

**DETERMINING PREMIUMS FOR SMALLHOLDER FARMERS  
IN KENYA FOR WEATHER INDEX INSURANCE**

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## DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the Research Proposal contains no material previously published or written by another person except where due reference is made in the Research Proposal itself.

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## Table of Contents

DECLARATION .....	i
Table of Contents .....	ii
Abstract .....	iv
1. Introduction.....	1
1.1 Background to the study .....	1
1.2 Problem Statement.....	2
1.3 Research Questions.....	3
1.4 Research Objectives.....	3
1.5 Justification .....	3
2. Literature review .....	4
2.0 Introduction .....	4
2.1 Weather index Insurance.....	4
2.2 The effect of drought on crop production in Kenya hence the need for crop insurance.....	5
2.3. Existing crop index insurance in Kenya.....	6
2.4 The advantages of weather index insurance.....	7
2.5 Theoretical Framework.....	7
2.5.1 The Black-Scholes Framework.....	7
2.5.2 The Black-Scholes model in Index Insurance .....	9
3. Methodology .....	12
3.1 Research design.....	12
3.2 Population and sample of the study.....	12
3.3 Data and Data collection methods .....	12
3.4 Data specification .....	12
3.5 Collection Methods.....	12
3.6 Data Validation.....	13
4. Results and Analysis.....	14
4.1 Rainfall levels in Narok .....	14
4.2 Rainfall and Planting seasons in Narok .....	14
4.3 Wheat yield in Narok.....	15
4.4 Pricing using Black-Scholes Framework .....	15
5. Conclusions.....	17

6. References.....	18
7. Appendix.....	21
7.1 Rainfall graph.....	21
7.2 Wheat yield in Narok.....	21



## **Abstract**

This research aimed to demonstrate that weather index insurance could be used by what farmers in Narok to protect themselves against adverse effects of drought. This involved determining the minimum amount of premiums that would be required from small scale wheat farmers. In this case a cash or nothing put option which has similarities with a weather index was considered. The methodology involved using rainfall data from Narok county over a period of 20 years. Data from 1993-2013 was provided by the Kenya Meteorological Department of Kenya. Narok was chosen as the study area since it is the highest net producing county of wheat in Kenya and it has previously been affected be droughts. The average amount of rainfall during the planting season was used as the trigger amount. A rate of 5% was assumed to determine the premiums. From the study's conclusion, it was established that the cash or nothing put option could be used to hedge for drought and it gave an affordable amount of premiums to be paid for 100 currency units.



## 1. Introduction

### 1.1 Background to the study

Agriculture is the backbone of many developing countries. It accounts for 30 to 60 percent of their GDP and employs more people than any other sector, both directly and indirectly (UNDP, 2007). Agriculture is the key pillar of Kenya's economy contributing 24% directly and 27% indirectly to the GDP. The sector accounts for 65% of Kenya's total export, and provides over 18% of formal employment and 60% of informal employment (ASDS, 2009). However, about 93% of the cropland is rain-fed with only 7% under irrigation, (Agriculture, 2012). This significant dependence on rainfall puts Kenya at a high risk in the wake of climate change. In the last 100 years, Kenya has experienced 28 droughts, three of which occurred in the last decade. (Huho & Mugalavai, 2010). The severity and frequency of droughts in Kenya has seemed to increase over time, with Africa bearing the brunt of the adverse effects of climate change (Wagacha, 2014). As the frequency of droughts increases, maize farmers face greater production risk.

More than 2.9 billion people across the world (Mahul & Stutley, 2010) live in rural areas, and 86% of those depend on agriculture as their source of livelihood. Approximately 1 billion people live on less than \$1 per day and three-quarters of those live in rural areas (Chen & Ravallion, 2007), and over one-half depend on agriculture or agricultural labor as their primary source of livelihood (International Fund for Agricultural Development). This means that majority of those participating in this sector are smallholder farmers whose farming is significantly dependent on rainfall. Smallholder farmers are therefore highly exposed to the negative impacts of climate change mainly reflected in drought (shortage of rainfall). 2001).

Maize farming in Kenya is the backbone of food security in the country. Maize is the most important cereal grown in Kenya in terms of production and consumption. Maize production is a very relevant activity due to its importance as it is a dominant food crop (Mantel & Van Englen, 1997). It is wholly produced under rain-fed conditions. More than 75% of maize area is cultivated by small-scale farmers who produce more than 65% of the maize produced for both home consumption and market- with small-scale farmers only selling an estimated 20% of their

production. Thus, poor rural households are particularly susceptible to the financial consequences of weather-related disasters. Water availability is the most critical factor for sustaining crop productivity in rain-fed agriculture. Rainfall variability from season to season greatly affects soil water availability to crops, and thus poses crop production risks.

Agricultural households in high income countries commonly use insurance and other financial products to protect themselves from shocks. Unfortunately, access to such types of formal financial risk management products is nonexistent in rural areas of developing countries.

It is important to mitigate these risks for smallholder farmers who cannot afford to pay premiums for traditional crop insurance. Weather index insurance offers the opportunity for farmers to manage climate risk in developing countries such as Kenya.

## **1.2 Problem Statement**

There is a complexity to the designing of weather index insurance products that requires a high correlation between a weather index and actual loss experienced by insured farmers. A low correlation creates basis risk which is the difference between the payout and actual loss experienced. In trying to ensure that basis risk is low as possible, insurers end up with products that are too costly or inflexible.

In traditional insurance, premiums are determined by using specific characteristics of a policyholder (e.g. age, health status, occupation). These characteristics help to determine the level of risks and thus amount of premiums to be paid by the specific policy holder. Individual characteristics change as individuals grow older and these changes are easy to identify during interactions with policyholders. In contrast, weather index insurance only uses historical data on climate patterns and current weather predictions to price their products. Climate changes increase the price of insurance products due to increasing weather risk. Uncertainty about the extent to which climate will change and the regional impacts it will have compounds pricing difficulties of weather index products.

The pricing of weather index products can never really cover all uncertainty there is about weather patterns. It is clear then that as the weather changes in a given region, the pricing of an insurance product has to change and this means that the amount of premiums policyholders are required to pay will increase. This might not sit well with the policyholders as most of them are

smallholder farmers who may not be able to afford an increased amount of premiums on the insurance products.

### **1.3 Research Questions**

1. What is the amount of premiums required from smallholder farmers for weather index insurance products?
2. How affordable are weather index insurance products for smallholder farmers in Kenya?

### **1.4 Research Objectives**

1. To determine the minimum amount of premiums required from smallholder farmers.
2. To evaluate the affordability of weather index insurance products for smallholder farmers in Kenya.

### **1.5 Justification**

Generally, Low-income citizens such as small-scale farmers cannot afford formal insurance to protect them from extreme weather events such as drought. Agriculture in Kenya is a significant driver of Kenya and therefore there is an increasing need to insure the smallholder farmers in developing countries. It is important for insurers to then learn how to price premiums for weather index insurance products for smallholder farmers such that they can afford to protect their crops from weather risks.

This study focuses on the premiums charged on these farmers and determining the minimum level of premiums that will be affordable for them.

## 2. Literature review

### 2.0 Introduction

As mentioned above, climate change affects agricultural production in Kenya and small-scale farmers need protection from the effects of weather variability on their crops. With farmers taking up weather index insurance they are able to manage the risks from climate change. However changes in climate pose risks to maize farmers in the country and lead to an increase in the pricing of weather index insurance products as well as an increase in the amount of premiums required from policy holders. This chapter provides a review of literature related to the pricing of weather index insurance products and premiums and the affordability of the same for smallholder maize farmers in Kenya.

### 2.1 Weather index Insurance

Weather index insurance is gaining increased attention as a potentially sustainable market mechanism to transfer weather risk in lower income countries (Collier, Skees & Barnett, 2009). Traditional crop insurance is often a very poor and unsustainable investment in lower income countries due to the prevailing poverty as well as asymmetric information problems. Weather index insurance presents a promising alternative to traditional crop insurance for many lower income countries.

In this type of insurance, the indemnity is based on the realization of a specific weather parameter measured over a specified period of time at a particular weather station. The insurance can be structured to protect against index realizations that are either too high or too low that they are expected to cause crop losses. An indemnity is paid whenever the realized value of the index exceeds a pre-specified threshold. The indemnity to be paid out is calculated based on a pre-agreed sum insured per unit of the index.

For smallholder farmers, weather index insurance serves as a poverty reduction tool in the sense that it is a cost-effective approach to agricultural insurance. Weather index insurance is cheaper because farmers are not required to submit claims and adjusters are not needed to verify damages to crops. Insured farmers may also be able to get credit from lenders who may have previously

viewed them not credit worthy thus leading to an increase in farmers' participation in the credit market, (Steve & Conner, 2010)

## **2.2 The effect of drought on crop production in Kenya hence the need for crop insurance**

In order to outline a weather index insurance contract for the farm sector, there must be a strong correlation between it and the meteorological phenomenon chosen (Hurduzeu & Constantin, 2008)

In reference to farming, there are three general risks experienced by a farmer. These are harvest risk, the probability of obtaining inferior yield, event risk, the probability of realizing an exceptional event characterized by great losses and relatively small frequency of occurrence and price risk, probability of a change in price (Hurduzeu & Constantin, 2008)

Drought as described by (Ngaira, 2004) is a form of environmental stress that originates from a deficiency in precipitation over an extended period of time long enough to cause moisture deficiency, crop failure, loss of lives both human and animals and general hardships.

In Kenya, drought conditions are very frequent and widespread, covering 83% of total land area mainly in the northern districts, southern rift valley, parts of the coastal and southern regions (P.K. Kimurto, 2010)

In the last 100 years, Kenya has experienced 28 major droughts, three of which occurred in the last decade (Huho & Mugalavai, 2010), declaring national disasters in 1991-2001, 2004-2006, 2008-2009 as a result of drought. The most recent drought experience in Kenya was in 2011. This, alongside the 2008-2009 drought have been documented as the worst droughts in recent years (Musingi J.B. Kioko, 2013). Between 1993 to date, Kenya has declared seven natural disasters in 1992-1993, 1995-1996, 1999-2001, 2004-2006 and 2008-2009 due to drought. Droughts therefore provide a major constraint to rain fed agriculture in Kenya as described by (Huho & Mugalavai, 2010), resulting in loss in production and nation-wide food shortages.

Drought results in a specific event risk. Specific events risks are described as events whose outcome is known with certainty (G. Turvey, 2001). This is as described in the introduction is drought experienced by wheat farmers increases the risk of complete crop failure creating a cause and effect. Weather derivatives on a specific event (cause) would be purchased to protect

against production risks (event) (G.Turvey, 2001). This would effectively hedge drought risk faced by farmers.

### **2.3. Existing crop index insurance in Kenya**

Index based insurance products are increasingly gaining traction in the Kenyan market. Index insurance uses indices that are correlated to the events that affect crop yield. These products are designed specifically for small scale farmers who do not have the economies of scale to access credit that will allow them to purchase quality seeds, agrochemicals or even tradition insurance products.

A harvest is necessary because it can act as collateral to obtain credit. In the event of weather risk and poor harvest, this opportunity does not exist. Several reasons have made it possible to provide insurance to small-scale farmers. Among these are the frequency of damage events that hit many farmers at once, unavailability of historic data, difficulty in measuring risk efficiently and expensive individual assessment, making insurance available to large scale and high value farmers only (Telemetry, 2012).

The most widely known index insurance product is the Kilimo Salama policy that covers maize and wheat yield against drought and excess rain. This project was initiated by the Syngenta Foundation for Sustainable Agriculture, which partners with input companies to share the premium costs of small scale farmer by insuring the farm inputs the farmer uses on his farm. Premium is shared on a 50 50 basis between the farmer and the input providers, subsidizing the premium costs incurred by the farmer (Telemetry, 2012). This method, however noble brings in the issue of long-term scalability of the product due to its subsidy feature.

## **2.4 The advantages of weather index insurance**

In theory, traditional insurance instruments like crop insurance can be used to transfer risks associated with extreme weather events. This however, is not practical in lower income countries because insurance markets are underdeveloped.

Unfavourable weather conditions like drought affect very large areas with the risks faced by different producers being correlated (Miranda & V.Vedenov, 2001). This correlation of risks proves to be a dilemma for traditional insurance as it is designed to pool a number of small unrelated risks rather than widespread catastrophic risks.

Index products potentially offer more advantages to traditional insurance in that payoffs are widely based on an objectively measured index, eliminating the need for farm level adjustment, reducing costs related to yield insurance (Vedenov & Barnett, 2004). In addition, the value of the index does not depend on the individual actions of market participants, therefore there is no adverse selection or moral hazard involved (Vedenov & Barnett, 2004).

Weather derivatives differ from traditional insurance in fundamental ways. There is no need to claim damages or file a claim, little moral hazard exists and unlike traditional insurance one has the opportunity to hedge against comparatively good weather in other locations which may be bad for local business. For example, a bumper crop of California oranges may lower the prices received by Florida growers (Campbell & Diebold, 2005).

## **2.5 Theoretical Framework**

### **2.5.1 The Black-Scholes Framework**

In their 1973 paper, Fischer Black and Myron Scholes put up a theorem for valuing option contracts under ideal conditions in the market for the stock and for the option. This theorem is what brought about the Black Scholes model and has since been used in valuing stock options.

The famous Black-Scholes model is the commonly accepted model for pricing of claims in the financial industry. The main assumptions are: the riskless interest rate is assumed to be a constant and the stock price process satisfies a geometric Brownian motion, which implies that stock returns are independent. Except for applying to the case of geometric Brownian motion, the Black-Scholes formula is valid under more assumptions of stock price processes. As shown in Klebaner (1998), the drift of the diffusion process does not affect the dynamics of the Q-

measure of stock prices, even when the drift is an arbitrary function of stock prices under the original measure.

Over time the framework has received criticism from different quarters. The main assumption of the Black-Scholes model is that the underlying stock price moves randomly following a geometric Brownian motion. However, the stock price distribution does not conform strictly to this assumption. In addition, the assumption of a constant and known short term interest rate is adopted for convenience and is not completely true. The focus on European options was designed to allow us to ignore the potential influence of early exercise (Fortune & Peter, 1996).

Merton (1973) however shows that if there are no additional payments made during the lifetime of the option then it would be irrational for an investor to exercise an American option before the maturity date. The Black-Scholes model can therefore be used to evaluate American options based on non-dividend paying common stocks. He further modified the equation to account for both American and European style options as well as stochastic interest rates.

Hong Boon Kyun (2004) applied the Black-Scholes warrant pricing model to the stock exchange of Malaysia. He concluded that despite the existence of strike price, time to maturity and variance biases in the model there were no significant differences between the market value of warrants and the Black-Scholes value of warrants.

Merton (1998) outlines the numerous applications of the Black-Scholes formula that have evolved together with financial innovations. One of the significant applications of the Black-Scholes approach to "option-like" securities involved the pricing of insurance contracts such as loan guarantees and deposit insurance policies. In essence, the strategy of acquiring both a put option on an asset and the asset as well can be viewed as an insurance policy against losses that would result from a decline in the asset price.

Merton (1976) and Cox & Ross (1976) further modified the model to allow for discontinuous stock price movements. Merton (1998) remarked that the influence of the Black-Scholes option theory in finance isn't limited to financial options traded in markets. It can also be used to price and evaluate risk in a wide array of applications, both financial and non-financial.

A European put option gives the buyer the right, but not the obligation, to sell an underlying asset at a pre-specified strike price and future maturity date. As such, the contingent payoffs

embodies in a put option replicate the payoffs under an insurance scheme, where the insurance guarantee level is the strike price and the insurable revenue index plays the role of the underlying asset price. This insight has led to several applications of the Black-Scholes put option pricing model to value agricultural insurance contracts, Turvey & Amanor-Boadu (1989).

### 2.5.2 The Black-Scholes model in Index Insurance

In essence, the Black-Scholes model states that by continuously adjusting proportions of stocks and options in a portfolio, the investor can create riskless hedge portfolio, where all market risks are eliminated. The ability to construct such a portfolio relies on the assumption of continuous trading and continuous sample path of the assets price. In the efficient market with no riskless arbitrage opportunities, any portfolio with a zero market risk must have an expected rate of return equal to the risk-free interest rate. For the traditional Black-Scholes model, let:

- $C(S, t)$  = the price of a European call option.
- $P(S, t)$  = the price of a European put option.
- $S$  = the strike price of the stock.
- $K$  = strike price of the option.
- $r$  = the annualized risk-free rate, continuously compounded.
- $\mu$  = the drift rate of  $S$ , annualized.
- $\sigma$  = the standard deviation of the stocks return.
- $t$  = a time in years.
- $\delta$  = dividend rate, continuously compounded.
- $N(x)$  = standard normal cumulative distribution function,

$$C(S, t) = Se^{-\delta t} N(d1) - Ke^{-rt} N(d2)$$

$$P(S, t) = Ke^{-rt} N(-d2) - Se^{-\delta t} N(-d1)$$

Where;

$$d1 = \ln\left(\frac{S}{K}\right) + (r - \delta - 0.5\sigma^2)t/\sigma\sqrt{t}$$

$$d2 = d1 - \sigma\sqrt{t}$$

A European put option gives the buyer the right, but not the obligation, to sell an underlying asset at a pre-specified strike price and future maturity date. As such, the contingent payoffs embodied in a put option replicate the payoffs under an insurance scheme, where the insurance guarantee level is the strike price and the insurable revenue index plays the role of the underlying asset price.

For index insurance, let  $S(t)$  equal the price of a stock at time  $t$ . A cash-or-nothing put option is one which the purchaser receives  $c$ , at expiry time  $T$ , if  $S(t) < K$ , 0 otherwise. Where  $c$  equals the payoff.

Black-Scholes proved that we can use the risk-neutral probability rather than the true probability to evaluate the price of an option, as long as we can discount at the risk-free rate instead of the true rate. The Black-Scholes also assumes  $\frac{S_T}{S_0}$  is log-normally distributed (Weishaus, 2009).

There are a number of similarities between index-based insurance and cash-or-nothing put options. Therefore, the index-based insurance can be priced just like a cash-or-nothing put option. To price an index insurance using Black-Scholes the following is considered;

- The trigger measurement in the index insurance is  $R_T$ .
- The payout structure for index insurance is a lump sum.
- The index follows a lognormal distribution.

The essential feature of an index-based insurance is that the insurance contract responds to an objective parameter (e.g. measurement of rainfall) at a defined weather station during an agreed time period. The purchaser of the index insurance policy (e.g. a smallholder maize farmer) will receive a payoff if rainfall measurements fall below the trigger amount which is determined based on historical rainfall data.

Let  $P$  denote the lump sum payment, then the premium of the index insurance is;

$$\text{Premium} = Pe^{-rt}N(-d_2)$$

Where;

$N(-d_2)$  = *the true probability that Rainfall is less than the trigger amount.*

$r$  = *continuously compounded interest rate over duration  $t$ .*



### **3. Methodology**

#### **3.1 Research design**

This study adopts a quantitative approach of determining premiums for smallholder farmers in Kenya by using the Black-Scholes model. The reason for this selective quantitative research design is because it provides empirical evidence of pricing of index insurance products using a weather index and historical weather data with relation to wheat yield in Narok.

#### **3.2 Population and sample of the study**

The population under study was all rainfall data in Kenya and all temperature data in Kenya. The sample considered was monthly rainfall and temperature from Narok county for the past 20 years from 1993-2013. Narok South constituency of Narok County is easily described as the wheat basket of Kenya. With over 100.000 ha of land cultivated solely for wheat, it is the highest wheat producing area in East Africa. It has distinct highland areas that lie 3000 metres above sea level, and rainfall ranges between 1200mm-1800mm the area is perfectly suited for wheat farming falling above the altitude requirement of 1500mm above sea level and rainfall requirement of above 860mm (FAO, Kenya-FAO wheat database).

#### **3.3 Data and Data collection methods**

Secondary data was used for this study. Secondary data refers to data that is already available, having been collected and analysed by someone else (C.R.Kothari, 2004). This data may be published or unpublished and may originate from various sources such as government publications, books, magazines among others.

Secondary data provides the researcher with the advantage that they will not have to collect original data. However, the researcher must be cautious in using secondary data as it may be unsuitable or inadequate for the study at hand (C.R.Kothari, 2004).

#### **3.4 Data specification**

The specific data that was collected was average monthly temperature and average monthly rainfall data. The data was obtained for a period of 20 years, from 1993-2013)

#### **3.5 Collection Methods**

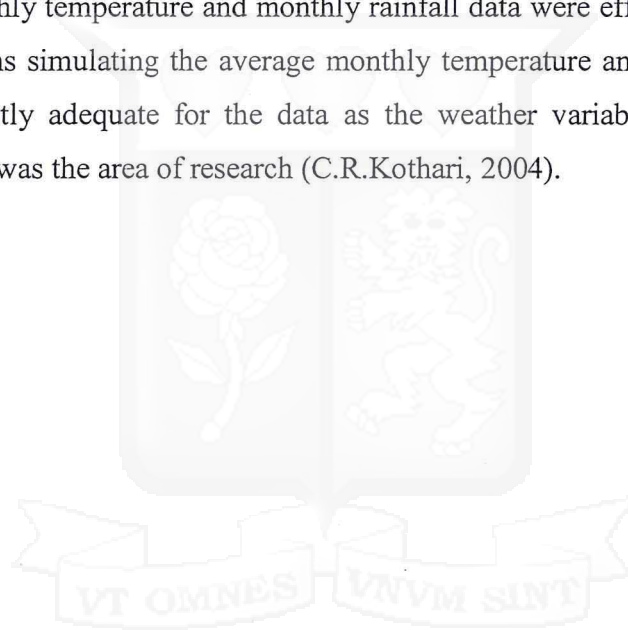
The data was obtained from Kenya Meteorological Department (KMD). Weather data for the Narok region was readily available for use from the weather department. An introductory letter

specifying the nature of the study was used to inform the meteorological department on the data's application to the study.

### **3.6 Data Validation**

To check if the data was suited for the study, reliability, suitability and adequacy tests were carried out.

The data for this study was reliable as it was collected by the Kenya Meteorological Department which is an accredited government data collection body and have invaluable historical records of climate data and operates extensive weather mentoring systems. The data was suitable for the study as the monthly temperature and monthly rainfall data were effectively applied to the mean reverting equations simulating the average monthly temperature and monthly speed of rainfall. The data was lastly adequate for the data as the weather variables were related to drought estimation which was the area of research (C.R.Kothari, 2004).

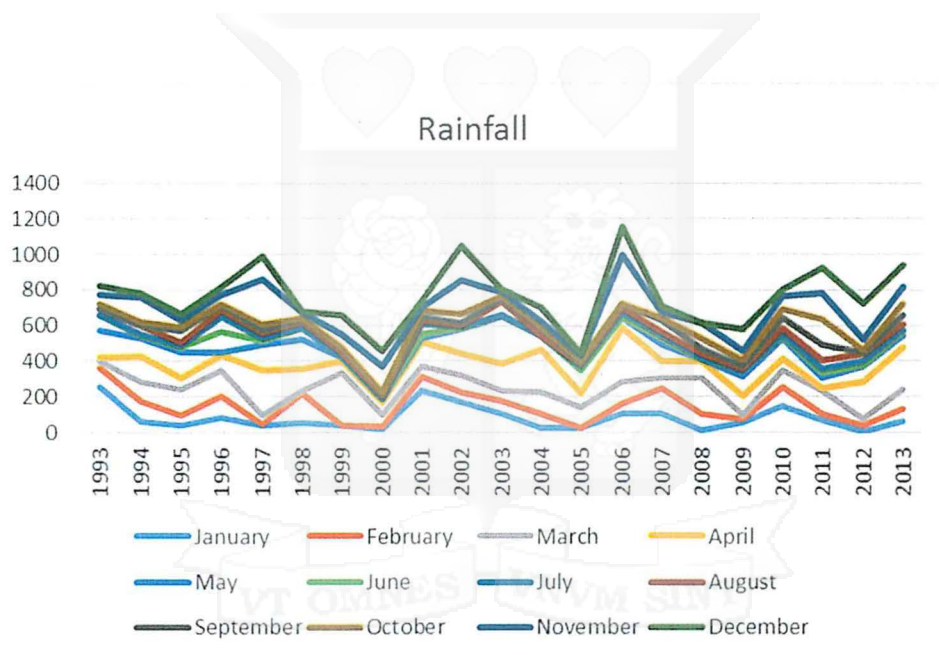


## 4. Results and Analysis

### 4.1 Rainfall levels in Narok

The population under consideration was all daily rainfall and daily temperature data available in Kenya. The sample under consideration was all daily rainfall and data from Narok County. The data was obtained from the Kenya Meteorological Department.

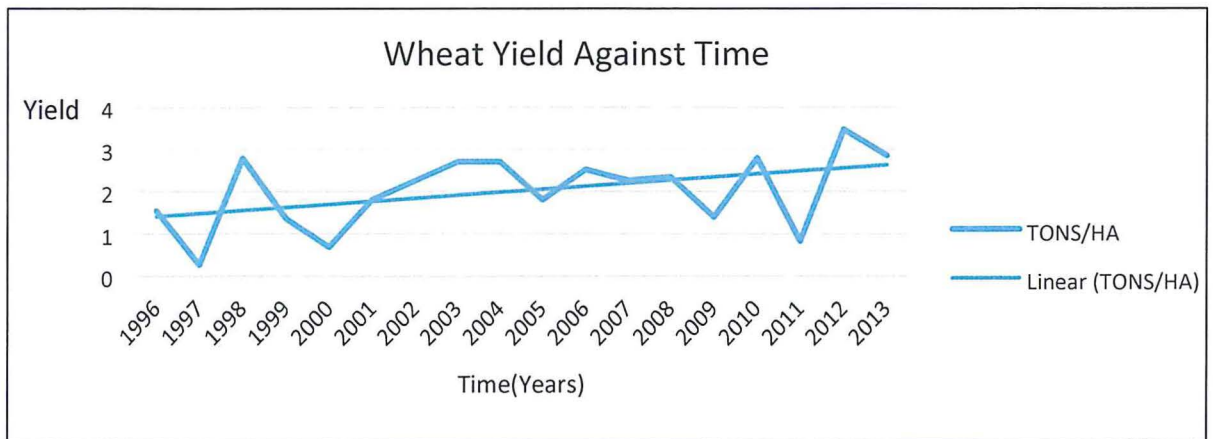
The Kenya Meteorological Department responded positively towards the request for the required meteorological data. The data provided was monthly rainfall and temperature data for the last 20 years (1993-2013).



### 4.2 Rainfall and Planting seasons in Narok

Planting of wheat is done just before the rainfall period starts. The long rains start in March/April and farmers start planting just before or when the rains start falling. The short rains fall in October where farmers can choose to plant wheat again.

### 4.3 Wheat yield in Narok



### 4.4 Pricing using Black-Scholes Framework

Consider a rainfall index insurance product which pays out 100 currency units when the rainfall  $R$  for the Narok county falls below the trigger rainfall measurement  $RT$

$$Payout = \begin{cases} 100 & \text{if } R < RT \\ 0 & \text{otherwise} \end{cases}$$

The rainfall for March/April was used as the base trigger because they are the two months where rainfall starts for the planting season. The trigger used was the average of the highest level of rainfall in the two months.

$$Premium = P e^{-rt} N(-d_2)$$

Where;

$N(-d_2)$  = the true probability that Rainfall is less than the trigger amount.

$r$  = continuously compounded interest rate over duration  $t$ . For this study a rate of 5% was assumed.

$$Premium = 100 * e^{-rt} N(-d_2)$$

$$d_2 = (\ln(R0/RT) + (\mu)t) / \sigma\sqrt{t}$$

Where  $\mu$  and  $\sigma$  are the parameters of the lognormal distribution from the rainfall data:

$t = 1$  year

$\mu = 63.7$

$\sigma = 62.78\text{mm}$

$R_0 = 240.7\text{mm}$  (most recent level of rainfall)

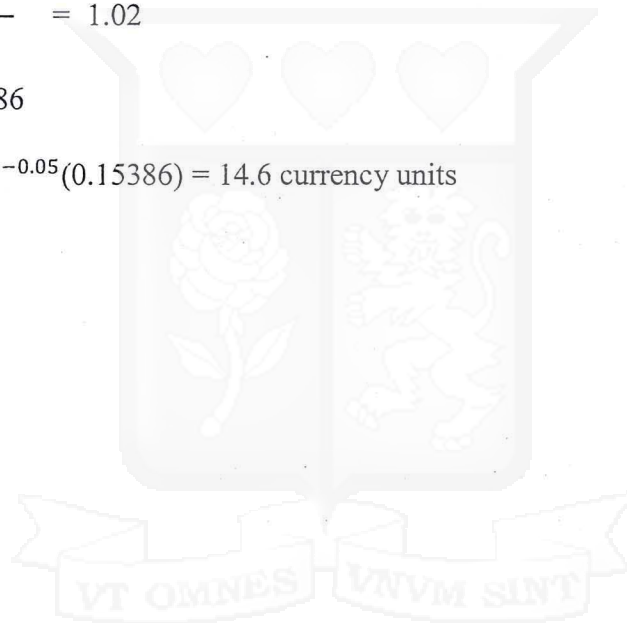
$R_t = 126.771\text{mm}$  (trigger rainfall which is the average amount of rainfall in the month of April)

$r = 5\%$  (assumed)

$$d2 = \frac{\ln\left(\frac{240.7}{126.771}\right) + 63.7}{62.78} = 1.02$$

$N(-1.02) = 0.15386$

Premium =  $100 * e^{-0.05} (0.15386) = 14.6$  currency units



## 5. Conclusions

The aim of this study was to determine the minimum amount of premiums required from wheat farmers in Narok county and their affordability.

This study found that there is a strong correlation between wheat yield and rainfall. The highest correlation was in the month of April. This is an important finding because the planting date for major season of Wheat is in April. This finding reinforce the knowledge that good amount of rainfall is needed in the flowering stages of wheat production.

The study also found that over the past two decades there exist an upward trend in rainfall data from January to October and a downward trend from October to December in Narok. This suggests the reason behind the major planting season being at the end of March in preparation for rainfall in April.

As a way of pricing index-based insurance a case was made for the Black-Scholes framework. This framework eliminates the disadvantage of high premiums associated with traditional insurance considering a farmer has to pay 14.6 currency units in order to receive 100 currency units when rainfall in during the planting season falls below the trigger amount.

The study also found that trigger measurement and payout structure have a huge effect on the premium of the contract. Designing index insurance products will be technically challenging hence insurance companies need to invest in a number of research activities in order to effectively capture the relationship between the index variable and crop loss. It must be noted that introducing index insurance requires the support of stakeholders: insurers, the Kenya Meteorological Department and government which provide the regulatory environment

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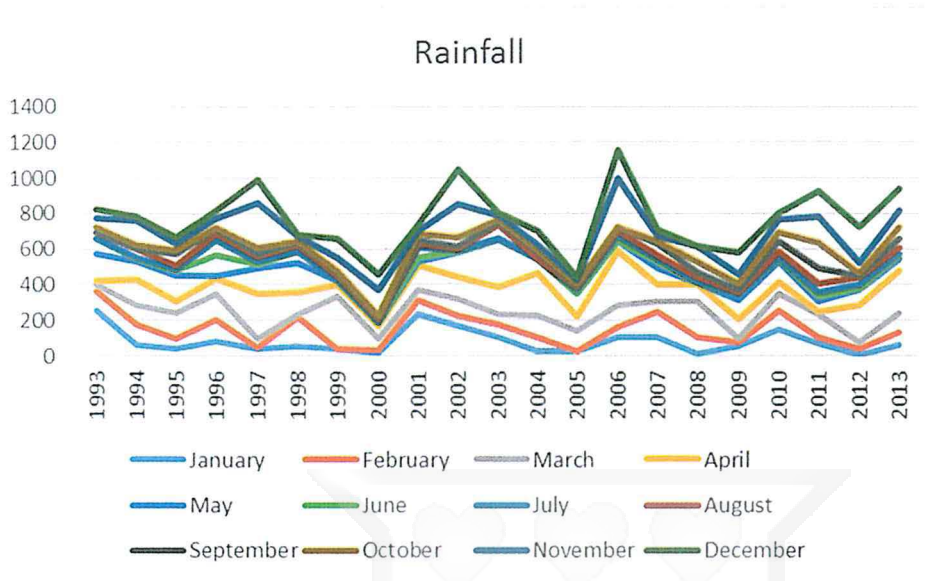
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## 7. Appendix

### 7.1 Rainfall graph



### 7.2 Wheat yield in Narok

