CHAPTER 1

Extreme Weather and Climate Events, and Farming Risks

John Hay

1.1 Introduction

Extreme weather events, and climatic anomalies, have major impacts on agriculture. Of the total annual crop losses in world agriculture, many are due to direct weather and climatic effects such as drought, flash floods, untimely rains, frost, hail, and storms. High preparedness, prior knowledge of the timing and magnitude of weather events and climatic anomalies and effective recovery plans will do much to reduce their impact on production levels, on land resources and on other assets such as structures and infrastructure and natural ecosystems that are integral to agricultural operations. Aspects of crop and livestock production, as well as agriculture's natural resource base, that are influenced by weather and climatic conditions include air and water pollution; soil erosion from wind or water; the incidence and effects of drought; crop growth; animal production; the incidence and extent of pests and diseases; the incidence, frequency, and extent of frost; the dangers of forest and bush fires; losses during storage and transport; and the safety and effectiveness of all on-farm operations (Mavi and Tupper 2004).

Figure 1.1 illustrates how the climate influences agricultural production – specific climatic conditions, including absence of extremes, are required for optimum production. There are major gaps between the actual and attainable yields of crops, largely attributable to the pests, diseases and weeds, as well as to losses in harvest and storage.

When user-focused weather and climate information are readily available, and used wisely by farmers and others in the agriculture sector, losses resulting from adverse weather and climatic conditions can be minimized, thereby improving the yield and quality of agricultural products. While most emphasis should be placed on preparedness and timely management interventions, there will always be a need for the capacity to recover quickly and minimize the residual damages of adverse events and conditions (Stigter et al. 2003).

This paper focuses on a risk-based approach to managing the detrimental consequences of extreme weather events and climatic anomalies such as those described above. Basic concepts related to risk and to risk management are explained, followed by a discussion of farming risks. Details of risk characterization procedures are provided, along with some practical examples. Given the important consequences of climate change for agriculture, attention is given to projection of risk levels into the future. Again some practical examples are provided. Finally, relevant aspects of risk management are discussed. Overall conclusions are also presented.

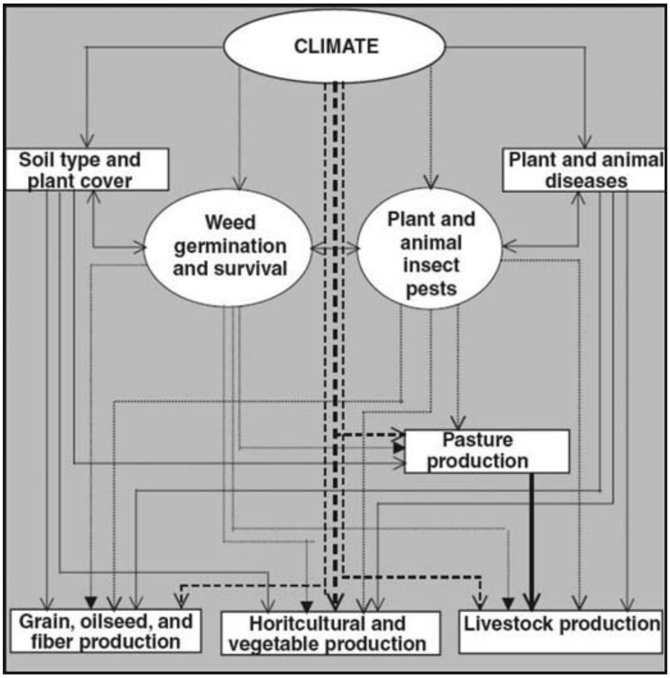


Fig. 1.1. The role of climate in agricultural production (from Mavi and Tupper 2004).

Why a risk-based approach? In recent decades there have been major advances in short-term and seasonal weather forecasting, as well as in long-term climate modelling. These have yielded major improvements in early warnings and advisories as well as in longer-term planning. This is resulting in increasing emphasis on proactive rather than reactive management of the adverse consequences of extreme weather events and anomalous climatic conditions on agriculture. It is also increasing the diversity of options available to farmers and others in the agriculture sector to manage those impacts. Increasingly, farm managers and other practitioners are seeking more rational and quantitative guidance for decision making, including cost benefit analyses. As will be demonstrated in the following sections, a risk-based approach to managing the adverse consequences of weather extremes and climate anomalies for agriculture goes a long way towards meeting these requirements. It also provides a direct functional link between, on the one hand, assessing exposure to the adverse consequences of extreme weather and anomalous climatic conditions and, on the other, the identification, prioritization and retrospective evaluation of management interventions designed to reduce anticipated consequences to tolerable levels.

Finally, risk assessment and management procedures have already been embraced by many sectors in addition to agriculture – e.g. health, financial, transport, energy, and water resources. As will be shown in the following section, a risk-based approach provides a common framework that facilitates coordination and cooperation amongst various players and stakeholders, including the sharing of information that might otherwise be retained by information "gate keepers".

1.2 Risk and Risk Management – Some Basic Concepts

Risk considers not only the potential level of harm arising from an event or condition, but also the likelihood that such harm will occur. In the present context, risk events include weather-related hazards such as extreme daily rainfall and frost. Risk conditions are climate-related and include hazards such as droughts and heat waves. Risk levels can change, including as a result of potentially detrimental changes in the climate (e.g. warming, decreasing rainfall). Changes in levels of exposure, due to altering levels of investment, can also influence risk levels. As defined above, risk combines both the likelihood of a harm occurring and the consequences of it doing so. Thus, in risk terms, an unlikely hazard or condition causing considerable harm (e.g. a category 5 hurricane, such the cyclone in the state of Orissa that devastated parts of India in 1999), may be compared to a hazard or condition which causes less harm but has a higher probability of occurring (e.g. a seasonal drought). By way of illustration, Figure 1.2 shows the likelihood of given extreme daily rainfall amounts for Delhi, India. A relatively common daily rainfall of, say, 30 mm will obviously result in far less devastation than the maximum observed daily rainfall of 192 mm.

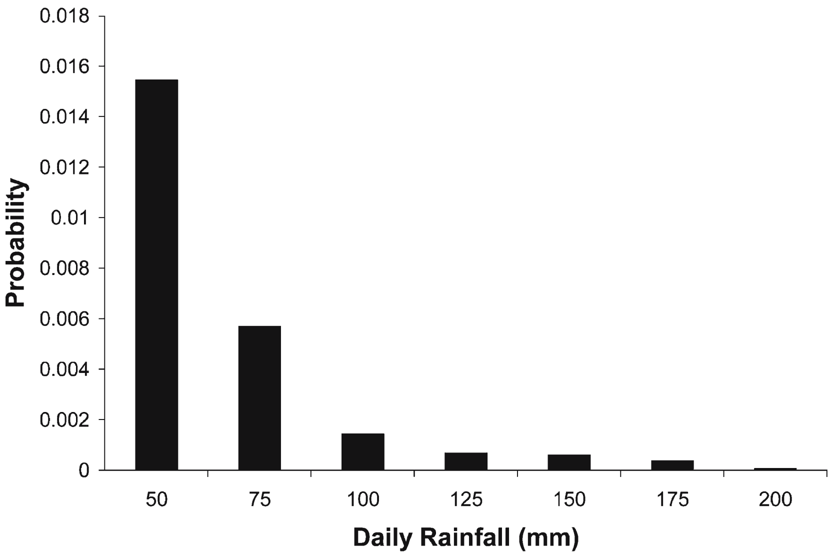


Fig. 1.2. Probability of a daily rainfall (mm) in 25 mm bands up to the given amount. Based on 1969 to 2004 data for Delhi, India. Data courtesy of India Meteorological Department.Ebunte

Harm may be expressed in many ways, such as loss of production in tonnes or number of livestock fatalities. Where the harm can be due to several different causes, use of the same units to describe the harm makes it possible to combine the different categories of risk. The result is the total risk. Thus:

$$\textit{Total risk} = \Sigma_i\,(\textit{Likelihood}_i * \textit{Harm}_i)$$

There is a well established approach to characterizing and managing risks (Figure 1.3). As noted above, the risk-based methodology makes explicit the link between weather- and climate-related risks and the actions required to reduce them to acceptable levels. The widely-used procedures for characterizing and managing risk provide the basis for procedures which relate more specifically to characterizing and managing weather- and climate-related risks of relevance to the agriculture sector (Figure 1.4).

1.2.1 Step A – Risk Scoping

Through a consultative process, involving stakeholders as well as relevant experts, as required, risk reduction targets and criteria are established. These are based on identifying acceptable levels of risk. Existing information sources, experience and expert judgment are used, as appropriate, to identify possible weather- and climate-related risk events and conditions. These in turn lead to identification of the associated sources of stress and the components ("receptors") of the agricultural system on which the stresses act. The pathways for these interactions are also identified.

1.2.2 Step B – Risk Characterization and Evaluation

For each of the risk events identified in 1.2.1 above, scenarios are developed in order to provide a basis for estimating the likelihood of each risk event, for present conditions and into the future if change is anticipated, for example as a consequence of climate change. The extent to which the climate changes into the future will influence the probability of the risk event occurring. The consequences of a given risk event are quantified in terms of individual and annualized costs. The overall findings are compiled into a risk profile.

1.2.3 Step C – Risk Management

In this step a number of questions are asked – all are with reference to the targets agreed in 1.2.1 above. Actions taken depend on the responses to a series of questions.

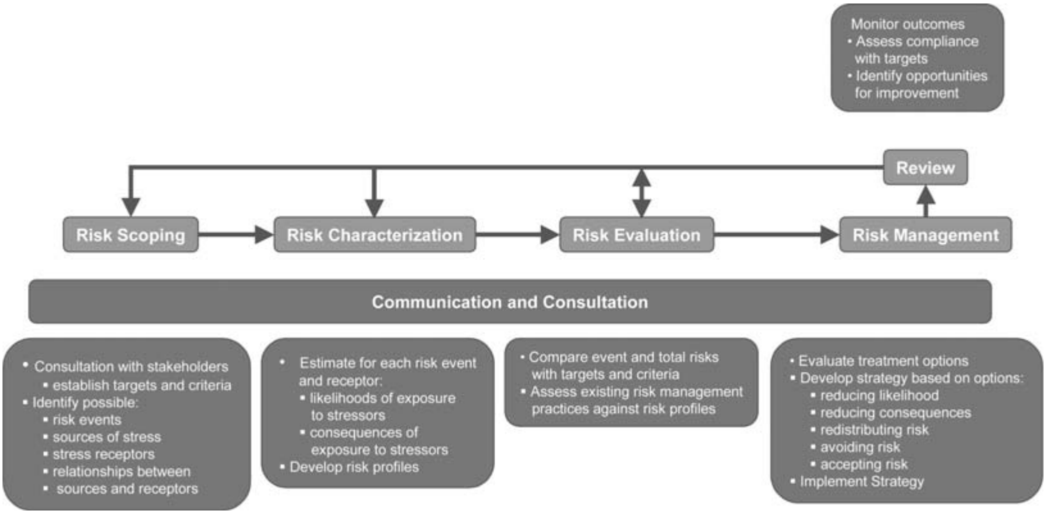


Fig. 1.3. Generic methodology for characterizing and managing risks.

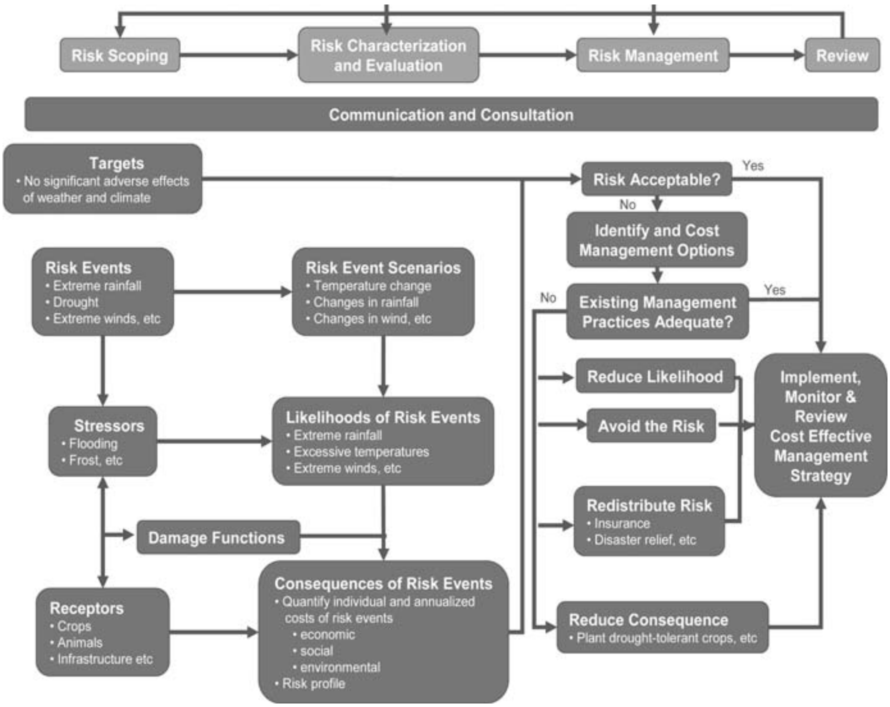


Fig. 1.4. Procedures for characterizing and managing risks, and their application to the agriculture sector.

Is the risk acceptable? – If "yes", it is appropriate to continue with current management approaches. These should include monitoring and reviewing as the acceptability of the risk may change over time into the future. If "no", risk management options are identified, and assessed in terms of costs and benefits.

Are the current risk management options adequate? – If "yes", it is appropriate to continue with the current approaches. Again, these include monitoring and reviewing, in part due to the possibility that the acceptability of the risk may change over time. If "no", one or more of the following risk management strategies should be implemented:

- Take actions to reduce the likelihood of the risk event occurring. For example, reduce greenhouse gas emissions by the agriculture sector and thereby reduce the rate of climate change and the resulting increased frequency of risk events such as drought and frosts.
- Avoid the risk. For example, avoid planting crops in areas that are exposed to risk events of concern.
- Redistribute the risk. For example, provide access to crop insurance cover or ensure disaster relief programmes are in place.
- Reduce the consequences. For example, plant drought tolerant crops if drought is a risk event of concern.

1.2.4 Step D – Monitoring and Review

The next step is to implement the risk management programme, and monitor and review the risk management outcomes in relation to the agreed targets. If the targets are not met it will be necessary to repeat one or more of the following steps: i) identify the problem and formulate a response plan; ii) enhance the quality of the risk characterization procedures and findings; and iii) enhance the quality of the risk management procedures and outcomes.

The process of risk characterization and management is iterative, to ensure that the quality of the outcomes are always consistent with the risk reduction targets that are established, reviewed, revised and reaffirmed through consultative processes.

1.3 Farming Risks

In both the developing and developed worlds risk exposure and management are important aspects of farming. Variations in the weather, climate, yields, prices, government policies, global markets and other factors can cause wide swings in farm production and, in the case of commercial agriculture, in farm income. Risk management involves choosing among strategies that reduce the social and financial consequences of these variations in production and income.

Five general types of risk in the agriculture sector are recognized (USDA 2006a):

- **Production risk** derives from the uncertain natural growth processes of crops and livestock. Weather, disease, pests, and other factors affect both the quantity and quality of commodities produced;
- **Price or market risk** refers to uncertainty about the prices producers will receive for commodities or the prices they must pay for inputs. The nature of price risk varies significantly from commodity to commodity;
- **Financial risk** results when the farm business borrows money and creates an obligation to repay debt. Rising interest rates, the prospect of loans being called by lenders, and restricted credit availability are also aspects of financial risk;
- **Institutional risk** results from uncertainties surrounding government actions. Tax laws, regulations for chemical use, rules for animal waste disposal, and the level of price or income support payments are examples of government decisions that can have a major impact on the farm business; and
- **Human or personal risk** refers to factors such as problems with human health or personal relationships that can affect the farm business. Accidents, illness, death, and divorce are examples of personal crises that can threaten a farm business.

This paper focuses on production risks, and specifically the way extreme weather events and anomalous climate conditions contribute to production risk. In this context, production risk is the risk associated with undesirable and often unanticipated weather and climatic conditions that affect the performance of crops and livestock. The relationships between weather, climate and production risk are well recognised (George et al. 2005). Some examples should suffice to illustrate the strength and importance of these relationships.

Climate-based models have been used to predict the potential for soybean rust spore production in the southern USA. This makes it possible to define regions where the climate is more favourable for rust to develop, expressed as the frequency of years a higher production of spores would be likely (Del Ponte and Yang 2006).

Figure 1.5 shows the likelihood that soybean rust in Texas, USA, will reach a severity of over 20 percent by late June if the rust is found in late May.

Figure 1.6 shows the strong influence of rainfall on cereal production in Niger.

Figure 1.7 shows drought risk for Gujarat, which is situated on the western coast of India. The drought risk map was obtained by integrating risk maps for both agricultural and meteorological drought. High drought risk prevails in nearly 30% of the area. This comprises districts that are major producers of food grains as well as oilseeds, emphasizing a critical need for drought management plans in these districts (Chopra 2006).

Figure 1.8 shows how anomalous climatic conditions in India influence food production.

1.4 Risk Characterization

As shown in Figure 1.3, risk characterization is an important step in the overall process of risk management. This section describes the methodology and pro-

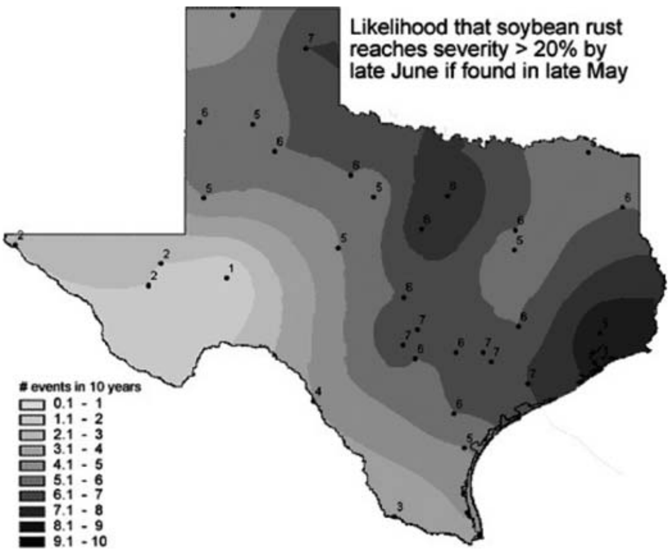


Fig. 1.5. Likelihood that soybean rust will reach a severity of over 20 percent by late June if found in late May (from Del Ponte and Yang 2006).

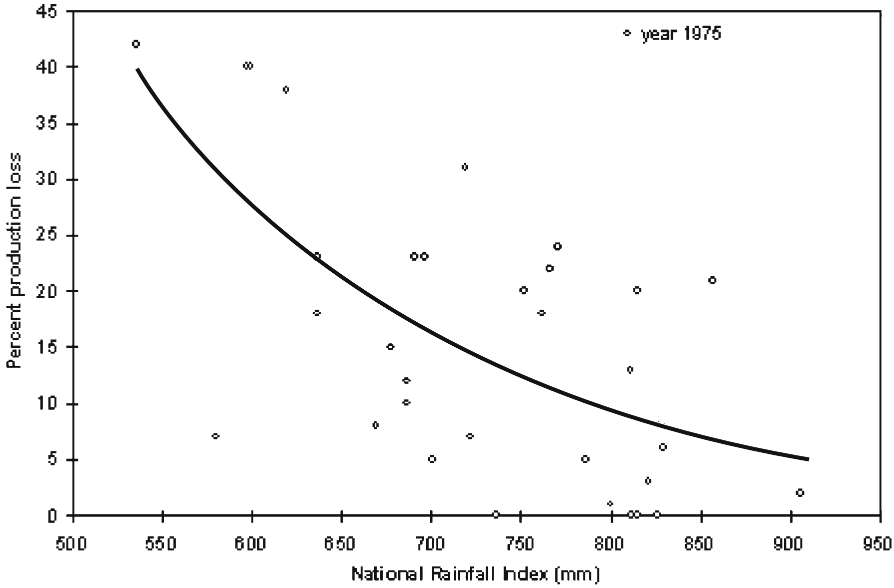


Fig. 1.6. Percent decrease in total cereal production for Niger as a function of the National Rainfall Index (Gommes 1998).

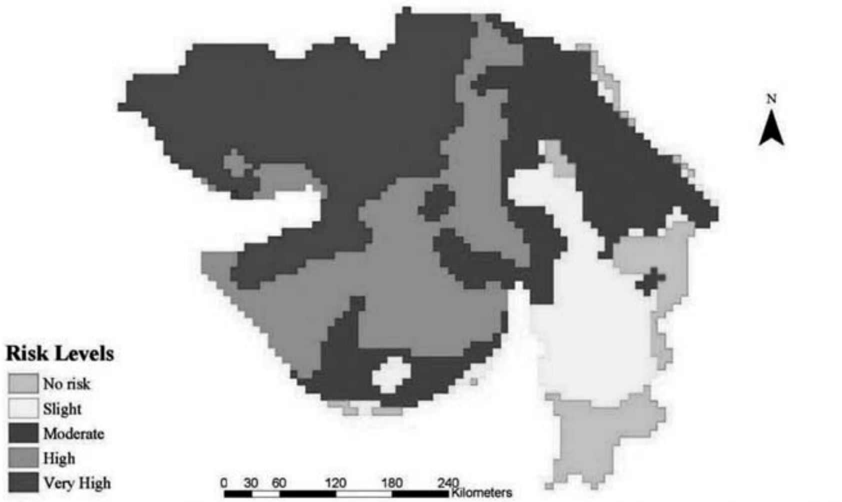


Fig. 1.7. Drought risk for Gujarat, India, determined by integrating risk maps for both agricultural and meteorological drought (Chopra 2006).

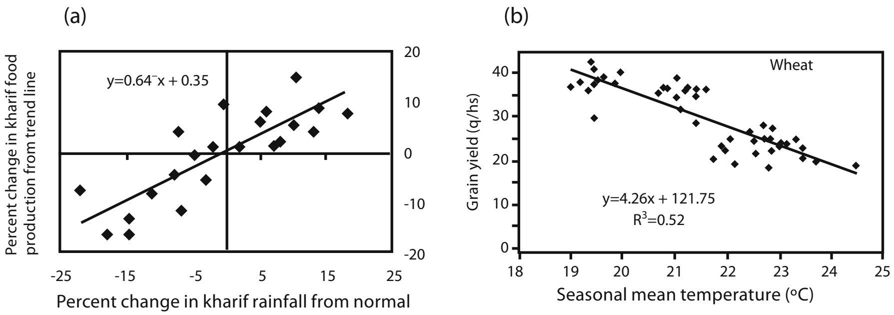


Fig. 1.8. Relationship between (a) monsoon season food production and seasonal rainfall and (b) regional wheat yields with seasonal temperature (Government of India 2004).

vides some illustrative results for characterizing levels of risk associated with both weather extremes and climate anomalies.

1.4.1 Weather Extremes

The *return period* (also know as the *recurrence interval* of an event) is a statistical measure of how often an extreme event of a given magnitude is likely to be equalled or exceeded, within a given time frame. For example, a "fifty-year rainfall event" is one which will, on the average, be equalled or exceeded once in any fifty-year period. Note: it does not mean that the event occurs every fifty years.

The likelihood or probability that an event of specific magnitude will be equalled or exceeded in any given year is the inverse of the return period, that is, 1 / Return Period

A one in fifty-year event has one chance in fifty of occurring in any specified year, that is, its probability is 1/50. Thus the probability equals 0.02, or 2%.

In some cases it is useful to know the probability that an event of at least a given magnitude will occur within a specified number of years, say five years. This probability can be calculated using the following equation:

probability of occurrence in n years = 1 –
(1 – probability of occurrence in any year)^n

For example, the probability that an event with a probability of 0.2 will occur in the next five years is:

$1 - (1\text{-}0.2)^5 = 0.67$

Note again that this probability applies only on average, and cannot be considered a forecast.

Table 1.1 provides return periods and probabilities for given extremes in daily rainfall, based on observed data for Delhi and Pune, India. It is clear that extreme rainfall events of a given magnitude at Delhi are substantially more frequent than those observed in Pune.

Similarly, return periods and probabilities for specified values of maximum air temperature and extreme wind speeds are given in Tables 1.2 and 1.3, respectively. The results show that both extreme high temperatures and extreme wind gusts are much more common at Delhi, relative to Pune.

Table 1.1. Return Periods for Daily Rainfalls of Given Amounts, for Delhi and Pune, India. Based on Data for 1969 to 2004, inclusive. [Data courtesy of India Meteorological Department]

Daily Rainfall of at Least (mm)	Delhi		Pune	
	Return Period (y)	Probability	Return Period (y)	Probability
50	1.1	0.94	1.2	0.80
75	1.3	0.75	2.3	0.40
100	2.0	0.49	5.8	0.20
125	3.6	0.28	16	0.06
150	6.9	0.14	48	0.02
175	14	0.07	140	0.01
200	28	0.04	>400	0.00

Table 1.2. Return Periods for Maximum Temperatures of Given Amounts, for Delhi and Pune, India. Based on Data for 1969 to 2004, inclusive. [Data courtesy of India Meteorological Department]

Maximum Temperature of at Least (°C)	Delhi		Pune	
	Return Period (y)	Probability	Return Period (y)	Probability
41	1	1	1.6	0.61
42	1	0.99	6.2	0.16
43	1.2	0.86	31	0.03
44	1.9	0.53	160	0.01
45	4.0	0.25	>800	0.0
46	9.7	0.10		
47	25	0.04		

Table 1.3. Return Periods for Maximum Annual Wind Gusts of Given Amounts, for Delhi and Pune, India. Based on Data for 1969 to 2004, inclusive. [Data courtesy of India Meteorological Department]

Daily Annual Wind Gust of at Least (km h^{-1})	Delhi		Pune	
	Return Period (y)	Probability	Return Period (y)	Probability
50	1	1	1.1	0.90
75	1.1	0.92	2.2	0.46
100	2.4	0.42	6.6	0.15
125	9.1	0.11	23	0.04
150	41	0.02	83	0.01

1.4.2
Climate Anomalies

Drought has a major impact on agricultural production, making it an important risk condition. Figure 1.9 shows the frequency of drought for Delhi, where in this instance drought is defined as months when the rainfall is at or below the ten-percentile for that month. It is clear that, based on this indicator, there is a high risk of at least a brief drought occurring in any given year. The risk of a prolonged drought is also very real.

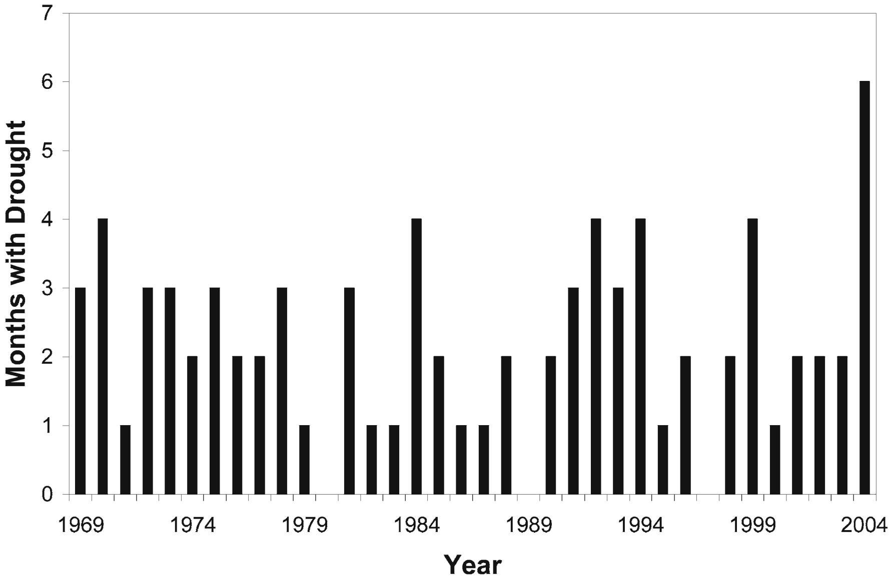


Fig. 1.9. The frequency of drought for Delhi, India, for 1969 – 2004. Drought is defined here as a month when the rainfall is at or below the ten-percentile for that month. Data courtesy of India Meteorological Department.

1.5 Changing Risk

Agriculture is one of the main sectors likely to be impacted by climate change. This section presents the results of analyses designed to show how risk levels for rainfall and temperature extremes, and drought, are projected to change over the remainder of the current century. One such change of importance to India is illustrated in Figure 1.10. A substantial increase in drought risk is expected during the current century. One consequence is a major decline in irrigated wheat yields in northern India during the coming decades (Figure 1.11). Clearly, and as would be expected, as the time horizon increases the confidence in the projections decreases.

Future changes in risk are estimated using the outputs of selected global climate models (GCMs)[1] run for a range of greenhouse gas emission scenarios (Figure 1.12). Table 1.4 lists the combination of models and emission scenarios on which the risk projections are based.

Differences in climate projections give rise to uncertainties in the estimated values of future climate risks. There are numerous sources of uncertainty in projections of the likelihood components of climate-related risks. These include uncertainties in greenhouse gas emissions as well as in modelling the complex interactions and responses of the atmospheric and ocean systems. Policy and decision makers need to be cognizant of uncertainties in projections of the likelihood components of extreme events.

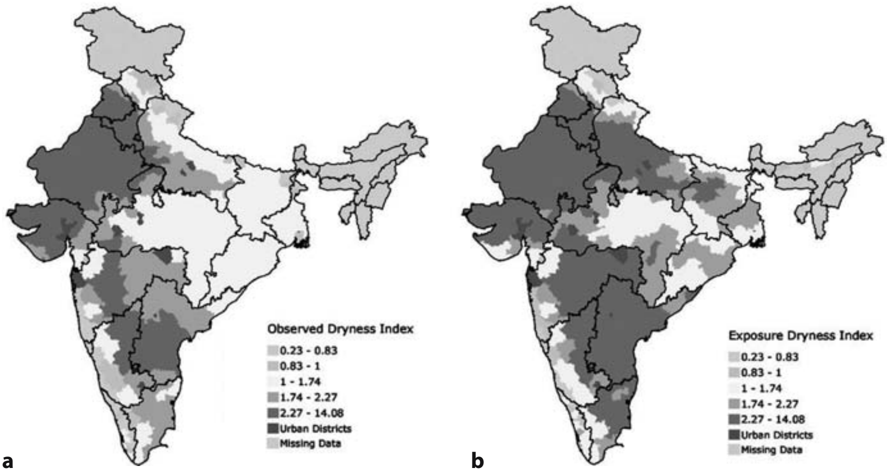
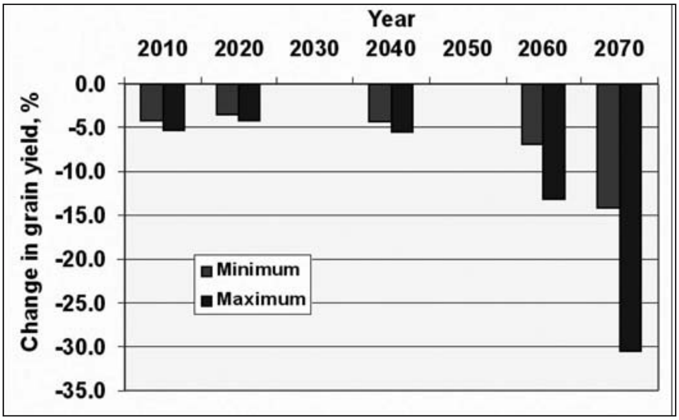


Fig. 1.10. Areas in India prone to drought (a) today and (b) in the mid 21st century, determined using a dryness index. The light shading indicates areas where rain exceeds evaporation. The darker shading identifies regions where evaporation is greater than precipitation – the darker the shading the drier the region, except that urban areas have the darkest shading (Schreiner 2004).

Fig. 1.11. Simulated impact of global climate change on irrigated wheat yields in North India (Aggarwal 2002).



Best estimates of future risk levels are based on an average of the estimates using a multi model and emission scenario ensemble. The range in uncertainty is determined using a model and emission scenario combination that produces the maximum and minimum rate of change in future risk levels.

Projected changes in the return periods of extreme daily rainfall events (Figure 1.13) are based on estimates using a multi model and emission scenario ensemble (see Table 1.4). It is anticipated that global warming will reduce the return periods

Table 1.4. Available Combinations of Global Climate Models and Emission Scenarios[1]

	CGCM	CSIRO	Hadley	NIES	GFDL	See Text
A1B	T, P[1]	T, P	T, P	T, P	S	W[1]
A1F	T, P	T, P	T, P	T, P	S	W
A1T	T, P, S	T, P, S	T, P, S	T, P	S	W
A2	T, P, S	T, P, S	T, P, S	T, P	S	W
B1	T, P, S	T, P, S	T, P, S	T, P	S	W
B2	T, P, S	T, P, S	T, P, S	T, P	S	W

[1] T = temperature, P = precipitation, W = wind

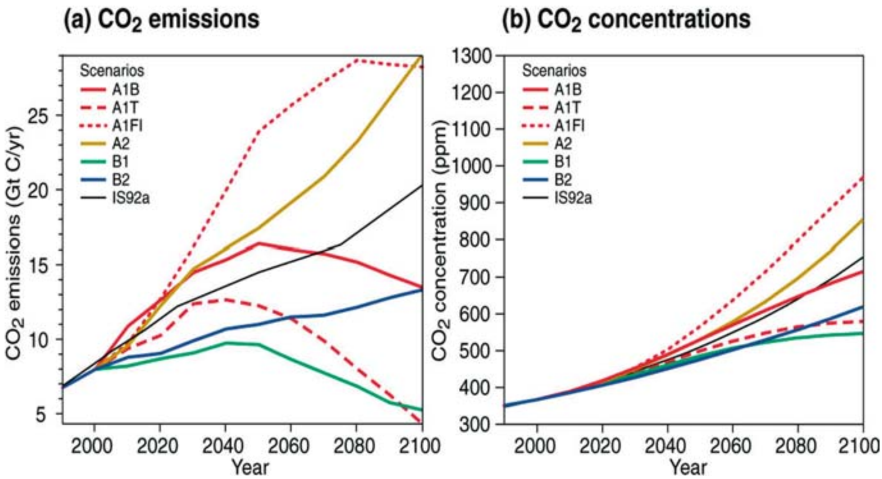


Fig. 1.12. Scenarios of CO_2 gas emissions and consequential atmospheric concentrations of CO_2 (from IPCC 2001).

of extreme daily rainfall events for Delhi – that is, the likelihood of such extreme events will increase in the future.

Projected changes in the return periods of extreme maximum temperature (Figure 1.14) are based on estimates using a multi model and emission scenario ensemble (see Table 1.4). It is anticipated that global warming will also reduce the return periods of extreme maximum temperatures for Delhi.

Estimates of changes in maximum wind gusts are based on the assumption that such wind gusts will increase by 2.5, 5 and 10 per cent per degree of global warming. Thus the emission scenarios listed in Table 1.4 are explicitly included in the estimates. The best estimate of the increase in maximum wind gusts is determined

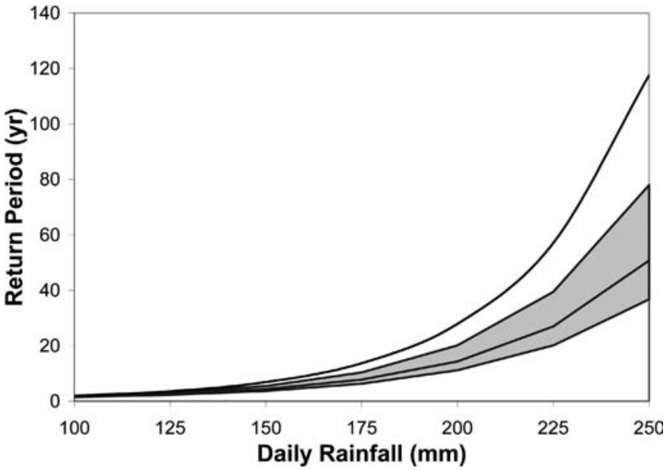


Fig. 1.13. Relationship between daily rainfall and return period for Delhi, India, for present day (black line) and 2050 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2050, based on all possible combinations of the available global climate models and emission scenarios.

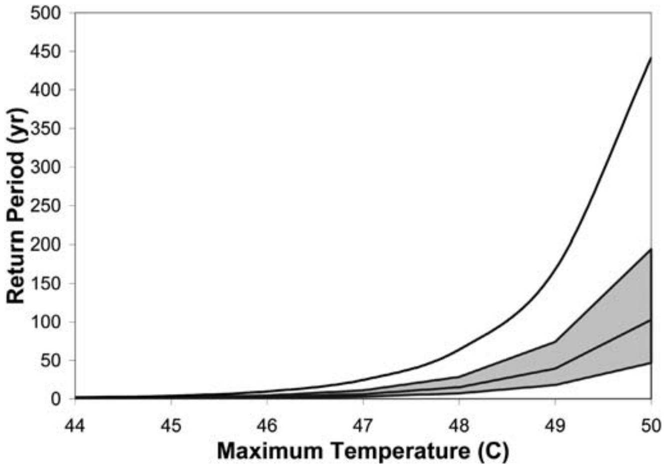


Fig. 1.14. Relationship between maximum temperature and return period for Delhi, India, for present day (black line) and 2050 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2050, based on all possible combinations of the available global climate models and emission scenarios.

by averaging the ensemble of estimates for all combinations of percentage increase and emission scenarios. As indicated in Figure 1.15, global warming will likely reduce the return periods of maximum wind gusts for Delhi.

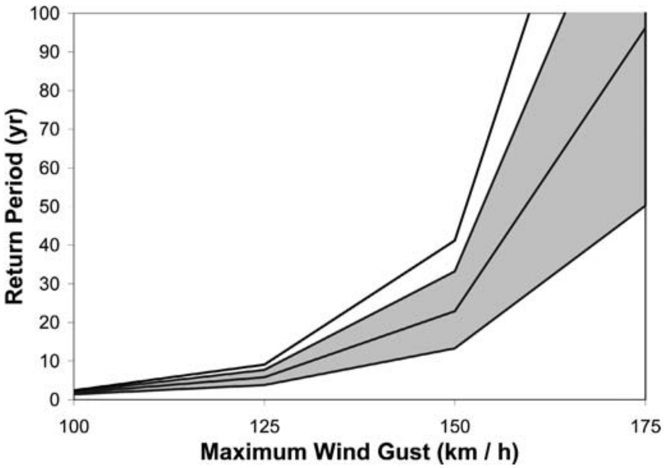


Fig. 1.15. Relationship between peak wind gust and return period for Delhi, India, for present day (black line) and 2050 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2050, based on all possible combinations of the percentage increases and emission scenarios.

1.6 Risk Management

Based on Clarkson et al. (2006), there are six requirements that must be met if farmers are to manage risks related to climate extremes, variability and change. These include:

- awareness that weather and climate extremes, variability and change will impact on farm operations;
- understanding of weather and climate processes, including the causes of climate variability and change;
- historical knowledge of weather extremes and climate variability for the location of the farm operations;
- analytical tools to describe the weather extremes and climate variability;
- forecasting tools or access to early warning and forecast conditions, to give advance notice of likely extreme events and seasonal anomalies; and
- ability to apply the warnings and forecasts in decision making.

Farmers have many options for managing the risks they face, and most use a combination of strategies and tools. Some strategies deal with only one kind of risk, while others address multiple risks. Some of the more widely used strategies include (USDA 2006b):

- **Enterprise diversification:** this is based on the assumption that incomes from different crops and livestock activities are not perfectly correlated, meaning that when some activities produce low incomes other activities will likely offset this decreased earning by producting higher income;

- **Financial leverage:** this refers to the use of loans to help finance farm operations; higher levels of debt, relative to net worth, are generally considered riskier; the optimal amount of leveraging depends on several factors, including farm profitability, the cost of credit, tolerance for risk, and the degree of uncertainty in income;
- **Vertical integration:** this can decrease risk associated with the quantity and quality of inputs or outputs since a vertically integrated firm retains ownership or control of a commodity across two or more phases of production and/or marketing, thereby spreading risk;
- **Contracting:** this can reduce risk by way of guaranteed prices, market outlets, or other terms of exchange which are settled in advance; contracts that set price, quality, and amount of product to be delivered are called marketing contracts, or simply forward contracts; contracts that prescribe production processes to be used and/or specify who provides inputs are called production contracts;
- **Hedging:** this uses futures, or options, contracts to reduce the risk of adverse price changes prior to an anticipated cash sale or purchase of a commodity;
- **Liquidity:** this refers to the farmer's ability to generate cash quickly and efficiently in order to meet financial obligations; liquidity can be enhanced by holding cash, stored commodities, or other assets that can be converted to cash on short notice without incurring a major loss.;
- **Crop yield insurance:** this pays indemnities to producers when yields fall below the producer's insured yield level; coverage may be provided through such instruments as private insurance or government subsidized multiple peril crop insurance;
- **Crop revenue insurance:** this pays indemnities to farmers based on gross revenue shortfalls instead of just yield or price shortfalls; for example, in most areas of the United States several federally subsidized revenue insurance plans are available for major crops; and
- **Household off-farm employment or investment:** this can provide a more certain income stream to the farm household to supplement income from the farming operation.

Most producers use a mix of tools and strategies to manage risks. Since the willingness and ability to bear risks differ from farm to farm, there is usually variation in the risk management strategies used by producers.

Specific risk management measures that can be used include irrigation and water allocation strategies; shelter from wind or cold; shade from excessive heat; anti-frost and anti-erosion measures, soil cover and mulching; plant cover using glass or plastic materials; artificial climates of growth chambers or heated structures; animal housing and management; climate control in storage and transport; and efficient use of herbicides, insecticides, and fertilizers. Weather and climatic conditions often determine the type of pests and diseases that will have to be controlled in a given growing season, as well as the efficacy of any control procedures.

1.7 Conclusions

Variations in the weather, climate, yields, prices, government policies, global markets and other factors can cause wide swings in farm production and, in the case of commercial agriculture, in farm income. Risk management involves choosing among strategies that reduce the social and financial consequences of these variations in production and income.

Extreme weather events, and climatic anomalies have major impacts on agriculture. In both the developing and developed worlds risk characterization and management are important aspects of farming. High preparedness, prior knowledge of the timing and magnitude of weather events and climatic anomalies and effective recovery plans will do much to reduce their impact. When user-focused weather and climate information are readily available, and used wisely by farmers and others in the agriculture sector, losses resulting from adverse weather and climatic conditions can be minimized.

In recent decades major advances in short-term and seasonal weather forecasting, as well as in long-term climate modelling, have yielded major improvements in early warnings and advisories as well as in longer-term planning. This is resulting in increasing emphasis on proactive rather than reactive management of the risks to agriculture resulting from extreme weather events and anomalous climatic conditions on agriculture.

There is a well established approach to characterizing and managing risks. The risk-based methodology makes explicit the link between weather- and climate-related risks and the actions required to reduce them to acceptable levels.

Farmers have many options for managing the risks they face, and most use a combination of strategies and tools. Some strategies deal with only one kind of risk, while others address multiple risks. Most producers use a mix of tools and strategies to manage risks. Since the willingness and ability to bear risks differ from farm to farm, there is usually variation in the risk management strategies used by producers.

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