are compromised.

Local Communities and Environments

Because the well-being of forestry communities is so closely linked to climate-sensitive forest environments, they may be vulnerable to increased risk of property damage in the case of flood or storm events, and job losses in the case of reduced yields. There is also the potential for prolonged heat waves and forest fires (with consequent heavy smoke conditions) to negatively impact health in forest-based communities.

Changing climatic conditions will also directly affect flora and fauna. Species will migrate to new locations in response to changes and may be lost from locations where they are currently found. Habitats will also be affected – for instance, coastal habitats could be lost as sea levels rise. New pests, diseases and invasive species may lead to local loss of protected species in the vicinity of a timber, pulp or paper facility. Activities at a facility could be held responsible for loss of species/habitats, whereas larger-scale factors associated with climate change are actually responsible.

Box 1: The Mountain Pine Beetle in British Columbia, Canada

The mountain pine beetle (MPB) lives under the bark of most pine species within its range, normally playing a vital role in the life of a forest. They attack old and weakened trees, speeding the development of new growth. In recent years, however, unusually hot, dry summers (favorable for beetle reproduction) and mild winters (which allow beetle larvae to survive) in central British Columbia have lead to the largest outbreak of MPB in history. The abundance of large, mature pine trees combined with fire suppression practices contributed to the size of the epidemic – the area affected by the outbreak was nearly 10 times greater than any previously recorded. In 2007, MPB infestations were recorded over 9.2 million ha of pine forests. To date, beetles have destroyed millions of lodge pole pine (the province's most abundant commercial tree species) in British Columbia.

Figure 25 shows the total area affected by MPB in 2006. At the current rate of spread, 80 per cent of the mature pine will be dead by 2013, and the consequences of the epidemic will be felt for decades throughout the province. The beetle is also posing a real threat to neighboring Alberta's lodge pole pine forests and the Jackpine stands of Canada's northern boreal forest.

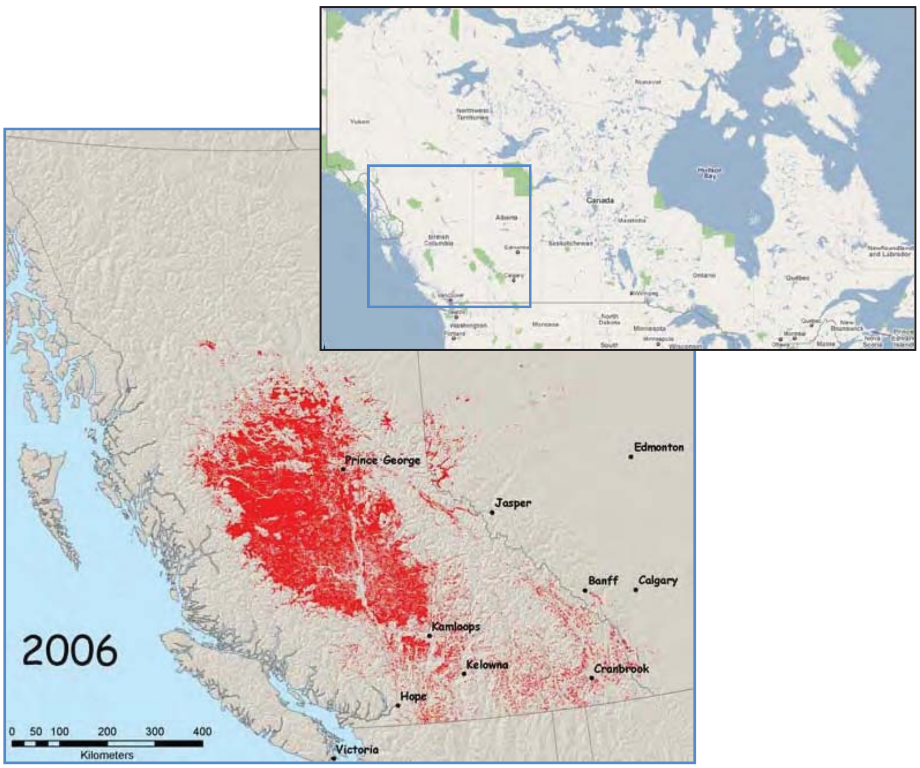

Figure 25. Total area affected by mountain pine beetle in Western Canada, in 2006 (Source: Canadian Forestry Service, accessed via Natural Resources Canada website [mpb.cfs.nrcan.gc.ca/map_e.html]). Inset map shows the area affected relative to the rest of Canada.

The range of MPB is currently expanding northward and eastward into habitat that was formerly limited by climate, but which has an abundance of pine forest. Modeling has indicated that favorable climatic conditions have recently increased the area of optimal PMB habitat by more than 75%, with significant consequences for pine forest in neighboring Alberta and northern boreal forest.

MPB-related tree mortality presents further climate risks for forest hydrology. The current and projected MPB epidemic in British Columbia will destroy a forest area sufficient to cause increased exposure of soils to precipitation, potentially deeper snow accumulation and earlier melt, thereby increasing the risk of flooding. According to the Forest Practices Board of British Columbia, similar changes to the forest hydrological cycle may be responsible for observed increases in base flows/low flows in watersheds affected by MPB. Some regions in the province have reported the occurrence of higher water tables, and The City of Prince George is concerned about the potential for a heightened risk of flooding in low-lying urban areas due to anticipated rises in the levels of the Nechako and Fraser rivers, especially during spring runoff.

Sources: Walker and Sydneysmith (2008); BC's Mountain Pine Beetle Action Plan (2006); Carroll et al (2003).

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9. Financial Analysis

In May/June 2009 Packages installed a new 41MW capacity power plant at BSPM. Now that these new assets are operational the plant has 100% spare capacity (i.e., twice what it requires). It can be assumed that the new assets were planned and installed to improve the engineering cost basis at the paper plant. The previous set-up (an 11MW plant, now on standby) had reached a capacity constraint.

The engineering analysis in Chapter 3 shows that rising temperatures will have a negative impact on steam turbine output. This decrease is minimal and will not affect operations, given that BSPM now has a power generating capacity that is double its requirements. It will, however, reduce the amount of generated electricity available to sell to the grid. The plant operators have two options:

1. They can burn more fuel, or
2. They can sell less electricity, generating less revenue.

The impact of increases in air temperature on boiler efficiency is small but positive. Based on an assumed \$14/MBTU and 340 operating days/year, higher temperatures lower the natural gas costs by \$31,700/year (for a 1.1°C rise by the 2020s), \$37,000/year (for a 1.26°C rise) and \$53,000/year (for a 1.88°C rise). The increase in air temperature also results in a slight decrease in power output of the steam turbine – by 0.20%, 0.23% and 0.35% across the range of temperature scenarios. The variable portion of the cost of electricity generation (unit cost) is also increased, because the amount of surplus power for export decreases. The reduction in revenue (assuming a \$0.10kW-hr and 340 operating days/year) from reduced sales amounts to \$53,000, \$65,000 and \$98,000/year respectively. The decrease in cost of steam generated as a result of increases in boiler efficiency is minor.

The slight increase in the cost of generating power is offset to a small degree by the increase in boiler efficiency, which will result in a reduction of natural gas requirement for fuel. The net effect (higher boiler efficiency/reduced natural gas purchases and reduction in revenue from reduced electrical exports) amounts to \$23,300, \$28,000 and \$45,000/year for temperatures increases of 1.1°C, 1.26°C and 1.88°C, respectively.

IFC's financial model for BSPM was drawn up in 2005 (Packages, 2005). At the time, the specification for the new engineering assets was not known; as a result it is not possible to use the model for this analysis. The financial model refers to an engineering set-up that no longer exists. The capital cost of the new assets is not known, nor is the new operating cost.

By using the estimated costs and offsets above, however, it is possible to give a rough estimate of the financial impact of warmer temperatures on turbine/boiler efficiency and fuel cost by the 2020s, as summarized in the table below.

	Temperature increase by 2020s		
	1.1°C	1.26°C	1.88°C
Decrease in power output of steam turbine (from current 17.85MW)	17.78MW	17.77MW	17.73MW
Reduction in revenue from reduced sales amounts (per year), based on an assumed $0.1/kW-hr and 340 operating days/year	$57,000	$65,000	$98,000
Offset by a reduction in natural gas requirement for fuel (due to increased efficiency of boiler)	-$25,300	-$28,000	-$45,000
Net cost (per year)	$31,700	$37,000	$53,000
Total cost from now until 2017 (the final year in Packages' financial model)	$253,600	$296,000	$424,000
Total cost, discounted year by year (using a 12% discount rate)	**$157,474**	**$183,803**	**$263,285**

Because detailed engineering details across BSPM are not known, this analysis presents the impact of a single, well-defined operational issue – temperature effects on turbine output and boiler efficiency. We recognize that this analysis relies on a number of assumptions (e.g., rough natural gas costs, and electricity prices), and is therefore presented only as a rough guide or starting point to the financial impact of climate change on operations. The Company will have a much better idea of current climate sensitivities and existing engineering bottlenecks which limit operational capacity. The Company will also have more robust information about the costs of operating the new turbine and of the sensitivity of the current system to changes in electricity costs, and will be able to perform this analysis more robustly.

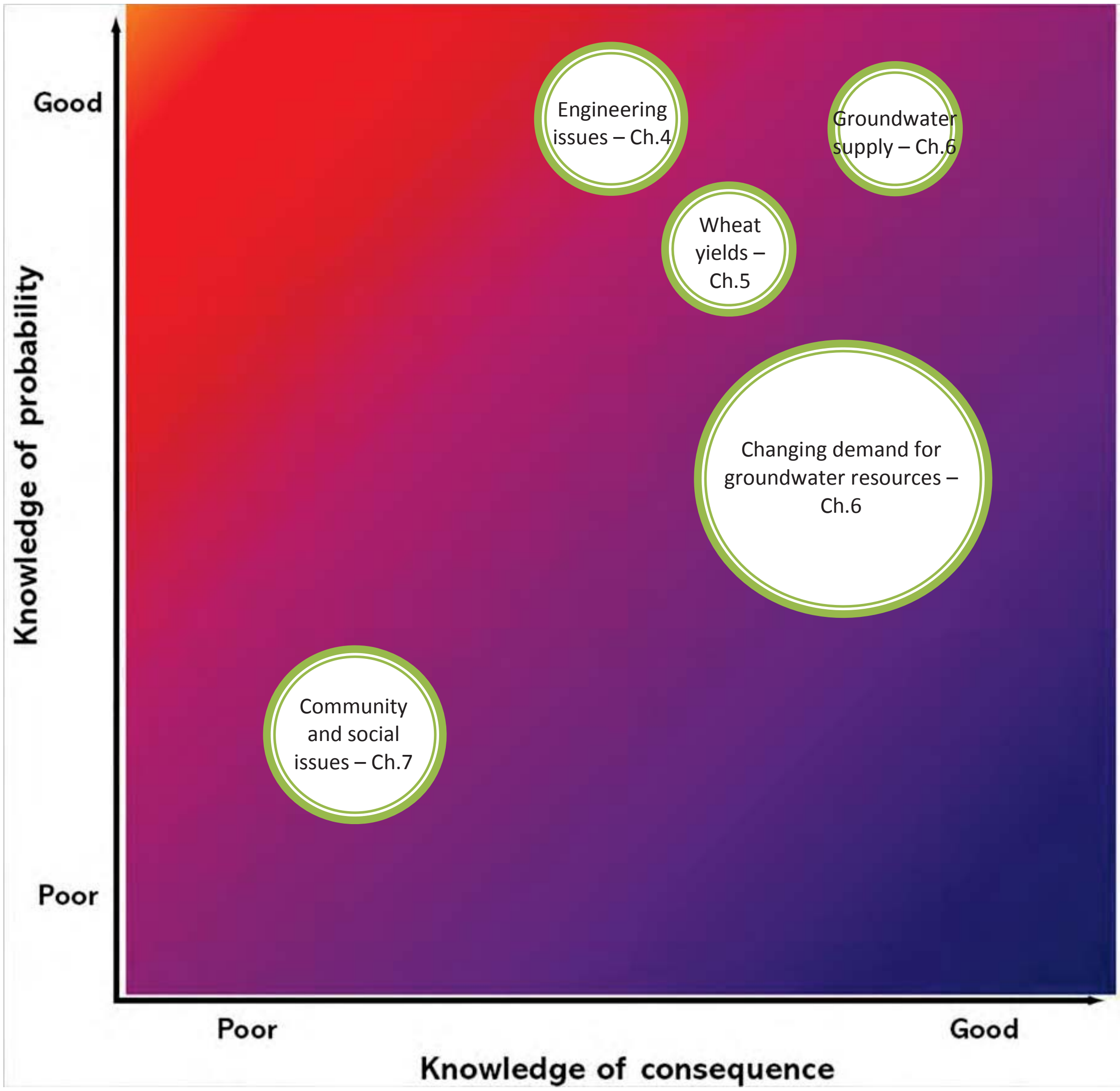

Figure 26. Knowledge and impact matrix for climate-related risks faced by BSPM.

Figure 26 illustrates our overall knowledge of the probability of a climate-related risk, as well as our knowledge of the presumed impact if it did occur. The size of each circle is roughly indicative of the size of the climate risk. For this desk-based case study it was only possible to value a single operational dimension – the new power plant assets – and the financial impacts of that risk are relatively small. However, there are potentially more significant operational risks that we can't quantify. The company already experiences changes in operational performance during unusually hot and/or humid weather, and it might be beneficial to investigate these climatic 'bottlenecks' in more detail. Similarly, in the absence of detailed information on aquifer characteristics and other groundwater users, it was only possible to quantify groundwater recharge (i.e., supply) rates. Though groundwater recharge impacts are not estimated to present a significant risk to the company, climate-related changes to demand for groundwater in the area are expected to be large.

9.1. Reference

Packages Limited (2005) IFC Financial Projections (2005–2017) Base Case Scenario.

Annex A1 – Climate Analysis

The climate of Pakistan varies widely across the country. The national Survey of Pakistan, responsible for major land surveys and cartographic records in the country, divides the country into eight climatic zones as shown in Figure 27. These range from regions characterized by mild, moist winters and hot, dry summers in the north to semi-arid and arid zones in the west and parts of the south. Thermal regimes exhibit extreme diurnal, seasonal, and annual variations: temperatures can fall as low as –26°C over the northern mountains and go as high as 52°C over the central arid plains. In the semi-arid plains, temperatures of 42°C are recorded at various stations in the months of May and June. The area around Kasur, indicated with a circle in Figure 27, is classified as 'Warm, semi-arid'.

The climate of Eastern Pakistan is normally described as having three important seasons: winter, which occurs from December through March; summer, from April through June; and a rainy season, running from July through September. October and November are often described as a 'shoulder' season. For the purposes of this case study analysis we have presented observed and projected climate information for January, May and August, which are representative of the winter, summer and rainy seasons respectively in Eastern Pakistan.

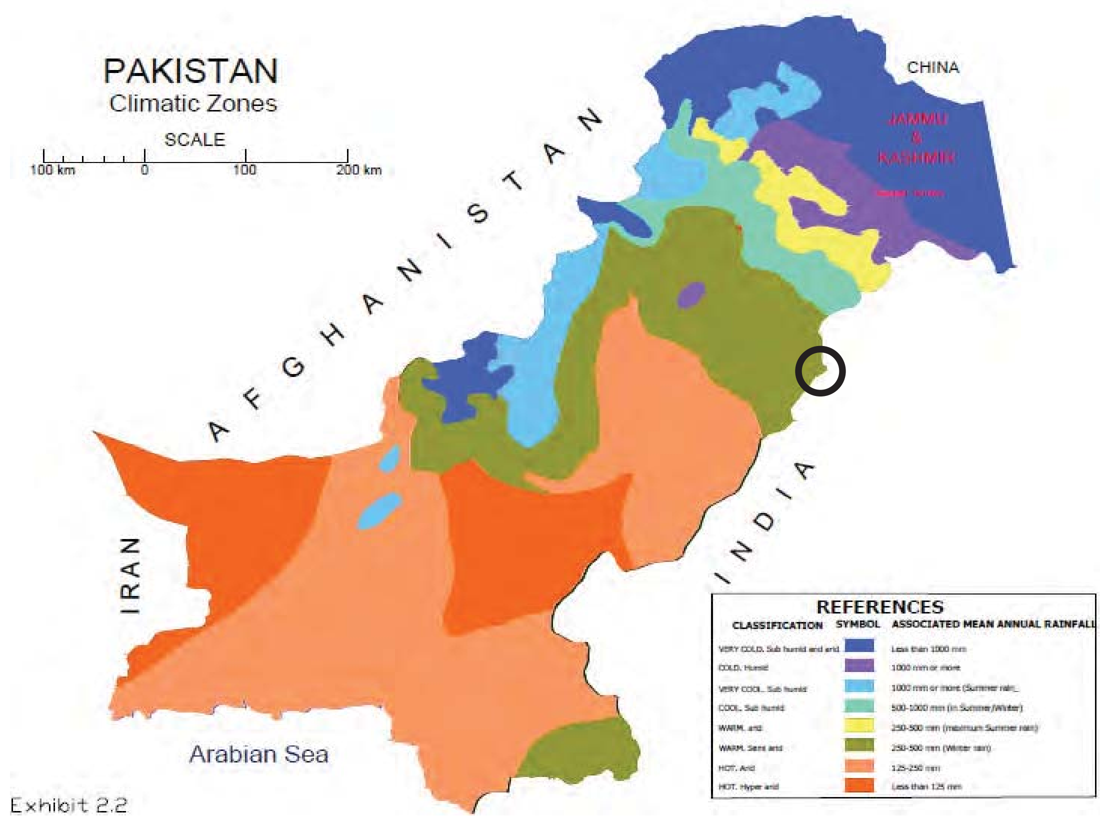

Figure 27. Climatic zones of Pakistan [Source: Pakistan's National Communication on Climate Change, 2003].

The observed regional baseline climate (averaged over the thirty year period from 1961–90) presented in Chapter 2 provides a ‘snapshot’ of the average conditions over a large geographical area centered on the case study location. The images presented were created using the data visualization tool available through the IPCC Data Distribution Centre (DDC) [http://www.ipcc-data.org/ddc_visualisation.html].

The data presented through the IPCC DDC are part of the ‘CRU Global Climate Dataset’, which was developed to show mean monthly climate (‘climatology’) for 1961–90 across global land areas (excluding Antarctica) at a gridded spatial resolution of 0.5°latitude by 0.5°longitude. These grids are publicly available through the Climatic Research Unit [http://www.cru.uea.ac.uk].

This mean 1961–1990 climatology dataset includes information on eleven surface climate variables: precipitation and wet-day frequency; mean, maximum and minimum temperature; vapor pressure and relative humidity; sunshine percent and cloud cover; frost frequency; and wind speed. These mean climate surfaces were constructed from a dataset of some 19,800 (precipitation) and 3615 (windspeed) meteorological station 1961–1990 climatological normals. The station data were interpolated as a function of latitude, longitude and elevation.

The observed timeseries of climatic conditions presented in Chapter 2 were recorded at individual meteorological stations over more than 140 years (1861–2008). Figure 28 shows the location of meteorological recording stations near Kasur, in both Pakistan and India. Of these, Lahore City (some 50km north of Kasur) retained the most complete, long-term record of several different climatological variables.

Figure 28. Map showing location of meteorological recording stations near Kasur [Source: Google Earth].

The data for this meteorological station provides a picture of year-to-year climatic variability and trends over a very long time period, at a geographical point very close to BSPM. These long-term data records were obtained through the Climate Explorer tool developed by KNMI (Royal Netherlands Meteorological Institute) [http://climexp.knmi.nl/].

The Climate Explorer tool allows users to download timeseries of meteorological data from stations throughout the world. The site also comprises a useful help section, along with an overview presentation that provides guidance on the system. Data from Lahore City station were used to create the charts of observed precipitation and temperature variability and trends in Chapter 2. Meteorological records from this station were also used for the engineering analysis in Chapter 3 and the groundwater modeling in Chapter 5.

To provide a basis for estimating future climate change, the Intergovernmental Panel on Climate Change (IPCC) prepared the Special Report on Emissions Scenarios, detailing 40 greenhouse gas and sulphate aerosol emission scenarios that combine a variety of assumptions about demographic, economic and technological factors likely to influence future emissions. Each scenario represents a variation within one of four ‘storylines’: A1, A2, B1 and B2. Further details of the storylines are provided below. Projected carbon dioxide, methane, nitrous oxide and sulphate aerosol emissions based on these scenarios are shown in Figure 29 below for six ‘marker scenarios’. All the scenarios are considered equally sound by the IPCC and no probabilities are attached.

Storylines for scenarios of greenhouse gas emissions:

> **A1**: The A1 storyline describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 storyline develops into three scenario groups that describe alternative directions of technological change in the energy system. They are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources and technologies (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).
>
> **A2:** The A2 storyline describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
>
> **B1:** The B1 storyline describes a convergent world with the same global population as in the A1 storyline (one that peaks in mid-century and declines thereafter) but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives, i.e., it does not include implementation of the United Nations Framework Convention on Climate Change or the Kyoto Protocol.
>
> **B2:** The B2 storyline describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

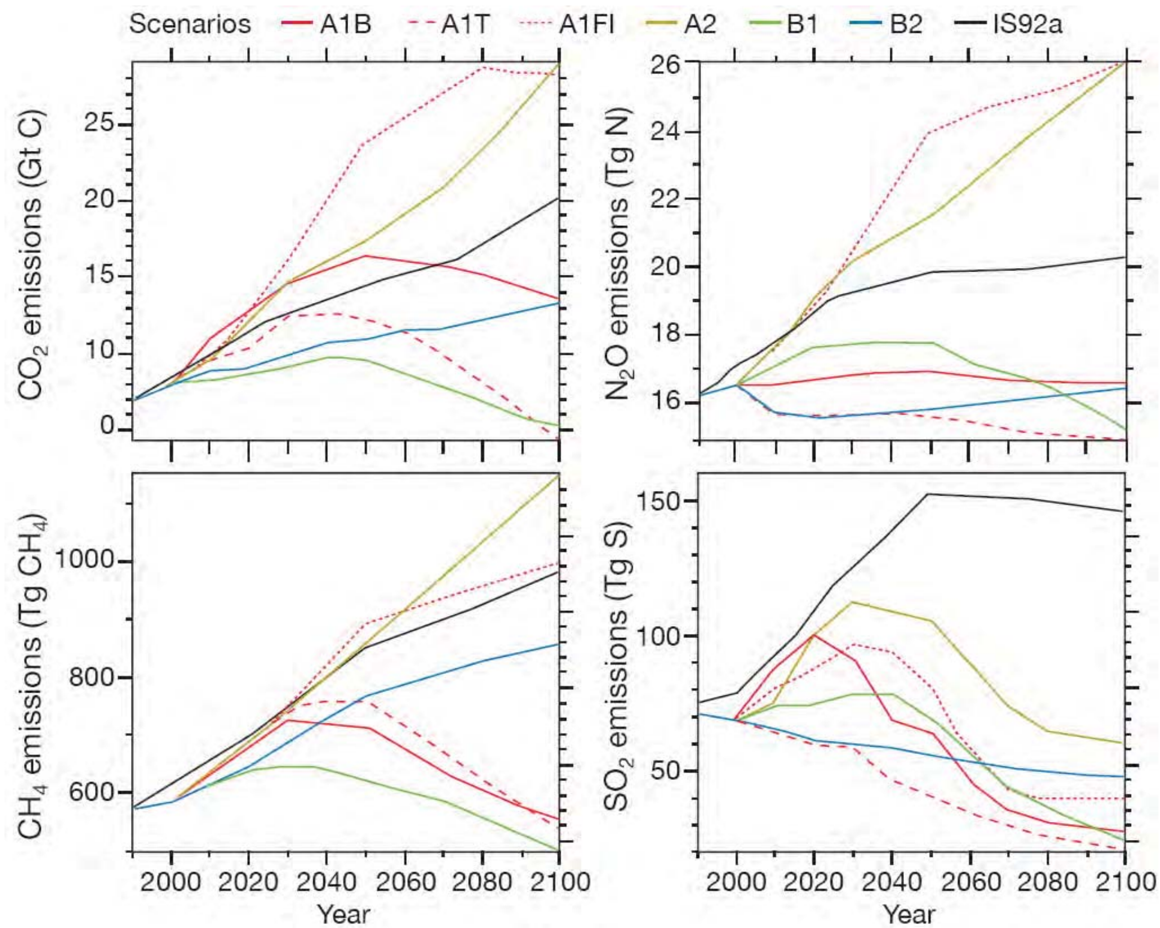

Figure 29. Anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur dioxide (SO_2) for six SRES scenarios (see Box 1) and the IS92a scenario from the IPCC Second Assessment Report in 1996 for comparison [Source: Nakićenović and Swart, 2000].

Future climatic conditions for Pakistan, as projected by an ensemble of 15 global climate models, were drawn from the UNDP's 'Climate Change Country Profiles' for Pakistan. These profiles were funded jointly by the National Communications Support Program (NCSP) and the UK Department for International Development (DfID), and were developed to address the climate change information gap in many developing countries by making use of existing climate data to generate country-level data plots from the most up-to-date multi-model projections. These use a consistent approach for 52 countries to produce an 'off the shelf' analysis of climate data, and also make available the underlying data for each country for use in further research. [http://country-profiles.geog.ox.ac.uk/]

The country profiles include analyses of the following climatic parameters on an annual and seasonal basis:

- Mean temperature
- Mean monthly precipitation
- Indices of extreme daily temperatures:
    - o Frequency of 'Hot' days: The temperature threshold for a 'hot day' in any region or season is defined by the daily maximum temperature which is exceeded on the 10% warmest of days in the standard climate period (1970–99).

    - Frequency of ‘Cold’ days: The temperature threshold for a ‘cold day’ in any region or season is defined by the daily maximum temperature below which the 10% coldest days in the standard climate period (1970–99) fall.
    - Frequency of ‘Hot’ nights: The temperature threshold for a ‘hot night’ in any region or season is defined as the daily minimum temperature which is exceeded on 10% of days in the standard climate period (1970–99).
    - Frequency of ‘Cold’ nights: The temperature threshold for a ‘cold night’ in any region or season is defined by the daily minimum temperature below which the 10% coldest days in the standard climate period (1970–99) fall.
- Indices of extreme daily precipitation:
    - Proportion of total rainfall falling in ‘heavy’ events: A ‘heavy’ rainfall event is defined by daily rainfall amount exceeded by the 5% of heaviest events in a given region or season. The total rainfall which falls in any events which are greater than this fixed threshold is then totalled, and expressed as a percentage of the total monthly rainfall in that season or year. This is then expressed as an anomaly against the total rainfall falling in ‘heavy’ events in the standard climate period (1970–99). Thus, an anomaly value of 4% means that an additional 4% of the total rainfall occurs in ‘heavy’ events, compared with the standard climate period.
    - Maximum 1-day rainfall: The magnitude of the annual maximum daily rainfall in a given period of time (mm). These data are expressed as anomalies from the 1970–99 mean.
    - Maximum 5-day rainfall: The magnitude of the annual maximum 5-day total rainfall in a given period of time (mm). These data are expressed as anomalies from the 1970–99 mean.

Additional documentation on the Climate Change Country profiles is available from http://country-profiles.geog.ox.ac.uk/UNDPCCCP_documentation.pdf

Figure 30 provides an example of the information available through the Climate Change Country profiles. The image shows temperature rise projected on a grid cell basis across Pakistan. The values indicated are the temperature rise projected (by an ensemble of climate models under the A2 scenario) relative to the mean climate of 1970–99. In each grid box, the central value gives the ensemble median, and the values in the upper and lower corners give the ensemble maximum and minimum.

Using the same format, Figure 31 shows the projected change in extreme temperatures for winter (top), summer (middle) and rainy (bottom) seasons in Pakistan. The grids display the projected change in the number of hot days (days when maximum temperatures exceed the current 10th percentile) and hot nights (when minimum, or nighttime, temperatures exceed the current 10th percentile) by the 2060s. The values represent the projected rise (by an ensemble of climate models under the A2 scenario) relative to the mean climate of 1970–99. In each grid box, the central value gives the ensemble median, and the values in the upper and lower corners give the ensemble maximum and minimum.

Finally, Figure 32 shows spatial patterns of projected change in monthly precipitation for two 10-year periods in the future (left column: 2030, middle column: 2060s). The right-hand column shows spatial patterns of projected change in the proportion of precipitation falling in ‘heavy’ (10th percentile) events by the 2060s. As with previous grids, values are the projected percentage changes (by an ensemble of climate models under the A2 scenario) in precipitation relative to the mean climate of 1970–99. In each grid box, the central value gives the ensemble median, and the values in the upper and lower corners give the ensemble maximum and minimum.

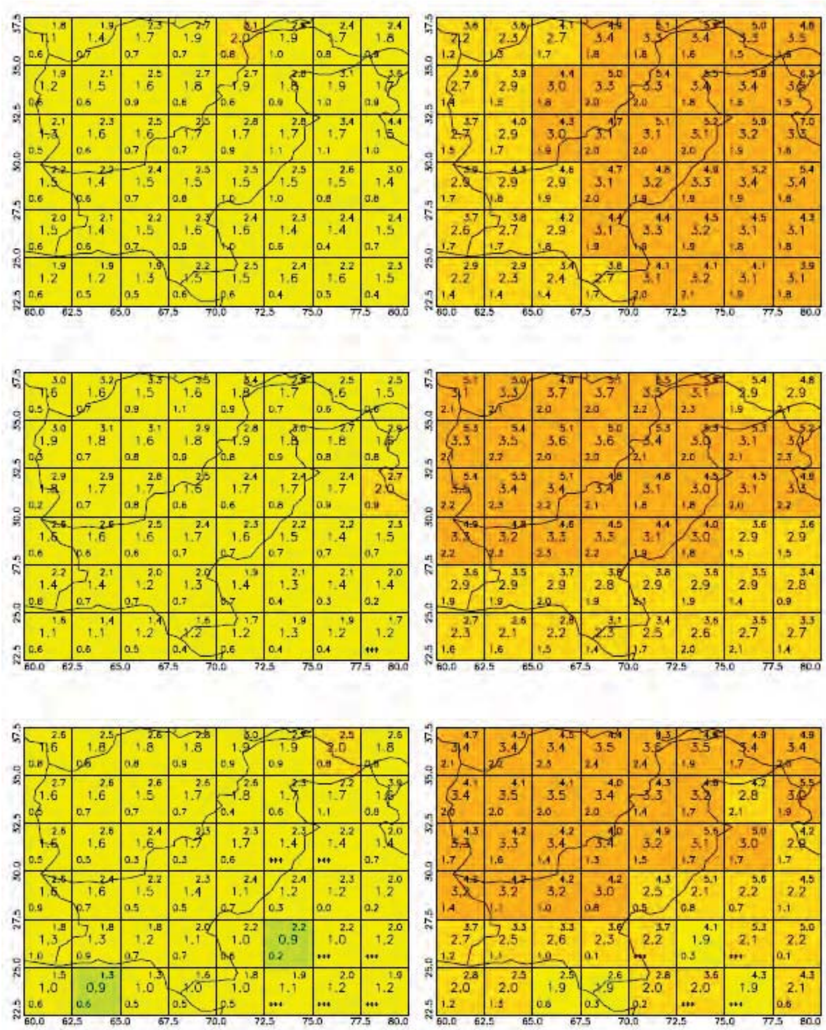

Figure 30. Spatial patterns of projected change in mean seasonal temperature (top: winter, middle: summer, bottom: rainy) for two 10-year periods in the future (left column: 2030s, right column: 2060s), as projected by 15 GCMs under a range of emissions scenarios [Source: Mcsweeney et. al., 2008].

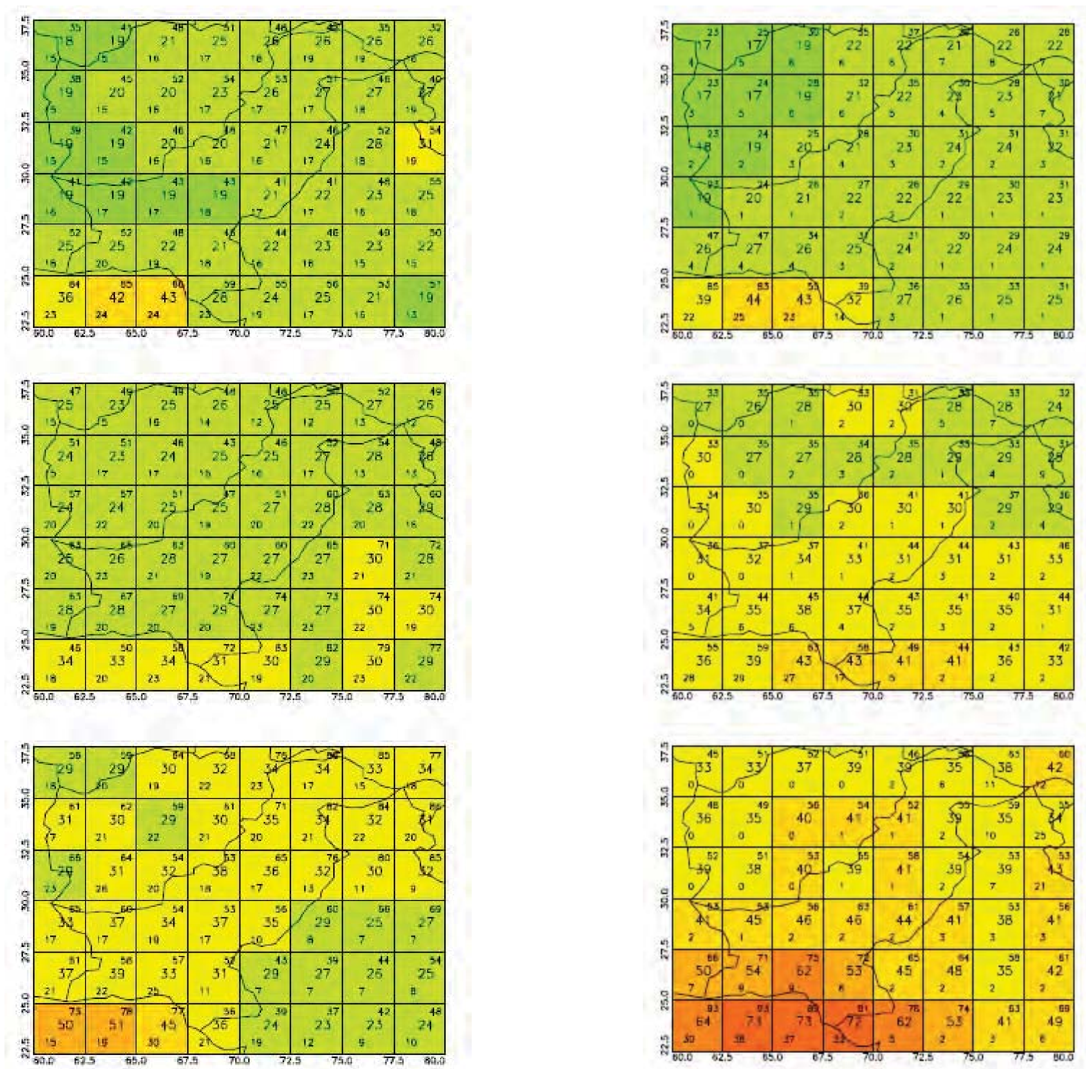

Figure 31. Spatial patterns of projected change in the number of hot days (left) and hot nights (right) by the 2060s, as projected by 15 GCMs under a range of emissions scenarios [Source: Mcsweeney et. al., 2008].

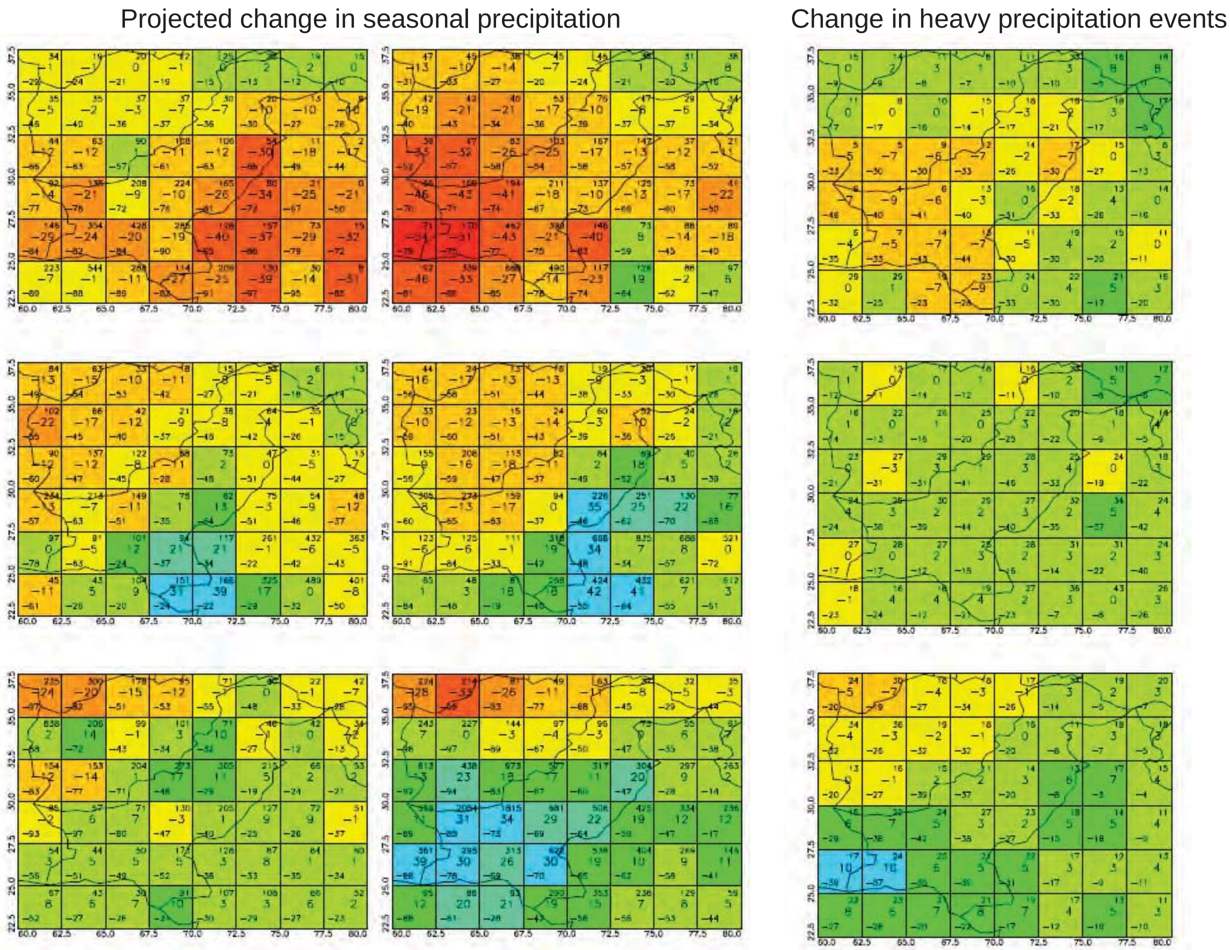

Figure 32. Spatial patterns of projected change in seasonal precipitation for the 2030s (left) and the 2060s (middle column), and in the proportion of precipitation falling in 'heavy' (10th percentile) events by the 2060s (right), as projected by 15 GCMs under a range of emissions scenarios [Source: McSweeney et al, 2008].

References

Nakićenović, N., and R. Swart, eds. (2000) Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

Annex A2 – Wheat Yields

Current Sensitivity of Wheat Yields

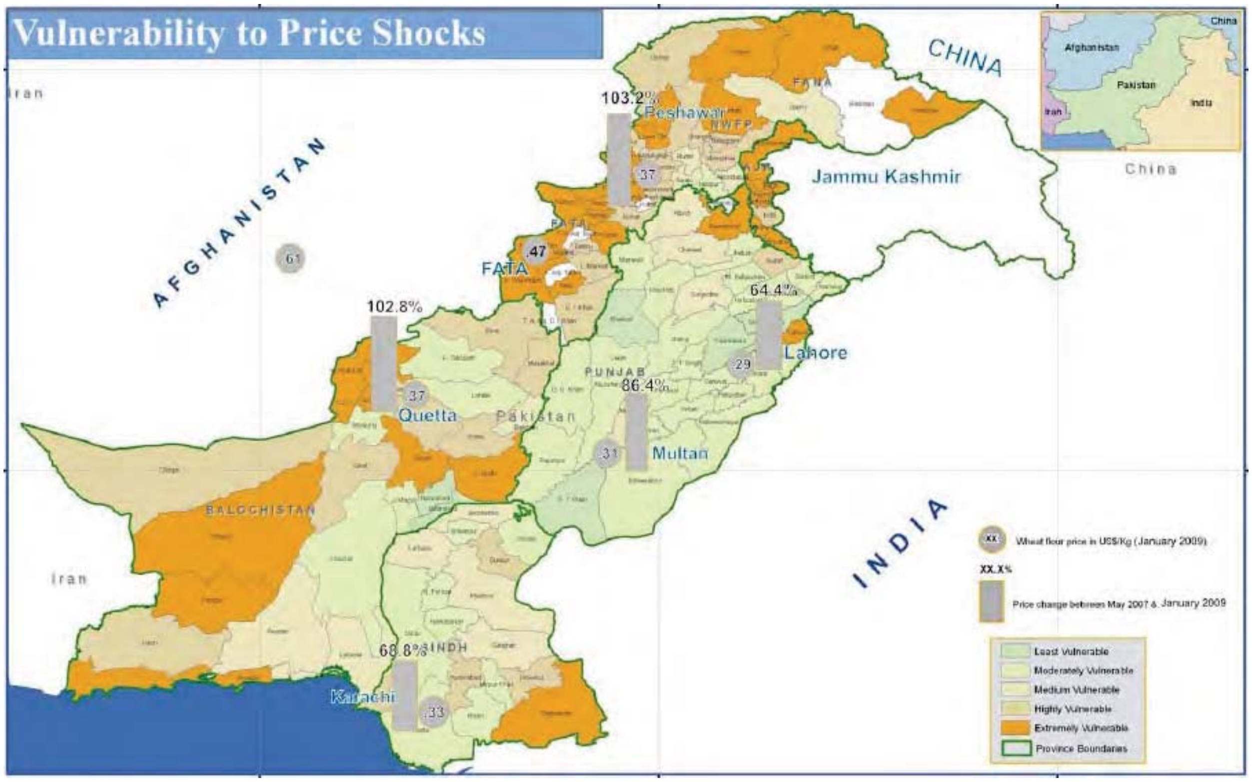

Figure 33. Vulnerability to wheat price shocks across Pakistan [Source: Pakistan Food Security Market Price Monitoring Bulletin, January 2009].

Figure 33 shows vulnerability to wheat price shocks across Pakistan (Solid green lines indicate provincial boundaries, which are further subdivided into *zillahs*, or districts). The grey columns indicate the change in wheat prices between May 2007 and January 2009. While wheat prices in Pakistan have not increased as much as they have elsewhere in the country, prices have nevertheless risen by 64.4% on average across the province in the last two years. The map shading indicates level of vulnerability to price shocks within each district, from green ('least vulnerable') to orange ('extremely vulnerable'). Though Punjab, as a prosperous and wheat-producing province, is relatively well insulated against price shocks, the Lahore is estimated to be extremely vulnerable – presumably as a result of its large urban population. Kasur district (directly below Lahore), is moderately vulnerable. If the wheat producing capacity of Punjab province were constrained by a changing climate, vulnerability to price shocks in the province would rise. As Punjab supplies the other provinces with wheat, a climate-related decrease in crop yield would have negative consequences for the rest of the country.

The following pressures (singly or in combination) can be exacerbated by a changing climate, or can increase sensitivity to climate change:

- soil erosion;
- salinization of irrigated areas;
- dryland degradation from overgrazing;
- over-extraction of ground water,
- forest fires;
- loss of biodiversity;
- increased vulnerability to disease and pests caused by the spread of monocultures,
- erosion of genetic resource base when modern varieties displace traditional ones

Future Vulnerability

The findings of the IPCC's Fourth Assessment Report confirm earlier IPCC Assessments (TAR, 2001), which indicated that "*crop production in (mainly low latitude) developing countries would suffer more, and earlier, than in (mainly mid- to high-latitude) developed countries, due to a combination of adverse agro-climatic, socio-economic and technological conditions*".

Since the IPCC's most recent assessment, several studies have been carried out to investigate the climate risks for food crops in food-insecure regions. Lobell et al used output from 20 general circulation climate models to create crop projections for 12 world regions, including South Asia (Pakistan, India and Bangladesh). In this study, average temperature changes from 1980–2000 to 2020–2040 were roughly 1.0°C in most regions, with few models projecting less than 0.5°C warming in any season and some models warming by as much as 2.0°C. Though each of the models projected a general warming pattern, projections were mixed in the direction of simulated precipitation change. All regions had at least one model with positive and one model with negative projected precipitation changes, with median projections ranging from about –10% to +5%. The crop impact projections are summarized in Figure 34, expressed as production changes for all crops as a percentage of average values for 1998 to 2002. The results for wheat show a very narrow confidence interval of impacts within 5% of zero. This reflects a relatively narrow range of rainfall projections during the growing season. Therefore, we can conclude that the likely impacts of climate change on wheat in this region appear small, given the current data sets and models used to describe crop responses to climate.

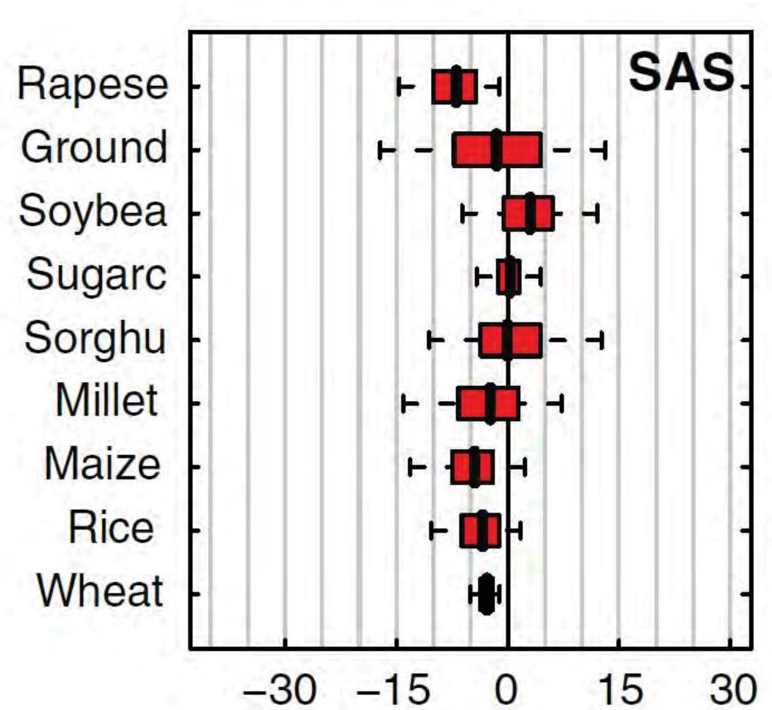

Figure 34. Probabilistic projections of climate change impacts on crop production in South Asia (SAS), which includes Pakistan, India and Bangladesh. Each of these crops is considered highly important to the region's food-insecure human population. Dashed lines extend from 5th to 95th percentile of projections, while boxes extend from 25th to 75th percentile, and the vertical line within each box indicates the median projection [Source: Lobell et al, 2008].

In a second study completed since the IPCC's Fourth Assessment Report, which focused specifically on the Punjab, a crop simulation model (CSM-CERES-Wheat) was used to study the impact of current and future climate change on agricultural production (Amgain et al., 2006). Because wheat requires cool temperatures and a long growing period for its higher yield potential, the analysis looked at both minimum and maximum temperatures. The study also took account of changes in solar radiation and atmospheric CO_2 concentration. The results show reductions in growing season length when temperature rises, regardless of changes in solar radiation or CO_2 concentration. With a rise in temperature alone, wheat yield decreases slightly (by 4%), but the projected increase in solar radiation and CO_2 more than compensates for this, resulting in a very small (2%) increase in overall crop yield. From this study, it would seem that climate change will not have an adverse effect on wheat yields in the Punjab. However, the analysis did not take account of the non-climatic pressures, many of them exacerbated by climate change, that could constrain wheat crop yields.

Change in climatic parameters during simulation	Results, as compared to observed baseline (1999-2003)
Reduction in maximum and minimum temperatures by 4°C	↑ Yield increased by 15% ↑ Growing season increased by 16 days
Reduction in temperatures (as above), plus increase in solar radiation of 1mJ/m^2/day	↑ Yield increased by 22% ↑ Growing season increased by 16 days
Reduction in temperatures and increase in solar radiation (as above), plus increase in CO_2 concentration of 20ppm.	↑ Yield increased by 23% ↑ Growing season increased by 16 days
Increase in maximum and minimum temperatures by 4°C	↓ Yield decreased by 4% ↓ Growing season decreased by 12 days
Increase in temperatures (as above), plus increase in solar radiation of 1mJ/m^2/day	↑ Yield increased by 1% ↓ Growth duration decreased by 10 days
Increase in temperatures and increase in solar radiation (as above), plus increase in CO_2 concentration of 20ppm.	↑ Yield increased by 2% ↓ Growing season decreased by 12 days

Table 5. Sensitivity analysis of wheat with changes in temperature, CO_2 concentration and solar radiation [Source: adapted from Amgain et al., 2006]

Most crop models include only the changes in average climatic conditions, but it is important to recognize that increased climate variability and/or increased frequency and severity of extreme events will also have impacts on crop yield and production. Floods, droughts, storms, fires and pest outbreaks can be devastating for crop yields, and are likely to be more frequent in future.

Annex A3 – Groundwater Resources

Current and Future Vulnerability of Fresh Water Resources

In India, Pakistan and Nepal, water resource problems have been arisen as a result of population growth, industrialization, steady urbanization, and inefficiencies in water use. Climate change impacts on fresh water demand, supply and quality have the potential to exacerbate all of these pressures. In the countries situated in the Brahmaputra–Ganges–Meghna and Indus Basins, water shortages are also attributed to the actions of upstream water users. Seasonal precipitation decline and occasional droughts in delta regions of Pakistan, Bangladesh, India and China have also resulted in drying of wetlands and severe degradation of ecosystems. In arid and semi-arid central and west Asia, changes in climate and its variability are challenging the ability of countries to meet growing demands for water (IPCC, 2007).

Pakistan has three main river basins: the Indus, the Kharan and the Mekran. The Indus Basin, which supplies the Punjab province where Kasur is located, is the largest and the most significant river basin in the context of the Pakistani economy (Nizamani et al., 1998). The Indus River has 2 main tributaries, the Kabul and the Panjnad. The Panjnad is the combined flow of five main rivers (Punjab means 'five waters'): the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej. Though irrigation has been practiced for centuries in arid regions of Pakistan, the vast network of canals and barrages currently employed was developed during the colonial years of the late 1800s. This extensive irrigation system feeds more than 40 million acres of irrigated land, giving Pakistan the highest irrigated and rain-fed land ratio in the world.

Pakistan's National Communication on Climate Change mentions briefly that the effect of climate change on the nation's water resources is expected to be significant, but it does not provide further detail. In semiarid and arid areas vulnerability to water stress is often aggravated by strong population growth and high demand for fresh water. A decrease in the availability of fresh water in these areas will be exacerbated by these other pressures. A growing population and increasing affluence will increase demand for fresh water; changes in land use may also add stress. If precipitation decreases in these areas, or if precipitation is increasingly variable, irrigation water demands (which make up the largest proportion of water use in most semi-arid river basins) would increase, making it more and more difficult – and perhaps impossible in some areas – to satisfy demand for fresh water.

Current and Future Vulnerability of Groundwater Resources

Rates of groundwater recharge vary spatially and temporally, largely in response to changes in precipitation. Groundwater levels tend to be more strongly correlated with precipitation than with temperature, although temperature becomes more significant for shallow aquifers and in very warm periods. In general, surface water systems generally respond more quickly to a changing climate than groundwater systems; although climate-related trends (e.g., reduced stream flow, glacial retreat) have already been observed in some surface water systems over the past decades, climate impacts on groundwater have not yet been detected.

Information on current groundwater recharge and levels in most countries is poor, and this lack of data often makes it impossible to determine whether groundwater states have changed in the recent past due to climate change. Observational data and data access are also necessary for adaptive management. There has been very little research on the future impact of climate change on groundwater, or groundwater–surface water interactions. Given the importance of groundwater systems for many regions, the IPCC has identified lack of data and knowledge about groundwater as a key research gap (Bates et al., 2008).

There are a few notable exceptions, however, where studies have examined the observed or modeled future response of groundwater systems to a changing climate, with very site-specific results. A study on the relation between observed climate variability and groundwater levels in southern Manitoba, Canada, showed that both precipitation and annual mean temperature display a strong correlation with annual groundwater levels in this aquifer, where the correlation with temperature becomes stronger during periods of higher annual mean temperatures (Chen et al., 2003). A second study modeling potential climate impacts on a highly permeable, unconfined aquifer in eastern Massachusetts resulted in either slightly higher, no different, or significantly less annual recharge and groundwater elevations, producing a variety of impacts on wetlands, water supply potential, and low flows (Kirshen, 2002). A third sensitivity analysis for the Grand Forks aquifer in southern British Columbia, Canada, found that variations in recharge to the aquifer under different climate change scenarios have a much smaller impact on the groundwater system than changes in river stage elevation (Allen et al., 2003). A fourth study of the impacts of climate change on groundwater recharge and stream flow in a central European low mountain range shows that effects on mean annual groundwater recharge and stream flow are small. In summer, however, mean monthly groundwater recharge and stream flow are reduced by up to 50% potentially leading to problems concerning water quality, groundwater withdrawals and hydropower generation (Eckhardt et al., 2003). In a study looking at climate change impacts on groundwater resources in a chalky aquifer in the Geer basin, Belgium, modeling results showed that most scenarios result in a decrease in groundwater levels and reserves in relation to variations in climatic conditions (Brouyere et al, 2004). Finally, a new analysis led by MIT researchers has found that changes in groundwater may actually be much greater than changes in precipitation – which could potentially be devastating for semi-arid and arid regions - though the report stresses that exact impacts depend on a complex mix of factors (e.g., soil type, vegetation and the exact timing and duration of rainfall events), and so detailed studies are required to determine the possible range of outcomes at specific locations (Ng et al, 2009).

Figure 35 shows the projected percentage change in long-term average annual groundwater recharge by the 2050s, as compared to the 1961–90 average. Projections for the A2 (medium) emissions scenario are shown in the middle row, and projections for the B2 (low) emissions scenario are shown in the bottom row. The overall pattern of change is very similar for all four simulations. In each case the area of the Punjab where Kasur is located is projected to experience changes in groundwater recharge of between -10 and +30%. As this study did not take account of expected future increase in variability of daily precipitation, projected decreases might be somewhat overestimated.

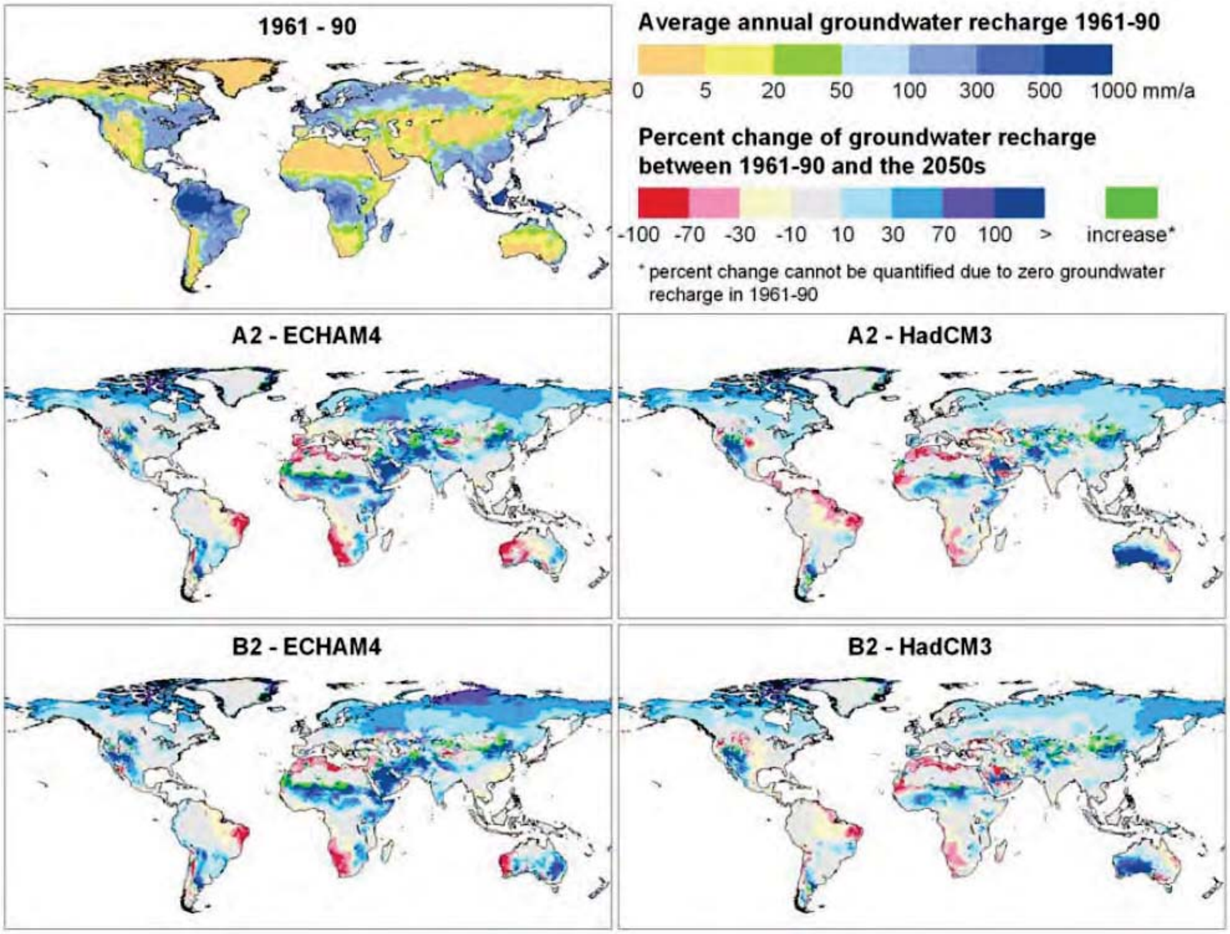

Figure 35. Percentage change in 30-year average groundwater recharge between 1961–90 and 2041–70 (the 2050s), as projected by two global climate models under two different climate change scenarios [Source: Doell and Floerke, 2005].

A single global-scale study has attempted to model world-wide groundwater recharge using models tuned to local data for arid and semi-arid regions (Doell and Floerke, 2005). Figure 36 presents a global map of average country values of computed groundwater recharge from this study, with Pakistan shown to currently receive 20–30mm/year on average (of course this will vary from place to place across the country). Please note the red dots, which indicate the independent local groundwater estimates against which the modeling for this study was tuned. The groundwater recharge modeling conducted for this case study (presented in Chapter 5) indicates that recharge rates for the area around Kasur are closer to 140mm/yr – higher than the Pakistan country average calculated by Doell and Floerke.

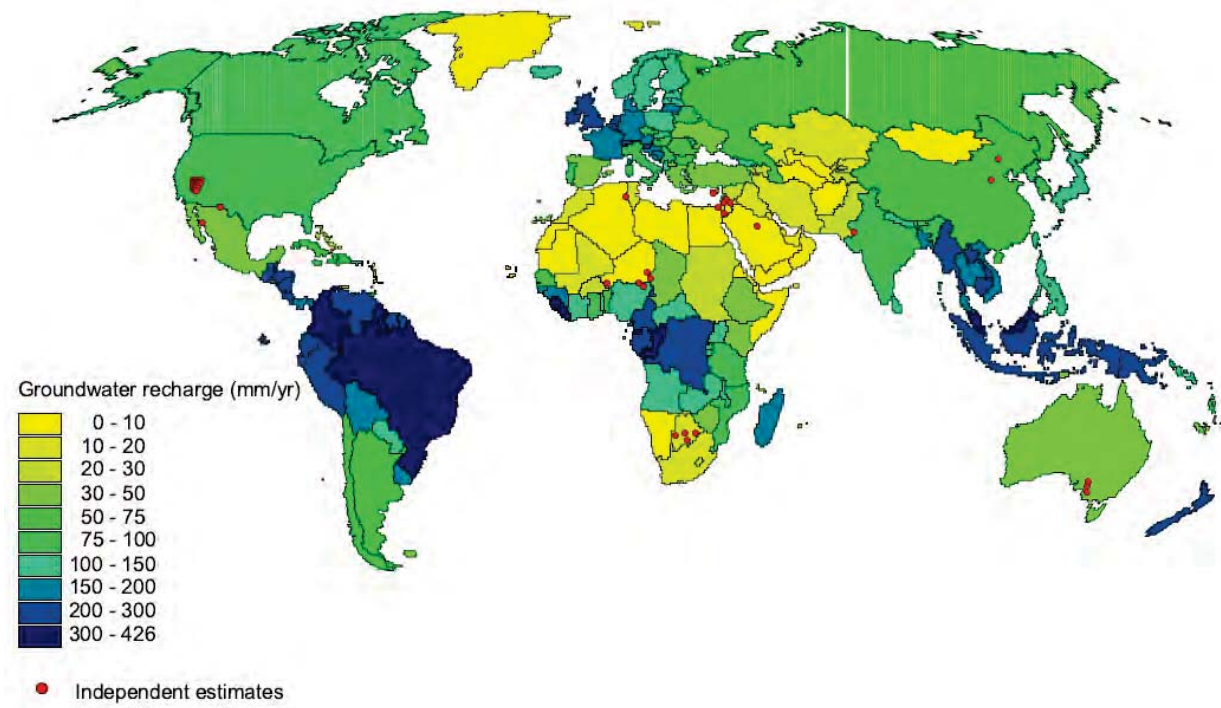

Figure 36. Long-term (1961-90) averages of groundwater recharge, averaged by country area [Source: Doell and Floerke, 2005].

The Indus Basin Irrigation System (IBIS), which is by far the largest irrigation system in Pakistan, covers areas in all provinces, including Punjab, where Kasur is located. In 1993, irrigated areas in the IBIS were estimated at 13 972 500 ha. This system is strongly reliant on groundwater resources. According to Pakistan's classification system, the country's irrigation network consists of:

- Government-owned canals: 11 310 000 ha in 1990, of which 74% in the Punjab;
- private canals: 430 000 ha;
- tubewells: 4 260 000 ha, of which 92% in Punjab province;
- open wells: 280 000 ha, of which 82% in Punjab province;
- tanks: 60 000 ha, all of them in Punjab;
- other means: 620 000 ha (Pakistan Country Profile, 1997).

Clearly any decrease in groundwater resources would have serious consequences for the region around BSPM. The following table provides a brief summary of the projections for groundwater resources, and the impacts associated with depletion of groundwater resources [Source: IPCC, 2007].

With increased evapotranspiration and in areas and seasons of *decreased* precipitation, the impact of climate change could result in declining groundwater levels, which would cause some wells to become dry while others would become less productive due to the loss of available drawdown. Human activities, such as the consumption of groundwater by pumping, could worsen the situation.
Long lasting severe dry weather conditions may even alter hydraulic properties of an aquifer, thus significantly altering recharge rates for major aquifer systems and affecting the sustainable yield of ground water in the region.
Climate change may also affect groundwater quality. For example, a decline in fresh groundwater levels may disrupt the existing balance of the freshwater/saline water boundary in carbonate rock aquifers, resulting in a saline water intrusion.
Increased precipitation variability may decrease groundwater recharge in humid areas because more frequent heavy precipitation events may result in the infiltration capacity of the soil being exceeded more often.
In semi-arid and arid areas increased precipitation variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating.
In areas where water tables are already high, increased recharge might cause problems in towns and agricultural areas through soil salinization and waterlogged soils.
In both developed and developing countries, emissions of organic micro-pollutants to surface waters and groundwater may increase, given that the production and consumption of chemicals, with the exception of a few highly toxic substances, is likely to increase. The projected increase in precipitation intensity is expected to lead to a deterioration of water quality, as it results in the enhanced transport of pathogens and other dissolved pollutants (e.g., pesticides) to surface waters and groundwater; and in increased erosion, which in turn leads to the mobilization of adsorbed pollutants such as phosphorus and heavy metals.
The demand for groundwater is likely to increase in the future, the main reason being increased water use globally. Another reason may be the need to offset declining surface water availability due to increasing precipitation variability in general and reduced summer low flows in snow-dominated basins.
Climate change may lead to vegetation changes which also affect groundwater recharge.
Also, with increased frequency and magnitude of floods, groundwater recharge may increase, in particular in semi-arid and arid areas where heavy rainfalls and floods are the major sources of groundwater recharge.

Groundwater Modeling at BSPM

Packages commissioned a Report on Groundwater Studies for the proposed site of BSPM in November 2005. At this time eight tubewells were planned for construction on site. The study involved:

- electrical resistivity survey at six proposed tubewell locations;
- a review of available data and reports;
- monitoring at neighboring tubewells;
- hydrogeological data analysis on existing water sources; and
- a specific capacity test on a tubewell installed on site 12-year previously.

Based on the results of the resistivity survey and hydrogeological analysis, the depth of the water table on site was determined to vary from 7.6–9.1m. The study identified three distinct zones within the aquifer, each having different prevailing water quality characteristics. Zone 1 extends from 7–20m to 50–165m, is characterized by brackish water and is not useful for industrial or drinking purposes. Zone 2 is nearest the surface and extends to a maximum depth of 4.5–20m; the water quality of this zone is marginal. Zone 3 contains fresh, good quality groundwater. It ranges from 50–165m and extends to the maximum depth of the groundwater investigation (i.e., 300m). The performance study of the existing tubewell indicated that a well field comprising eight tubewells was sensible to install on site. The report recommended that tubewells be drilled to a maximum depth of 225–245m, which would provide a 150% designed capacity.

Packages state that they do not believe their groundwater resources to be vulnerable, based on groundwater monitoring on site. However, we thought it would be useful to test this by developing a groundwater model for the area and perturbing it using the climate change projections, to generate data on projected future groundwater yields. This following analysis provides a quantitative analysis of the impact of changing patterns of precipitation on groundwater resources for Packages.

BSPM Site Hydrogeology

BSPM is located in the northeast of the state of Punjab, bordering India. The state lies in the Indus deltaic plain which runs from the foothills of the Himalaya to the Arabian Sea. The region is bordered by the Ravi River, 40km to the northwest and Sutlej River, 20km to the southeast, in an area called Bari Doab. Due to the Indus Treaty, the Sutlej River often runs dry outside of the monsoon season.

The Punjab plain is underlain by over 300m of unconsolidated alluvium forming a unified highly permeable unconfined aquifer and precipitation is a significant source of recharge (Kidwai and Swarzenski, 1963). There have been a number of published studies around the Punjab region which have attempted to calculate the groundwater recharge (e.g., Ashrafi and Ahmad, 2008; Hassan and Bhutta, 1996; Khan et al. 2008) using sophisticated groundwater models requiring a large amount of field data. Unfortunately, none of these have been conducted in the Bari Doab.

Methodology

There are three main elements to the methodology:

- processing of climate data (precipitation and temperature) to represent the recent past (or baseline between 1970 and 1999) and the future (2000 to 2100)
- translating the monthly/seasonal climate data to daily precipitation and temperature
- feeding the climate information into a groundwater recharge model which calculates recharge from daily precipitation and potential evaporation (PE).

These steps are summarized in Section 5.2.

Details of Groundwater Recharge Formulae

The Amritsar formula was developed in 1973 by Sehgal for the Irrigation and Power Research Institute, Punjab, to estimate the annual natural recharge. This formula was developed using regression analysis for certain doabs in the Punjab (Kommadath, 2000; Kumar, 2004) and is represented by the following expression

$$R = 63.5\left(\frac{P}{25.4} - 16\right)^{1/2} \tag{2}$$

where R is the annual natural recharge (per year), P (per year) is the precipitation and both are measured in inches. The formula has been shown to hold for areas where rainfall is 600–700mm/year which is within the range observed in the Bari Doab. There are obvious caveats to using such statistical relationships which are based on the assumption that the climate is stationary (i.e., that there will be no climate change), and any interpretation of such analysis should be made with caution.

CATCHMOD is a simple water balance model which has previously been set up in a large number of catchments including those that are dominated groundwater processes. It is a conceptual model that divides the catchment into different units according to the soil and land-use type. Two components contribute to the natural recharge: direct percolation and the portion of precipitation which remains after evapotranspiration calculated using the Penman drying curve, details of which can be found in Wilby *et al*. (1994).

Two parameters representing the root constant and the gradient of the soil drying curve are required for the water balance model to determine the actual evaporation. These parameters are usually determined by calibration to observed river flows. In absence of these values, the parameters have been estimated by considering values published in Grindley (1970), Laghari *et al*. (2008), Mishra *et al.* (1997) and de Silva and Rushton (2008), assuming representative soil types from the groundwater survey and vegetation from agricultural statistics published by the Government of Pakistan (Federal Bureau of Statistics, 2009), where for 2006–2007 agricultural areas constituted approximately 83% of the state. These statistics were then used to set up a region representing the Packages site comprising cropped unit, urban unit and a non-cropped shrub unit.

The cropped unit was assumed to be rice-wheat, and a value of 43% was used in this study for the direct percolation for this unit. The urban unit was assumed to cover about 5% of the region, to have no direct percolation and that precipitation evaporates at the potential rate. The remaining 12% of the region was assumed to be shrub with no direct percolation.

Annex A4 – Community and Social Issues

The population of Pakistan currently stands at over 150 million people and is expected to rise to 210 million by 2025, making it the eighth most populous country in the world. Over the last 25 years, Pakistan's urban population has been growing at more than 3% per annum. Urban settlements have grown so quickly that today nearly 30% of Pakistan's population is contained in less than 0.75% of its area. This rapid urban growth has also meant that basic services and infrastructure such as clean water and sanitation have struggled to keep pace. As climate change has the potential to negatively affect rural livelihoods in Pakistan, migration toward urban areas for employment is likely to continue to rise. (Pakistan National Climate Change Communication).

Agriculture is the single largest sector of Pakistan's economy, contributing 24% of GDP, and employing 48.4% of the total workforce. This is followed by manufacturing, which accounts for roughly 17%, and wholesale and retail trade, which contributes 14.9%. Farming in Pakistan is conducted on a small scale: 81% of farms in Pakistan are smaller than 5 hectares.

One of the key sources of water for Pakistan's agricultural sector is the Indus basin, a large network of rivers flowing from the Himalaya Mountains through Indian and Pakistani Punjab to the Arabian Sea. In 1960 India and Pakistan signed the Indus Water Treaty which sets out how the waters of the rivers in the Indus Basin are to be shared. The Treaty confers the exclusive rights of the three eastern rivers (Ravi, Sutlej and Bias) to India and the three western rivers (Indus, Jhelum and Chenab) to Pakistan. The mismatch between the location of Pakistan's water (in the western rivers) and the major irrigated areas in the eastern parts of Pakistan was addressed through the massive Indus Basin Project, under which two large dams (Mangla and Tarbela), several major barrages and inter-river link canals were constructed (see Figure 37 below). The lower mountain ranges in north-eastern Pakistan receive high monsoon rainfall in summer and snow precipitation in winter. The snow and glaciers of the Himalaya range are a major source of water for irrigating crops in the Indus Basin. 97% of water extracted from the Indus Basin is used for agriculture, with just 2% being used for domestic consumption (Agha Ali Akram, Indus Basin Water Resources, January 2009, Tiempo Issue 70). The irrigation System of Pakistani Punjab consists of approximately 23,184 miles of canals and small channels which distribute water from 14 barrages on the main rivers of the Indus Basin and is one of the largest contiguous irrigation systems in the world (Government of Punjab, Irrigation and Power Department).

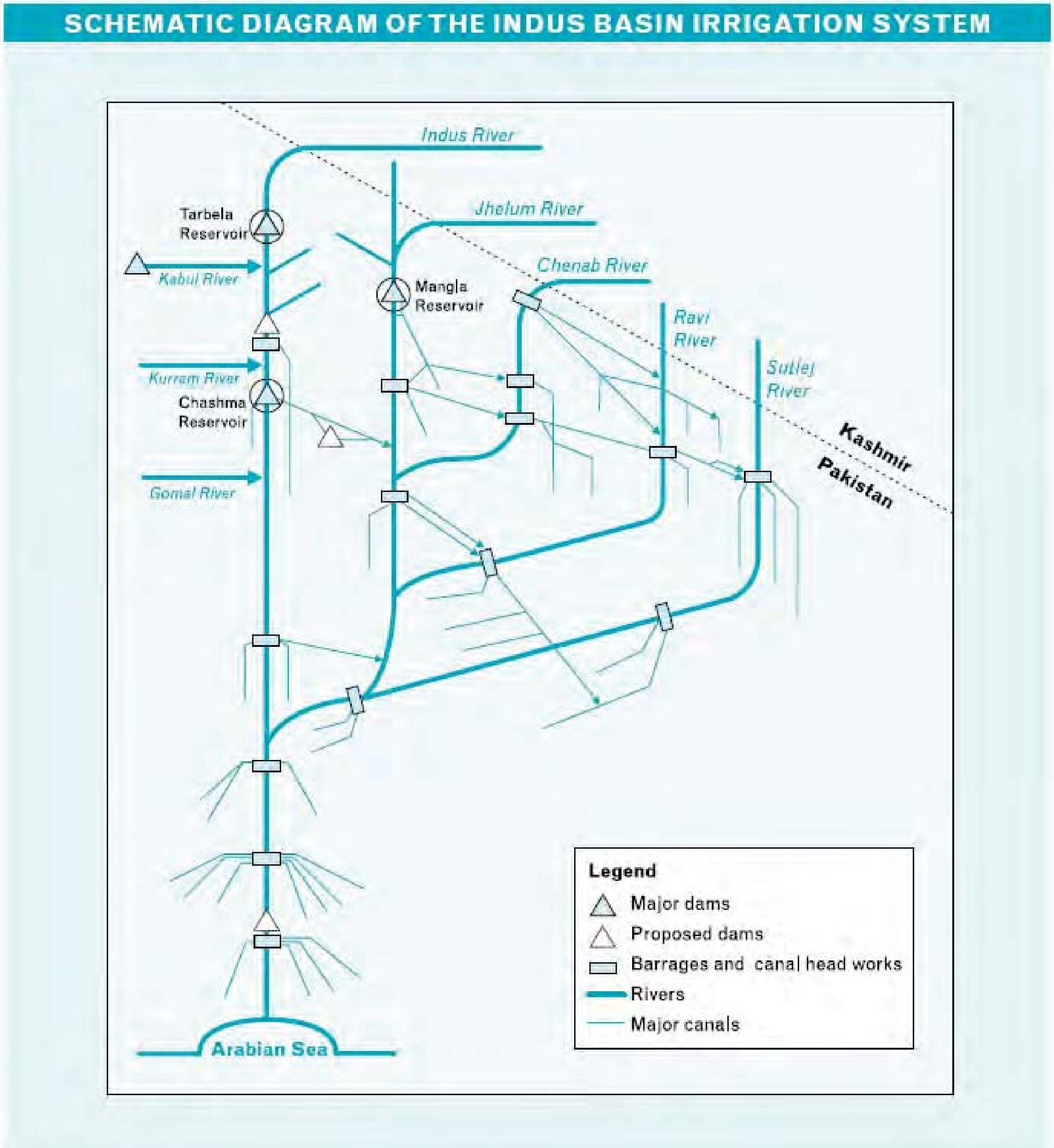

Figure 37 The Indus Basin Irrigation System
Source: Agha Ali Akram, Indus Basin Water Resources, January 2009, Tiempo Issue 70

Agriculture contributes 25% of Punjab's GDP and provides employment to 45% of its work force. Over 90% of the agricultural output comes from irrigated land. Despite this, water is considered to be the major limiting factor to growth in the agricultural sector of the Punjab (Punjab Economic Report 2005). Although the modeled changes to future recharge described in Chapter 5 indicate that groundwater supply (assuming constant demand) at BSPM will not be depleted over the lifetime of the project, the farmers of the Punjab are nevertheless likely to be negatively impacted by climate change. The network of irrigation canals, built in the 1960s, is currently in poor repair. The major challenges to irrigation in the Punjab are related to infrastructure and organization and are as follows:

- deteriorating hydraulic infrastructure– the infrastructure that was build several decades ago has been neglected and requires considerable maintenance for which funding is not available;
- water scarcity has led individuals to sink bore holes of their own which has led to saline intrusion and inefficient extraction of groundwater;
- low water use efficiency and productivity;
- over exploitation and deteriorating quality of groundwater and secondary soil salinization – brackish and poor quality water has been used resulting in the deterioration of soils and reduced yields;
- poor irrigation service delivery and a lack of transparency in water allocations, measurement and deliveries, resulting in inequities in water distribution – irrigation channels are in disrepair, water is siphoned off illegally, rent seeking behavior is involved in water distribution and deliveries; and
- lack of user participation in operation and maintenance.

(World Bank, Program Document on a Proposed Punjab Irrigation Sector Development Policy Loan to the Islamic Republic of Pakistan, April 2005.)

Some areas of Pakistan are also prone to drought. The most recent and the worst experienced for one hundred years affected several districts in the provinces of Sindh and Balochistan during 1999–2000. This drought is estimated to have affected over 3.3 million people and 30 million heads of livestock. (Pakistan National Climate Change Communication, 2003). According to the Pakistan National Climate Change Communication, like most other developing countries, monitoring systems for predicting the likelihood of the occurrence of extreme events, or for assessing possible changes in weather patterns, are not yet sufficiently developed for short term response or disaster mitigation strategies.

Since the Green Revolution of the 1960s in Pakistan agricultural output has grown largely thanks to the increased use of irrigation and pesticides. 80% of the productive land in Punjab is irrigated. However, in recent years productivity has been falling as land has been degraded by the use of poor quality water and continuous cereal mono-cropping. Together, these factors have held back the growth of productivity. (Punjab Economic Report, 2005, World Bank/Government of Punjab). Regular use of pesticides has also resulted in serious pollution and health problems among farmers. Pesticide use increased from less than 1000t in 1980 to 70,000t in 2002—most of which is used in the Punjab. Most pesticide is insecticide and most of this is applied to the cotton crop (Punjab Economic Report).

Pakistan’s status as a developing country dependent mainly on agriculture makes it particularly vulnerable to the effects of climate change. Many of the challenges associated with water described above will be exacerbated by the effects of climate change. Similarly the root of many of the social and developmental challenges described below lies in the lack of availability and access to water.

Studies described in Chapter 4 indicate that, in the near term, climate change is not likely to have an adverse effect on irrigated (i.e., not rain-fed) wheat yields in the Punjab. However, other pressures (many of them exacerbated by a changing climate) have the potential to constrain wheat crop yields. Non-climate pressures include the limited capacity of the irrigation system.

Aggarwal, Lal and others predict that crop yields will decrease by up to 30% in South Asia as a result of climate change. Crop simulation modeling studies undertaken for South Asia using future climate change scenarios indicate likely substantial losses in rain fed wheat yield by up to 0.45 tonnes per hectare.(Lal et al., 1998; Kaira et al., 2003) In other studies undertaken this translated to a 2–5% drop in wheat and maize yields. (Aggarwal, 2003 in Food Security report). These falls in productivity elsewhere may result in greater pressure on agriculture and demand for land in productive regions such as the Punjab, and may encourage migration to the area.

Falling yields in other major crops may adversely impact the incomes of rural households. Over 1.3 million farm households, or 30% of the total reporting establishments, reported having some area under cotton in the 1990 agricultural census and 53% of these were farms up to 3 hectares in size. Similarly, 27% of reporting households had paddy fields, and 57% of such households were those having less than 3 hectares of land (ACO, 1999). Decreased cotton yields may have particularly adverse impacts on the earnings and incomes of rural women in cotton growing areas that are traditionally employed on daily wages to carry out the cotton sowing and picking activities. Livestock are susceptible to new strains of disease, to drought and to flooding.

Pakistan is also susceptible to natural and political events that influence food security. Food security exists when all people, all the time, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO 1996). Food security is based on four determining factors: availability – the quantities of food physically present and available for consumption; access – the ease with which people can gain access to food and eat it, usually determined by price; absorption – the ability of people to absorb nutrients from food, usually determined by their general health and access to clean water; and stability – the extent to which the previous three factors fluctuate or remain constant, usually determined by political unrest or natural disasters. All four of these determining factors are threatened to a greater or lesser extent across Pakistan's provinces.

Wheat is the staple food of Pakistan and plays a significant role in determining the food security status in the country. Wheat production has generally remained behind the national consumption level, except in 2007 when a bumper crop encouraged the government to export large quantities. By the end of the year the country was facing a shortage and forced to buy wheat on the international market at higher prices than it had sold it for earlier in the year (Food Security, Where we are and Where we want to go, SDPD and UNDP, 2009). This meant that food was in short supply, and led to increases in prices and reduced people's access to food. The global increases in food prices during 2008 also contributed to this worsening situation in Pakistan.

The Punjab province is one of the most food secure provinces in Pakistan, and is considered by some as the bread basket of Pakistan. Table 6 shows that two thirds of the districts in Punjab had surplus food production compared with three other provinces which were not producing enough to feed their population.

	Punjab	**Sindh**	**NWFP**	**Balochistan**	**Northern Areas**	**AJK**	**FATA**	**Total**
Extreme Deficit	3	2	17	12	4	7	7	52
High Deficit	1	1	3	5	-	-	-	10
Low Deficit	3	1	3	4	1	-	-	12
Sufficient production	6	2	1	3	-	-	-	12
Surplus Production	21	11	-	2	-	-	-	34
Total districts	34	17	24	26	5	7	7	120

Table 6 Net food availability ranking (per capita per day consumption vs. Production) of rural Pakistan (number of districts)

Source: Food Insecurity Analysis of Rural Pakistan, WFP- SDPI, 2004

Linkages have been made in many parts of the world between climate change, food security and conflict. Climate change could lead to greater competition for natural resources including fertile land, water and wood, all of which are essential for survival. It is also expected to result in population migration, which would place an even greater strain on limited resources. Finally, climate-related extreme events such as floods, cyclones or fires could cause economic shocks and disruption.

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