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A Prototype to forecast trends in rainfall amounts in Kenya

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A Prototype to forecast trends in rainfall amounts in Kenya

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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 thesis contains no material previously published or written by another person except where due reference is made on the thesis itself.

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SUPERVISOR'S DECLARATION.

This research proposal has been submitted for review with my approval as a university supervisor.

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Abstract

Food security has been a key subject of interest to governments, non-governmental organizations such as the World Food Programme (WFP), and the Food and Agriculture Organization of the United Nations (FAO), and the local population worldwide. One of the growing problems in the food security arena is the continual rise in the number of people who are food insecure in recent years. Previous solutions have included government interventions through food pricing and agricultural subsidy policies, and non-governmental interventions through harmonization and distribution of information on food security. However, the need to come up with more and better solutions to the growing problem has been emphasized, with calls to different groups and individuals being invited in recognizing that food security is a shared responsibility. The proposed research is an application research, which employs the use of a prototype to show rainfall trends in rainfall. In a bid to reduce the time taken to access data, the research seeks to employ the use of existing data which can be accessed from online sources, with deliberate sampling employed as the main data collection method. Data sets will be sourced from the World Bank online portal. The research will then recommend the proposed prototype as a base for the measurement of rainfall that will influence decision making on food security at a local, national and regional level to local and regional food security institutions, the government of Kenya and other interested organizations.

Acknowledgements

I wish to extend my sincere gratitude to Prof. Ismail Ateya, for his immense contribution towards the development of this proposal.

Abbreviations/Acronyms

AfDB	-	African Development Bank.
ASCU	-	Agricultural Sector Coordination Unit.
AUC	-	African Union Commission.
DIA	-	Dietary Intake Assessment.
ECA	-	United Nations Economic Commission for Africa.
FAO	-	Food and Agriculture Organization of the United Nations.
FNS	-	Food and Nutrition Security.
GHI	-	Global Hunger Index.
HESM	-	Household Expenditure Survey Method.
MDG	-	Millennium Development Goals.
SDG	-	Sustainable Development Goals.
PHI	-	The Poverty and Hunger Index.
PhilFSIS	-	The Philippine Food Security Information System.
SOFI	-	State of Food Insecurity in the World.
UNICEF	-	United Nations Children's Fund.
WFP	-	World Food Programme.
WFS	-	World Food Summit.

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Chapter 1 Introduction

1.1 Background of the Study

Food security is understood to exist when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (Food and Agriculture Organization of the United Nations [FAO], 2001). Food is categorized as a basic human right, yet, food and nutrition insecurity is a daily reality for millions of Kenyans living in both the rural and urban areas (as cited by Kamau, Githuku, & Olwande, 2011).

According to a report by (Food and Agriculture Organization of the United Nations, 2009) The world's population is expected to grow by over a third by 2050. Hence, the report the indicates, market demand for food is also expected to grow. (McKenzie & Williams, 2015) indicate that 'Meeting this future food demand has widely been articulated as a crisis of supply alone by some dominant institutions and individuals'. The author further states that the crisis can be avoided by looking into other factors in addition to food supply, to add more value to the food security debate.

In his report on corn, wheat and rice production in Kenya, (Gitonga, 2017) indicates that one of the methods that is used to assess food production patterns is forecast information from Kenya's Meteorological department which for the year 2017/18, had 'forecast favorable weather patterns…expectations are that Kenya's corn production will rebound'. Other interventions included the Kenya government 'establishing storage facilities to reduce post-harvest losses. This is in addition to distribution of certified seeds and fertilizers to farmers'.

Still in Kenya, other additional past efforts to address food security that have included interventions at government level, have been the setting of price ceilings on food commodities and strengthening of nutrition information at country and subnational levels (Agricultural Sector Coordination Unit(ASCU), 2011).

However, the challenge of addressing food security is still highlighted by institutions like FAO (2009) which has projected increased population growth that would require 'raising overall food production' since according to the institution 'market demand for food would continue to grow'. ASCU (2011) has also called on the need for more participation from both individuals and other bodies, both in the public and private sector, in addressing the issue of food security.

The objective of the study is to generate knowledge through forecasting trends in rainfall amounts in Kenya. Such information could then be used by non-governmental bodies and the government to come up with better policies and measures to curb food insecurity at an individual, regional and national level.

1.2 Problem Statement

According to the Agricultural Sector Coordination Unit (ASCU), a food security agency owned by the Government of Kenya, it is estimated that the number of people who are food insecure has been on the rise in recent years especially during seasons of drought, heavy rains or floods. (Agricultural Sector Coordination Unit(ASCU), 2011).While there have been previous efforts to address food security concerns in Kenya, such as government interventions in setting grain prices, provision of fertilizer subsidies, emergency responses in management of acute malnutrition and formation of education programs for food and nutrition in both rural and urban areas, the initiatives undertaken have only met limited progress and success (Agricultural Sector Coordination Unit(ASCU), 2011). One of the lessons learnt by ASCU over time has been the need to make the problem of food security a shared national responsibility. The agency recognizes the need for broad stakeholder participation that involves the private sector, markets, civil society and local communities and individuals to come up with different solutions and systems that will address the problem of food security. (Agricultural Sector Coordination Unit (ASCU), 2011)

A proposed solution by the researcher to address the problem of food security is the development of a prototype to forecast trends data for rainfall, thereby assisting the government and other interested institutions with their future planning. For example, food distribution initiatives and setting prices caps for different food items. The prototype will make use of existing online data sets, sourced from the World Bank online portal to come up with the measurements.

1.3 Research Objectives

i. To identify data used by organizations to address food security.

ii. To identify current challenges faced when addressing food security.

iii. To review existing techniques used to address food security.

iv. To develop a prototype to forecast trends in rainfall.

v. To test the prototype.

1.4 Research Questions

i. What data is used to address food security?

ii. What challenges are faced when addressing food security?

iii. Which techniques are currently used to address food security?

iv. How will the proposed prototype be presented?

v. How will the prototype be tested?

1.5 Justification

The research is necessitated by the need for effective systems by the Kenyan Government through its affiliated food security institutions, like the Agricultural Sector Coordination Unit (ASCU), which deals with food security planning and policy implementation and which invites individuals, groups and corporate institutions for contributions towards resolving the problem of food security, in order to improve on its policy implementation (Agricultural Sector Coordination Unit(ASCU), 2011). The prototype to be developed is one that will provide more accurate information in a faster and less costly manner, which can then be used by government institutions like ASCU to come up with better decisions and implement better policies to tackle the problem of food security more effectively.

1.6 Scope

The main input data for the research will include online rainfall trends data covering Kenya. The proposed solution will be a prototype that forecast trends in rainfall amounts, based on a statistical dataset on rainfall in millimeters, from the years 2001 to 2015.

1.7 Limitations

Challenges that are beyond the control of the researcher, which are expected to affect the outcome of the research include the following.

i. Inability to factor in all the components that are used by different organizations to come up with conclusive statistics on food security. Documented data on criteria used may vary form one organization to another.
ii. Data collected may be biased.
iii. It is difficult to choose a sampling frame for data collected online.

To work around the above mentioned limitations, the research will incorporate the use of datasets from the World Bank online portal.

The research will concentrate on discussions surrounding food security and how forecasting of rainfall can facilitate planning towards food accessibility by the government.

1.8 Ethical Considerations

In order to avoid any conflicts arising from breach of confidentiality, any data which requires the informed consent of the author(s), will be collected with the consent of the authors. The data will also be kept confidential, as per the request of the author(s).

Chapter 2 Literature Review

2.1 Introduction

Food security is an important aspect in society and can therefore not be ignored. There are a number of risk factors that result from a food insecure society. To address food security at any given time, there is a need to look at the components involved, and the levels at which food security can be addressed. To assist in assessing food security, research groups and organizations, use different frameworks, models and systems, depending on their different needs. It is however important to note that the outcomes on food security will vary depending on the variables and models used to address food security.

2.1.1 Background on Food Security

Global hunger has been a widely discussed topic over the years, with the FAO providing annual reports on of food insecurity around the world. The 2015 annual State of Food Insecurity in the World (SOFI) review progress report indicates a general decline in global hunger, with up to 72 out of 129 countries achieving the Millennium Development Goals (MDG) hunger target. However, the report also indicates that much remains to be done to eradicate hunger and achieve food security, despite the achievements made (FAO, 2015). According to a report by the The Consultative Group to Assist the Poor (CGAP), a partnership consisting of more than 30 leading organizations and housed at the World Bank, one of the mentioned Sustainable Development Goals (SDG) that also form the vision 2030 development agenda is the reduction of hunger through efforts such as financial inclusion of farmers to help boost food production(Klapper, El-Zoghbi, & Hess, 2016).

2.1.2 Fundamental Threats Caused by Food Crisis

The potential lack of food security causes fears of negative occurrences in other aspects of the general human population, both from an individual level, to group and national levels. The following are some of the threats that are linked to food insecurity.

Moral and Humanitarian Threat: Hunger reduces the body's physical defenses against most diseases. It is known to be the main risk factor for most illnesses throughout the world. People living in poverty do not have enough capacity to produce or buy enough food for consumption and are therefore more susceptible to diseases as opposed to their counterparts who have access to food. Hunger is also known to be a major constraint to a country's immediate and long term economic, social and political development. The search for food has led to massive deforestation, that has consequently led to climatic, environmental and health problems (Ilaboya, Atikpo, Omofuma, Asekhame, & Umukoro, 2012).

Developmental Threat: Food crisis leads to a weaker workforce, which slows down the overall development. The economic gains of the past decades in fields such as education, health and economic development are all eroded. In cases where the trend is not reversed, it could lead to a disabled generation which is both physically and mentally stunted (Ilaboya et al., 2012).

Strategic Threat: Rising food and fuel prices has reduced the purchasing power of the poor. This causes a threat to the stability of these countries (Ilaboya et al., 2012).

2.1.3 Components of Food Security

According to the FAO (FAO, 2008), factors affecting food security worldwide are classified into four main components. These include:

A**vailability:** this is determined by the level of food production, stock levels and net trade (FAO, 2008). At the household level, this is determined by quantity of food available through own production or at local markets, wild foods and gifts. At a national level, this is determined by factors such as national production, imports and food aid (Shwe & Hlaing, 2011)

Accessibility: factors such as food supply, incomes and expenditures, markets and prices, all contribute to accessibility of food (FAO, 2008). Other factors of importance include employment opportunities and working resources including labour and capital, which directly affect the level of income. (Shwe & Hlaing, 2011)

Utilization: nutrient intake is a key component, which is largely determined by feeding practices, food preparation, diversity of the diet, household distribution and biological utilization of food consumed (FAO, 2008).

Stability of the three factors mentioned above. Adverse weather conditions, political instability or economic factors such as unemployment and rising food prices could lead to instability (FAO, 2008).

2.1.4 Food and Nutrition Security Levels

Food security can be computed at different levels, broadly categorized into two levels:

Micro Level: This mainly concentrates on food security indicators at both the individual and household levels. At the individual level, factors such as the dietary intake, labor supply and gender are taken into account when assessing food security. Outcomes of food security assessments are also heavily influenced by household behavior, preferences of household members, intra household bias on food distribution and physiological requirements of different groups. For example, women and children's nutritional requirements. (Pangaribowo, Gerber & Torero, 2013).

Macro Level: Indicators affecting food security at a national, regional and worldwide are factored in at this level. At a national level food security is determined by a country's ability to provide food for its population. The same applies at the regional and worldwide levels. Some of the factors included here include the international food prices, political stability, population predictions and overall economic growth (Pangaribowo, Gerber & Torero, 2013).

The figure below shows a graphic illustration of the levels at which the Food Security can be assessed.

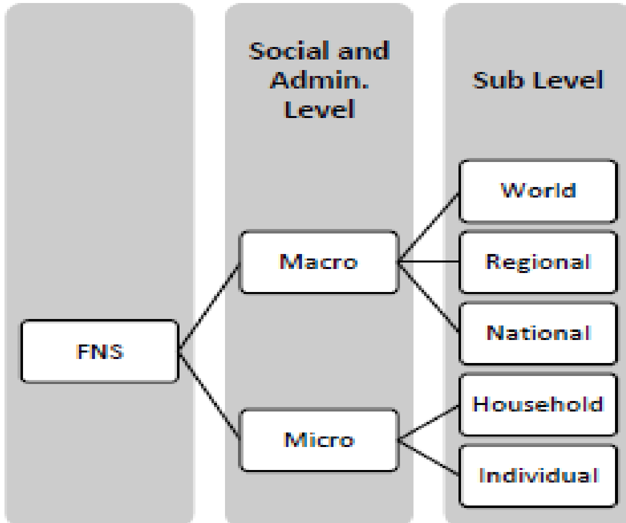


Figure 2.1 Levels of Food Security Assessment

(Pangaribowo, Gerber & Torero, 2013)

2.2 Addressing Food Security

2.2.1 Importance of Food Security Statistics Computation

Food security statistics are of interest to policy makers, economists, nutritionists, food programme planners and others, in helping them identify and locate food-insecure people. They are also useful for evaluating the effectiveness of intervention programmes using trend analysis. This is in line with the concerns of the international community as mentioned in the MDG and the World Food Summit (WFS), which aim to reduce the undernourished population by half by 2015. (Cara, O. & Negruta, A., n.d.).

2.2.2 Food Security Indicators in Statistics Computation

Food security is a multidimensional aspect. The available food security indicators do not capture all the aspects, hence there is no agreement on what indicators to use. Moreover, there is no consistent way to define where the food security has been affected exactly, when using which indicators. Another challenge towards computation of food security data is data availability and the challenges encountered when conducting household surveys, which are used in their construction (as cited by Racha Ramaddan, 2015). Consequently, given the multidimensional nature of food security, practitioners and policy makers have long recognized the need for a variety of means of measurement (as cited by Maxwell, Coates, & Vaitla, 2013).

2.2.3 Existing Food Security Indicators

There have been a number of food security indicators which have been used and or are still used to measure food security at global, national, household and individual levels. Some of the commonly used indicators include the Household Expenditure Survey Method (HESM) which is a direct method to obtain information from households, the Dietary Intake Assessment (DIA) method, in which data is collected via interviews and observations then estimations done to determine the nutrient intakes (as cited by Bashir & Schilizzi, 2012), and The Poverty and Hunger Index (PHI) which is calculated using the proportion of the population living on less than a dollar per day as one of its main factors (as cited by Pangaribowo, Gerber & Torero, 2013).

The aforementioned indicators are formed by a combination of other sub-indicators which revolve around the four components that are used to measure food security.

2.3 Food Security Frameworks

2.3.1 Conceptual Framework on Food Security

The four main components which include availability, accessibility, utilization and stability, are what form the conceptual framework for the measurement of food security. The framework illustrates the different indicators among the four components, which provide an insight on the information that could be included the development of the proposed prototype. The diagram below shows a conceptual framework of the four food security components.

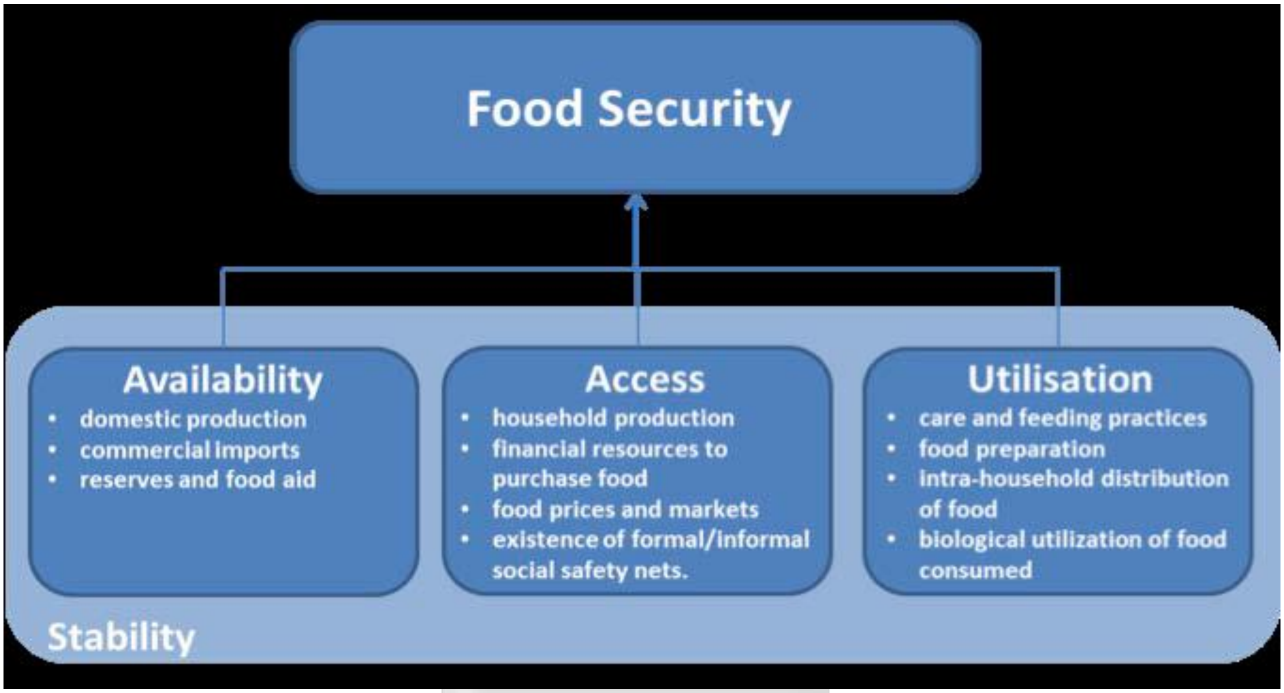


Figure 2.2 Food Security Conceptual Framework
(Hjelm, L & Dasori, W, 2012)

'There is wide range of potential indicators that could be monitored, analyzed and reported by food security information systems' (Shwe & Hlaing, 2011). The figure below by (Shwe & Hlaing (2011) provides a grouping of potential indicators at both the macro and micro levels.

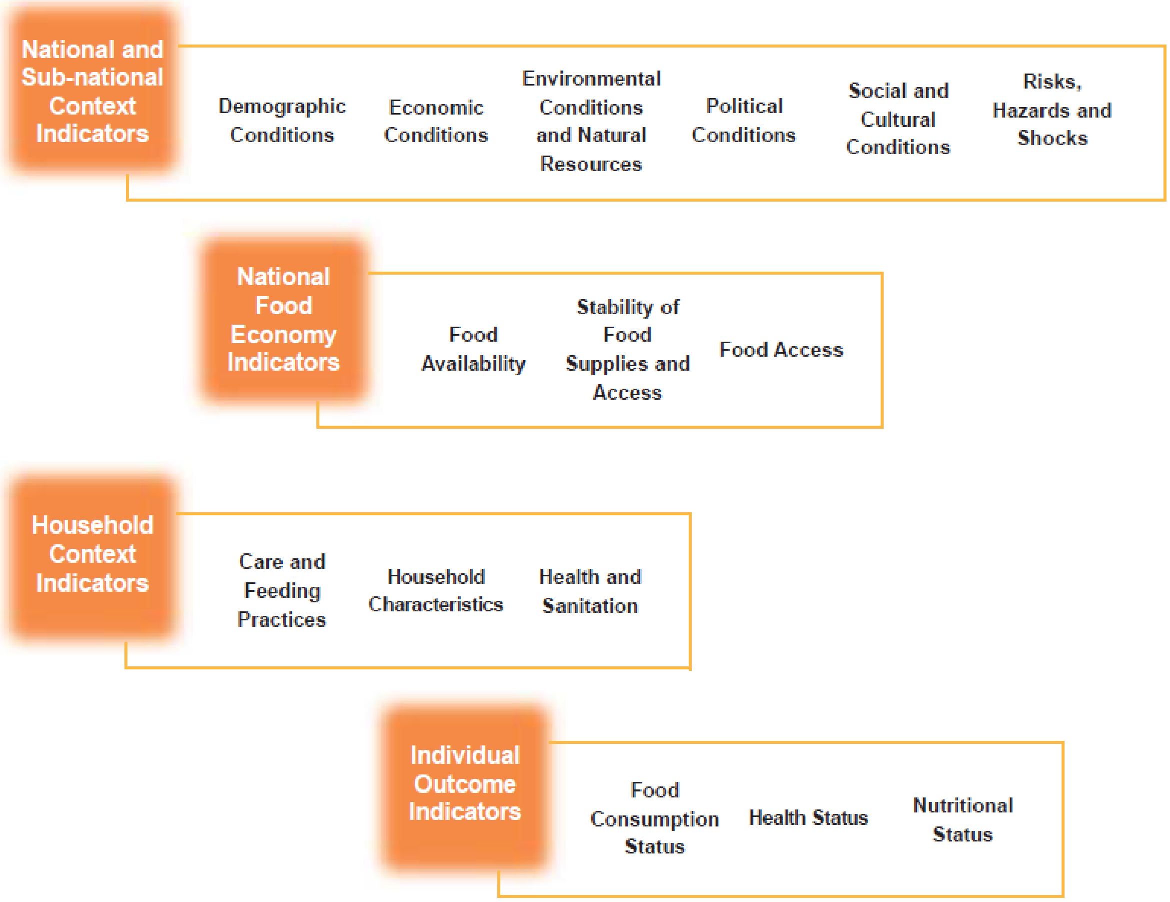


Figure 2.2 Grouping of Potential Indicators at Macro and Micro Levels
(Shwe & Hlaing, 2011)

Given that food security is multidisciplinary in nature, the choice of indicators vary depending on the needs of a given population, both at the micro and macro levels. The figure below gives an illustration of the process of choosing indicators.

Source: FIVIMS Secretariat

Figure 2.3 Flowchart for Choosing Food Security Indicators
(Shwe & Hlaing, 2011)

2.3.2 PhilFSIS Operational Framework

This is a framework developed to guide the development of a food security information system for the Philippines and 'provides the interactions between and among major components essential in operationalizing the PhilFSIS'. The information is obtained from different data systems and data-producing agencies and are organized into different databases (Recide & Jalisan, n.d)

Figure 2.4 PhilFSIS Operational Framework
(Recide & Jalisan, n.d)

The use of multiple databases is outlined as a factor to enable more efficient management, computation and maintenance of food security indicators. However, the downside in using multiple databases is in their maintenance. More resources in terms of additional server space and up to date databases are required as opposed to the operation of a single database.

2.4 Models Used to Address Food Security

There are a number of models that use the mentioned food security indicators to measure food security for a given population. Some of the models include the following:

2.4.1 Logit Models for Household Insecurity Classification

These models use a quantitative method for measurement of food security that incorporates many measurable variables of all food security components (availability, access and utilization). A list of indicator variables for each of the components is generated and analyzed. Food survey data used in these models were collected from household surveys, with different scenarios being used to assess food security. These include difficulty accessing food, food stored and food harvested, with a different logit model drawn up for each scenario. Comparisons and conclusions were then drawn on the logit model that best represented the outcome of food security (Owino Y., 2014)

One of the merits noted for the above mentioned model include the use of a hybrid dependent variable to come up with better results in classification of households when assessing their food security status (Owino et al., 2014).

The use of different variables to come up with different Logit models contributes towards the flexibility to choose on how best to measure food security, using household surveys as an indicator.

Demerits of the logit model include the overreliance on household survey data. The results are further influenced by responses collected from households depending on their perceptions on their levels of food security. Some of these perceptions could be as a result of the cultural mindset of the people. For example, two households with the same resources and capacity may differ in food security status as a result of their different perceptions, attitudes and mindset. One last disadvantage is that the model requires two sets of data which should have been collected during the same periods of time (Owino et al., 2014).

2.4.2 Application of Rasch Model on Household Survey Data

This model is used to measure the magnitude and severity of food insecurity. The model can be used to achieve different objectives. Some of the objectives include to estimate the stability of parameters for estimated models and to examine the estimated order of severity of the different measurement items. The measurement items refers to the set of responses to household survey questions. The models is was used to fit, test and generate results, using a household's reaction to a stimulus as a function characterizing the household's food insecurity level, for a research done from a household surveys. (Owino, Wesonga, & Nabugoomu, 2014).

Merits attributed to the Rasch model include its ability to estimate parameters even when there is nonresponse or when there are different but partially overlapping response items. It can also easily generalize data where items have different discriminating power. It does so, by assuming that respondents randomly guesses answers to some or all items (Owino et al., 2014).

One demerit attributed to the Rasch model are that it does not cover all potential household food insecurity experiences as it concentrates on perceptions, attitudes and feelings. It however does not allow gender, household or demographic characteristics and their interactions, as covariates in the model when computing security scores for individual households (Owino et al., 2014).

Another demerit is that generalization from the model could be misleading. Given that it uses a one dimensional scale, it leaves out from its analysis household food experiences that are multidimensional. For example, the cultural experiences of different individuals (Owino et al., 2014)

2.4.3 Vulnerability Analysis Model

Many of the solutions and food policies provided concentrate on current conditions of different households. This model on the other hand provides a quantitative estimate of the probability that a given household will lose access to sufficient food in the near future. The model is used to construct an estimation procedure that can be easily replicated using data from a single household survey and whose results have a straightforward interpretation to come up with security policies. The model identifies the risks that households are exposed to. It also estimates the magnitude of the impact of these risks on household food security, depending on the risk management strategies adopted. This helps in policy making as it helps in the planning of interventions based on the likelihood that different risks will materialize, the expected food security impact of these risks on different types of households and the effectiveness of different risk management options (Capaldo, Karfakis, Knowles, & Smulders, 2010)

An advantage of this model is the additional flexibility in categorization of households. Unlike the static food security analyses which categorize households as “food secure” or “food insecure”, the model allows households to be classified into four categories of food security. That is “chronically food insecure”, “transitory food insecure”, “permanently food secure” and “transitory food secure". On the contrary, the downside of this model is the scarcity of relevant time series and panel data, which the models rely on (Capaldo, et al., 2010).

2.5 Information Systems on Food Security

2.5.1 Decision Support System for Agricultural Droughts and Food Security

The decision support system is a proposed system by Enenkel et al. (2015) that is intended to assist in assessing the agricultural drought situation and resulting food insecurity in a given area and to assist 'governments, aid organizations and people affected by drought to mitigate the resulting impact on both water resources and crops' (Enenkel et al., 2015).The aim of the system is to link scientific findings to actual user requirements of governments and aid organizations, and to turn data streams into useful information for decision support. The system uses different approaches ranging from the integration of satellite derived soil moisture measurements that link atmospheric processes to anomalies on the land surface, to the use of smartphone applications to validate satellite derived datasets, or collect additional information or to disseminate relevant information to users (Enenkel et al., 2015)

One of the benefits attributed to the system is its ability to make reliable predictions regarding the location and magnitude of drought and food security in an area, months in advance. The downside however, is that information derived from this system is focused at a continental or global scale. The information is not tailored to the needs of end users.

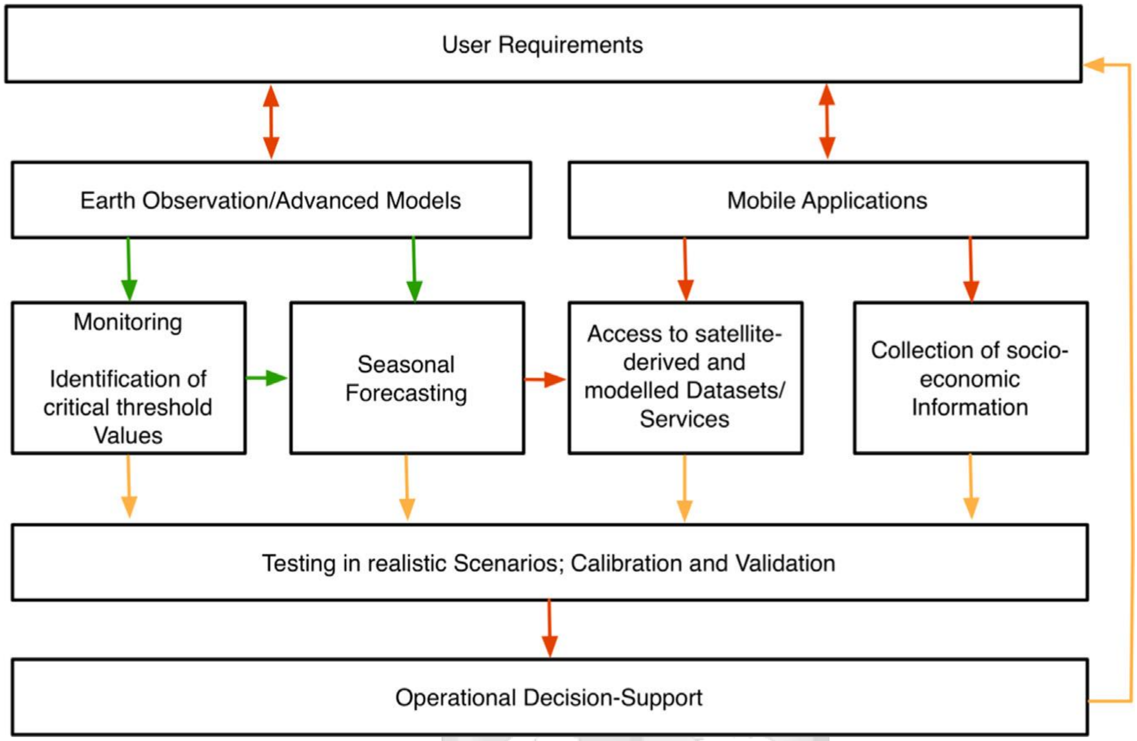


Figure 2.5 Decision Support System
(Enenkel et al., 2015)

2.5.2 The Philippine Food Security Information System (PhilFSIS)

This is a web based information system whose establishment was funded by the FAO in the Philippines in 2012. The aim of the system's development was 'to enhance food security planning, implementation and evaluation through improved organization, analysis and dissemination of relevant information'. The approach of the system is commodity specific, and this includes the top ten foods that are important in the daily diets of the Filipino households. The system consists of 13 modules, two of which are related to food security; Food consumption and Nutrition and Food Self-sufficiency and Security. 'Central in the operationalization of this information system is the PhilFSIS website' (Recide, R.S. & Jalisan, J.B., n.d.).

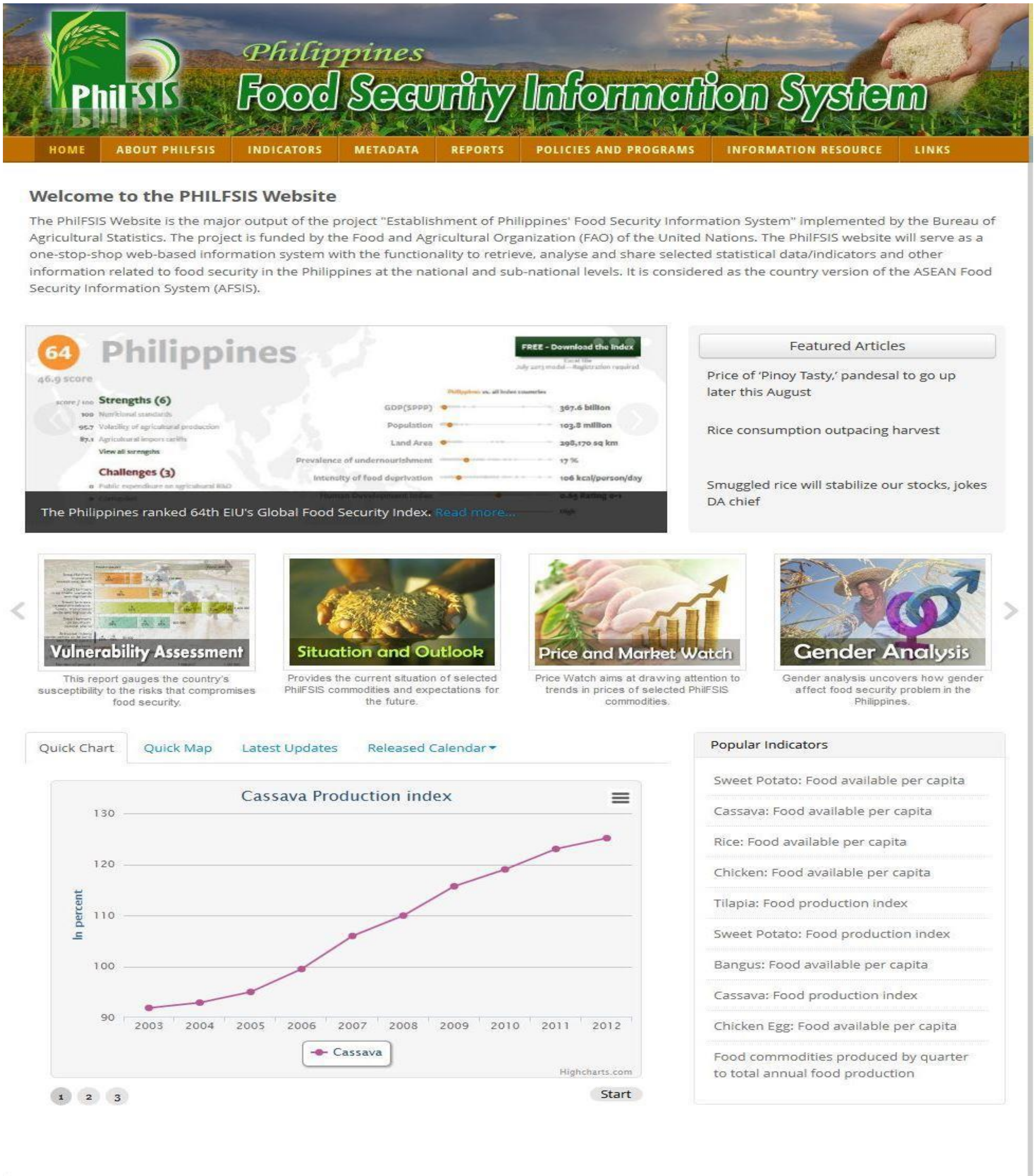


Figure 2.6 PhilFSIS Information System
(Recide,R.S & Jalisan, J.B., n.d)

2.6 Food Security Challenges

There are some challenges that are encountered when assessing food security using the different indicators and models available. The following are some of the challenges that are encountered in the measurement of food security.

Biased Information: Collecting data from interviews, either from individuals or households leads to data that is not easily measurable in an objective manner. Information collected could be biased, with respondents providing information that are influenced by their perceptions and or their respective cultural backgrounds on the issue of food security (Owino et al., 2014).

Biased Measurement: Food security is a multidimensional aspect. There are many indicators and models that are used to measure food security. As a result, there is no defined way that is acceptable worldwide that can be used to measure food security. Results obtained from different indicators are always relative to the indices used to measure food security.

Outcomes Determined by Food Security Index or Model used: There is the possibility of some biased results depending on the model or index used to measure food security in a selected region. It is difficult to determine which method would provide the best results when applied to a given population. In most cases, the decision on the method to use is usually the researcher's.

2.7 Conceptual Design

The prototype showing trends for agricultural data will be developed to show future trends in production, for food security policy implementation. To curb the slow data collection process, online datasets from a credible institution, which is the World Bank Group, will be used. The area of concentration will be rainfall data from 2001 to 2015. Further limitations discussed and which the prototype will address will include the use of a single database and a system that can address food security using data that represent statistics at a national level.

2.7.1 Research Variables

According to Degu & Yigzaw (2006), a research variable is 'a characteristic of a person, object or phenomenon that can take on different values'. The variables to be studied are selected on the basis of their relevance to the objectives of the investigation (Degu & Yigzaw, 2006). The variables that the researcher intends to use to measure food security for the selected area of study are grouped into two broad categories:

2.7.1.1 Independent Variables

These are the variables that are used to describe or measure the factors that are assumed to influence the problem(Degu & Yigzaw, 2006).They are the input variables to a model, which can be changed by the researcher in order to influence the output. The independent variable that the researcher intends to use is climate data, sourced from the World Bank Group online portal, between the years 2001 and 2015, and which will be used to compute the outcome of the research. This is mainly rainfall data.

2.7.1.2 Dependent Variables

These are the variables that are used to describe or measure the problem under study. These variables are affected by the independent variables. In the study that the researcher is undertaking, the outcome of the forecast will form the dependent variable.

Chapter 3 Research Methodology

3.1 Introduction

Research methodology refers to the procedures by which researchers go about their work of describing, explaining and predicting phenomena. It is also defined as the study by which knowledge is gained. It is necessary for a researcher to design a methodology for the research problem. Research methodology details the research variables used, the data collection methods, the types of data collected, and how the data will be processed. It also details the sampling methods that the researcher intends to use and the development approach used to come up with a solution. The suitability of the methodology chosen for the research problem is determined at this point (Rajasekar, Philominathan, & Chinnathambi, 2006).

The data collection methods used is largely determined by the research design selected, which is in turn determined by the research problem and objectives (Degu & Yigzaw, 2006). Moreover, to come up with a solution, an analysis of the data collected provides the researcher with an opportunity to describe the outcome of the research. To guide the entire research process, usually the researcher outlines a plan of how the activities that make up the entire research methodology will be executed

3.2 Unit of Analysis

The unit of analysis that will be used will include datasets obtained online. That is, rainfall data from the World Bank Group.

3.3 Research Design

A study design is the process that guides researchers on how to collect, analyze and interpret observations(Degu & Yigzaw, 2006).The type of research design that the researcher intends to use is historical design. ‘Historical studies concern the identification, location, evaluation, and synthesis of data from the past. Historical data should be subjected to both external and internal criticism. External criticism is concerned with the authenticity of the data, whereas internal criticism is concerned with the accuracy of the data'. ("Qualitative Research Designs", n.d). The research design will also be quantitative as the researcher will be using quantifiable variables to compute outcomes in the prototype that is to be developed. This will include rainfall precipitation data between the years 2001 and 2015.

3.4 Research Site

Improving access to food for its people is a key factor for the Kenyan government and other private institutions such as ASCU and the Famine Early Warning Systems Network Kenya (FEWS NET KENYA). According to a report by FEWS NET KENYA food security is gradually declining as food commodities' supply to the markets dwindle, while market demand continues to increase. The situation is attributed to the below- average crop production in the country.

The research rainfall precipitation data which form the dataset used in the research covers the entire Kenyan region.

3.5 Population/Sampling

3.5.1 Population

The research population refers to a group of individuals' persons, objects, or items from which samples are taken for measurement (Mugo Fridah, 2011). For example, a population of people or records. The population under study is defined in terms of place and time and is usually determined implicitly at the time when the research problem is selected. The proposed population is one that would provide the required information. In some cases, the researcher may require purposively selecting a study population, and in so doing, she must consider questions of appropriateness and practicability (Degu & Yigzaw, 2006). The population for the research will be the rainfall data dating between the years 2001 and 2015 making the population size 15.

3.5.2 Sampling

A sample is a finite part of a statistical population whose properties are studied to gain information about the whole. Sampling on the other hand is the act, process, or technique of selecting a suitable sample, or a representative part of a population for the purpose of determining parameters or characteristics of the whole population(Mugo Fridah, 2011). The research will consider the sample size and sampling method as follows:

3.5.2.1 Sampling Method

Samples from online repositories will be collected using purposive sampling method. This sampling method involves purposive or deliberate selection of particular units of the universe for constituting a sample which represents the universe(Alvi, 2016). This is due to the nature of data collection, which is being done from online sources.

3.5.2.2 Sample Size

The sample frame for the proposed study is composed of online rainfall data from the year 2001 to 2015. 'Statistical tests of forecast performance are commonly conducted by splitting a given data set into an in-sample period, used as an initial parameter estimation and model selection, and an out of sample period to evaluate forecast performance'… 'The sample split defining the beginning of the evaluation period is a choice variable'(Hansen & Timmermann, 2012). 'The accuracy of forecasts can only be determined by considering how well a model performs on new data not used to estimate the model, with the size of the test data being typically about 20% of the total population'. (Hyndman & Athanasopoulos, 2014).

Selection of data will be accomplished as follows:

Population size is from years 2001 to 2015 =15 years

Sample split=80%: 20%

In Sample period/ Sample size = 80% * population size = 12 years

Out of Sample Period/ Forecast period = 20% * population size = 3 years

3.6 Data Collection Method

The sources of historical data are frequently referred to as primary and secondary sources.

Primary Data

Primary sources are those that provide firsthand information or direct evidence. Primary data was sourced from case study material from the Agricultural Sector Coordination Unit, a government institution that implements policies on Food security. The institution reports on the levels of food security in Kenya in its policy implementation.

Secondary Data

Secondary sources are secondhand information, or sometimes third or fourth hand. Secondary data will be collected from the World Bank Group online portal, mainly rainfall data.

3.7 Data Analysis Method

The analysis of data requires a number of closely related operations and then drawing statistical inferences. Analysis of data is performed to ensure that the data is complete and consistent. Exploratory Data Analysis is ‘a method of looking at data that does not include formal statistical modeling and inference’, usually to detect mistakes and assist in the preliminary selection of appropriate models(Seltman, 2012). The researcher will analyze secondary data collected by performing an exploratory analysis to determine the proportion of any missing data within the dataset, for the selected years.

3.8 Prototype Design and Development Approach

The development approach selected for this research is the Rapid Application Development (RAD). ‘The aim is to produce high quality systems quickly through the use of iterative prototyping (at any stage of development) with the use of computerized development tools. These tools may include Graphical User Inter Computer Aided Software Engineering (CASE) tools, Database Management System (DBMS), fourth-generation programming languages, code generators, and object-oriented techniques. Key emphasis is on fulfilling the business need, while technological or engineering excellence is of lesser importance' (Mukumbira, 2013).

The aim, at the end of the systems development phase, is to come up with a prototype of a food security information system. The selected approach is arrived at on consideration of the time constraints involved in the project process. There are also changes in the overall design of the system which are expected to take place during the development process. The RAD approach selected will be combined with prototyping.

The RAD method, according to Mukumbira (2013) and Centers for Medicare & Medicaid Services(2008) consists of the following steps:

Initial Investigation: This phase involves defining the type of system that is to be developed. In this case, it is a prototype to measure/predict household food security (outcomes).

The initial investigation phase is followed by an iterative three step phase which consists of the following:

i. Requirements definition

This phase involves defining the problem and the inputs to the system. Achievement of the above mentioned involves the use of document reviews and use of data obtained from an online portal. The main input to the system will include the rainfall data selected for the study.

ii. System design

The achievement of this phase is done via the use of Unified Modelling Language (UML) diagrams. It will include the drawing use case diagram, UML sequence diagram, data flow diagram and class diagram to map out the entities to the system. The diagrams will also be used to show the inter-relationships between the entities.

iii. Systems development and testing.

This entails coming up with a workable prototype, and various tests done on the prototype to determine its usability. The development phase involves coming up with the prototype; mainly the rainfall forecasts from the inputted data.

The testing bit involves performing checks against the requirements, to determine whether or not the requirements have been met. It will include identification of failures against expected results. Some of the tests that are anticipated include functional testing, which will be mapped to the requirements, and usability testing to determine whether the system is usable.

The three iterative phases result in the development of a prototype for rainfall forecasts, which keeps improving with increased iterations. The last two stages include the following:

iv. System Implementation.

This entails setting up the prototype in an environment where it can then be operational. The prototype will be run from a local PC.

v. System Maintenance.

This phase involves making changes to the system once it has become operational. The process may involve system amendments following future changes in requirements, or addition of new features with the introduction of new requirements or updates in existing requirements. The objective is usually to improve the user's experience.

Implementation and maintenance of the system come after testing. The two steps will not be followed through in the case of this research.

Below is an illustration of the prototyping approach which will be used as part of RAD.

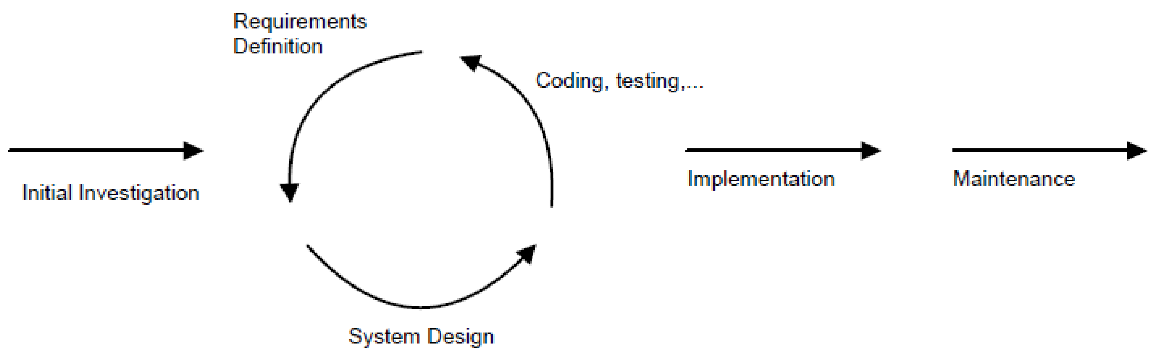


Figure 3.1 Prototyping Development Approach
(Centers for Medicare & Medicaid Services, 2008)

Chapter 4 System Design and Architecture

4.1 Introduction

The architecture of a computing system, according to the Carnegie Mellon software engineering institute, is 'the structure or structures of the system, which comprise software elements, the externally visible properties of those elements and the relationships among them' (Rozanski & Woods, 2005). The researcher will discuss the outcome of the data collected. To display the data analysed, the use of bar graphs and a line graph will be employed. The functional requirements which also consists of the elements of design will be discussed, with design diagrams being used to show the relationships between elements and the flow of information between entities. The quality requirements of the proposed prototype will also be discussed, in addition to the system architectural style selected.

4.2 Data Analysis

The researcher collected data consisting of rainfall data between the years 2001 and 2015 from the World Bank Group's Climate Change Knowledge Portal. The rainfall data is broken further into data per month, for each year, and the also converted to annual average yearly rainfall. Rainfall data coverage is for the entire Kenyan region.

4.2.1 Trends in Rainfall Amount

Rainfall data selected for the study represents a section of a wider dataset covering rainfall in millimeters in Kenya. An analysis of the rainfall recorded trends for each year over the selected duration of 15 years is outlined as follows:

4.2.1.1 Year wise Trends in Rainfall Amount – Year 2001

The year wise trends in recorded rainfall are done for the years appearing at the beginning, middle and end of the dataset.

The first analysis is for the year 2001, which is the first year in the dataset. The rainfall amount recorded indicates overall fluctuations in the entire year, with relatively higher numbers of above

60 mm recorded in the months of January, April and November. The lowest rainfall amount recorded was in the month of February, followed by the month of September.

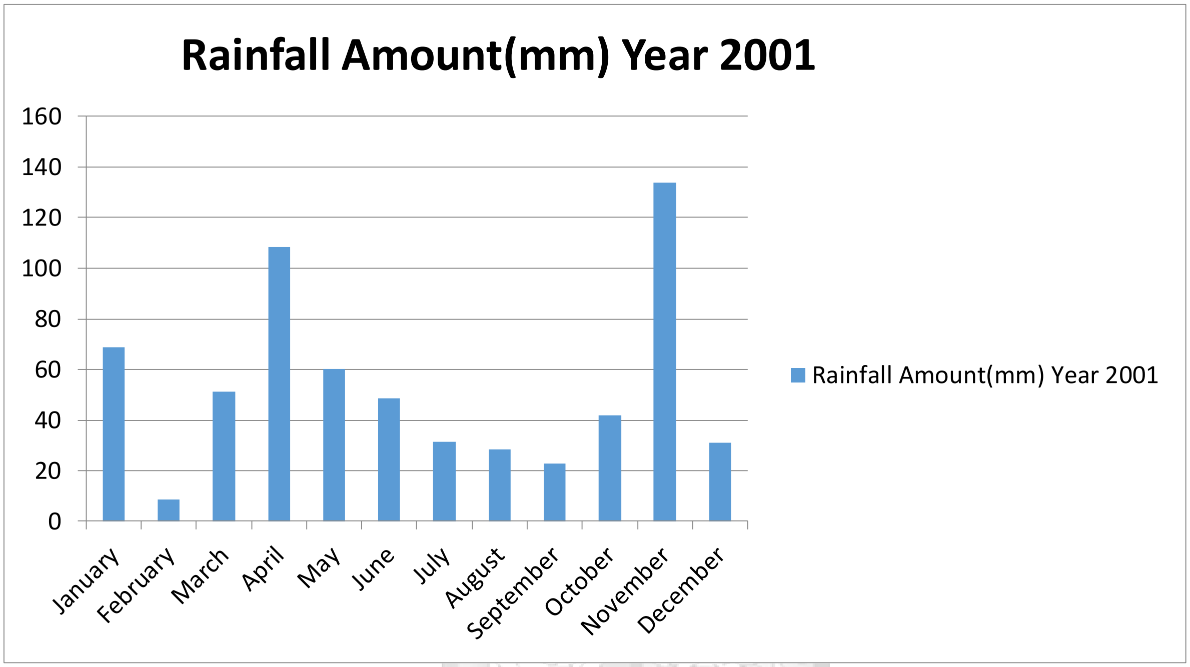


Figure 4.1 Trends in Rainfall for Year 2001

4.2.1.2 Trends in Rainfall Amounts for Year 2008

The rainfall amounts recorded in 2008 indicates high rainfall amounts in the months of March and November, with rainfall amounts of over 100mm. In between, there is a steady decline in rainfall amounts from March to July, followed by a rise in rainfall amounts in the subsequent months up until the month of November. The months of January, February and December also recorded relatively low amounts of rainfall of below 40mm.

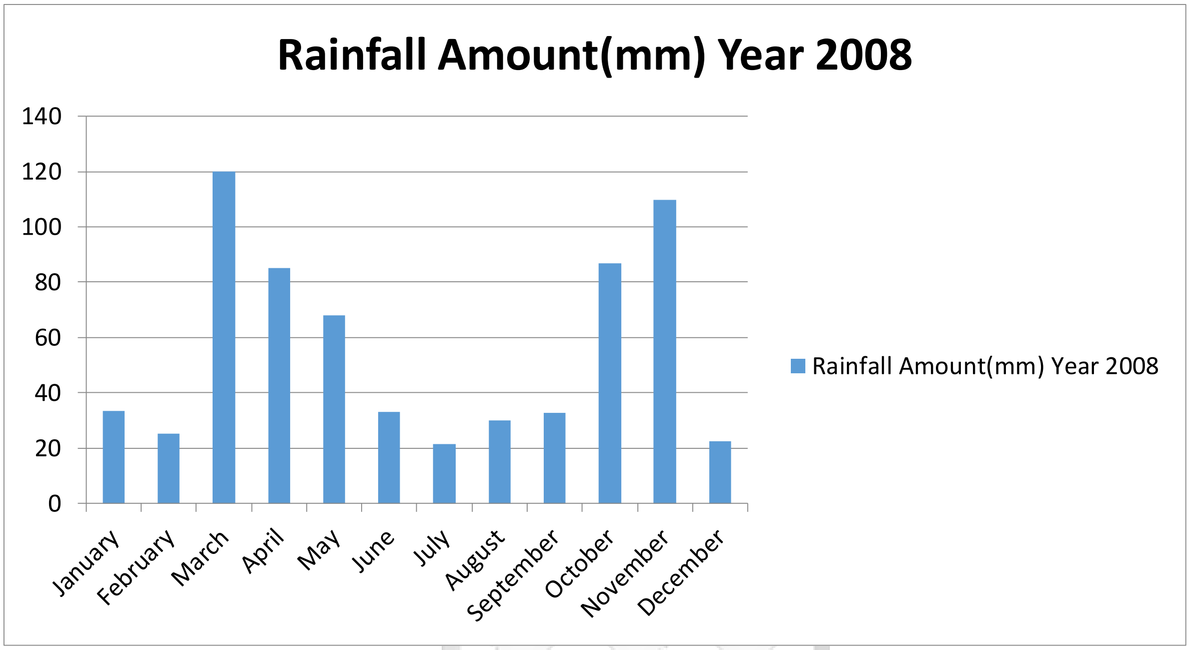


Figure 4.2 Trends in Rainfall for Year 2008

4.2.1.3 Trends in Rainfall Amounts for Year 2015

The year 2015 is the last year in the rainfall dataset. Rainfall amounts recorded during the first two months are relatively low at slightly over 20mm. However, there is a rise in the rainfall amounts recorded in the months of March and April, with April recording the second highest amount of rainfall in the year at slightly over 140mm. There is a decline in rainfall amounts from May to August, followed by a rise in recorded amounts in the months of September to November, with the highest amount of rainfall recorded in November. There is a significant drop in recorded rainfall amounts in December. In general, the rainfall amounts recorded show fluctuations throughout the year.

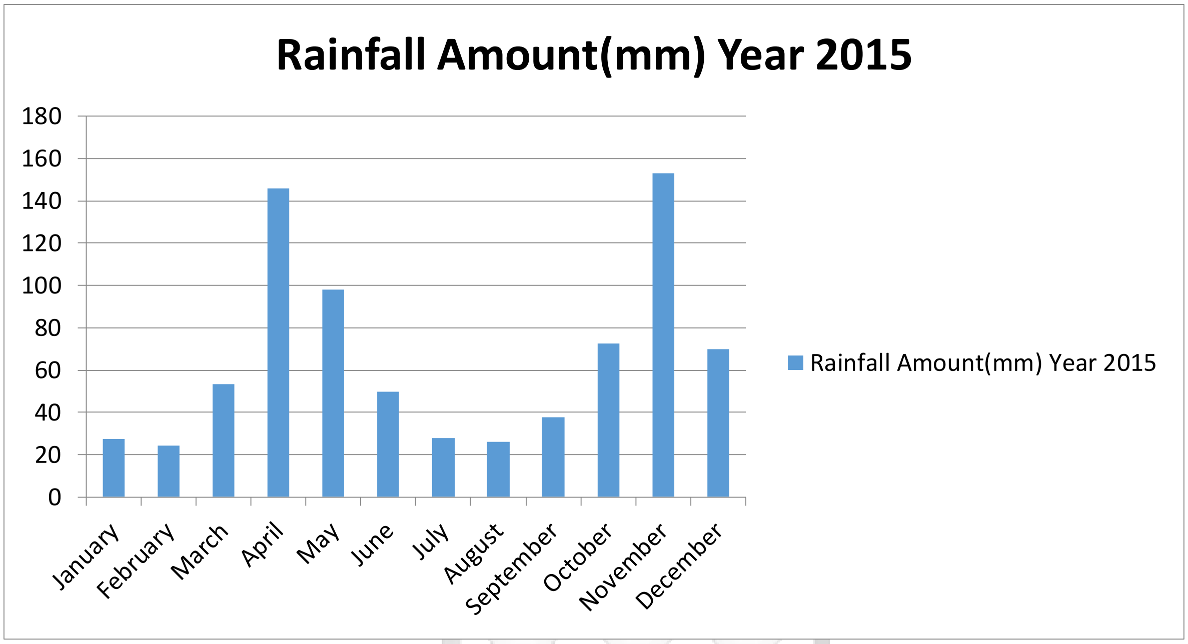


Figure 4.3 Trends in Rainfall for Year 2015

4.2.2 Comparison of Overall Yearly Rainfall Trends

A comparison of the overall rainfall amounts indicates an overall trend of fluctuations for the different years. There are some years that recorded higher numbers during the selected period of study. A case in point is the year 2006, which recorded much higher average yearly rainfall numbers at over 60mm. The same applies for the years 2013 and 2015. The year 2005 recorded the lowest rainfall amount on average. There was also a general decrease in rainfall amounts from the years 2002 and 2005, and again between the years 2006 and 2011. A reverse in rainfall patterns shows between the years 2005 and 2006, where the highest increase in rainfall amounts is recorded. Increased rainfall is recorded again between the years 2011 to 2013 and again from 2014 to 2015. The equation below was used to compute the average rainfall amount for each year for the dataset.

Equation 4.1Average Annual Rainfall

$$Average\ rainfall\ per\ year\ \bar{x} = {\sum_{i=1}^{n} x_i}/{n}$$

Where:

$\bar{x}$= Average rainfall computation for each year.

n = Total number of months per year.

x_i= Rainfall ith observation for rainfall variable x.

$\sum_{i=1}^{n} x_i$= summation of all the x_i values for each year.

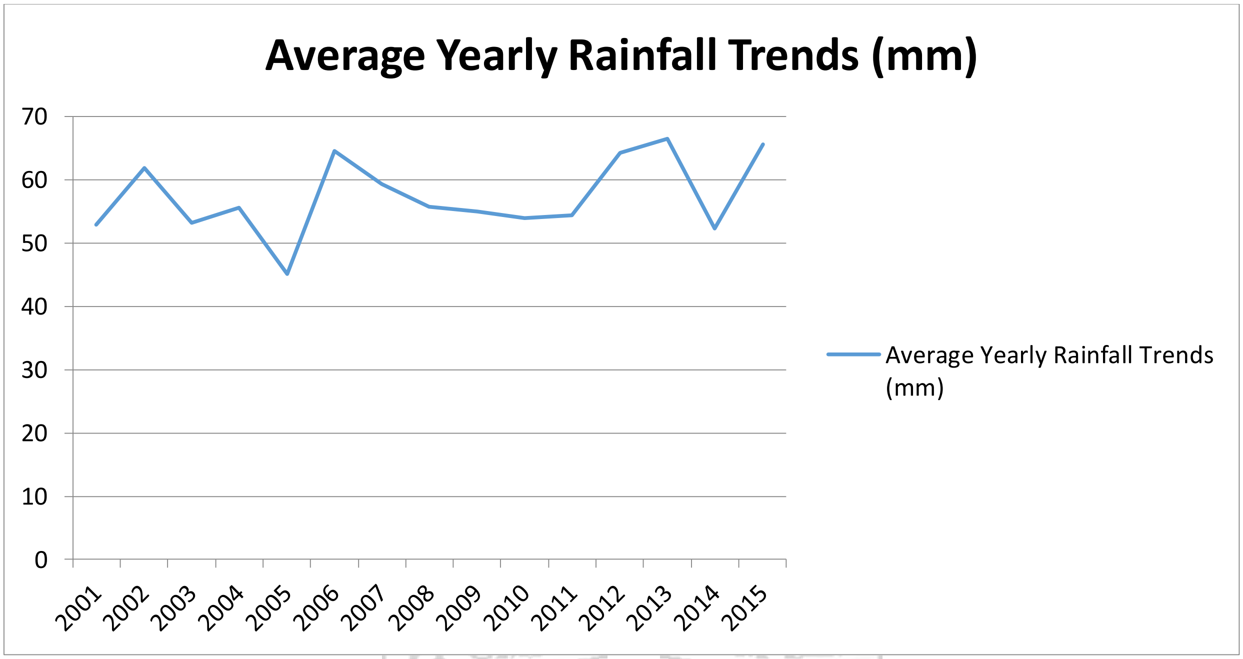


Figure 4.4 Overall Yearly Rainfall Trends 2001 to 2015

(Average Annual Rainfall)

4.2.3 Overall Year Wise Performance

The performance in terms of numbers reported for the selected years was based on Figure 4.6 above. In general, the year that recorded the best results in terms of rainfall amounts, was the year 2013. The highest average yearly rainfall amounts reported were at over 66mm. The lowest numbers for the selected years of study were reported in 2005.

4.3 Functional Requirements

Functional requirements of a system ‘capture the intended behavior of the system, which could be in the form of services or functions that the system is required to perform’(Malan & Bredemeyer, 2001). To capture functional requirements, the researcher used use case, class diagrams, data flow diagram and sequential diagrams.

4.3.1 Use Case Representation

A use case defines a set of interactions between external actors, who are the parties outside the system who interact with the system, and the system under consideration (as cited by Malan & Bredemeyer, 2001). The use case diagram shows how the two main users, the analysts and the policy makers will interact with the system. The analyst will upload datasets to the system, process the data and finally output the results. The policy maker will access the information by viewing the processed data, and if need be, download the results for future reference. The policy maker can however double up as an analyst and therefore execute the role of the analyst, from beginning to end. The following is a use case representation of the policy maker and data analyst interacting with the food security prototype.

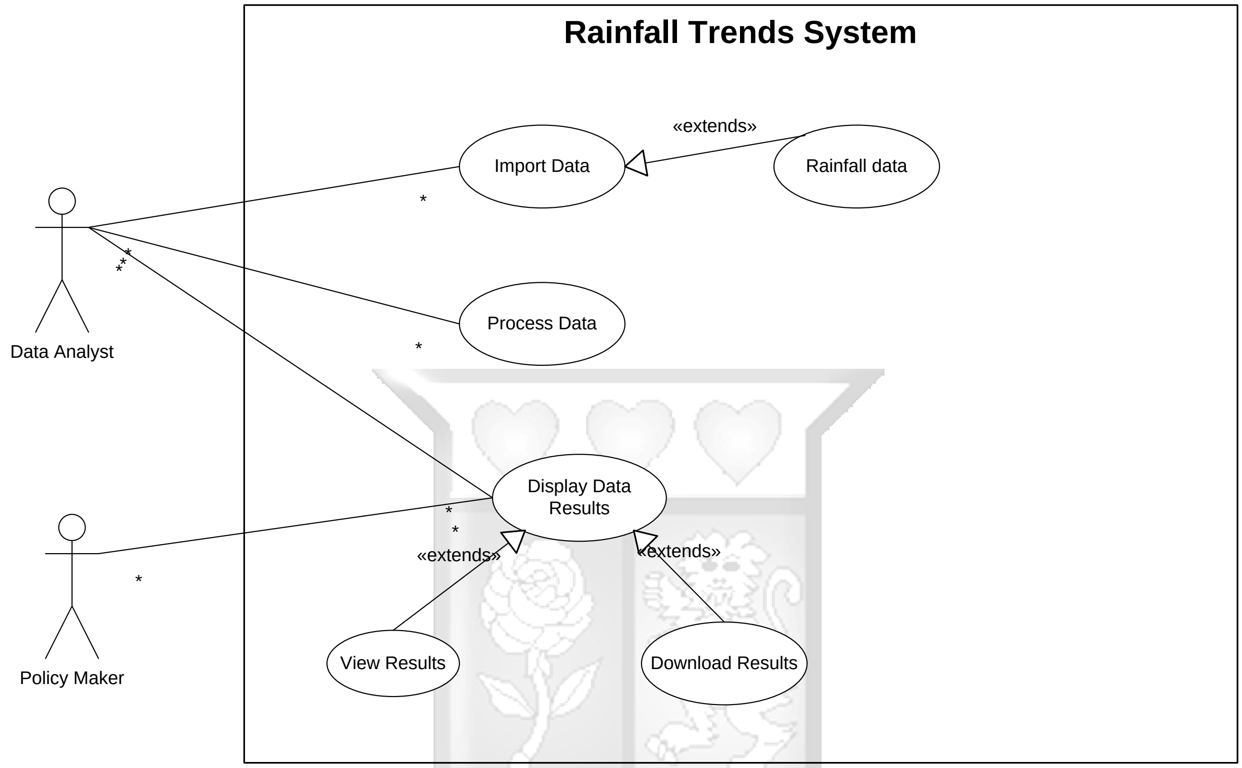


Figure 4.5 System Use Case Diagram

4.3.2 Data Flow Diagram

A data flow diagram represents the processes, data flows and external entities in a system. It also shows the connecting data flows(Aleryani, 2016). The data analyst, who takes up an administrative role in this case, is responsible with the upload of datasets in the system. In addition, the data analyst can process the data to show the prediction results. The role of the policy maker however is limited to processing uploaded data. The data diagram illustrates the processes between the data analyst and the system. It also shows the processes between the policy maker and the system.

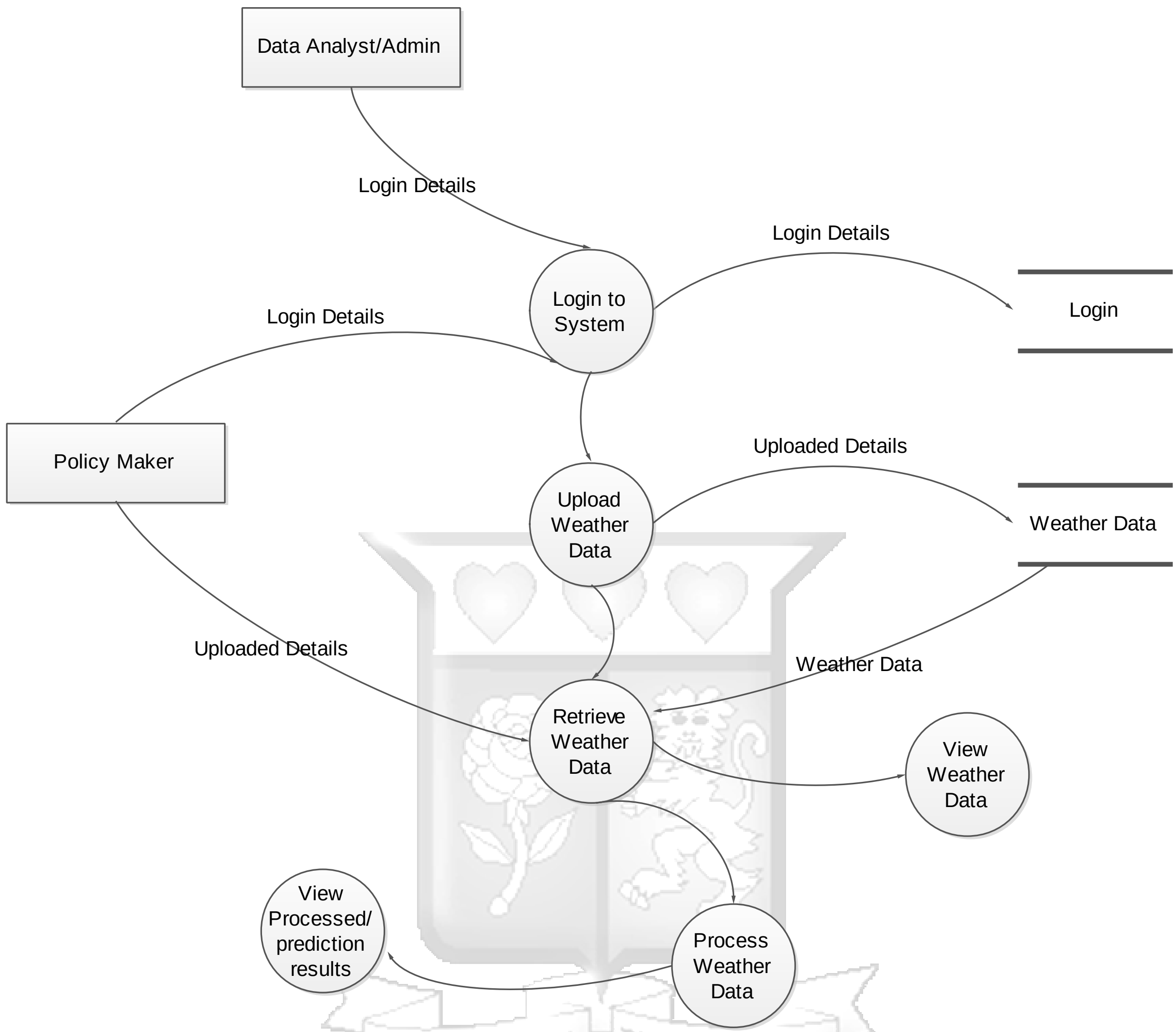


Figure 4.6 Data Flow Diagram

4.3.3 Sequential Diagram

A sequence diagram is an interaction diagram that represents the interaction between objects through messages. The objects communicate through messages, represented by horizontal arrows from the sender to a recipient of the message (Mukherjee, Upadhyay, & Achariya, 2015). The sequence diagram details the interaction between the system actors and the rest of the objects. In this case, the login interface, the database and the system front end.

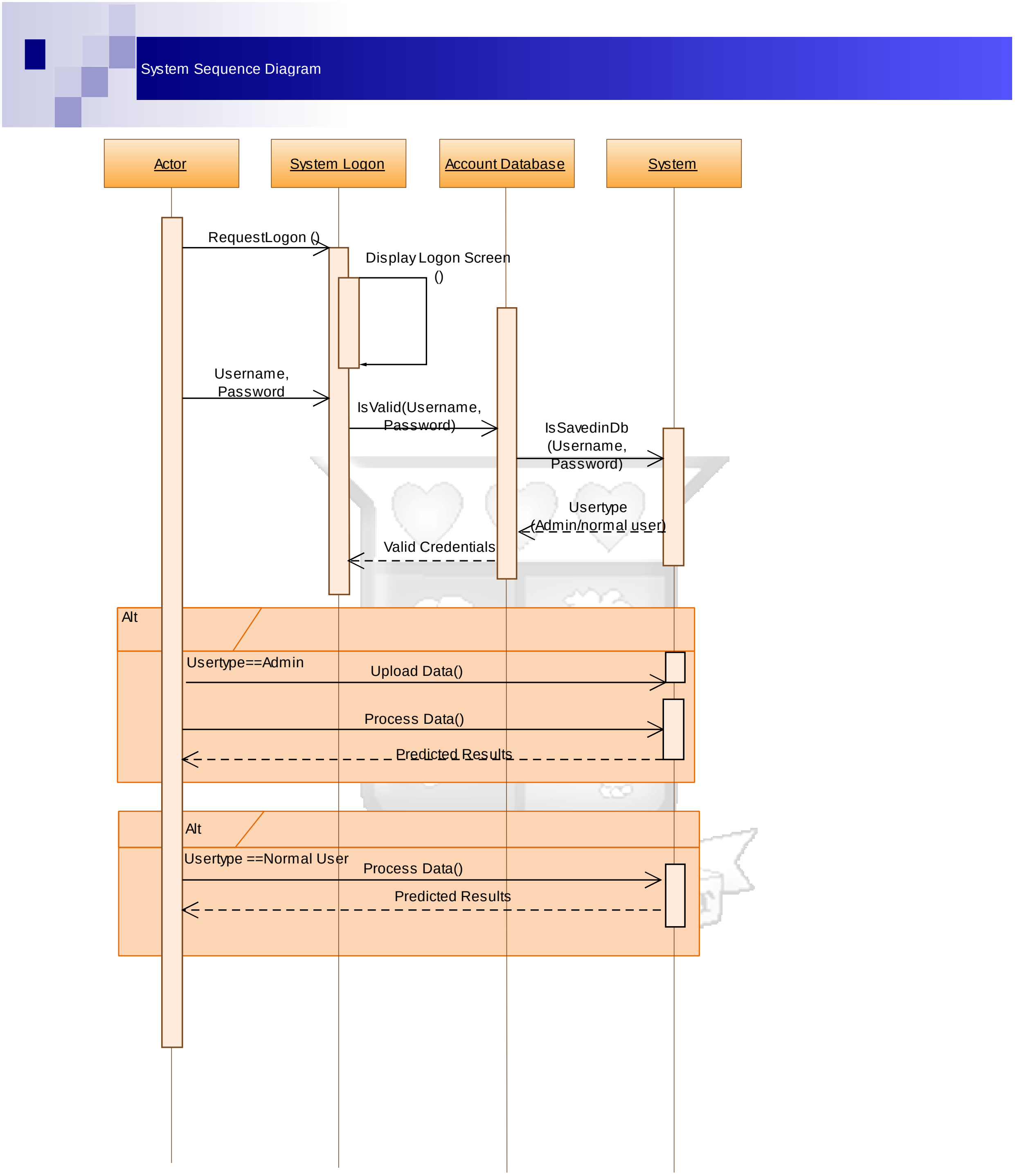


Figure 4.7 Sequential Diagram

4.3.4 Class Diagram Representation

A class diagram shows the static structures of an application or a database station. It also shows how the different entities which include people, things and data relate to each other (Lee, 2012). The food security prototype's static structures will be composed of entities which include the data analyst and policy maker, the wage employment dataset details and computed results. The class diagram will also show how the mentioned entities will relate to each other.

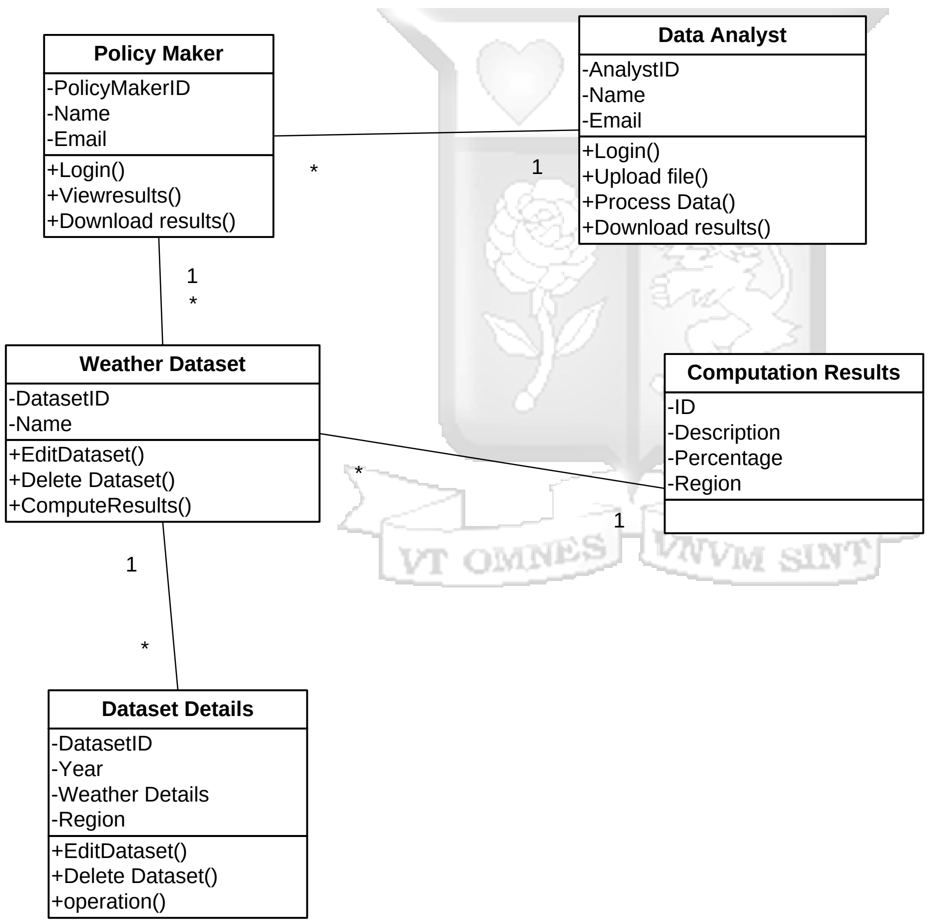


Figure 4.8 Class Diagram

4.4 Quality Requirements

A quality attribute or non-functional requirement is one that ‘restricts the product under development, development process, specifying external constraints to be met by the product’(Mahalakshmi & Prabhakar, 2013). One of the requirements that the system will meet is accessibility, whereby different users are able to access and utilize the user interface. Another attribute that will be tested will include reporting. This will mainly be the forecast reports generated from the proposed prototype.

4.5 System Architecture

Software architecture ‘is the high level structure of a software system…it sits between analysis/specification and design/implementation’(Clements, 2016). The architecture of the prototype will consist of a front end interface, where rainfall data will be uploaded and the resulting generated charts viewed. The researcher also intends to have a database to store uploaded data. The diagram below illustrates the architecture of the prototype.

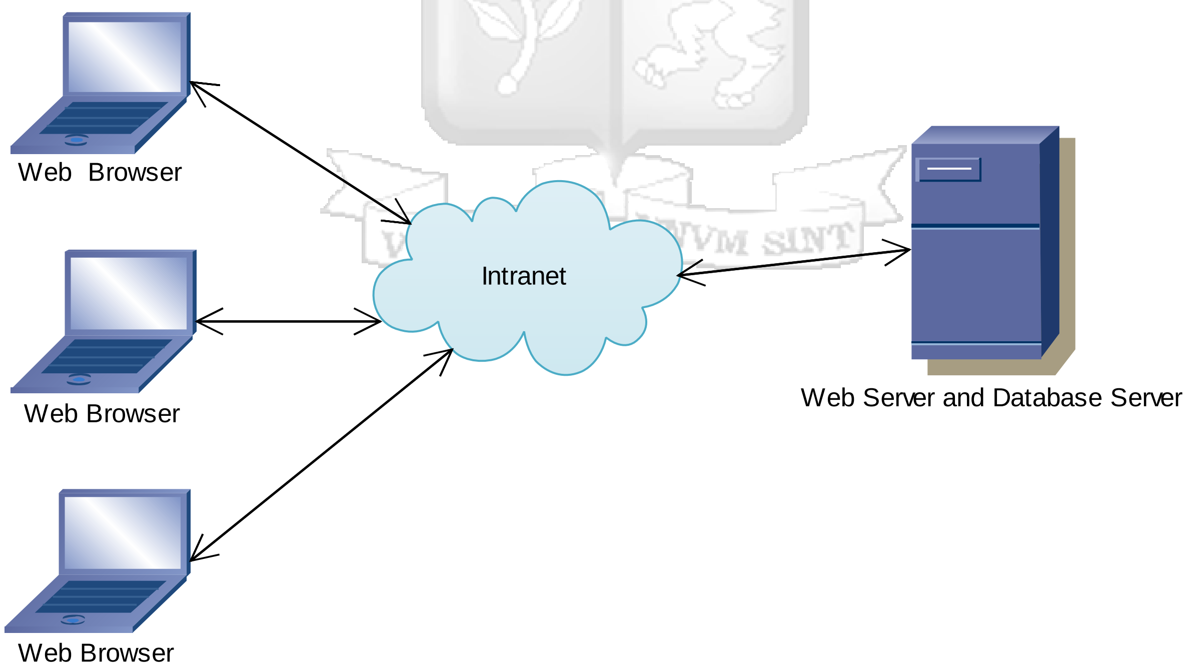


Figure 4.9 System Architecture

Chapter 5 Implementation and Testing

5.1 Introduction

The implementation phase of a system 'consists of developing and testing the system's software, documentation and operating procedures'(Dennis, Wixom, & Roth, 2012). This chapter discusses how the implementation process is to be done. It will include a discussion of the implementation environment, the outcome of the implementation and the test outcomes. Activities that were undertaken to implement the proposed prototype involved collecting the input data, rainfall data, processing of the data and the output of the resulting process.

5.2 Implementation Platform

The implementation was done on a Windows 7 machine, with the language of choice being R language. The language selection was based on the type of program implementation, which is a machine learning program implementation; R is one of the languages recommended for machine learning related programs. The development environment used was RStudio. Input data to the application was done by use of Microsoft Excel. Chart generation was done using R Forecast and Highcharts libraries. The prototype is run on a local personal computer.

5.3 Actual Implementation

5.3.1 Forecasts Derived from In Sample Data

The process of implementation involved the use of two datasets. The first dataset included only the in sample data, which included rainfall data from 2001 to 2012, whereas the second dataset included both in sample and out of sample data. The out of sample data includes rainfall data from 2013 to 2015. The in sample data was used to first generate the resulting rainfall patterns, as shown:

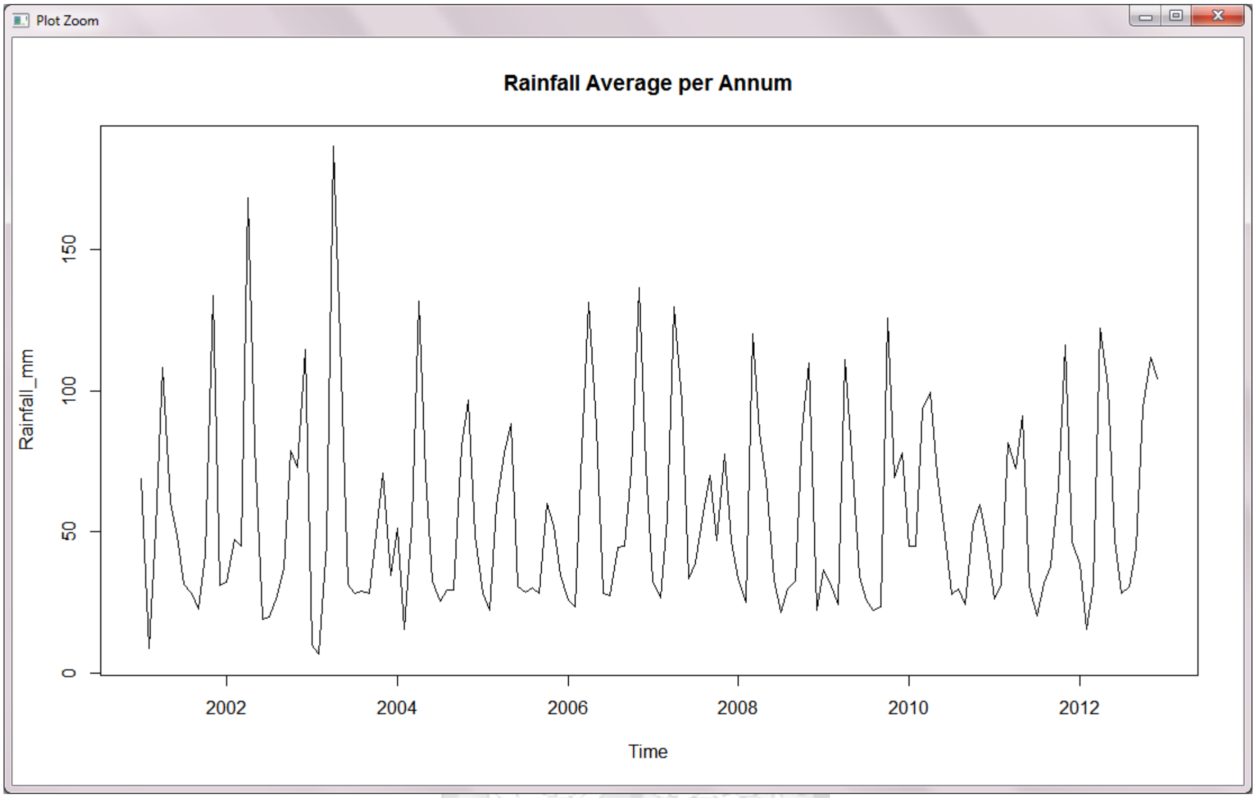


Figure 5.1 In sample rainfall data.

To train the data for predictability, the Holts Winters method was used to test for data fitting. Holt Winters is an approach used to forecast outcomes for data that contains a trend and seasonal pattern. ‘All data values in the dataset contribute to the calculation of the prediction’(Tirkeş, Güray, & Çelebi, 2017) The resulting graph after data fitting is as shown below, with the initial data in black color and the fitted data in red color.

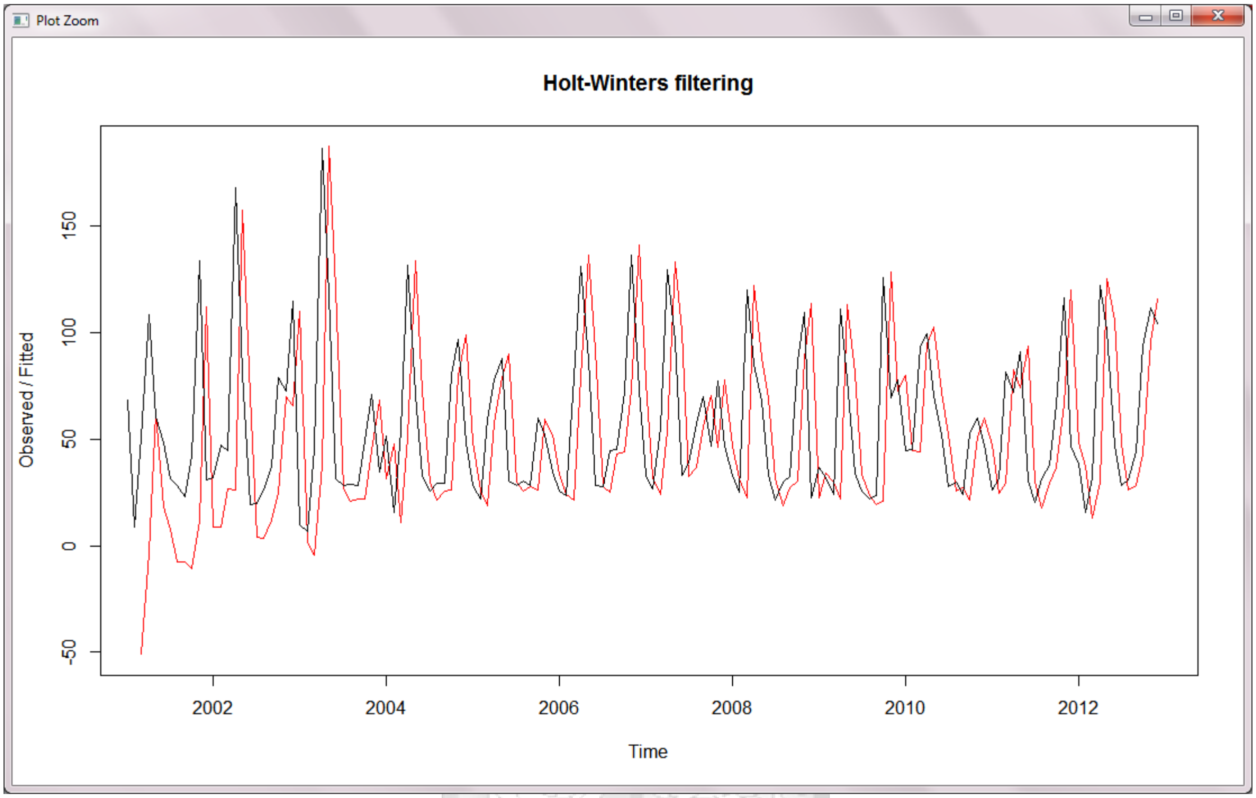


Figure 5.2 Observed and fitted data using Holt Winters approach

The above graph shows the fitted data for the uploaded data ending the year 2012, which allows for a prediction to be done from the years 2013. To predict the rainfall amount from the years 2013, the confidence levels used were at 80% and 95%. The following graph shows the prediction done from the year 2012, which marks the end of the in sample data. The areas shaded in grey indicate predictions at a confidence level of 80%, while the areas in pink indicate predictions at a confidence level of 95%. The forecast line is marked in black.

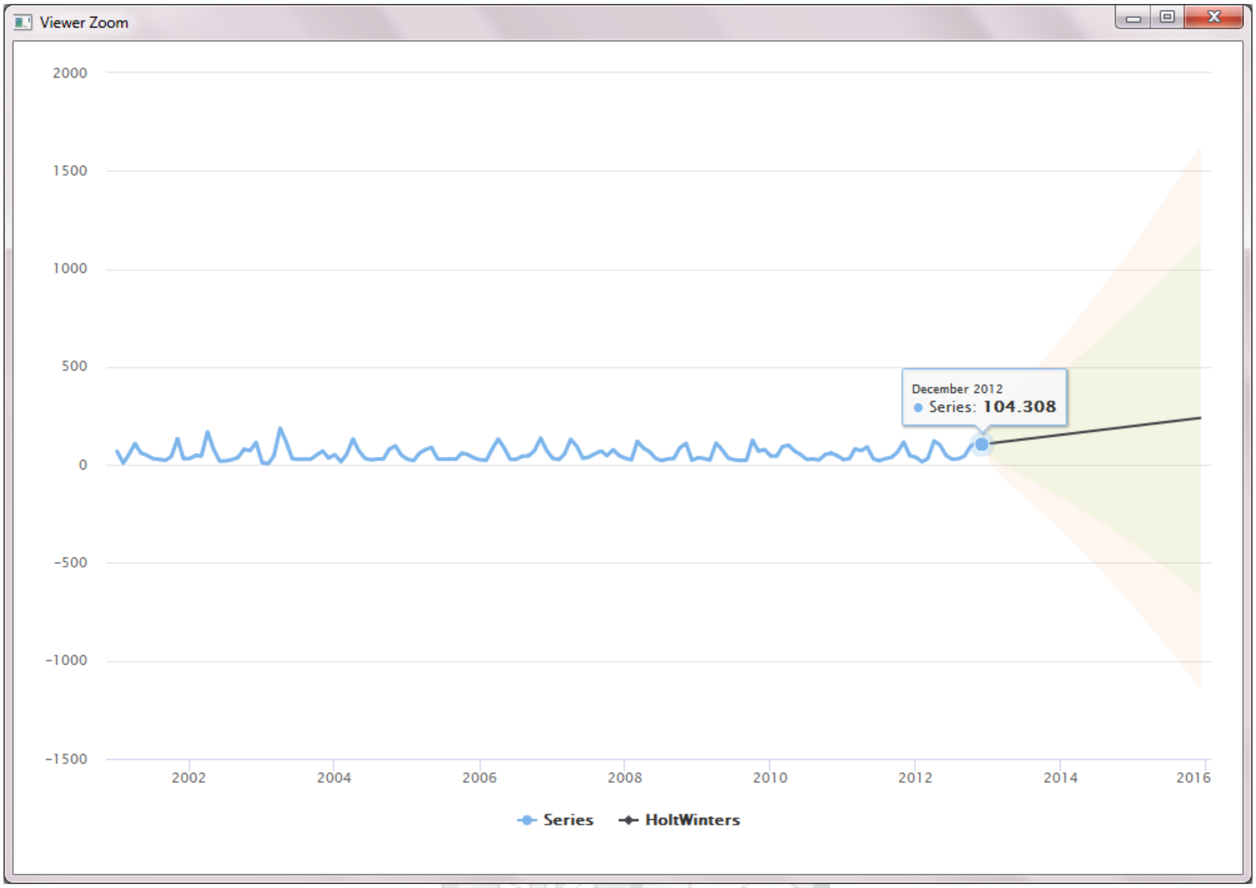


Figure 5.3 Forecasting using Holt Winters Approach.

5.3.2 Comparison between Forecasted Data and Actual Data

To determine the level of accuracy of the forecasted data, a comparison is done by beteen data from the out of sample dataset, and compared to the projected numbers from the in sample dataset. The below graphs indicate projected data from the in sample dataset. At a confidence level of 80%, the projected numbers for the month of April 2014 falls within the range of -219.14mm and 548.17mm. At a confidence level of 95%, the projected numbers fall within the range of -422.24mm and 751.27mm.

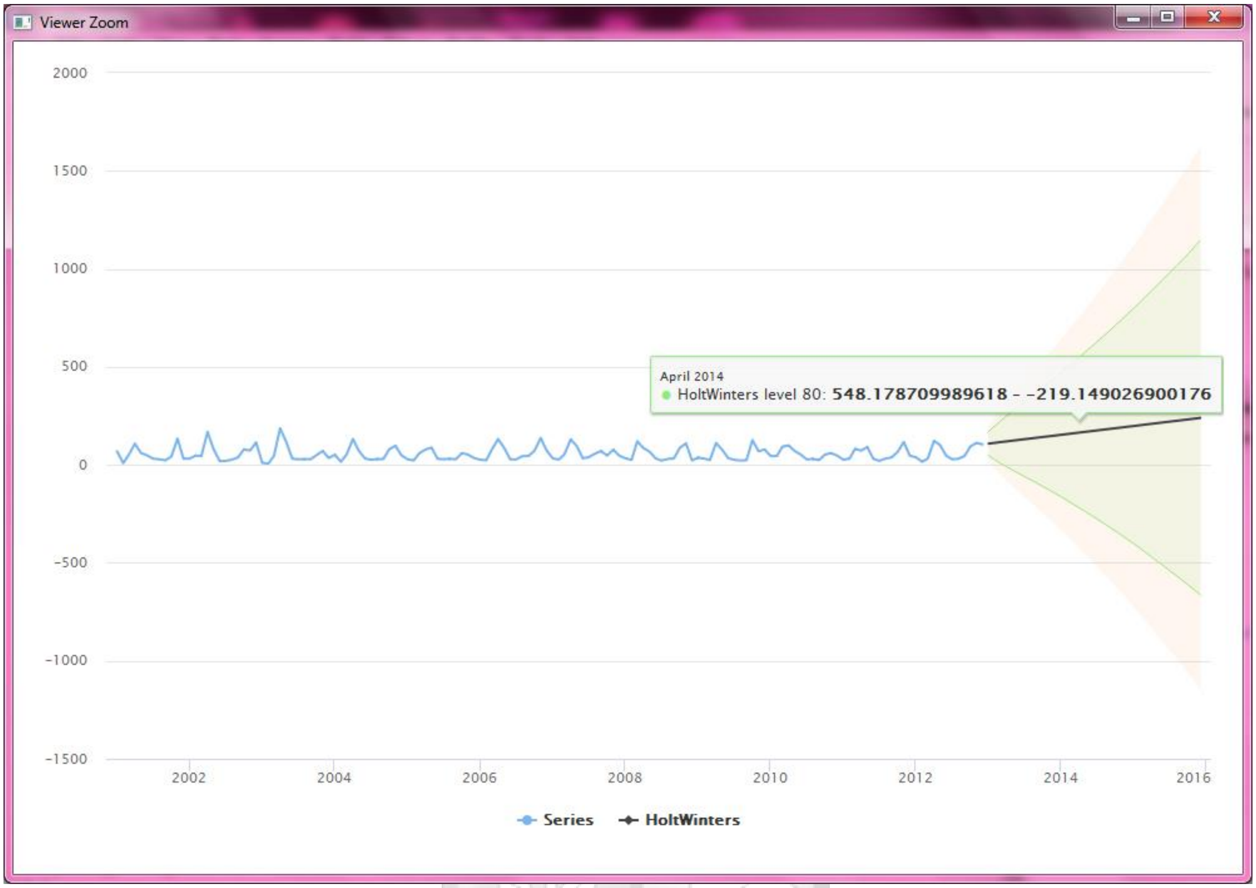


Figure 5.4 Forecast at 80% confidence level

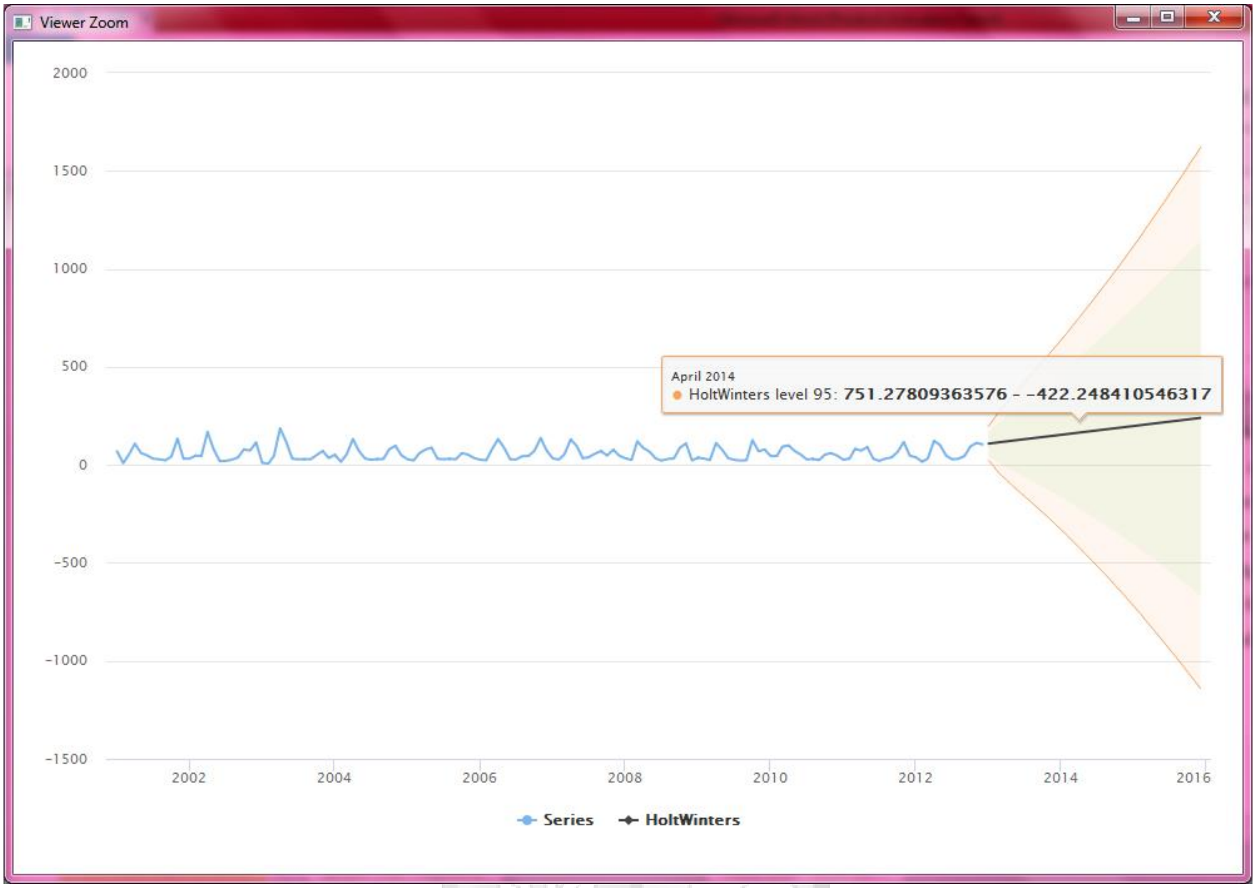


Figure 5.5 Forecast at 95% confidence level

The actual data from the out of sample dataset indicates a recorded rainfall amount of 69.89mm. This falls within the projections made at 80% and 95% confidence levels.

5.3.3 Forecasts from In Sample and Out of Sample data.

The same process was applied using the entire dataset. The dataset details trends in monthly rainfall data from 2001 to 2015. The resulting output is used to forecast trends in rainfall amounts for the years beyond the years appearing in the dataset, as outlined as follows:

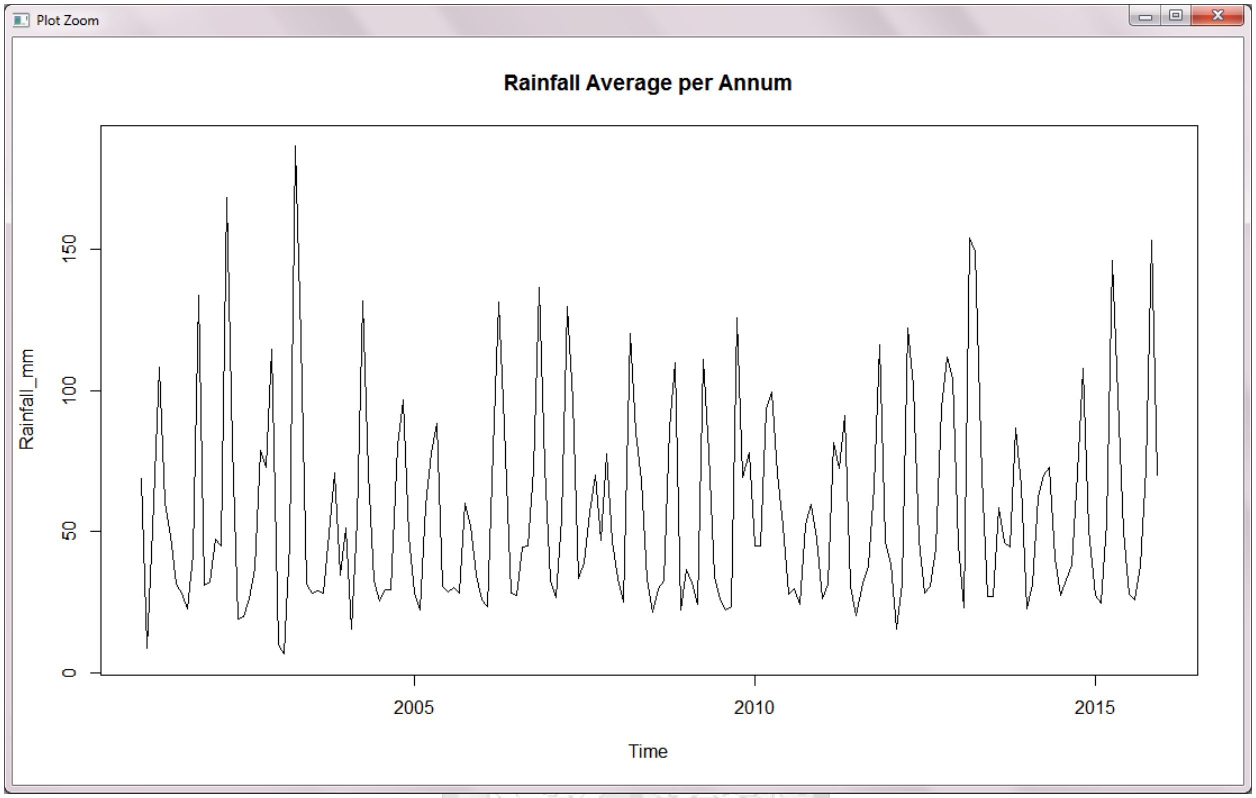


Figure 5.6 Rainfall data trends for In and Out of sample data

Holt Winters approach was also applied to the above graph for data fitting, reluting to the below graph:

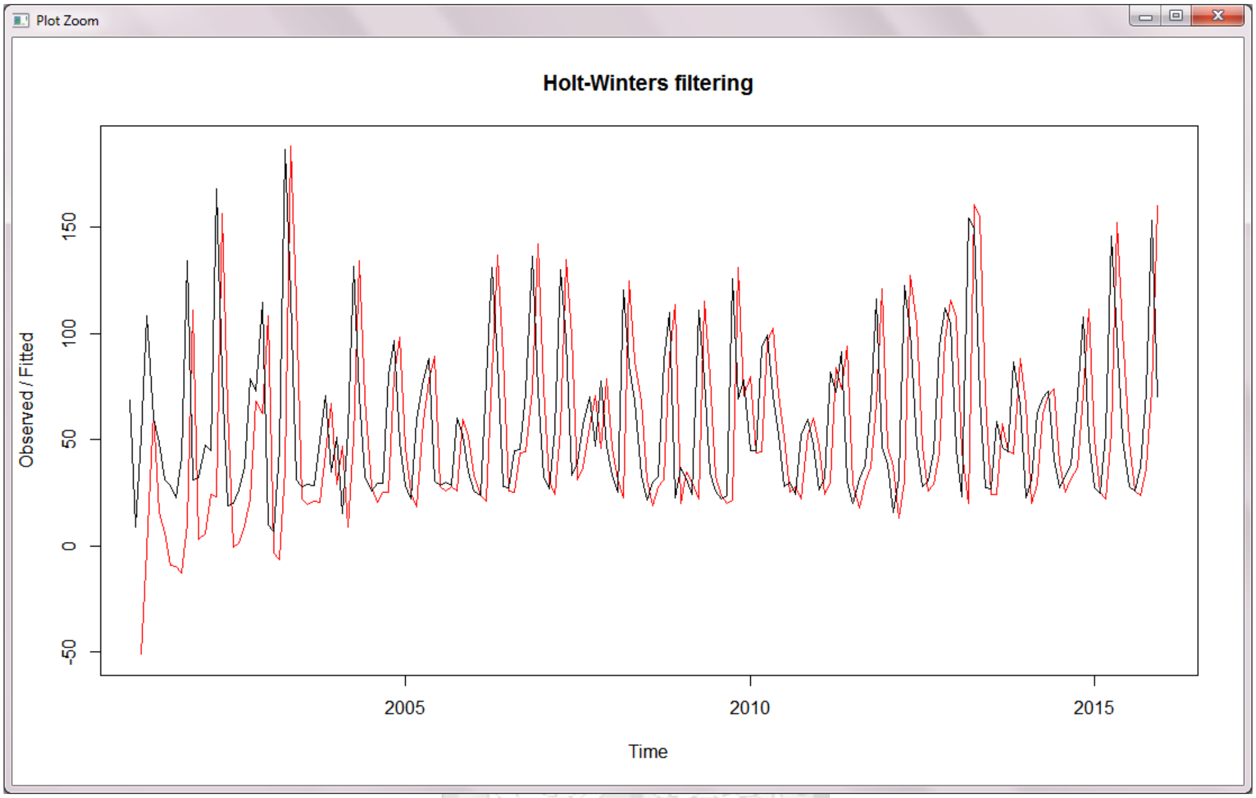
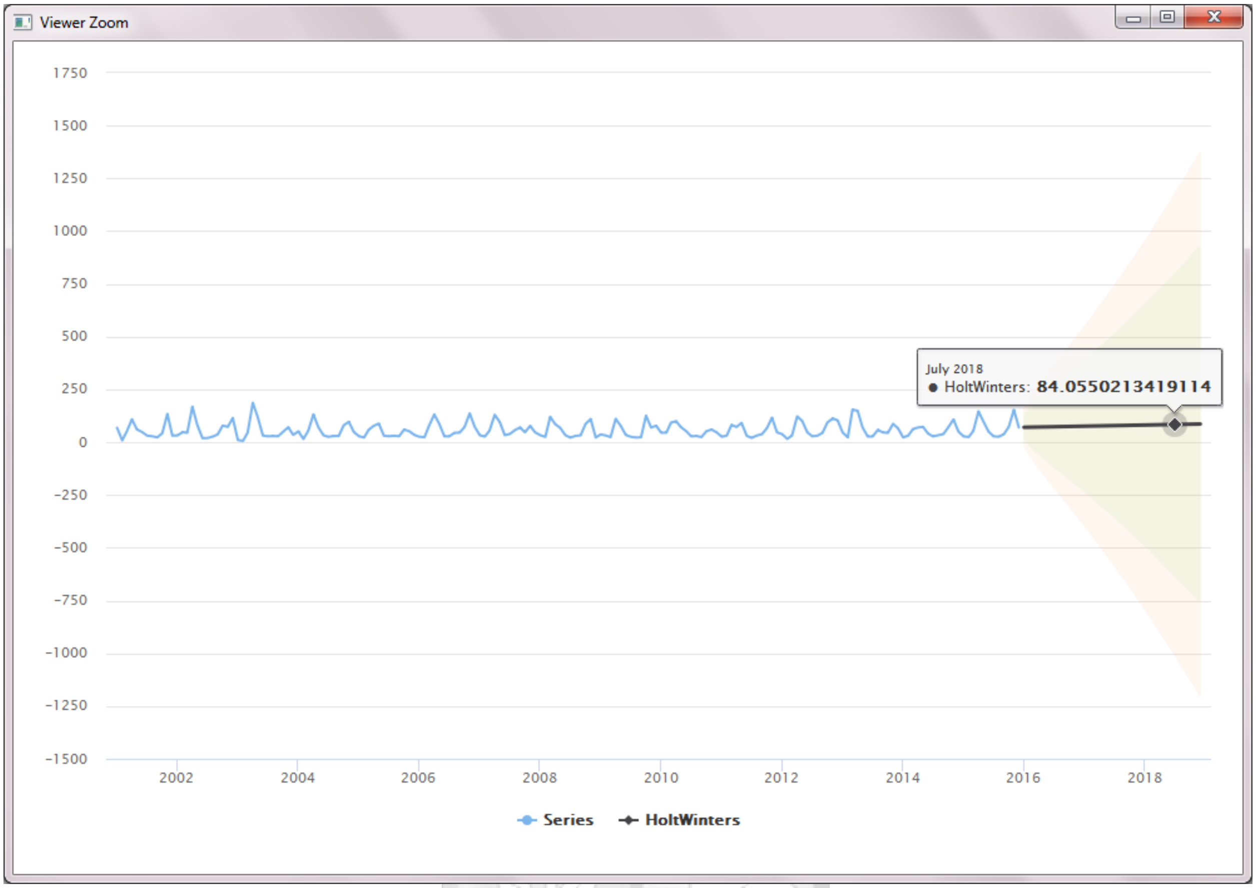


Figure 5.7 In and out of sample data with fitting

The resulting graph contains forecast data spanning beyond the data collected. That is, from 2016 going forward, as shown below:



5.4 Prototype Testing

Testing of the prototype was done to determine functionality and usability. To test for functionality, in sample data, spanning from the years 2001 to 2012, as mentioned in 5.3 above was used as the sample data. The forecasted data included the out of sample data, spanning from the years 2013 to 2015, which formed the test data. The results of the out of sample data was tested against the actual data.

Testing of data was also done without the sample split. In sample data included the entire data set; what was initially both in sample and out of sample data. Below is a graphical view of the newly forecasted data after fitting using the Holts Winters approach.

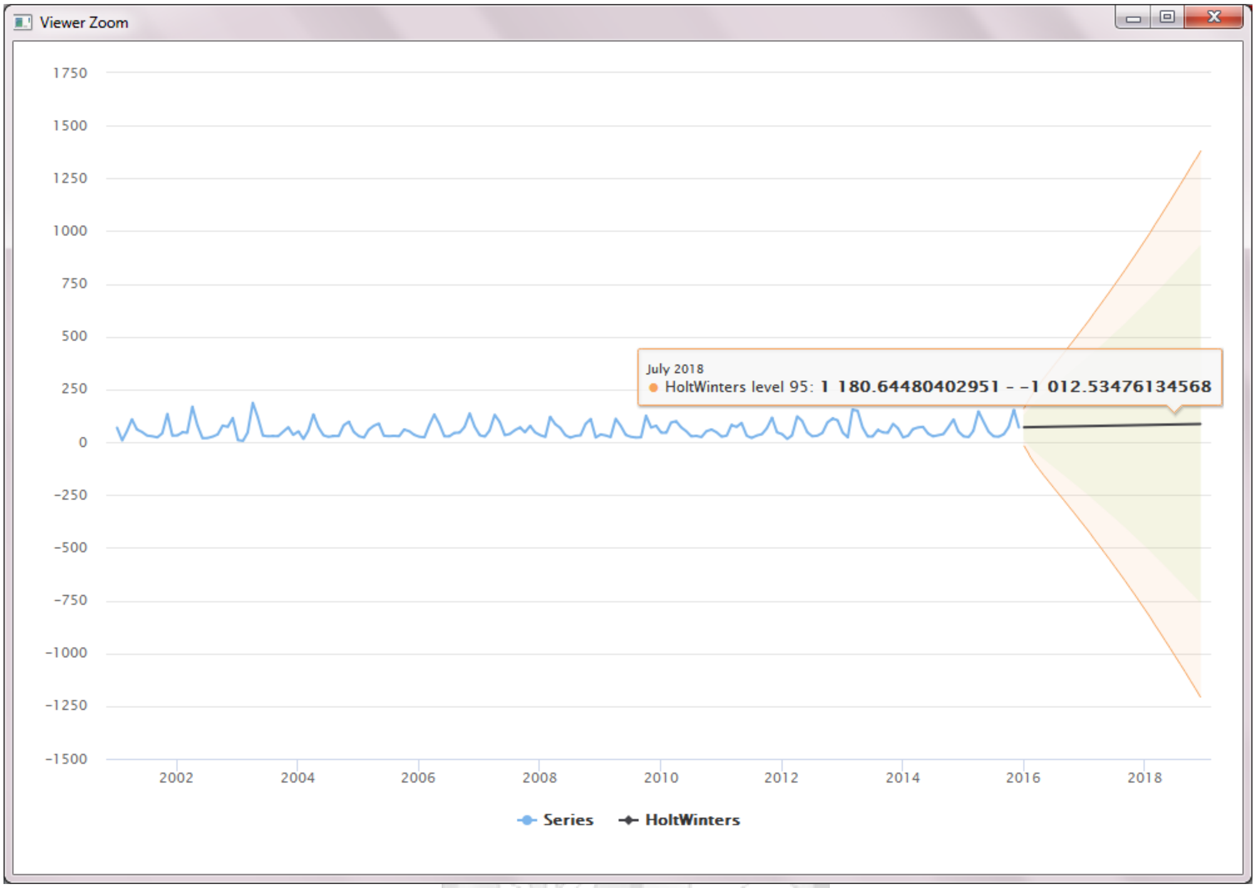


Figure 5.8 Forecasted data using entire dataset as in sample data

Another test that was done was reporting. The main output from the prototype was graphical reports to indicate the forecasts from uploaded rainfall data.

5.5 Acceptance Testing

The acceptance testing process involved performing an overall review of the implementation process. A summary of the tests done was outlined in the set of test cases below.

Table 5.1 Acceptance Test Cases

Test No.	Test Case	Outcome	Comment
i.	Upload observation data	Pass	Ok
ii.	Generate initial graphs for fitting	Pass	Ok
iii.	Fit observation graph to fitted graph	Pass	Ok
iv.	Generate forecast reports	Pass	Ok
v	Save data to database	Fail	Data save not successful. Data processing done from Rstudio with no connection to database

Chapter 6 Discussion

6.1 Introduction

This chapter discusses the results of the research in relation to the objectives. It outlines how this has been achieved through discussions in the literature review, through to the design and implementation processes. It also discusses the parameters used as a check for the results of the implementation. An outline on the resulting findings and suggestions on future research is also mentioned.

Rainfall plays a role in agriculture and ultimately food production. The research was aimed at coming up with a solution as one of the ways that would contribute towards resolving issues affecting food production. Rainfall amounts would be predicted with past data collected forming the basis for the prediction. The rainfall patterns prediction prototype was developed to predict future rainfall amounts, with the assumption that other factors affecting rainfall remain constant. To enable the prediction, past rainfall data was used as sample data. The prediction data was generated at two levels of confidence intervals. The algorithm used to generate the forecast data results was a machine learning prediction approach known as Holt Winters.

6.2 Comparisons with Previous Researches

6.2.1 Comparison with Logit and Rasch Models

In a bid to resolve the issue of growing demand for food caused mainly by the steady rise in population, one of the models researched upon includes the Logit Models for Household Insecurity Classification, by (Owino,Y.) 2014. The model focuses mainly on household survey data, which is heavily influenced by the cultural practices of the communities from where the data is collected. The same applies with the Rasch model, by (Owino et al.) 2014, which focuses on household survey data, with more interest leaning on the severity of the responses obtained. The implementation done focuses on the use of rainfall data, which is a deviation from the two models mentioned. There is also a difference in terms of the type of data used. The Rasch and Logit models' research outcome is a conclusion on how safe an area is in terms of food availability, based on the data collected; the conclusion is based on the present. This contrasts with the rainfall prototype implementation which provides a future projection of the possible rainfall amount outcomes.

6.2.2 Comparison with Vulnerability Analysis Model

The Vulnerability Analysis model, by (Capaldo et al.) 2010, also bases its information on household survey data. It slightly compares to the current implementation, given that the model provides an estimate that a household will face problems accessing sufficient food in the nearby future, based on household survey data collected previously. However, while the current implementation provides definite forecasted rainfall amounts within given confidence levels, the Vulnerability Analysis model bases its estimates on severity levels. For example, A household could face extreme starvation, or moderate starvation based on household survey done. Another deviation, similar to discussions in 6.2.1 above, the data collected and used to provide the estimates is also different; the Vulnerability analysis model is reliant on household survey data.

6.2.3 Comparison with the Philippine Food Security Information System (PhilFSIS)

The PhiFSIS system was meant to aid in food security planning by the Phillipine government, as discussed by (Recide & Jalisan) nd. In terms of implementation, the approach used was to use commonly consumed food items to show patterns of production for a selected duration in the past. The outcome of existing trends in production would then be used in policy making. This differs with the current implementation where rainfall data is used instead to show forecasted rainfall amounts, in addition to the trends displayed from past data.

6.2.4 Comparison with Decision Support System for Agricultural Droughts and Food Security

The system proposed by (Enenkel et al) 2015, uses different approaches to aid the decision making process for policy implementation. Data collection could range from use of satellite data on soil humidity to data on anomalies on land surface. The data collected is then used to predict the areas that are likely to be affected by drought. The system has some similarities to the current implementation, in that there is the component of forecasting, based on collected data. However, the deviation of the current implementation from the Decision support system is that whereas the system does a forecast on the land areas that are likely to experience drought, the current implementation forecasts on future possible rainfall patterns.

6.3 Design Process Implementation

The process of accessing the system once operational would be through a front end interface, where uploaded data would be selected and a chart showing the trend data and the forecasted data is generated as the resulting output. To aid the process, the flow of information was documented through the use of UML design diagrams. This included use case diagrams, data flow diagrams, sequential and class diagrams. The interaction between the system users and the system was also done.

6.4 System Functionality

Functionality was measured in terms of the ability to generate the forecast data, using the available datasets uploaded. The resulting forecasted data was outputted at two confidence intervals of 80% and 95%.

6.5 Accuracy of Outputted Results

To measure the accuracy of the forecasted results, the original sample data was split into in sample and out of sample data on an 80%:20% ratio. The in sample data formed the input/ upload data, which was from the years 2001 to 2012, while the out of sample data formed the test data, covering the years 2013 to 2015. The forecasted data was sampled against the originally collected out of sample data.

A sample measure taken was rainfall data for the month of April 2014 and compared to the forecasted data. The following table indicates the comparison between the actual data and range within which the forecasted data falls at 80% and 95% confidence intervals.

Table 6.1 Data Accuracy Comparisons

Actual Rainfall Data(mm)	Forecasted Data Range at 80% confidence interval	Forecasted Data Range at 95% confidence interval
69.896	-219.149 to 578.178	-422.248 to 751.278

6.6 Research Contributions

The research prototype was focusing on rainfall and forecasted rainfall amounts that would improve the decision making process with regards to food production by governmental and non-governmental institutions and other interested parties in the private sector. The forecasted numbers provide a range of rainfall amounts at different times of each year, for each forecasted year, which would form the basis for future decision making on agriculture and food production.

6.4 Weaknesses in the System

Some of the weaknesses that were observed in the system include the following:

i. The forecasting of rainfall was done under the assumption that all other factors affecting food production remain constant.

ii. The range of forecasted rainfall amounts was a much wider at the given confidence levels at a given time.

iii. The system cannot be run from a front end, and would largely dependent on the input of the data analyst.

Chapter 7 Conclusions and Recommendations

7.1 Conclusions

The main objective of the research was to come up with a solution to mitigate the problem rising demand for food, which is brought about by factors such as a rise in population growth. The research discussed the steps taken to mitigate the problem in the past, and the call for more institutions and individuals to come up with even more solutions. Other objectives of the research included performing literature reviews on the data used during previous researches, challenges faced and implementations done in the past in an attempt towards providing solutions. The research focused on forecasting trends in rainfall amounts as a means to help improve the decision making process on matters touching on food production. This is because rainfall is one of the factors that affect agricultural produce. The main deliverable was a prototype showing graphs of rainfall trends and forecasted rainfall for different months for the years within the forecast period. This involved the use of already existing datasets documenting rainfall amounts in past years, as a basis for the forecasts. The process also involved the data fitting on dataset uploaded, and which formed the observed data, before using the fitted data to do the forecast. The forecasted results were shown at two different confidence intervals.

Based on the research, some of the objectives were met fully. There are others that were met, but partially. A case in point is the prototype development, which was initially intended to be a web based system. However, the chart generation was run directly from the coding environment, which is not a user friendly environment for a normal end user. Hence, the dependence on a data or systems analyst for generation of chart forecasts.

7.2 Recommendations

The following recommendation is made with regards to the research.

i. Improvement of the prototype to include saving of data to a database, and coming up with a front end interface from which users can interact with the prototype. This was the original intention as per the architectural discussions, and would eliminate the need for interactions from a code level.

7.3 Suggestions for future Research

Future research suggestions include the following:

i. The use of different machine learning approaches that could help to produce even more accurate forecast outcomes.

ii. The use of additional parameters in addition to rainfall, which also contribute towards food production. This could include temperature and soil type. The research mainly focused on rainfall, and the assumption made that other food production factors remained constant.

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