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MAY 29, 2018

BAHIR DAR, ETHIOPIA

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A Thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the degree of

Master's degree in Computer Science in the Faculty of Computing.

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May 29, 2018

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DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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II

DEDICATION

This thesis work is wholeheartedly dedicated to the Almighty God, thank you for the guidance, strength, power of mind, protection and skills and for giving me a healthy life.

This thesis is also dedicated to my parents, aunts, sisters and brothers and my beloved wife whom I am truly grateful for having them in my life and who have been my source of inspiration and strength when I thought of giving up, who continually provide their moral, spiritual, emotional support.

Also to all my best friends and classmates who shared their words of advice and encouragement to finish this study and whose good examples have taught me to work hard for the things that I aspire to achieve.

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ABSTRACT

Flood is one of the most devastating natural disasters that occurs frequently and can affect large community areas. It has become the main threat to people's life and properties. This problem is more acute in highland areas of Ethiopia under strong environmental degradation due to population pressure. That is why, flood prediction has long been a popular subject matter to researchers around the world. Among other flood prediction alternatives, fuzzy logic is a formal attempt to capture, represent and work with objects with unclear or ambiguous boundaries.

The main objective of the research is to design a flood predictive model that deal with reasoning that is approximate in the fuzzy environment. A methodology was proposed and applied to assesses the potential of fuzzy logic approach for real time flood level prediction using Mamdani fuzzy inference system. The main contribution of the research is to capture, both fuzziness and uncertainty inherent in the input/output data during prediction by apply Re-Partitioning Discretization(RPD) algorithm that, optimized the interval length between each fuzzy sets and significantly improves the prediction accuracy of the model.

The study also has contributions in reduction of losses of life and property by alerting the community in the study area based on the outputs of the prediction model via SMS automatically to take immediate actions before the disaster occurs, assist local authorities, government practitioners, flood risk forecasting and warning authorities to accelerate the process of evacuating flood victims to the relief center.

The accuracy of the prediction model, which is 91.57%, obtained after the validation of the model using test dataset showed a general agreement with the results from the measured value of the output. This also shows the acceptable levels of the prediction model, and which implies the potential of establishing a flood prediction model by using the fuzzy logic approach in the study area.

Keywords*:* Flood Prediction, Fuzzy Logic, Fuzzy Inference System, SMS, Early Warning**.**

LIST OF ACRONYMS

FFPM	Fuzzy Flood Prediction Model
FEWS	Flood Early Warning System
FLC	Fuzzy Logic Control
FIS	Fuzzy Inference System
SMS	Short Message Service
SMSC	Short Message Service Center
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HTTP	Hyper Text Transfer Protocol
SMPP	Short Message Peer to Peer
IP	Internet Protocol
KB	Knowledge Base
NMA	National Metrology Agency
MAPE	Mean Absolute Percentage Error
MF	Membership Function
RPD	Re-Partitioning Discretization
DPFSCO	Disaster Prevention and Food Security Coordination Office
COG	Center of Gravity
COA	Center of Area
GIS	Geographical Information System
WRF	Weather Research and Forecasting
SWAT	Soil and Water Assessment Tool
FP	Flood Prediction
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System

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CHAPTER - ONE

1 INTRODUCTION

Flood is one of the most devastating natural disasters that occurs frequently and can affect large community areas. It has become the main threat to people's life and properties. Topographically, Ethiopia is both a highland/mountainous and lowland country. Due to its topographic and altitudinal characteristics, flooding, as a natural phenomenon, is not new to Ethiopia. They have been occurring at different places and times with varying magnitude. Some parts of the country do face major flooding. Most prominent ones include: extensive plain fields surrounding Lake Tana and Gumara and Rib Rivers in Amhara Regional State; areas in Oromia and Afar Regional States that constitute the mid and downstream plains of the Awash River; places in Somali Regional State that fall mainly along downstream of the Wabishebelle, Genalle and Dawa Rivers; low-lying areas falling along Baro, Gilo and Akobo Rivers in Gambella Regional State; downstream areas of Omo River in the Southern Nations, Nationalities and Peoples Regional State(Setegn et al., 2011).

Overflow of Ribb and Gummara rivers and backwater effects from Lake Tana has affected and displaced thousands of people since 2006(Desalegn, Demissie, & Admassu, 2016). Heavy rainfall for a number of days in the upper stream part of the catchment caused the river to spill and to inundate the floodplain. Therefore, the use of flood prediction model and early warning systems is mandatory to reduce huge losses of life and property. Because early warning systems are applied as cost effective risk mitigation measures against natural hazards such as flood and drought, which provide timely information on future or ongoing events to reduce loss of life and damages. In contrast to structural protection measures such as dams, galleries and rock fall nets, early warning systems are cheaper, have shorter installation time and have lower impact on the environment(Assilian, 1999).

Currently the tremendously increased penetration of mobile services in our country offers great opportunities to solve the information gap for this target groups regardless of their literacy level, technical skill and languages barriers and lack of proper infrastructure. This research exploited this opportunity to close the information gap. The research is started from review the literatures on fundamental concepts about fuzzy set theory and fuzzy logic, tools and techniques followed, related works and then design a prediction model and early warning system finally evaluate the accuracy of the prediction model and use the outputs of the prediction model as input for the early warning system to disseminate the predicted values and risk levels of flood using SMS message for the downstream community.

1.1 Statement of the Problem

In Ethiopia flooding is common in major river catchments owning to heavy summer rainfall and mountainous topography. In 2006 a total of 357,000 people were affected and about 136,528 people who had to abandon their homes. Predicting the incoming flood events and information regarding its levels and effects is essential for flood management bodies and the community for decision making in the flood management strategies to develop a flood emergency plan. The lower part of Ribb-Gumara catchment is known as one of the flood prone areas by annual flooding in the Fogera floodplain. In, 2006 an extreme flooding affected 43,127 people and 8728 people displaced in the region(Tarekegn, 2009).

Its topography and location expose Nabega and Wagetera to regular devastation by floods. Flooding usually starts in July (***Hamle 1***) and does not recede or dry out until late September (***Meskerem 15***) to mid-October (***Ttikimt 05***). If there is belg rain, the flood may occur earlier than July that is in May or June. The villages that are more affected by flood incidences are: Fogere Bet, Sarko, Tigre Mender, Deqie Bet, Aja Geba, and Riq than the remaining seven villages in the kebele. Floods often result in human deaths in Nabega and Wagetera Kebele. In 2008 floods one man, a father of 4, died from flash floods in Nabega Kebele and a three-year-old child was confirmed dead from drowning during the floods in Wagetera Kebele(Nile & Regional, 2010).

Though flooding is frequently observed in the floodplain, in addition to this most inhabitants of the area are farmers employed in rain-fed subsistence agriculture, frequently affected by floods. In spite of the recurrent flood problem, the existing disaster management mechanism has primarily focused on strengthening rescue and relief arrangements during and after flood disasters and ignored the pre-preparedness plans and early community warning practices by adopting the latest technologies.

Now a day, there are many flood warning alternatives worldwide, but there are a number of reasons for the ineffectiveness of them, when we consider our country Ethiopia. The first reasons for the ineffectiveness of them is digital divide and the second one is bureaucratic inefficiency(Desalegn et al., 2016).

- **Digital Divide:** A flood might occur at any time of the day or night. For people in a remote area, particularly in developing countries, technology availability and accessibility such internet access or TV sets might be an issue, if flood information is issued via these channels. Moreover, if a flood occurs during the night time, warning, people in these areas might be difficult because delivery devices such as TVs or radios might be switched off at night. Mobile phones are an available alternative to deliver a warning messages because most people have a mobile phone and they can be left on at night.
- **Bureaucratic Inefficiency**: Bureaucracy is one of the main reasons for delays in flood warnings because the warnings go through several steps before reaching the people in a flood affected area.

1.1.1 The Community's Flood Knowledge and Preparedness Practice

The community had been known to monitor the water level manually by putting measurements in certain areas along the rivers to determine the level of water. From time to time, a representative has to go to these Emergency zones to check any changes in the water level. These manual staff gages and flood markers used to measure the water level, which were painted on bridge's pier, walls and posts lack durability since they are usually fade up within a short period of time. Even though they try to forecast the intensity of flood incidences traditionally, there is no systematic preparedness measure carried out by the community to mitigate the risks of flood collectively. In addition to this, to reduce the flood impact, construct ridges and waterways around their farmlands and homes, fill the floor of their house with soil above the ground level to control easy flow of water into the house, build an elevated bed, locally known as 'Kot', high above the ground near the roof, make elevated racks for storing grains and crop residues in a similar fashion to protect them from wetting if flood enters the room. Moreover, some farmers in the area prepare traditional boats from papyrus in the dry season as a preparedness measure to evacuate their families in cases of severe flood incidences.

Figure 1.1 shows the manual water level monitoring pole marked with different color codes installed by the community in the study area. (Source: Amhara Region DPFSCO Office)

Figure 1.1 Manual Water Level Monitoring Pole in the Study Area

Majority of the flood proven inhabitants usually send their animals to relatives living in the high land areas before occurrences of flood. The forecasts made by the elderly depend on the direction of cloud accumulation in reference to the area, darkness of the cloud and on the time of onset of rainfall. Accordingly, it is believed by the community that the flood incidence is sever when the direction of the cloud accumulation is from south of the kebeles, the cloud is dark and when there is no or low ‘belg’ rain. The regional food security program coordination and disaster prevention office try to establish early warning system from region to kebele level (Nile & Regional, 2010). A committee of flood early warning and preparedness is established in the kebele in such a way that each of the villages is represented. Among the committee members, four Nabega and Four from Wagetera are provided with mobile telephones to send and receive messages regarding flood.

However, the technical capacity in early warning data collection, analysis and reporting at all level is limited and information dissemination system does not reach to the “Gott” level timely and it is not effective. This shows that strong early warning and preparedness information dissemination system that genuinely participates the community at all levels is indispensable.

The current flood prediction and early warning system practice by the community is proven to data accuracy and delay of warning information. Thus, this research came up with an advance flood prediction model and early warning system using SMS technology. The flood prediction and early warning system technology developed in this study assuming a remote monitoring device with software and hardware components designed to monitor the water levels using an ultrasonic sensor, server computer and web interface and mobile SMS service.

Previous researches have utilized various techniques to produce flood disaster prediction models. Linear regression and multivariate analysis are among the techniques proposed to predict accuracy. The above mentioned models manage accuracy and uncertainty separately. In addition, they lack a mechanism to organize flood knowledge and warn the community in the flood risk area.

The concept of fuzzy logic and fuzzy set theory were introduced to cope up with the ambiguity and uncertainly of most of the real-world problems. In classical models variables have real number values, the relationships are defined in terms of mathematical functions, and the outputs are numerical values ‘‘crisp’’. Whereas models with fuzzy logic have variables which influence system behavior and relationships among the variables which describe the system in terms of linguistic terms such as ‘‘low, high, large, medium, and small’’, and the outputs are fuzzy subsets which can be made ‘‘crisp’’ using defuzzification techniques(Chissom, 1991).

Fuzzy logic tries to equip computers with the ability to process special data of humans and to work by making use of their experiences and insights. Adapting human logic system to computers/machines increase problem solving ability of computers/machines. Verbal terms and variables are expressed mathematically as membership degrees and membership functions. Fuzzy decision- making mechanisms use symbolic verbal phrases instead of numeric values. Transferring these symbolic verbal phrases to computers are based on mathematics. This mathematical basis is fuzzy logic. Systems that use fuzzy logic are alternatives to the difficulty of mathematical modelling of complex non-linear problems and fuzzy logic meets mathematical modelling requirement of a system. Systems that use fuzzy logic can produce effective results based on indefinite verbal knowledge like humans. In fuzzy logic, information is verbal phrases such as big, small, very, few etc. instead of numeric values. If a system's behavior can be expressed by rules or requires very complex non-linear processes, fuzzy logic approach can be applied in this research(Mark & Freksa, 1999).

The proposed solution of this research is designed to be robust and integrated approach. Which, incorporate two main techniques which are the fuzzy flood prediction model to predict uncertain flood events and SMS based early warning system to give notification for the community in the flood risk areas.

1.2 Research Questions

In this research work three research questions are formulated, which are constructed as follows:

- RQ1: How to adopt fuzzy logic as a flood prediction model in the study area?
- RQ2: How can we evaluate the accuracy of the prediction model?
- RQ3: How to integrate the prediction model with the SMS Service to warn the community in the flood affected area?

1.3 Objectives of the Research

1.3.1 General Objective

The objective of the study is to design a Fuzzified Flood Prediction Model (FFPM) and check the performances of developed model for their efficiencies in predicting the river water levels during flood events in terms of Lake Tana water level in the study area.

1.3.2 Specific Objectives

The general objective of this research achieved using the following specific objectives:

- Optimize the partitioning of the interval lengths for input/output water level data using appropriate algorithm
- Design the flood prediction model by adopting fuzzy logic approach
- Evaluate the accuracy of the prediction model
- Design a flood early warning system using SMS service for the flood affected community.

1.4 Scope and Limitations

This study focus on designing of a flood prediction model using Mamdani type of fuzzy inference modeling approaches and evaluate the model using the testing dataset then implement SMS based early warning system using the defuzzified values of the output variable of the prediction model. However, hydrological techniques and any water-related science and flood management strategy or flood relief are not considered in this study.

This study could be missing other relevant factors which could be suitable for the case study area as an input for the fuzzy logic prediction model. due to lack of a responsible and organized bodies to organized and management of the collected data. There are different organizations who collect the same data but the use it for different purpose in order to fulfill their responsibilities posed by the objective of the respective organizations.

1.5 Significance of the Study

This study has a great contribution for researchers and students who want to solve real-world community problems by applying fuzzy logic and fuzzy set theory. With Fuzzy Logic it is possible to describe available knowledge directly in linguistic terms and rule based systems in order to solve really exist problems in our community. Quantitative and qualitative features can be combined directly in a fuzzy model. This leads to a modeling process which is often simpler, more easily manageable and closer to the human way of thinking compared with conventional approaches. This research also provides a practical solution to awoken the community who lives in the flood proven areas to take immediate actions in order to save lives and damages of properties before the occurrence of floods.

This research also has a great significance for local authorities, government practitioners flood level forecasting and warning authorities to assist and accelerate the process of evacuating flood victims to the relief center before the occurrence of flood in the study area.

1.6 Background of the Study Area

Fogera Woreda lies to the south-eastern shore of Lake Tana on the road from Bahir Dar to Gondar, 625 km from Addis Ababa and 55 km from Bahir Dar. Fogera is bordered to the south by Dera Woreda, to the west by Lake Tana, to the North by Libo Kemkem Woreda, and to the East by Farta Woreda. The major town in Fogera Woreda is Woreta which is the capital of the Woreda. The area is located between 11° 57' and 12030' N latitude and 37° 35' E and 37058' E longitude(Nile & Regional, 2010). This Woreda is found in the downstream part of the Ribb–Gumara river catchment where Ribb and Gumara Rivers join to Lake Tana. Overflow of these rivers and back flow of Lake Tana frequently flooded this Woreda than other woredas in the Catchment and therefore selected for this study. Gumara and Ribb Rivers has their source in a mountainous area and in their lower reaches, these rivers flow through a large flat to very gentle sloping plain which is exposed to serious floods. Thus, a flood early warning system is essential to provide sufficient time for the communities and authorities to

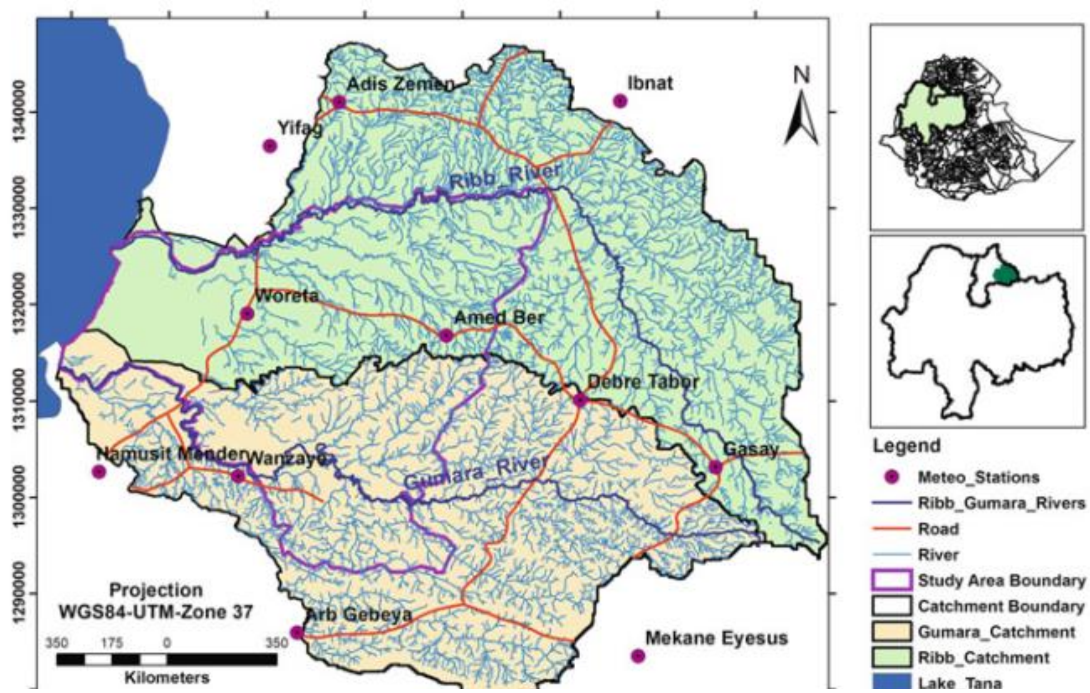

Figure 1.2 Location Map of the Study Area

evacuate to safer places and take necessary measures to protect physical properties in vulnerable areas. *Figure 1.2* showed the location map of the study area(Setegn et al., 2011).

1.6.1 Flood Vulnerability Profile

In Fogera Woreda two kebeles (Nabega and Wagetera) are extremely susceptible to flood destruction since they are bounded by Rib and Gumara Rivers in North and South respectively and bordering Lake Tana to its west. This is due to periodic breaching of the banks of both the Ribb and Gumara rivers and seasonal backflow from the Lake. *Figure 1.3* showed the topography and location map of Nabega and Wagetera Kebeles which are regular devastation by floods(Nile & Regional, 2010). **(**Source**:** E. Nile and T. Regional, 2010**).**

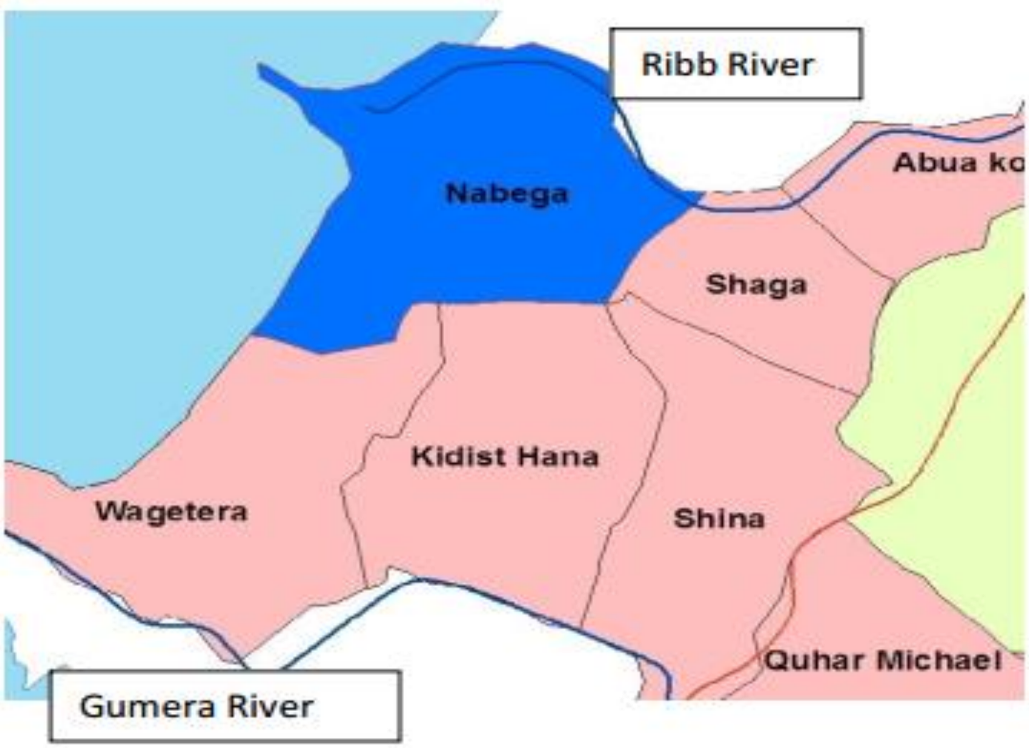

Figure 1.3 Location Map of the two specific Kebeles affected by flood regularly

1.7 Thesis Organization

The thesis is organized in seven chapters. Chapter-one which introduces background, problem statement, objective and scope and the study area descriptions of the research. The second chapter discusses about literature review, related works. In this chapter, we have reviewed literatures related to our research and programing tools and other information sources. The third chapter discusses about the research methodology followed during data collection, data analysis and data processing and designing of the prediction model. The fourth chapter discusses about the designing procedures and principles followed to design “Fuzzy Flood Prediction Model (FFPM)”. The fifth Chapter discusses about the implementation of the SMS based early warning system, the sixth chapter is discussed about validation of the flood prediction model, and interpretation of the results. The last concludes the research by discussing on overall achievements of the study and suggesting some recommendations as future work for the authors of this research and other researchers for further study based on the results obtained from this research work.

CHAPTER – TWO

2 LITERATURE REVIEW AND RELATED WORKS

This chapter discusses two relevant sub sections, the first sub section is about the literature review on soft computing, fuzzy set theory and fuzzy logic basic concepts, which includes fuzzy logic controller, fuzzy logic models, fuzzy inference systems, membership functions and the tools libraries applied in this research. In this section, also discussed about SMS services and SMS based early warning systems. The second sub section discusses about the previous researches that had been done before using this technique and the final sub section compares the related works with this research work.

2.1 Literature Review

This section presents the fundamentals of fuzzy logic, fuzzy set, fuzzy inference system and other related concepts tools and libraries used in this research.

2.1.1 Soft Computing Techniques

Soft computing techniques is a term applied to a field within computer science and engineering which is characterized by the use of inexact solutions to computationally-hard tasks (Abadi, 2011)(Ogbonna, 2014). Soft computing techniques include fuzzy systems, neural networks, genetic algorithms and their hybrids. As universal approximators, they have the capability of modelling the complexities and non-linearities in natural processes without making assumptions in the structure of the processes or data. These techniques deal with fuzziness, complexities, imprecision, uncertainty, partial truth, and approximation to achieve predictability, tractability, robustness and low solution cost (Abadi, 2011). Hence, soft computing techniques have been used to model the complexity of relationships in nonlinear time series to a relatively higher degree of accuracy.

2.1.2 Fuzzy Set Theory

The Fuzzy sets theory, introduced in 1965 by Lotfi Asker Zadeh, can be defined as a mathematical formulation of variable sets that enables the elimination of indefiniteness and deal with incomplete, inaccurate information of both qualitative and quantitative nature (Zadeh, Introduction, & Navy, 1965)(Ogbonna, 2014).

Fuzzy set theory is a generalization of the classical set theory to situations where data are modeled by entities whose attributes have zones of gradual transition, rather than sharp boundaries to allow partial membership(Duminda, Perera, & Lahat, 2015)(Vinaykumar,

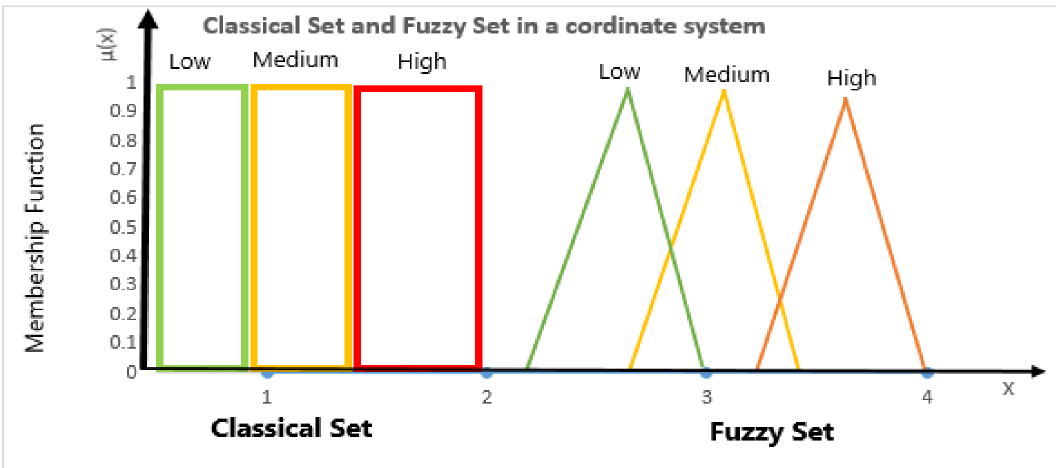

Figure 2.1 The Difference Between Classical Set and Fuzzy Set

M.C.K, Ravi, 2009). The best way to introduce fuzzy sets is to start with a limitation of classical sets. A set in classical set theory always has a sharp boundary because membership in a set is a black-and-white concept, i.e. an object either completely belongs to the set or does not belongs to the set at all. The degree of membership in a set is expressed by a number between “0” and “1”; 0 means entirely not in the set, 1 means completely in the set, and a number in between means partially in the set. This way a smooth and gradual transition from the region outside the set to those in the set can be described. *Figure 2.1* shows the differences between these two set theories in a graphical manner.

2.1.3 Fuzzy Logic

The concept of fuzzy logic and fuzzy set theory were introduced to cope up with the ambiguity and uncertainly of most of the real-world problems (Chissom, 1991). The fuzzy logic system is a computing framework based on the concepts of fuzzy set theory, fuzzy “IF-THEN” rules, and fuzzy reasoning. It was designed to mathematically represent uncertainty and vagueness and to provide a formalized tools to dealing with the imprecision intrinsic to many problems and to model uncertainty and the human way of thinking, reasoning and perception(Alavi, 2013).

It is an extension of the classical (Boolean) logic that can be used to handle mathematically the vagueness of human linguistics and thinking to apply the model to problems according to needs(Variables, 1996). It has applications in areas such as automatic control, time series prediction, robotics and pattern recognition(Ogbonna, 2014).

The other advantages of fuzzy logic include: the potential for improved performance, faster model development and execution times and the ability to provide a measure of prediction certainty due to these reasons, it is the present trend for decision making, classification and prediction where problem can be formulated by mapping input variable with output variable or where simple solution does not exist(Mark & Freksa, 1999).

2.1.4 Fuzzy Logic Model

A fuzzy logic model is a logical-mathematical procedure based on a "IF-THEN" rule system that allows for the reproduction of the human way of thinking in computational form(Alvisi & Franchini, 2006). In general, a fuzzy rule system has four components: One of the possible applications of fuzzy logic is prediction in the fuzzy environment. A fuzzy logic model for two input and one output can be represented by a black box diagram. *Figure 2.2* shows the input and output variables are represented as fuzzy sets.

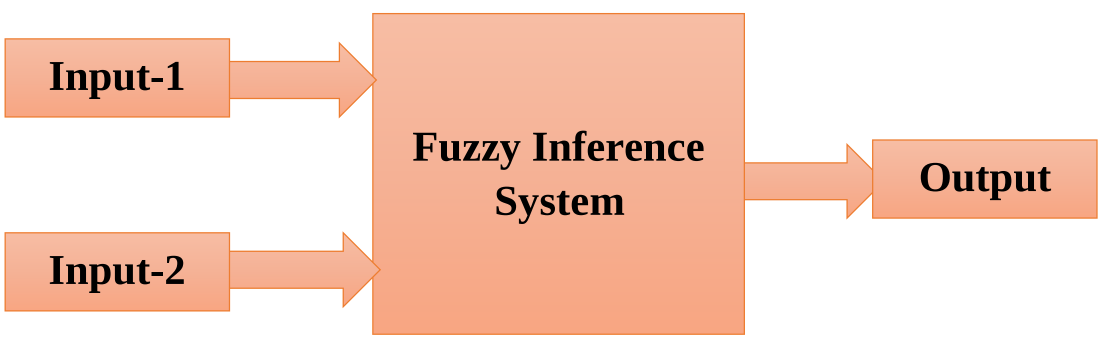

Figure 2.2 A Fuzzy Logic Model for two Input and one Output

2.1.5 Fuzzy Inference System

Fuzzy systems are means of capturing humans' expert knowledge about the process, in terms of fuzzy (IF–THEN) rules(Alavi, Nozari, & Mazloumzadeh, 2010). Fuzzy Inference System (FIS) incorporate an expert's experience into the system design and they are composed of four blocks, which consists of : Knowledge-Base, that includes the information given by the expert in the form of linguistic fuzzy rules, a fuzzifier, which transforms the crisp inputs into degree of match with linguistic values, an inference system (Engine), that uses them together with the knowledge-base to make inference by means of a reasoning method, and a defuzzifier, which transforms the fuzzy results of the inference into a crisp output using a defuzzification method. *Figure 2.3* shows the generic structure of a FIS architecture (Variables, 1996).

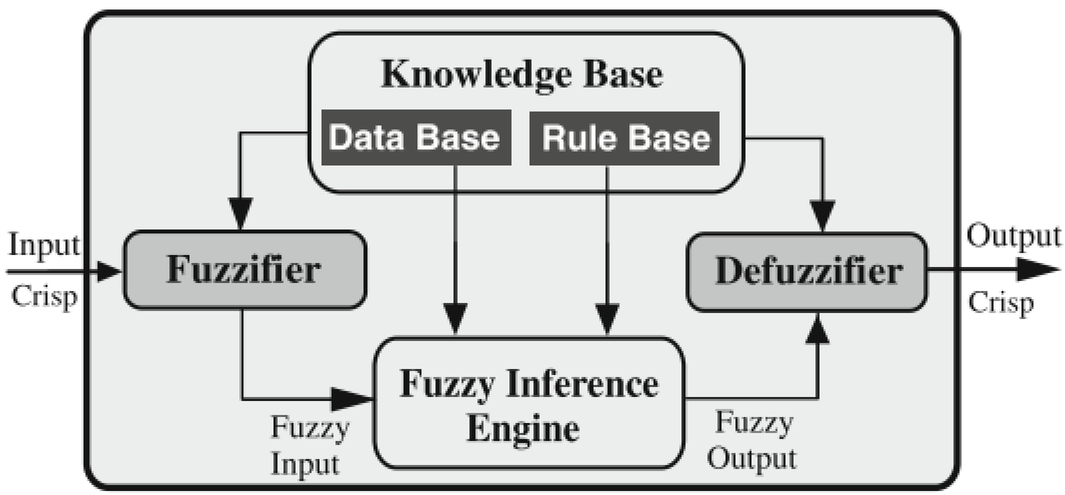

Figure 2.3 Block Diagram of Fuzzy Inference System

I. **Knowledge base:** The knowledge base encodes the expert knowledge by means of a set of fuzzy control rules. A fuzzy control rule is a conditional statement in which the antecedent is a condition in its application domain, the consequent is a control action to be applied in the controlled system and both, antecedent and consequent, are associated with fuzzy concepts; that is, linguistic terms. The KB includes two components: The Data Base and the Rule Base.

- The Database: It normalizes the input crisp values and contains the fuzzy partitions of the input and output space contains the definitions of the linguistic labels; that is, the membership functions for the fuzzy sets.
- The Rule Base is a collection of fuzzy control rules, comprised by the linguistic labels, representing the expert knowledge of the controlled system. Fuzzy rules can be derived based on the available data or/and using the knowledge of experts. The truth value of a fuzzy rule is known as the degree of fulfillment which takes values in the range of 0 and 1. In the fuzzy logic approach input and output relationships are described verbally rather than considering the known physical relationships. Establishment of these relationships depends on the observations of trends between the inputs and outputs variables.

II. **Fuzzification:** In the fuzzification process, the crisp values of the input data transformed into suitable linguistic values, which may be viewed as labels of fuzzy sets and are used in the fuzzy inference process.

III. **Inference Engine:** The decision making logic or inference engine has the capability of simulating human reasoning based fuzzy concepts and of inferring with fuzzy actions by employing the rules of inference. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made. Generally, the basic function of the engine is to control the overall output of the output variable based on the individual contribution of each rule in the fuzz Base(Alavi et al., 2010).

IV. **Defuzzification:** The process of converting the fuzzy results into crisp results is called as Defuzzification. The Defuzzification has the result of reducing a fuzzy set to a crisp single valued quantity or to crisp set. It combines the fuzzy variables to give a corresponding real [crispy] output, which can then be used to make the final decision.

2.1.6 Fuzzy Logic Controller (FLC)

A Fuzzy Logic Controller (FLC) is a software component that controls the output variables of a system according to its inputs and a set of rules expressed with the uncertainty of human terms. FLCs, as initiated by Mamdani and Assilian(Mamdani, Eng, Ph, & Mem, 1974)(Assilian, 1999) are currently considered to be one of the most important applications of the fuzzy set theory proposed by Zadeh(Zadeh et al., 1965). Fuzzy Logic Controllers (FLCs) are a specific model of Fuzzy Rule Based Systems (FRBSs) that provide a tool which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy(Alcala-fdez, 2015).

2.1.7 Membership Function

The membership function assigns value based on the degrees of membership which associated with the fuzzy set(Duminda et al., 2015). Determining or finding input/output membership functions (MFs) is the first step of the fuzzy logic control process. The fuzzy algorithm categorizes the information entering to a system and assigns values that represent the degree of membership in each category. The input/output MFs can take several forms such as triangles, trapezoids, bell curves or any other shape as long as those shapes accurately represent the distribution of information within the system, and as long as a region of transition exists between adjacent MFs. Triangular MFs are commonly used than other shapes due simplicity and computational efficiency. So, in this research we use the Triangular Membership function to represent the inputs/output linguistic terms as follows. The following figures show the triangular membership function for the two inputs Ribb and Gumara River Water Level and the output Lake Tana Water Level Respectively.

2.2 SMS Based Flood Early Warning System

Natural disasters such as floods are a worldwide phenomenon, they are occurring more frequently and lead to devastating loses. In developing countries, the effects of flood are more harmful than in developed countries. Developed countries have also had large floods, but with less property and life loss. Whereas in developing countries the large losses were caused due to the lack of a flood warning system and poor information dissemination at the community level. However, flood impact can be reduced by effective flood risk management and timely dissemination of flood warnings to citizens(Keoduangsine & Goodwin, 2012).

2.2.1 SMS Service

SMS services have been initiated and accepted by many organizations and governmental institutions worldwide. SMS services cover a wide range of applications from interpersonal communication to provision of government services such as SMS-based notification, SMS-based e-government, SMS-based business and SMS-based natural disaster warning [25].

SMS-based disaster warning services have been adopted in many countries, both developed and developing countries and is used to warn of tsunami, bushfire and flood. The following Countries are use SMS early warning service to warn the people in their country when abnormalities are occurred related with the environment. Some of these countries are: The Queensland Government has sent SMS messages to alert the public about severe floods (Report, 2012). In the United Kingdom, SMS-based warnings are provided by the Environment Agency and people who register with “Flood line Warning Direct Service” receive an automatic warning by SMS, telephone and email, In the United States of America, the Integrated Public Alert and Warning System allows a single alert message to be delivered over many communication mediums including to mobile phones via SMS. In 2014, the Indian Meteorological Department launched an SMS-based cyclone warning system, the system provides alerts to a wide range of users including disaster managers, targeted users and the general public. And these system have resulted in a significant reduction in loss of life and property(Keoduangsine, 2015). The United Nations report identified mobile phones as one of the best means for dissemination of disaster alerts, replacing radio and television as the best communication channel for reaching communities in disaster areas. The communities can be warned about risks using the common alerting protocol, short message service (SMS) (Nations, 2011).

2.2.2 Tools and libraries

We use Fuzzy Logic Control library for the implementation of this research. Fuzzy logic control libraries are powerful when solving a wide range of problems and its simplicity and interpretability that makes it an attractive choice to address problems that involve uncertainty or are just too complex to address with conventional techniques, but their implementation requires a certain programming expertise. In the last few years, many fuzzy logic software tools have been developed to minimize this requirement. Although many of them are commercially distributed, for example MATLAB Fuzzy logic toolbox one of them and its toolbox are sold separately under restrictive and costly proprietary licenses and even the toolbox has not been updated since 2005(Rada-vilela, 2012).

In this research jfuzzylite library is used for implementation of the FFPM prediction model using java programming language. Jfuzzylite is a cross-platform, free and open-source library released under the Apache License to provide the design and operation of Fuzzy Logic Controls with an object-oriented approach and also, it comes with an application named qtfuzzylite to visually the design of FLC system model(Rada-vilela, 2012) and to design SMS based early warning system android mobile phone is used as an SMS Gateway, windows 10 operating system environment and NetBeans IDE 8.2 is used for the development of the flood prediction and SMS application using java.

2.3 Related Works

Previously some research works were carried out in Fogera floodplain to assess the causes of flooding events and its consequences. According to the research conducted on Fogera Flood plain which focused on Ribb catchment to study the flood characteristics in the floodplain using a two-dimensional (2D) hydrodynamic modeling approach to simulate the August 2006 flood event. He uses 1D/2D SOBEK model to represent the topography with the proper applications of GIS. Result of this study shows that when the Lake Tana water level rise propagates to upstream and affects the flooding patterns of Ribb floodplain(Tarekegn, 2009).

The other research conducted in the study area was to assess flood hazard and risk of Fogera Woreda using GIS and Remote sensing. According to this research Flood frequency analysis was done using Ribb and Gumara Rivers annual maximum daily gauge levels and flood inundation map was developed for Ribb-Gumara catchment with a particular return period of flood levels which is computed from frequency analysis of river level data. The flood hazard map provides information about flood inundation corresponding to different probabilities in the catchment whereas the flood risk map provides quick information for the receptors at risk and probable damages during flooding(Setegn et al., 2011).

There are also other researches, conducted by applying fuzzy logic prediction approach throughout the world. According to the research conducted in Sri Lanka on flood risk analysis using fuzzy model is one of them. The research is all about the risk with respect to floods can be assessed using a fuzzy logic approach, by taking flood extent and mean flood depth as hazard indicators while population density and dependency ratio as vulnerability indicators. Based on these indicators, flood risk was determined for the lowest administrative divisions within the inundated area using conventional risk assessment approaches. They proposed and applied a methodology to assess risk assuming the above indicators as fuzzy variables. They compared the results obtained from the two approaches (Hydrologic Engineering Center’s Hydrologic Modelling System (HEC-HMS) and fuzzy logic modeling) the result obtained by proposed fuzzy-based method, which takes uncertainty in the determination of hazard, vulnerability and risk levels into account, as providing more accurate results(Management, Ratnayake, & Teknologi, 2011).

According to the research conducted in Malaysia which a proposed a flood prediction model to handle the accuracy and uncertainty issues which incorporates three hybrid techniques consisting of agents to give notification, ontology to organize flood knowledge in order to support agent communication and fuzzy to predict uncertain situations as flood is an uncertain catastrophe beyond human expectations(Duminda et al., 2015).

According the research conducts on Rainfall prediction using Fuzzy Logic principles, knowledge of variables like temperature and wind speed, are used to predict likelihood of rainfall and the outputs of the prediction help to better plan for a better resource utilization and prevention of associated disaster. The authors recommended that application of fuzzy logic is necessary in other domains since the binary logic principles cannot solve many of such problems(Polytechnic & Sciences, 2013).

In general, as a preliminary work, some of the aforementioned literatures written and the related works reviewed helps to know and understand some characteristics of flood prediction model for this study. Nevertheless, this research outlines a general flood prediction model and an early warning system for the community. To predict the occurrence of flooding we used fuzzy logic Mamdani inference rule based prediction models, because the fuzzy approach does not need standardization as the input and output membership functions are always in the scale of 0–1 irrespective of the variation of the factors considered. The outputs of the fuzzy logic flood prediction model used as the calibration of SMS based early warning system to warning the flood affected community according to the status of the predicted value Lake Tana Water level readings.

This research work is different from each of the above mentioned related works with the design of the input/output variables, the tools and libraries used, and the algorithm used to optimize the partitioning of the interval lengths for input/output water level data.

CHAPTER – THREE

3 RESEARCH METHODOLOGY

In this chapter the major research methodologies applied are represented by the diagram in Figure 3.1. The uncertainty about flood prediction is usually quite high, because introducing some modifications in the interval length of input/output variables can affect the result in fuzzy logic approach. In the present research work fuzzy sets are used for modeling uncertainty and imprecision in an efficient way with Re-Partitioning Discretization algorithm.

The first step of the research methodology is data collection and in this step secondary data is collected from Abay Basin Authority in Bahir Dar and Ministry of Water, Irrigation and Electricity in Addis Ababa upon request.

The second step is preprocess data collected from the secondary sources to fit for the design flood prediction model, this task is done using Re-Partitioning Discretization algorithm in order to optimized the partitioning of the interval lengths for input/output water level data.

The third step is defining linguistic terms for each of the intervals, the fourth step is establishing the fuzzy membership functions and the fuzzy sets, the fifth step is fuzzify the data set and establish the fuzzy relations and the sixth step is design the FFPM model using Mamdani fuzzy Inference System based on the fuzzified data sets and defuzzify the output value and evaluate the accuracy of the FFPM model.

The final step is design SMS Based EWS and integrate with the FFPM Model and send SMS based early waning message for the community based on the results of the prediction model the calibration of the early warning system configured to send SMS for the target audiences.

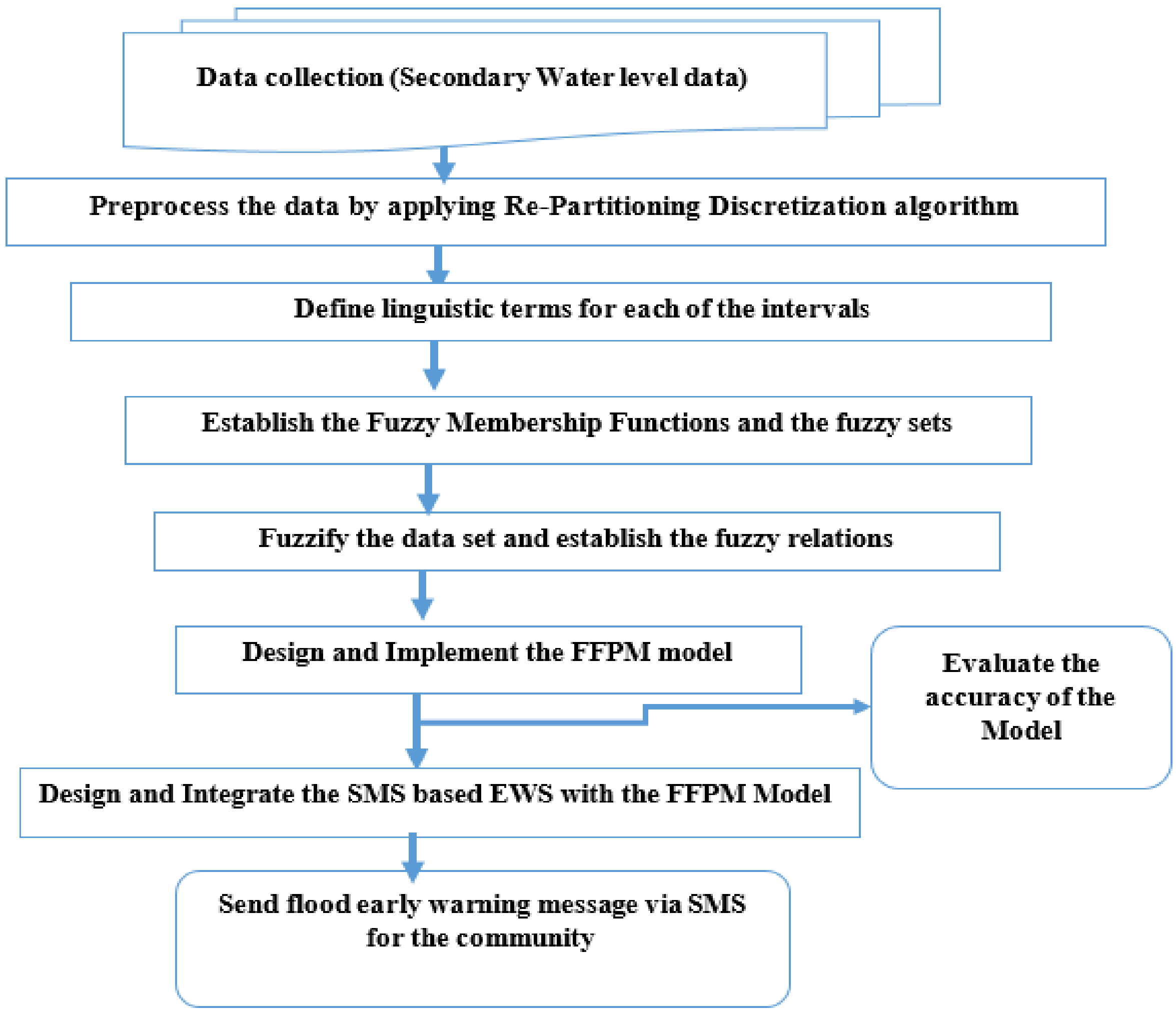

Figure 3.1 Research Methodology

3.1 Data Collection

Data collection and selection of input variables (Water Levels) for this study is conducted after a discussion with experts in the area from Bahir Dar University (Disaster Prevention and food security Institute and faculty of Civil and Water Engineering). Water levels is selected as the most significant variable which is recorded and send to the data center in an hourly basis from the telemetric station by different governmental organizations for different purpose and objective in the study area. The time series water level data is provided by Abay Basin Authority in Bahir Dar and Ministry of Water, Irrigation and Electricity in

Addis Ababa upon request. Some tasks already started by the Abay Basin Authority such as installation of hydrometric gauge station connected with the central main station through GSM network and this data from each telemetric stations are sent in an hour interval by radio-communication to the server to Abay Basin Authority. But nothing has been done on flood prediction using the time series data and designing an early warning system to warn the flood affected community before the disaster happens. *Figure 3.2* shows the existing meteorological network installed in the Tana and Beles sub-basins, to record the hourly water level for the study area (source: NMA, 2010).

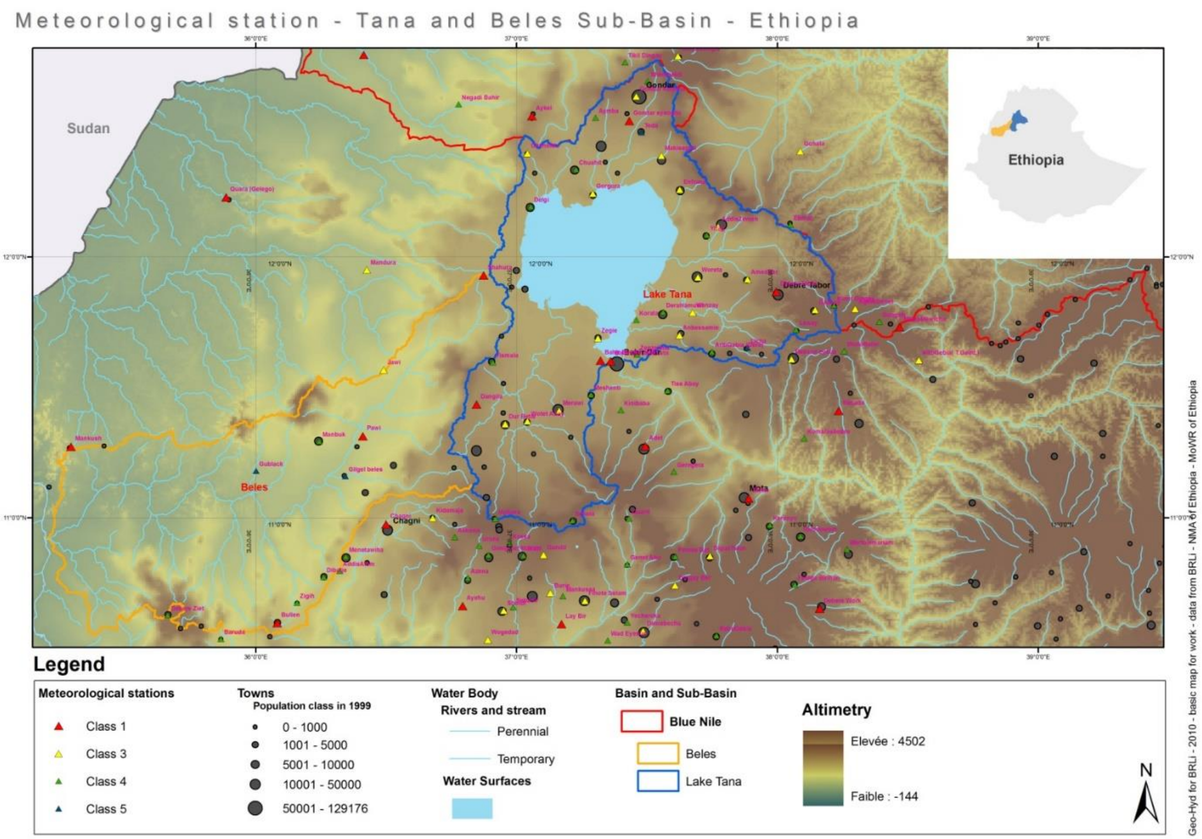

Figure 3.2 Meteorological network in Tana-Beles Basin

3.2 Preprocessing of Input/Output Data

After selection of the time series historical water level data collected from each input/output telemetric stations has done, preprocessing of the input/output data is done using a Re-Partitioning Discretization (RPD) algorithm(Ogbonna, 2014). Re-Partitioning

Discretization (RPD) algorithm is applied to optimized both the interval lengths and the universe of discourse (Singh & Borah, 2013). The main steps involved to adopt the RPD approach are as follows:

Step I. Compute range (**R**) of sample **S**:

$$\mathbf{R} = \mathbf{Max_{Value}} - \mathbf{Min_{value}} \quad \text{……………………………………} \ \mathbf{(3.1)}$$

Step II. Split the data **R** into **M** equally spaced classes:

$$\mathbf{M} = \mathbf{1} + \boldsymbol{log_2^n} \quad \text{……….………………………………} \ \mathbf{(3.2)}$$

Where n is the size of the sample **S**.

Step III. Calculate the width of the interval **H**.

$$\mathbf{H} = \frac{\mathbf{R}}{\mathbf{M}} \quad \text{..……….………………………………} \ \mathbf{(3.3)}$$

Step IV. Define the universe of discourse **U** of the sample **S**:

$$\boldsymbol{U} = [\boldsymbol{l_b},\ \boldsymbol{u_b}] = [\boldsymbol{lower\ bound}, \boldsymbol{upper\ bound}] \quad \text{………..………} \ \mathbf{(3.4)}$$

Where $\boldsymbol{l_b} = \mathbf{Min_{value}} - \mathbf{H}$ **and** $\boldsymbol{u_b} = \mathbf{Max_{value}} + \mathbf{H}$ **.**

Step V. Partition the universe of discourse $\boldsymbol{U}$ into M equal fuzzy set using the interval length **H**:

For this research the sample size (**S**) = 12 for each inputs -output data with different universe of discourse (**U**) prepared. Then apply the RPD approach to partition the universe of discourse in equal classes of fuzzy set. The samples are extracted from the (**June, July, August** and **September)** daily water level data of 2011. Since the study area experiences the maximum rainfall during these month's(Tarekegn, 2009)**.** The **(Minimum, Average** and **Maximum)** values are taken from each month for calibration of the two inputs and the output water level. This gives a sample size of (4 months' x 3 values =12).

Table 3.1 shows the sample (S) with (sample size n =12) for calibration the fuzzy prediction model of Inputs (**Ribb River and Gumara)**.

Table 3.1 The Samples to Calibrate the Input Fuzzy Sets

No.	Sample of Ribb River Water Level (m)	Gumara River Water Level (m)	Remarks
1	4.44	2.5	Sample from June
2	4.93	2.4	
3	6.01	2.84	
4	5.26	3.46	Sample from July
5	6.40	5.17	
6	8.01	6.35	
7	6.02	4.7	Sample from August
8	7.20	5.87	
9	8.25	6.5	
10	5.32	3.20	Sample from September
11	6.59	5.07	
12	8.00	6.16	
	4.44	2.4	Minimum
	8.25	6.5	Maximum
	3.81	4.1	Range(R)=(max-min)

To apply Re-Partitioning Discretization (RPD) partitioning approach on the sample (S) for each input data the minimum and maximum values are identified and the range(R) is computed using Equation (3.1) as showed in the *Table 3.1*. So, for each input sample data (S) we applied the RPD algorithm as follows:

<u>Case –I:</u> For Input -1 (Ribb Water Level) partitioning repeat the same steps from Case-I.

Step I: Computation of the Range(**R**) of sample (**S**)

The minimum and maximum of the sample (S) for Ribb Water Level from the **Error! Reference source not found.** are **4.44** and **8.25** respectively.

Using Equation (3.1) above: $\mathbf{R_{Ribb}} = 8.25 - 4.44 = 3.81 \cong 4$

Step II: Split the data Range(R) in M equal space classes.

Using Equation (3.2) above: $\mathbf{M_{Ribb}} = \mathbf{1} + \boldsymbol{log_2^{12}}$ **=1 + 3.58 =4.58 ≅ 5.**

Step III: Compute the width of the interval $\mathbf{H_{Ribb}}$.

Using Equation (3.3) above: $\mathbf{H_{Ribb}} = \frac{\mathbf{R_{Ribb}}}{\mathbf{M_{Ribb}}} =$ **4/ 5 = 0.8.**

Step IV: Define universe of discourse **U** of the sample **S**. But in our case we ignored the lower bound $\mathbf{l_{Ribb}}$ ***value*** since its effect for the prediction of flood is low(the minimum value of the sample is enough). We only consider the upper bound $\mathbf{u_{Ribb}}$ ***value*** of the universe of discourse for the Flood Level Prediction. So, using Equation (4.4) above: $\mathbf{U_{Ribb}} = [\mathbf{l_{Ribb}}, \mathbf{u_{Ribb}}] = [\mathbf{4.44}, \quad \mathbf{8.25 + 0.8}]$ $\mathbf{U_{Ribb}} = [\mathbf{4.44}, \mathbf{9.05}]$

Step V: Partition the universe of discourse $\mathbf{U_{Ribb}} = [\mathbf{4.44}, \mathbf{9.05}]$ into **5** equal fuzzy set using the interval length **0.8**:

u_{1r}**= [4.44, 6.04]**

u_{2r}**= [5.24, 6.84]**

u_{3r}**= [6.04, 7.64]**

u_{4r}**= [6.84, 8.44]**

u_{5r}**= [7.64, 9.24]**

Case –II: For Input - 2 (**Gumara Water Level**) partitioning.

Step I: Computation of the Range($\mathbf{R_{Gumara}}$) of sample ($\mathbf{S_{Gumara}}$)

The minimum and maximum of the sample ($\mathbf{S_{Gumara}}$) for Gumara Water Level from the **Error! Reference source not found.** are 2.4 and 6.5 respectively. So, using Equation (3.1) a bove: The Range of Gumara sample is calculated as:

$\mathbf{R_{Gumara}} = \mathbf{R} = \mathbf{Max_{Value}} - \mathbf{Min_{value}}$ =6.5- 2.4 = 4.1

Step II: Split the data Range(R) in M equal space classes.

So, using Equation (3.2) above: $\mathbf{M_{Gumara}} = \mathbf{1} + \boldsymbol{log_2^{12}}$ **=1 + 3.58 =4.58 ≅ 5.**

Step III: Compute the width of the interval H.

Using Equation (3.3) above: $\mathbf{H_{Gumara}} = \frac{\mathbf{R_{Gumara}}}{\mathbf{M_{Gumara}}} =$ **4.1/ 5 = 0.82**

Step IV: Define universe of discourse **U** of the sample **S**.

Using Equation (3.4) above: $\mathbf{U_{Gumara}} = [\mathbf{lb_{Gumara}}, \mathbf{ub_{Gumara}}] = [\mathbf{2.4}, \quad \mathbf{6.5 + .82}]$

$$\mathbf{U_{Gumara}} = [\mathbf{2.4}, \mathbf{7.32}]$$

Step V: Partition the universe of discourse $\mathbf{U_{Gumara}} = [\mathbf{2.4}, \mathbf{7.32}]$ into **5** equal fuzzy set using the interval length $\mathbf{H_{Gumara}}$ =0.82.

$\boldsymbol{u_{1g}}$**= [2.4, 4.04]**

$\boldsymbol{u_{2g}}$**= [3.22, 4.86]**

$\boldsymbol{u_{3g}}$**= [4.04, 5.68]**

$\boldsymbol{u_{4g}}$**= [4.86, 6.5],**

$\boldsymbol{u_{5g}}$**= [5.68, 7.32]**

Case –III: For Output (**Lake Water Level**) partitioning.

To partition the output universe of discourse we take 8 sample size (June –September minimum and maximum values). Since the number of simple size determines the number of classes. *Table 3.2* shows the sample(S_{LT}) from the four month's Minimum and Maximum Water Level data of Lake Tana.

Table 3.2 The Samples to Calibrate the Output Fuzzy Set

No.	Lake Tana Water Level (m)	Remarks
1	2.88	Sample from June
2	3.80	
3	3.82	Sample from July
4	5.15	
5	3.60	Sample from August
6	5.80	

7	3.21	Sample from September
8	5.05	
	Minimum = 2.88	
	Maximum = 5.8	
	Range(R) = 2.92	

Step I: Computation of the Range($\mathbf{R_{LT}}$) of sample ($\mathbf{S_{LT}}$)

The minimum and maximum of the sample ($\mathbf{S_{LT}}$) for Lake Tana Water Level from the *Table 3.2* are 2.88 and 5.80 respectively. So, using Equation (3.1) above: The Range of Lake Tana sample(S_{LT}) is calculated as:

$\mathbf{R_{LakeT}} = \mathbf{R} = \mathbf{Max_{Value}} - \mathbf{Min_{value}}$ =5.80- 2.88 = 2.92

Step II: Split the data Range(R) in M equal space classes. (Sample Size n= 8 in this case)

So, using Equation (3.2) above: $\mathbf{M_{LakeT}} = \mathbf{1} + \boldsymbol{log_2^8}$ **=1 + 3 =4**

Step III: Compute the width of the interval H.

Using Equation (3.3) above: $\mathbf{H_{LakeT}} = \frac{\mathbf{R_{LakeT}}}{\mathbf{M_{LakeT}}}$ = **2.92/ 4 = 0.73**

Step IV: Define universe of discourse **U** of the sample $\mathbf{S_{LT}}$.

Using Equation (3.4) above: $\mathbf{U_{LakeT}} = [\mathbf{lb_{LakeT}},\ \mathbf{ub_{LakeT}}] = [\mathbf{2.88} - \mathbf{0.73},\ \ \mathbf{5.8} + \mathbf{0.73}]$ $\mathbf{U_{LakeT}} = [\mathbf{2.15}, \mathbf{6.53}]$

Step V: Partition the universe of discourse $\mathbf{U_{LakeT}} = [\mathbf{2.15}, \mathbf{6.53}]$ into **3** equal fuzzy set using the interval length $\mathbf{H_{LakeT}}$ = 0.73. to make the output clear and unbiased, the symmetrical, non-overlapping equal-size membership functions were used for the output variable. So, the following fuzzy set are representing the output.

$\boldsymbol{u_{1LT}}$**= [2.15, 3.61],** $\boldsymbol{u_{2LT}}$**= [3.61, 5.07],** $\boldsymbol{u_{4LT}}$**= [5.07, 6.53]**

CHAPTER-FOUR

4 DESIGN OF THE FUZZY FLOOD PREDICTION MODEL (FFPM)

In this chapter the design and implementation of the input-output relation of a fuzzified flood level prediction model has been discussed.

4.1 Design and Implementation of the Fuzzy Flood Prediction Model

The design and implementation of the Fuzzy Flood Prediction Model (FFPM) consists of modelling the system inputs and outputs as linguistic variables, and creating the necessary inference rules that control the system output *Figure 4.1* shows the proposed Fuzzy Flood Prediction Model High Level Architecture.

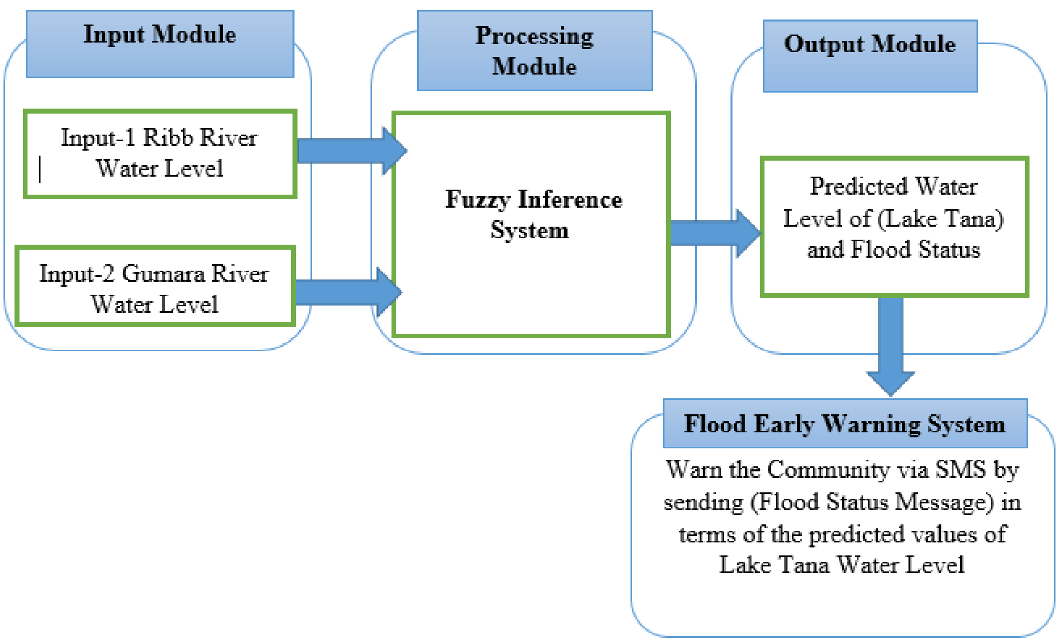

Figure 4.1 High Level Architecture of the FFPM and SMS Based EWS

The model uses the water level of two upstream stations as an input for the prediction model and predicts the water level of the Lake Tana as an output by applying the fuzzy logic prediction approach then in terms of the predicted water levels of Lake Tana, flood waring messages dispatch to the community via mobile SMS service. The algorithms we followed to design the prediction model is presented as follows:

1. Defining Fuzzy Terms
   - ❖ Define linguistic terms for each interval obtained in Step 1
   - ❖ Define fuzzy membership function and fuzzy sets
2. Fuzzify the data into fuzzy sets both in linguistic and numeric terms to capture the uncertainty and fuzziness inherent in the data
3. Create the fuzzy relationships using a fuzzy Inference System of rule based on the fuzzified input values and
4. Defuzzify the output into crisp values then predicted flood status using the crisp values of the output water level values along with the model's rule.

4.2 Defining the Fuzzy Linguistics Terms:

The set of terms of a linguistic variable is a fuzzy set when each value of the system variable belongs with degrees of certainty to one or more of its linguistic terms according to their respective membership functions(Rada-vilela, 2012). Assuming that the historical data is distributed among the intervals of $\boldsymbol{u_1, u_{2,} \dots , u_n}$ $\boldsymbol{fuzzy\ set.}$ Therefore, the five linguistic variables/fuzzy sets defined for the two inputs (Ribb and Gumara River Water Level) are: **(**Very Low, Low, Medium, high and Very High**).** And three linguistic variables/ fuzzy set defined for the output variable (Lake Tana water level) are: **(**Normal, Warning and Emergency**).** *Table 4.1* shows the linguistic variables and numeric intervals for the two input variables Stations. The Numbers which represent the numeric intervals of the two inputs and the output variable are the ranges each linguistic term/ fuzzy set covers. And *Table 4.2* shows the output variable Station.

Table 4.1 Mapping of Linguistic Terms and Numerical Intervals for the Inputs

No.	Input Linguistic Terms/Variables (Fuzzy Set)	Input-1 Interval	Input-2 Interval
		Ribb River Water Level	Gumara River Water Level
1	Very Low	4.44-6.04 m	2.4-4.04 m
2	Low	5.24-6.84 m	3.22-4.86 m
3	Medium	6.04-7.64 m	4.04-5.68 m
4	High	6.84-8.44 m	4.86-6.5 m
5	Very high	7.64-9.24 m	5.68-7.32 m

Table 4.2 Mapping of Linguistic Terms and Numerical Intervals for the Output

No.	**Output Linguistic Terms/variables (Fuzzy Sets)**	**Output-Water Level Interval at Lake Tana Station**
1	Normal	3.61-5.07 m
2	Warning	4.34-5.80 m
3	Emergency	5.07-6.53 m

4.3 Define Membership Function

After partitioning of the input and output variables a membership function was defined for each linguistic terms of the input output variable. Using a membership function μ, we can define a fuzzy set F on a universe of discourse U of each input-output pairs. The membership function is nothing but a mapping from the universe of discourse U into the unit interval [0,1] and μF(x) represent the extent to which x belongs to fuzzy set F. The concept of membership functions allows any element within the universe of discourse to have partial membership to a specific fuzzy set and also to have partial membership to other fuzzy sets.

On the other hand, in fuzzy logic, a membership function (MF) is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1(Variables, 1996). In the following diagrams each fuzzy set/ linguist term is represent by a triangular and trapezoidal shape membership functions the height of each shape is the maximum of the degree of membership for each linguistic term/fuzzy set.

4.4 Input Variable Membership Functions

The vertices of each fuzzy set/ linguistic terms for Input-1- Ribb River water level with the five linguistic terms or fuzzy sets such as (Very Low, Low, Medium, High and very High) represented as follows:

a. Vertices of **Very Low** Trapezoid (a, b, c, d) = **(4.44,0), (4.44,1), (5.24,1), (6.04,0) respectively**
b. Vertices of **Low** Triangle (a, b, c) = **(5.24,0), (6.04,1), (6.84,0)**
c. Vertices of **Medium** Triangle (a, b, c) = **(6.04,0), (6.84,1), (7.64,0)**
d. Vertices of **High** Triangle (a, b, c) = **(6.84,0), (7.64,1), (8.44,0)**
e. Vertices of **Very High** Trapezoid (a, b, c, d) = **(7.64,0), (8.44,1), (9.24,1) (9.24,0)**

The diagram in *Figure 4.2* is showed the representation of each fuzzy set/ linguistic terms for Input-1- Ribb River water level with two different shapes Trapezoid and Triangle for each fuzzy set represented by five linguistic terms. As clearly shown in the diagram the first and the last linguistic term is Very Low and Very High which are represented by the Trapezoidal shape and the rest three linguistic terms Low, Medium and High are represented by the Triangular shape.

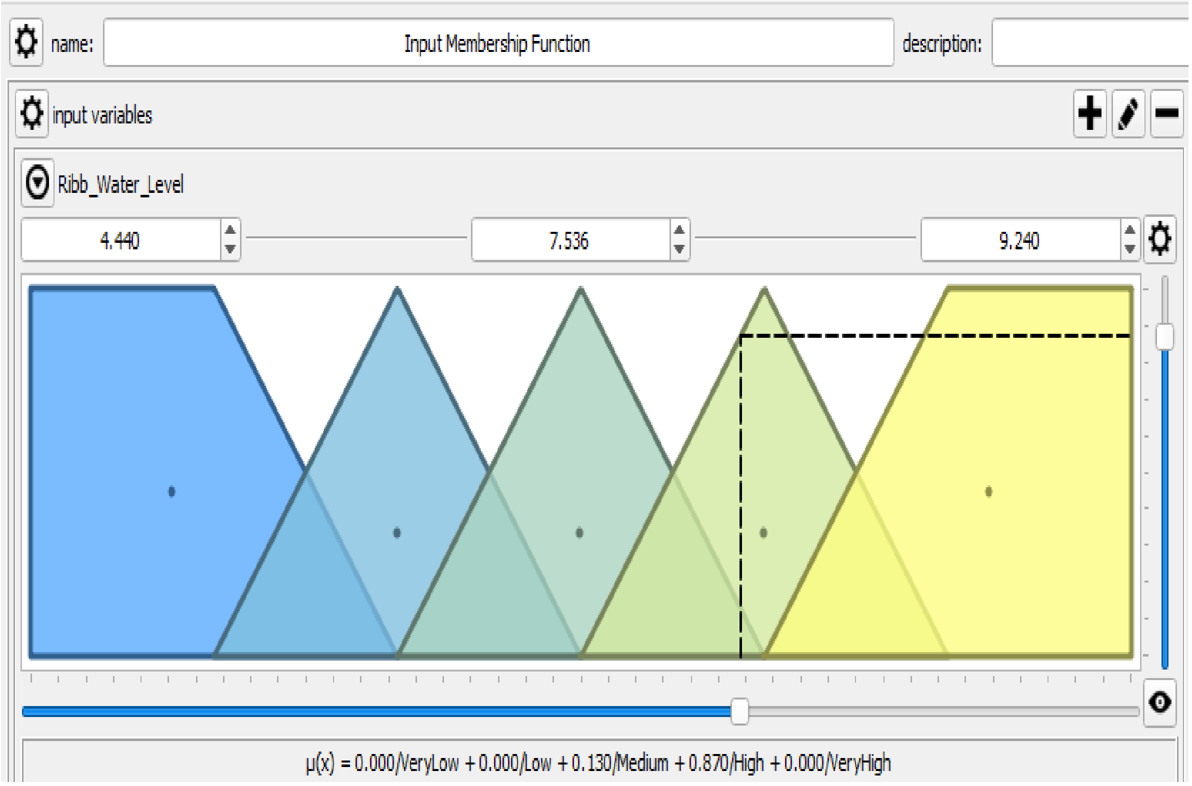

Figure 4.2 Membership Function for Input-1 Ribb River Water Level

The vertices of each fuzzy set/ linguistic terms for Input-2 – Gumara River water level with the five linguistic terms or fuzzy sets such as (**Very Low, Low, Medium, High and Very High**) represented as follows:

a. Vertices of **Very Low** Trapezoid (a, b, c, d) = **(2.4,0), (2.4,1), (3.22,1), (4.04,0)** respectively
b. Vertices of **Low** Triangle (a, b and c) = **(3.22,0), (4.04,1), (4.86,0)**
c. Vertices of **Medium** Triangle (a, b and c) = **(4.04,0), (4.86,1), (5.68,0)**
d. Vertices of **High** Triangle (a, b and c) = **(4.86,0), (5.68,1), (6.5,0)**
e. Vertices of **Very High** Trapezoid (a, b, c, d) **= (5.68,0), (6.5,1), (7.32,1) (7.32,0)**

The diagram in *Figure 4.3* is showed the representation of each fuzzy set/ linguistic terms for Input-2- Gumara River water level with two different shapes Trapezoid and Triangle for each fuzzy set represented by five linguistic terms. As clearly shown in the diagram the first and the last linguistic term is Very Low and Very High which are represented by the Trapezoidal shape and the rest three linguistic terms Low, Medium and High are represented by the Triangular shape

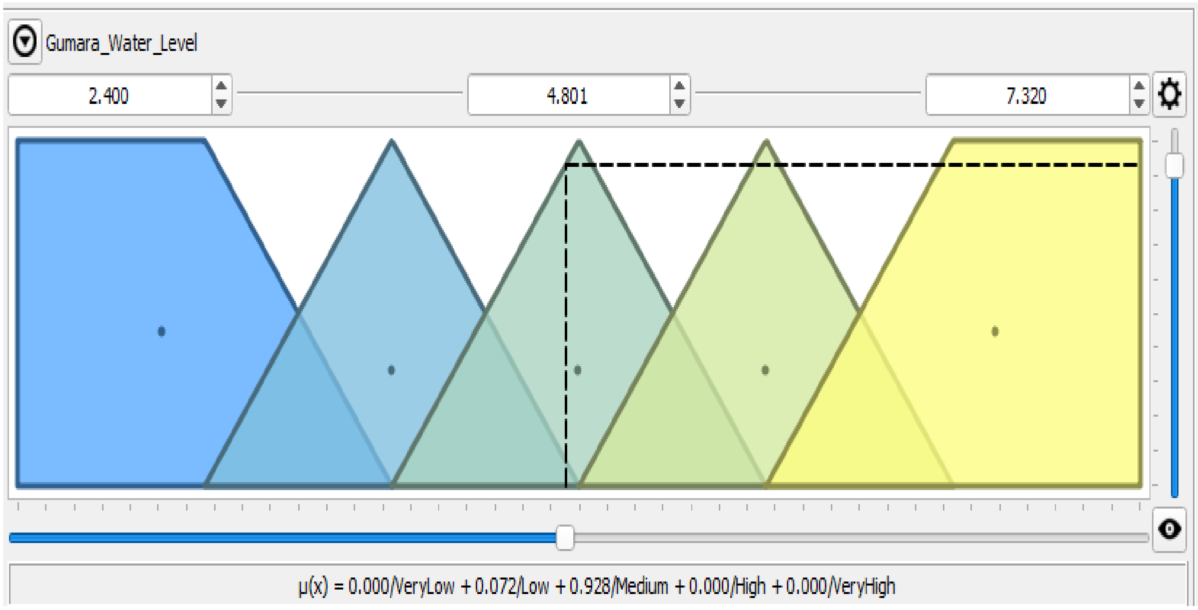

Figure 4.3 Membership Function for the Input-2 Gumara Water Level

4.5 Output Variable –Membership Function

The vertices of each triangle (each fuzzy set/ linguistic terms) for Output – Lake Tana water level with the three linguistic terms or fuzzy sets such as (**Normal, Warning, and Emergency**) represented as follows:

a. Vertices of **Normal** Triangle (a, b and c) = **(3.61,0), (4.34,1), (5.07,0) respectively**

b. Vertices of **Warning** Triangle (a, b and c) = **(4.34,0), (5.07,1), (5.80,0)**

c. Vertices of **Emergency** Triangle (a, b and c) = **(5.07,0), (5.8,1), (6.53,0)**

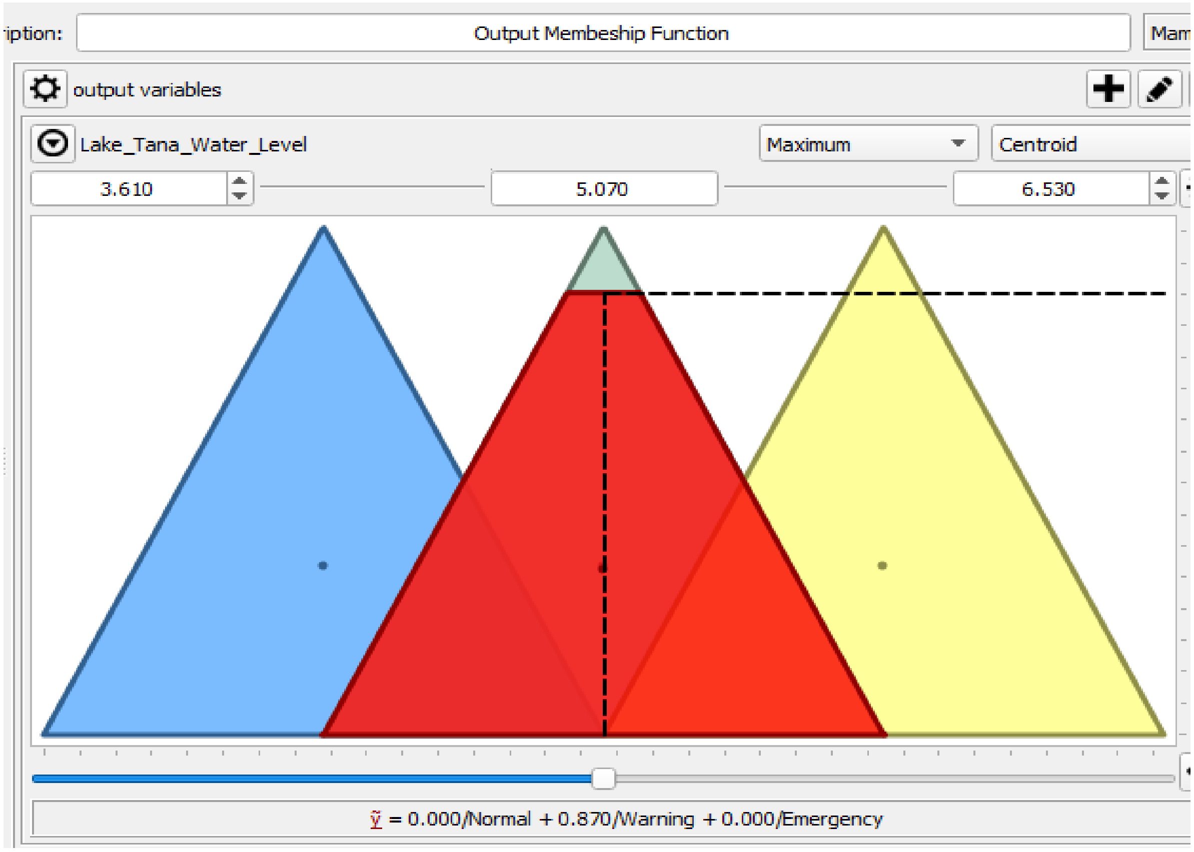

Figure 4.4 Output Variable Membership Function

The diagram in *Figure 4.4* is showed the representation of each fuzzy set/ linguistic terms for output water level with Triangular shape in terms of membership function representation.

4.6 Fuzzy "IF-THEN" Rule Formulation

As shown in the *Table 4.3* below, In this study, the expert was asked to summarise the knowledge about the system in the form of a cause and effect relationship. From these, the rules were formulated and our fuzzy model has 5x5 = 25 rules based on the MF considered for the two inputs. These IF-THEN rules are collated with AND operator because all the input variables must be captured simultaneously and applied in decision making by fuzzy logic for the prediction of the flood status in terms of Lake Tana water level. The rules can be written as: If **(Ribb water Level is μ_{ij}) and (Gumara water Level is μ_{ij}) then**

$R_{k=}\mu_{ok}(Z;\ a_{ok}, b_{ok}, c_{ok})$ for k=1, 2, ……,25. Where μ_{ij} is the j^{th} MF of the i^{th} input and μ_{ok} is the k^{th} output MF; R_k is the output of the k^{th} rule; a_{ok}, b_{ok}, c_{ok} are the parameters that represent the shapes of the output MFs. The following rules are formulated from the knowledge of the experts in the study area.

Table 4.3 Fuzzy Rule Formulation by the Experts Knowledge

Ribb WL / Gumara WL	Very Low	Low	Medium	High	Very High
Very Low	Normal	Normal	Normal	Normal	Normal
Low	Normal	Normal	Normal	Normal	Normal
Medium	Normal	Normal	Normal	Warning	Warning
High	Normal	Normal	Warning	Warning	**Emergency**
Very High	Normal	Normal	Warning	**Emergency**	**Emergency**
	Lake Tana Water Level				

4.7 Mamdani Fuzzy Inference Prediction Model

The diagram in the *Figure 4.5* is showed the Mamdani type Fuzzy Inference Flood Prediction Model with the five processes, fuzzification, calculation of degree of membership, implication, aggregation and defuzzification. The fuzzification process converts the crisp value of inputs in to fuzzy sets/linguistic terms for each of the two inputs (Very Low, Low, Medium, High and Very High). The diagram also shows the fuzzy logic operators and methods applied in each the five processes.

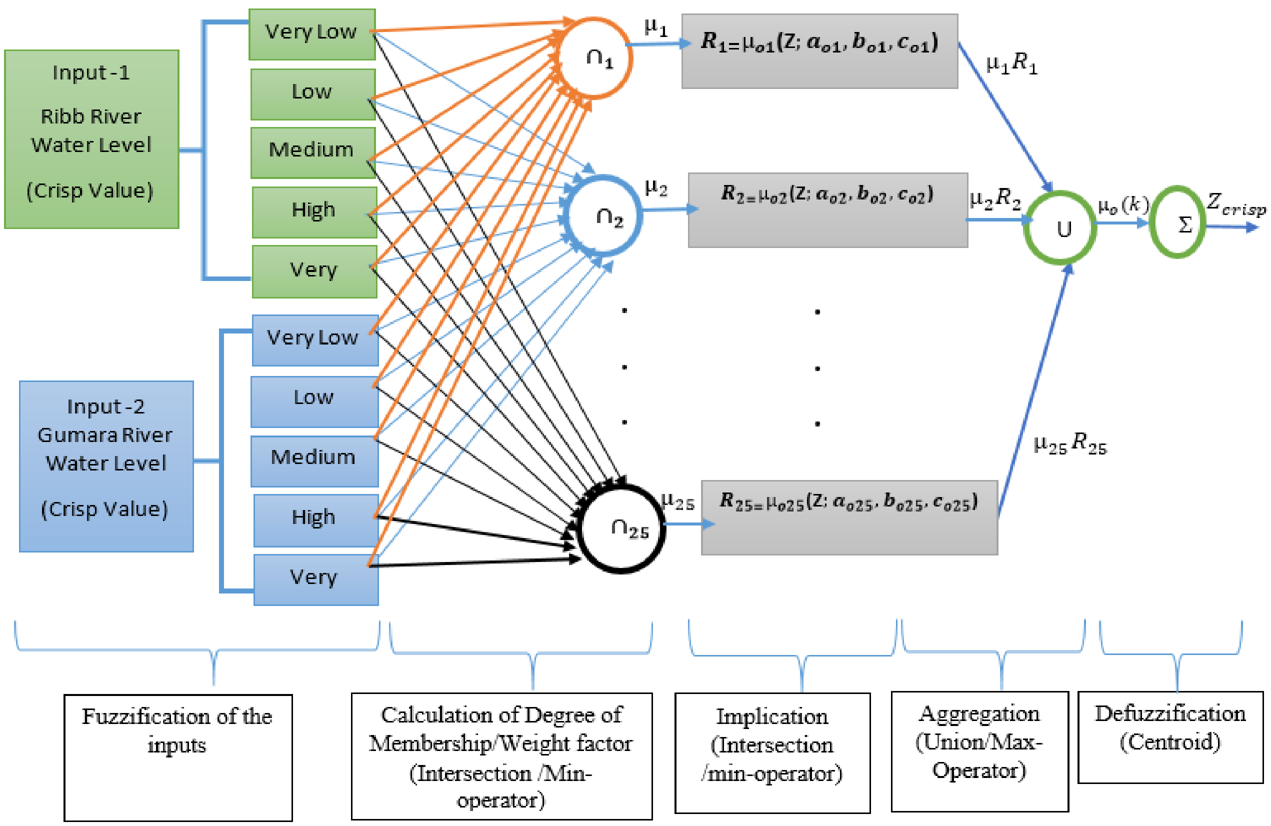

Figure 4.5 Fuzzy Inference Flood Prediction Model

4.7.1 Fuzzification

Fuzzification is the first step in a Fuzzy Inference System process and it is used to apply the inputs and determine the degree to which they belong for each of the fuzzy sets via membership function. This is required in order to activate rules that are in terms of linguistic variables. Once membership functions are defined, fuzzification takes the crisp input value and compares it with the stored membership function to produce fuzzy input values. In order to perform this mapping, we can use fuzzy sets of any shape, such as triangular, trapezoid, Gaussian, π-shaped, etc. For this research, two types of shapes are applied, the trapezoidal and triangular membership function. *Figure 4.6* shows the fuzzification process.

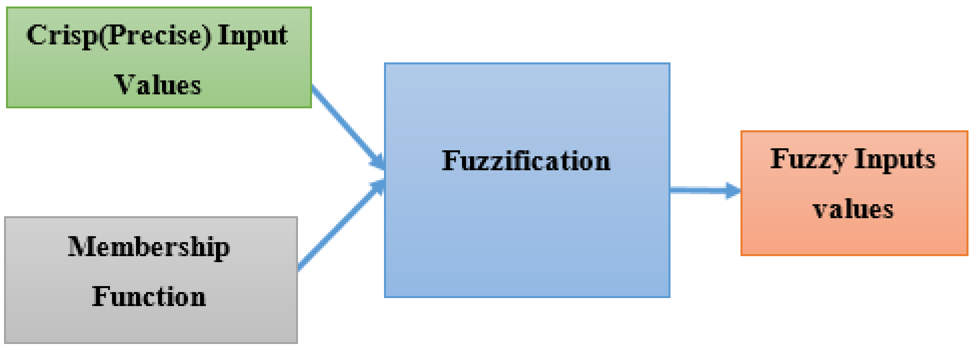

Figure 4.6 Fuzzification Process Input Values

4.7.2 Calculation of Weight Factor

A fuzzy rule base system contains a set of fuzzy "if - then" rules. Generally, if-then-rule can be interpreted by the following three steps:

1. Resolve all fuzzy statements in the antecedent part to a degree of membership, $\mu_{k}(x)$ between 0 and 1.
2. If the rule has more than one antecedent, the fuzzy operator is applied to obtain one number that represents the truth value of applying that rule. The truth value of a fuzzy rule is known as the degree of fulfillment (Duminda et al., 2015). In our case the antecedent part has two inputs and therefore it is combined with the intersection operator 'AND (∩)'. (such as for example, ***IF Ribb water level is high AND Gumara water level is high THEN Lake Tana is Emergency***). Therefore, we can calculate the weight factor, μ_{k} as follows:

$$\mu_{k} = min(\mu_{ij}(Ribb), \mu_{ij}(Gumara)) \quad \text{……………………} \quad (4.5)$$

Where, $\mu_{ij}(\boldsymbol{Ribb})$and $\mu_{ij}(\boldsymbol{Gumara})$ are the degree of membership value of Ribb and Gumara River water Level respectively and $\mu_{k}$is the antecedent part of the rule which is called weight factor and used to shape the output fuzzy set that represents the consequent part of the rule and k=1,2……,25, which is the number of rules.

4.7.3 Apply Implication Operators

The implication method is defined as the shaping of the consequent, which is the output fuzzy set, based on the antecedent. The input for the implication process is a single number given by the antecedent, and the output fuzzy set. Commonly Minimum (Intersection) operator is used as an implication operator(Variables, 1996). Which is represented by the following equation:

$$\mu_{imp,k} = \boldsymbol{min}(\mu_k \boldsymbol{R_k}) \text{ ……………………. } \textit{(4.6)}$$

where μ(y) is the output degree of membership value, and $\mu(y_{iLT})$ is the output fuzzy sets and k= 1, 2, ….,25.

4.7.4 Apply Aggregation Operators

Aggregation takes all truncated or modified output fuzzy sets obtained as the output of the implication process and combines them into a single fuzzy set(Zadeh et al., 1965)(Variables, 1996). The output of the aggregation process is a single fuzzy set that represents the output variable. The aggregated output is used as the input to the defuzzification process. Since decisions are based on the testing of all of the rules in the model, rules must be combined in order to make decision. In this model, the aggregation was performed by using union (maximum) operator, which was represented as:

$$\mu_o(\boldsymbol{k}) = \boldsymbol{max}(\mu_{imp,k}) \text{ ……………………. } \textit{(4.7)}$$

$$= \boldsymbol{max}(\boldsymbol{min}(\mu_k \boldsymbol{R_k}))$$

$$= \boldsymbol{max}(\boldsymbol{min}(\mu_k, \mu_o(\boldsymbol{k})))$$

$$\boldsymbol{where}, \boldsymbol{k} = \mathbf{1}, \mathbf{2}, \dots, \mathbf{25}.$$

4.7.5 Defuzzification

Defuzzification is the process of converting fuzzified result into crisp value. Among the different defuzzification such as center of sums, center of largest area, first of maxima, middle of maxima and center of gravity (COG/COA) method is the most widely used in practical applications, because it is known to have a less mean square error and better steady-state performance(Mahalakshmi & Ganesan, 2015). Centroid finds the point where a vertical line would slice the aggregate set into two equal masses(Uraon & Kumar, 2016). Mathematically this center of area (COA) can be expressed as:

$$Z = \frac{\sum_{i=1}^{n} a_i c_i}{\sum_{i=1}^{n} a_i} \quad \text{……………………………………..(4.8)}$$

Where $a_1, a_2, \ldots, a_n$ is the areas of the truncated triangular areas under the aggregated function and $c_1, c_2, \ldots, c_n$, be the coordinates of their center on the x-axis, n is the number of areas and Z is the location of the centroid of the total areas which determines the defuzzified output crisp value.

4.8 Fuzzy Flood Prediction Model Implementation

The proposed fuzzy flood prediction model is designed and implemented as a fuzzy rule-based system based on the Mamdani's fuzzy inference method which uses decision method for fuzzy logic operators "AND": = minimum, decision method for fuzzy logic operators "OR": = maximum, implication process operator "AND": = minimum and aggregation process operator "OR": = maximum, rule activation method is the highest value and defuzzification process carried out using "centroid" center of gravity (COG) methods. *Figure 4.7* shows the implementation of the proposed fuzzy flood prediction model using Qtfuzzylite graphical user interface. As shown in the diagram on left side of the diagram there are two inputs, Ribb water level with its value ranges from 4.440 -9.240 metres and Gumara water level with its values range from 2.40 to 7.320 meters and on the right side the Lake Tana water level with its value ranges from 3.610 to 6.530 meters. Based on this the diagram show the specific results obtained when we give specific values for each inputs in the given range. So, as shown in the diagram below: The value of Ribb water level is 7.536-meter which is crisp value and interpreted based on the design of the input membership function as μ(x)=0.000(Very Low) +0.000(Low) +0.130(Medium) +0.870(High) + 0.000(Very High). The value of Gumara water level is 4.801-meter which is crisp value and interpreted based on the design of the input membership function as

μ(x)=0.000(Very Low) +0.072(Low) +0.928(Medium) +0.000(High) + 0.000(Very High). Then the value of Lake Tana water level is 5.070-meter which is crisp value and interpreted based on the design of the output membership function as

Y(x) = 0.000(Normal) +0.870(Warning) + 0.000(Emergency)=>Which gives the final output of Lake Tana =5.070 meters belongs to Warning Linguistic term/fuzzy set. Which is expressed in the fuzzy rule formation as:

"If Ribb water level is high and Gumara water level is medium the Lake Tana water level is warning"

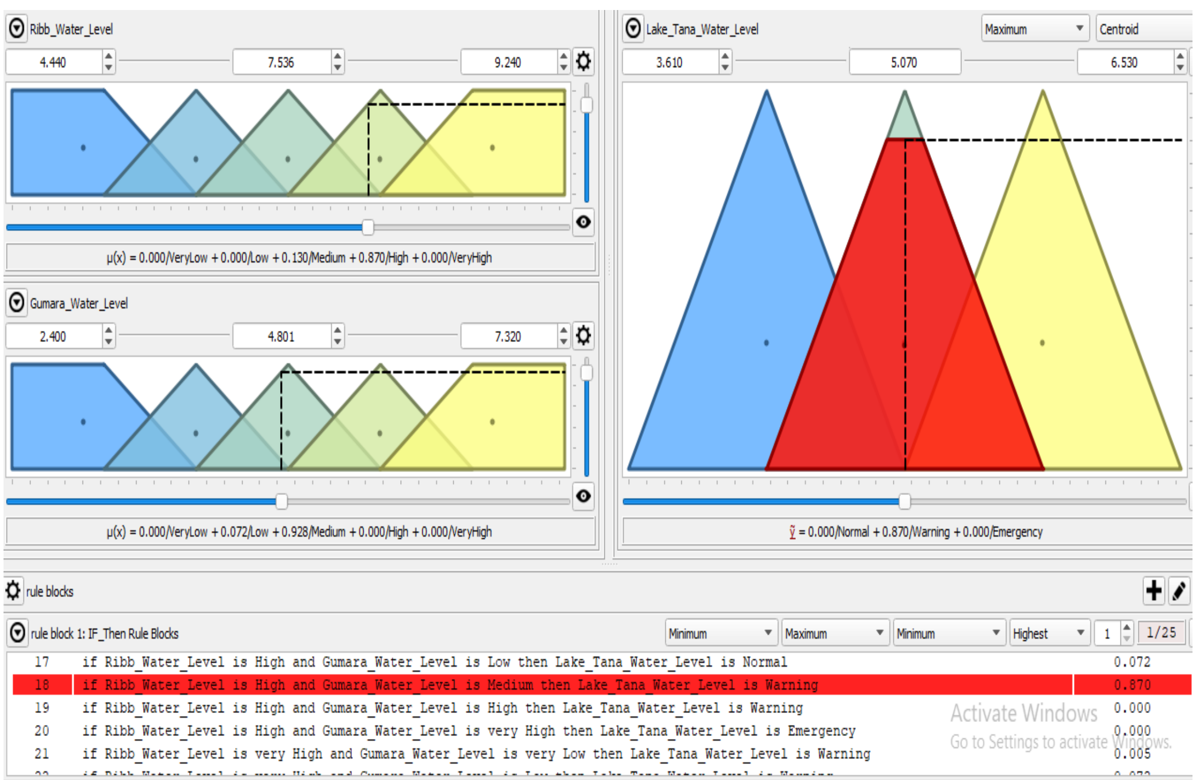

Figure 4.7 Demonstration of the Mamdani Type FFPM Model

CHAPTER – FIVE

5 IMPLEMENTATION OF SMS BASED EARLY WARNING SYSTEM

This chapter discusses about the two major sections of this research. In the first section the implementation of the SMS based early warning system, the components and the communication protocols are discussed.

5.1 Implementation of SMS Based Early Warning System

The implementation of flood early warning system is designed to send an automatic flood status notification via SMS to the community located in the flood risk areas with mobile phones. To effectively perform this functionality, it has the following components. These includes: The Fuzzy Flood Prediction Application and the SMS sending in Java programming language, the SMS Gateway and the User Categories who received the warning Message, *Figure 5.1* below shows the communication between these main components to send an early warning message.. HTTP is used to establish connection and which categories of user groups are considered to receive the message.

The second major component is the SMS Gateway Device/ Hardware whether it GSM/GPRS modem or any android smart phone which with SMS Gateway Server install on it. The SMS Gateway allows the PC to send or receive SMS messages to or from a telecommunications network. It is able to send the SMS messages coming from the Java application through HTTP to the SMSC (Short Message Service Center) of the Mobile Service Provider via SMPP IP SMS connection or a GSM modem. between the Java application and the SMS Gateway can be used to send SMS messages and provides the decision making parameter that decides what type of message to be sent.

The third major component is the recipient of the early warning messages sent from the flood prediction java application through HTTP to the different recipient telephone numbers. The type of notification message to be sent to the community is varies according to the predicted water levels values of Lake Tana. The messages are prepared once and stored in a file/database and when the output values of the prediction system run, the SMS early warning system triggered and send the flood warning message automatically for the list of contacts in the contact list according to the rules defined which type of messages to be sent, when the predicted water levels of Lake Tana exceeds the threshold value for each classes of warning levels.

5.2 SMS Based Early Warning System Screen Shoot

The screen shoot in *Figure 5.1* showed the early warning notification for the two kebeles Nabega and Wagetera which are living in the flood risk area continuously affected by the flood in the study area(Statement of the Problem). As shown from the screen shoot two type

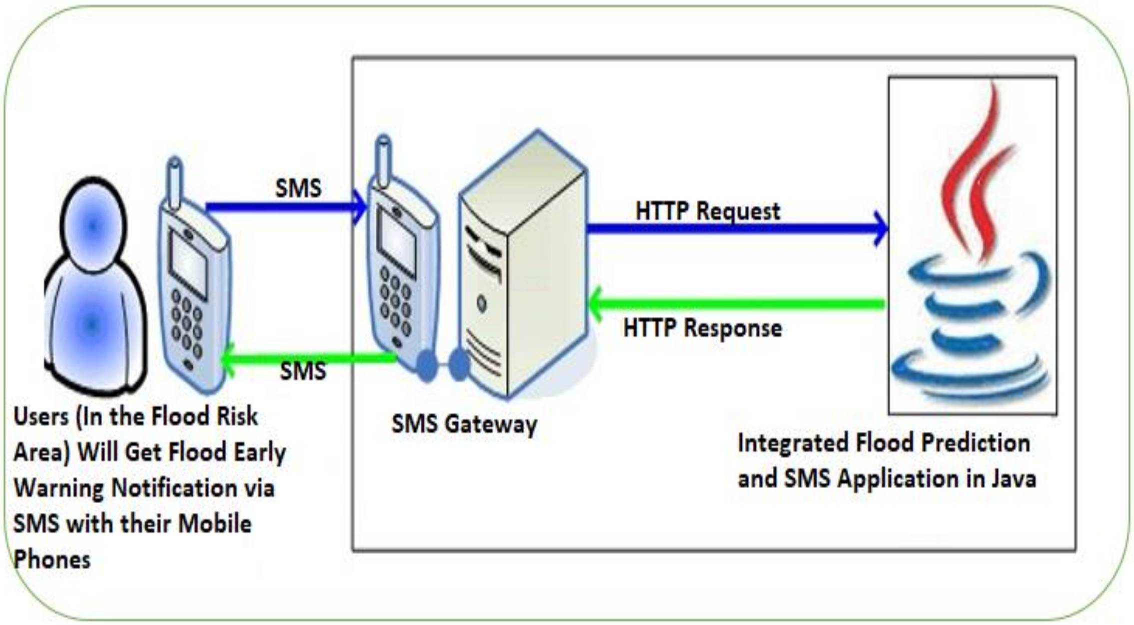

Figure 5.1 Inter Communication Java Application, SMS Gateway, End User

of messages are going to be sent for the end users. The first message is an "Emergency Message" which sent when the predicted value of the output exceeds the warning level and the second type of message is sent when the predicted value of the output exceeds the normal level.

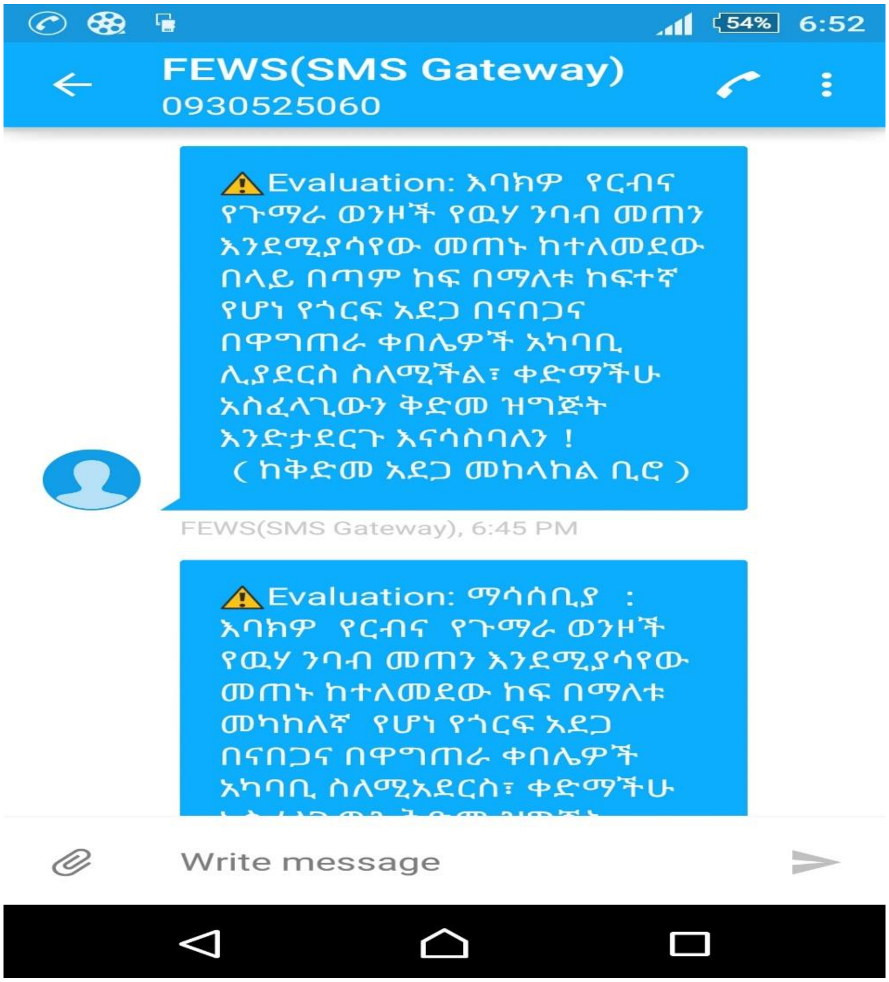

Figure 5.2 SMS Based Early Warning Message Screen Shoot

CHAPTER SIX

6 VALIDATION OF THE PREDICTION MODEL

In this section the validation of the prediction model, the preparation and generation of the validation data set, the statistical measurement applied to measure the accuracy of the prediction model and comparison of the predicted value with the measured value and interpretation of the result in tabular and graphical chart formats are discussed

Validation is a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy(Mahalakshmi & Ganesan, 2015) . For validation of the designed fuzzy flood prediction model, first prepared 9(nine) hourly water levels from each four different day's and month's (June –September, 2016) with a total of 36 testing data. Then simulate the designed FFPM model using this testing dataset to predict the output water levels of Lake Tana, which determines the status of the up-coming flood in the study area. *Table 6.1* shows the validation dataset prepared to test the prediction model for the two inputs Ribb and Gumara water level, the results obtained in crisp(precise value), which is obtained after the defuzzification of the fuzzy value of the output using centroid defuzzification method and the membership value which tells us the degree of membership or the % to be normal or warning and/or emergency warning level and the last column of *Table 6.1* shows the interpretation of the crisp(precise value) of the output in linguistic terms.

Table 6.1 The Validation Dataset

Date and Time	**Input-1 Water Level**	**Input-2_Water Level**	**Output Predicted Water Level**	**Linguistic Terms of the output**
16-06-16 8:00	5.28	4.73	4.340	Normal
16-06-16 9:00	5.91	5.74	5.800	Emergency
16-06-16 10:00	5.83	4.18	4.340	Normal
16-06-16 11:00	6.06	5.69	5.800	Emergency
16-06-16 12:00	5.72	4.67	4.340	Normal
16-06-16 13:00	5.62	4.9	4.340	Normal

16-06-16 14:00	5.4	4.4	4.340	Normal
16-06-16 15:00	6.5	4.88	4.340	Normal
16-06-16 16:00	6.12	5.55	4.340	Normal
05-07-16 15:00	6.09	4.56	4.340	Normal
05-07-16 16:00	6.59	5.82	5.800	Emergency
05-07-16 17:00	6.41	5.88	5.800	Emergency
05-07-16 18:00	6.36	5.44	5.800	Emergency
05-07-16 19:00	6.91	4.8	4.340	Normal
05-07-16 20:00	6.82	5.96	5.070	Warning
05-07-16 21:00	6.28	5.39	4.340	Normal
05-07-16 22:00	6.1	5.71	5.800	Emergency
05-07-16 23:00	7.24	5	5.070	Warning
07-08-16 8:00	5.99	4.54	4.340	Normal
07-08-16 9:00	8.01	5.5	5.800	Emergency
07-08-16 10:00	7.76	5.62	5.800	Emergency
07-08-16 11:00	8.25	5.352	5.800	Emergency
07-08-16 12:00	7.28	5.68	5.800	Emergency
07-08-16 13:00	7.32	6.2	5.070	Warning
07-08-16 14:00	7.13	6.64	5.800	Emergency
07-08-16 15:00	6.62	6.04	5.070	Warning
07-08-16 16:00	8.23	5.8	5.800	Emergency
03-09-16 8:00	8.12	5.52	5.800	Emergency
03-09-16 9:00	8	5.6	5.800	Emergency
03-09-16 10:00	7.14	5.34	5.070	Warning
03-09-16 11:00	6.66	6.1	5.070	Warning
03-09-16 12:00	6.87	5.77	5.070	Warning
03-09-16 13:00	6.66	5.64	5.800	Emergency
03-09-16 14:00	6.62	6.16	5.070	Warning
03-09-16 15:00	6.82	5.5	5.070	Warning
03-09-16 16:00	6.72	5.38	5.070	Warning

6.1 Results and Discussion

The statistical performance indicator considered here to measure the accuracy of the FFPM model is Mean Absolute Percentage Error (MAPE). The prediction error obtained using the MAPE is 0.0597, which shows reasonable agreement between the predicted and measured values for the testing datasets and which gives 94.03 % of accuracy for the prediction model. *Table 6.2* summarizes the **p**redicted results of the output variable using the FFPM model with the testing dataset at (t) hr., with the measured water level values of the output variable at (t) hr. using the input water levels at (t-1)hr., and the status of flood mapped in to linguistic terms. As *Table 6.2* showed the slight deviation of the predicted value from the measured value is due to the water level of Lake Tana affected by other source of tributaries in that specific study area.

6.2 Interpretation of the Result Using Table

The result showed in *Table 6.2* is the comparison of the predicted value with the measured value of output water level, which shows reasonable agreement between the predicted and measured values for the testing datasets.

Table 6.2 The Predicted Vs Observed Values of the Output

Date and Time	Lake Tana Predicted Water Level	Lake Tana Measured Water Level
16-06-16 8:00	4.34	4.02
16-06-16 9:00	5.8	5.17
16-06-16 10:00	4.34	4.16
16-06-16 11:00	5.8	5.26
16-06-16 12:00	4.34	4.07
16-06-16 13:00	4.34	3.95
16-06-16 14:00	4.34	4.29
16-06-16 15:00	4.34	4.57
16-06-16 16:00	4.34	4.11
05-07-16 15:00	4.34	4.42
05-07-16 16:00	5.8	5.32
05-07-16 17:00	5.8	5.43
05-07-16 18:00	5.8	5.41
05-07-16 19:00	4.34	3.92
05-07-16 20:00	5.07	4.96
05-07-16 21:00	4.34	5.47

05-07-16 22:00	5.8	4.53
05-07-16 23:00	5.07	4.42
07-08-16 8:00	4.34	5.49
07-08-16 9:00	5.8	5.28
07-08-16 10:00	5.8	5.97
07-08-16 11:00	5.8	5.47
07-08-16 12:00	5.8	5.23
07-08-16 13:00	5.07	4.78
07-08-16 14:00	5.8	5.44
07-08-16 15:00	5.07	4.57
07-08-16 16:00	5.8	5.92
03-09-16 8:00	5.8	5.33
03-09-16 9:00	5.8	5.95
03-09-16 10:00	5.07	4.82
03-09-16 11:00	5.07	4.65
03-09-16 12:00	5.07	4.63
03-09-16 13:00	5.8	5.85
03-09-16 14:00	5.07	4.68
03-09-16 15:00	5.07	5.66
03-09-16 16:00	5.07	4.68

6.3 Interpretation the Result Using Graphical Charts

The graph in *Figure 6.1* showed the comparison of the predicted value with the measured value of output water level, which shows reasonable agreement between the predicted and measured values for the testing datasets. From the graph the red line represents the predicted value of the output value and the blue line shows the measured value of the output value.

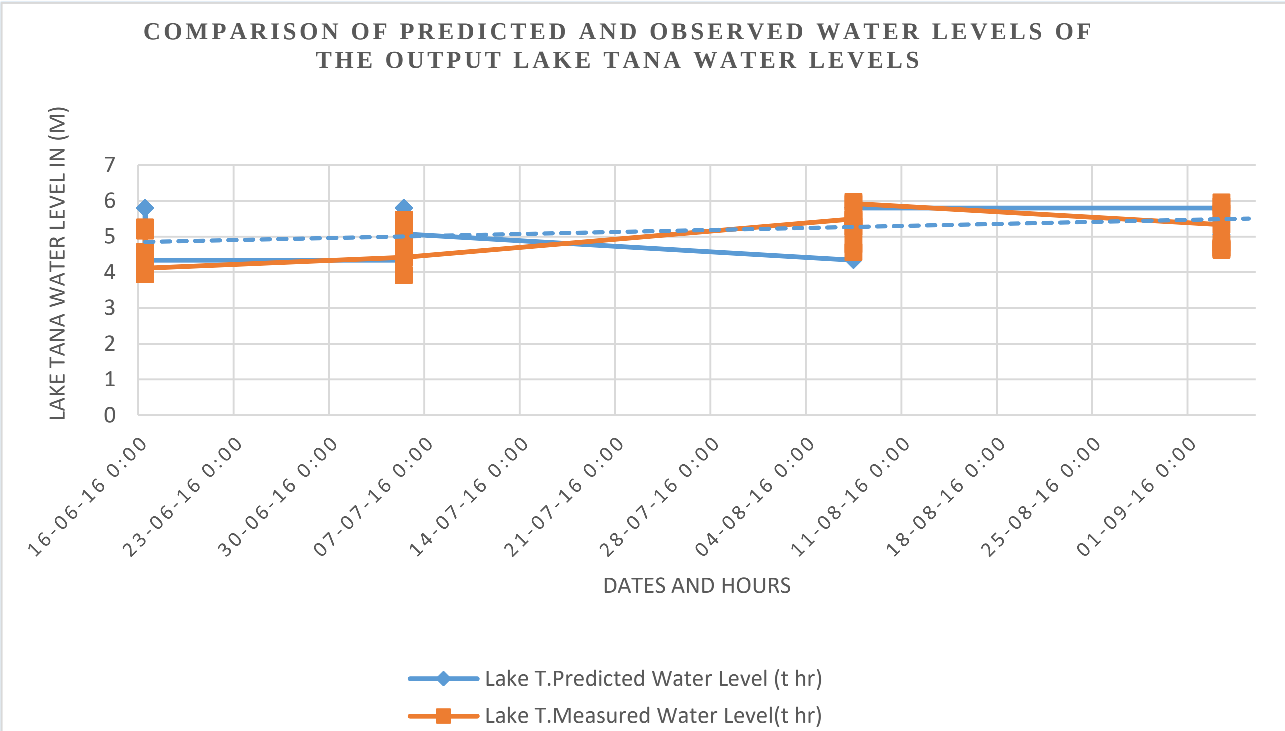

Figure 6.1 Comparison of the Predicted and Measured Value of the Output

6.4 Contributions of the Research

This research solves problems which is unable to solved by classical models by adopting fuzzy logic approach with having variables which influence system behavior and relationships among the variables which describe the system in terms of linguistic terms such as ‘‘very low, low, medium, high and very high’’, and the outputs are fuzzy subsets which can be made ‘‘crisp’’ using defuzzification techniques. The above linguistic terms are expressed mathematically as degree of membership functions and the fuzzy decision- making mechanisms use linguistic terms instead of numeric values. Transferring these linguistic terms to numerical value to make the final decisions is based on mathematics. This research contributes by showing systems that use fuzzy logic can produce effective results based on indefinite verbal knowledge expressed by humans.

The results of this research showed the potential of interval length during partitioning of the given data set in to overlapping fuzzy sets on the overall accuracy of the prediction model. The main goal partitioning the data set in to overlapping fuzzy sets is to provide proper mapping of the degree values to the boundary values which helps the Mamdani Fuzzy Inference System for improved performance, faster model development and execution times and the ability to provide a measure of prediction certainty.

CHAPTER-SEVEN

7 CONCLUSIONS AND RECOMMONDATIONS

Fuzzy logic provides an alternative to represent linguistic and subjective aspects of the real world problems in computing. The intention behind the selection of fuzzy logic model in this study is that system uses fuzzy logic model conveys valuable and real results depending on the uncertain, vague and imprecise verbal knowledge just like logic of a human being. Moreover, it takes long time to use the other methods for such problem and by using fuzzy we can reach a general solution by doing only limited number of experiments. A two input one output Mamdani type fuzzy inference system has been designed in this study for flood status prediction in the study area. The results obtained from fuzzy flood prediction model showed a good general agreement of (91.57%) with the results from the measured value Lake Tana Water Level. Future works are needed on establishing fully-fledged early warning system that include an application to analyses data in near real time basis, historical data management for further studies, and location mapping by developing a web-based system integrated with Google maps.

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9 ANNEX

9.1 Annex A. Photos of Flood Affected People in the Study Area