Rainfall Measurement And Flood Warning Systems: A Review

Edward B. Panganiban

Abstract: Flood is regarded as a chaotic natural disaster that threatens people's lives and properties. Flood warning and rainfall measuring systems dealing with different processes and multiple methodologies, providing data and information to maintain flood warning transportation and alternatives to crises for people around the world. To provide comparatively accurate and reliable flood prediction, prediction models are essential to be propelled by data input and further controlled by historical data and real-time observations are processed through the various algorithms. Flood prediction techniques traditionally include the use of rain gage for rainfall measurement and a simple flood warning system circuit. Emerging flood warning systems technologies and development have the potential to provide alternative solutions to allow timely and reliable flood calculations. It has shown a growing interest in investigating the use of more technological methods to anticipate floods through this. This paper reviews, therefore, from traditional flood forecasting to recent progress with the integration of emerging technologies for a more reliable and accurate flood warning system. This paper discussed patented flood warning systems, rainfall measuring systems, and published papers on flood warning systems. The result ended up with an idea that will be proposed for better accuracy and timely applications.

Index Terms: Flood forecasting, flood prediction, rainfall, technologies, flood warning systems, remote

1 INTRODUCTION

Flood is a water overflow that usually overflows dry land. Due to its ability to destroy houses, buildings, crops, and other properties, the flood can be deadly and devastating. Most urban centers in Southeast Asia found in low-lying areas next to the shores of major water bodies are prone to flooding, according to a study. Manila, along with the cities of Bangkok, Hanoi and Kuala Lumpur, is one of the identified flood risk cities at the outlets of river systems such as the Pasig-Marikina Rivers in the Philippines, Vietnam's Red River, Indonesia's Ciliwung River, Bangkok's Chao Praya, and Malaysia's Gumbak-Klang-Batu Rivers [1]. Because of its position on the globe, this country, the Philippines, is prone to tropical cyclones and low-pressure areas. The Philippines is one of the World's most prone to flooding, according to the report. Over the past 10 years, over 60 major floods have been reported in the Philippines [2]. Typhoons can enter the Philippine Area of Responsibility (PAR) even during the summer, and they can flood and damage the country every time they land. Every time the season has passed into the rainy season, this country is experiencing most of its average annual precipitation. This means that flash floods in the low-lying areas are to be expected. There are numerous reasons for flash flooding. The two main elements, however, are the duration of rainfall and intensity of rainfall. The amount of rainfall is the intensity, and how long the rain takes a while is the duration. Factors can also be soil conditions, soil, and topography [3]. The national government has a primary weather monitoring agency, the Philippine Administration of Atmospheric, Geophysical and Astronomical Services (PAGASA). They are responsible for monitoring this country's weather and climate.

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They provide the public with warnings, advisories and weather data via their website, social media accounts and public announcements. They measure the amount of rainfall using rain gauges which are deployed across the country. These devices are checked every hour and measurements in liters per square meter (L/m2) or millimeter (mm) are provided. PAGASA also uses water level sensors to collect data on dam height in the vicinity of cities. To date, the most severe cause of incorrect measurement is due to wind conditions [4]. It was found that the gauge's design shape plays an important role in the measured catch of rainfall. This is based on comparisons of the rain gage performed for different types of rain gauges at a standard level. By monitoring clouds, wind, patterns, atmospheric pressure, and temperature, they also predict the coming weather. All these data are integrated, studied and published for the public flood projection, announcements, and advisories. PAGASA measures the status of the dams being monitored and advises floods depending on the amount of rainfall, particularly in the catch basin areas. In a single city or municipality as a whole, these warnings are issued. PAGASA uses its website to provide the public with warnings and advisories. The agency also uses the media to relay information and, if necessary, contact each city's local government units for evacuations. The actual amount of rainfall is not taken for a particular area. Motorists and commuters are unaware of whether the streets are still passable and can still be used safely. People who are in low-lying areas are informed to evacuate about flash floods and emergencies by local government officials. To further warn people, a study was conducted using GIS-based risk assessment of multiple criteria to improve the accuracy of flood risk assessment for Metro Manila, considering the barangay, Philippine society's smallest political unit [5]. Hence, this paper concerns on what technology will be proposed and developed for future implementation by the government to solve the stated problem. In the next section, a review of different flood warning technologies is presented. This paper, therefore, concerns what technology will be proposed and developed by the government to solve the stated problem for future implementation. A review of various flood warning technologies is presented in the next section.

2 EXISTING FLOOD WARNING SYSTEMS

The author discussed technologies in this section, starting with the early inventions of devices used for flood detection, emerging flood prediction technologies up to rainfall measurement technologies.

2.1 Patented flood warning devices

An Early Flood Warning System (shown in Figure 1) is an advanced warning of likely flash floods and periodic floods by collecting and evaluating rainfall and watercourse level data to potential flood victims. This device also provides a means to spread alarms and orders in threatened areas to individuals [6].

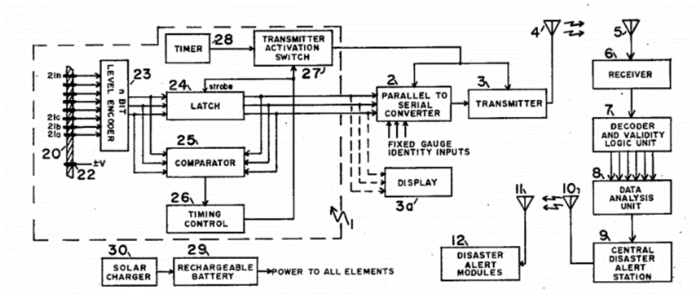

***Fig. 1**. Block diagram of the Early Flood Warnings System (adapted from [6])*

A water level detector or flood alarm device was invented in 1998, which will trigger a warning once the water has reached a predetermined level and is likely already harmful or unsafe. This invention consists of a housing that maintains a traditional float switch activated by mercury, an alarm attached to the switch, a mounting device, and a mechanism for attachment [7]. Figure 2 shows the patent claims of this invention.

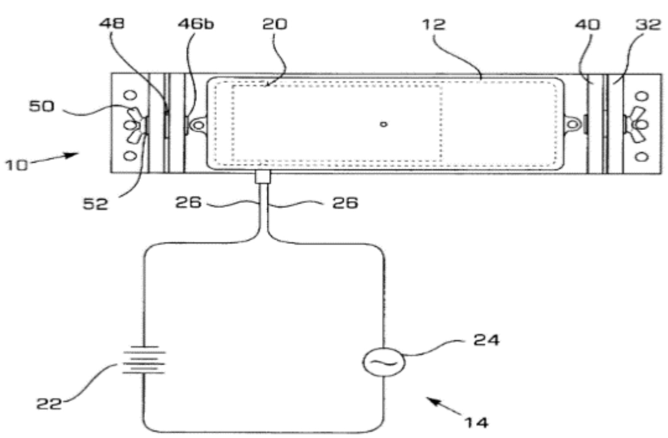

***Fig. 2**. Alarm devise for detecting predetermined water level (adapted from [7])*

In 2001, a water level calculator and water level forecasting system and the method were patented to achieve water level forecasting of a river with a limited calculation volume and high accuracy by numerical calculation. A measuring device is arranged to have water measuring part at a specified time interval to measure the water level of a river and a rainfall measuring part at a specified time interval [8]. An alarm reporting system has been invented after a year. This is an automatic alarm reporting system for mobile phone users and a mobile terminal. Those who want to know any hazards, and the like, in a relevant basin, an upstream region, an upper stream, an outer basin, or an area where danger is assumed. When the alarm trigger details (alarm reference value) are set to either telemeter water level, telemeter time rainfall, accumulation rainfall or radar rainfall (time, accumulation, rainfall region movement) and the like to start an alarm trigger, alarm information such as mails and alarm signals is automatically reported to the mobile phone user and the mobile terminal for reporting alarm information [9]. Predicting the amount of precipitation was also patented in 2003, allowing the user to see how much precipitation over the target area or point is estimated to occur. Predicted rainfall amounts are collected attributable to each cell expected to move across the target point and their output as a predicted amount of rainfall for the target point. If the target point is a multi-cell watershed, then predicted precipitation amounts are averaged for each cell in the watershed to deliver a predicted amount of precipitation for the watershed [10]. Figure 3 explains this patent's process.

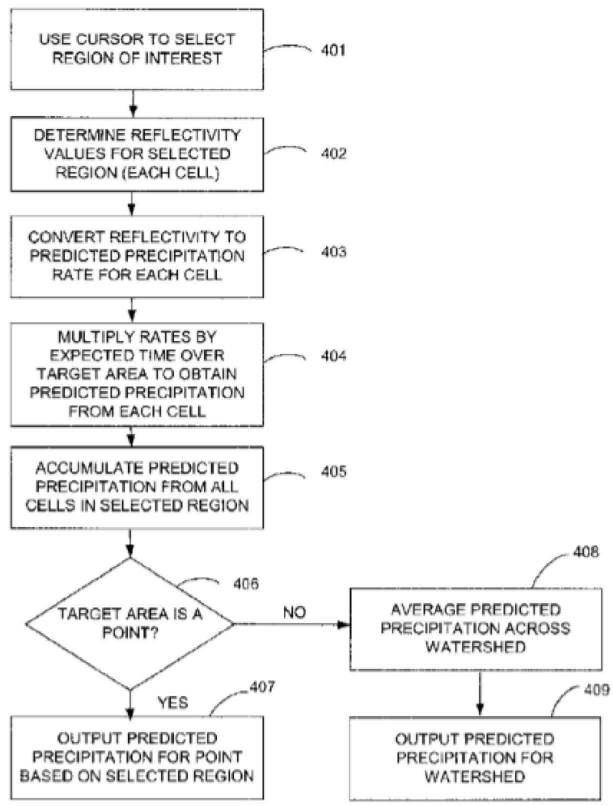

***Fig. 3**. Quantitative precipitation prediction method (adapted from [10])*

An invention provided an evacuation guidance system for a water disaster that accelerates a rescue operation by estimating a region with the possibility of a water disaster occurring to announce the water disaster automatically in advance and to automatically notify persons involved of optimum information on the evacuation route [11]. This system selects an optimal evacuation guide route map to an evacuation site from the region. Another flood warning system was invented to provide a simplified rainfall alarm with a simple and inexpensive structure that can easily and easily measure cumulative rainfall, inform residents of the rainfall by lighting an alarm lamp and an alarm buzzer easily performs its maintenance and facilitate it [12]. In 2006, a nationwide combined radar rainfall information system was patented to solve a problem where continuous radar rainfall cannot be precisely determined since, in combination with the observation results of an adjacent radar rain gage, the difference in observation characteristics in each radar rain gage cannot be perfectly corrected and a step takes place at the junction therebetween [13]. In 2008 an invention relates to a method and system for automated location-dependent recognition of flood risks, the measurement of flood states and the determination of location-dependent probability values. In particular, the invention relates to a system and method in which a country-specific flood zone table, such as the First American 100-year flood zone table, is used for generalized insurance risk factors to derive high-resolution data on vulnerability factors [14]. Figure 4 provides a schematic overview of an incarnation of this invention.

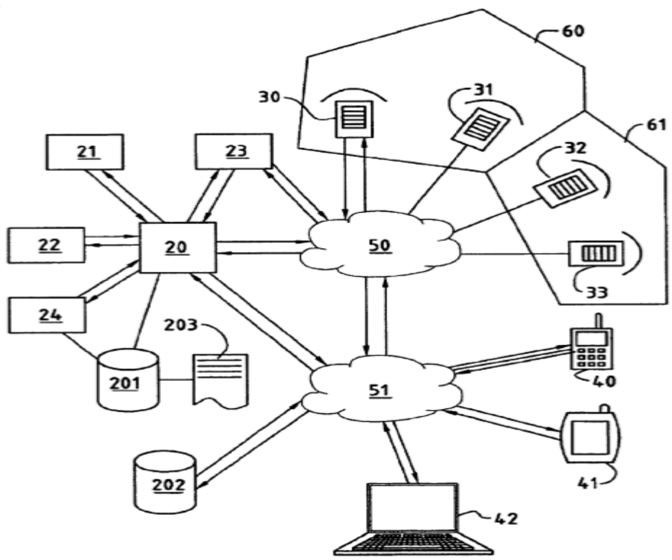

Fig. 4. *System for automated location-dependent recognition of flood risks (adapted from [14])*

In the year 2008 when image processing was used for water level observation. This system is equipped with a photographing means such as a CCTV camera, a static image acquisition for acquiring image data from the photographing means as a static image. It also contains a water level device for measuring the water level by image processing. I also feature a water level display for displaying the water level longitudinally and an alarm/delivery for issuing an alarm to a river manager [15]. Another development came when a prediction system was discovered for concentrated heavy rainfall. In this concentrated heavy rainfall prediction system, an insolation amount meter is installed at such points as not shaded, in other words on an electric pole and upper surface of a building, for measuring insolation amount for each several seconds [16]. Sudden flood risk avoidance system and method a flood detection device were installed on a road on which a vehicle pass is configured to compute the water height of a flood on the road. This also compares the increase rate of the pertinent water level with a preliminarily set risk increase rate and detects whether or not it is put in a flood risk state due to locally heavy rainfall. Following the result of the comparison, a road information display device was installed on the road and is configured to display a flood occurrence situation [17].

2.2 Rainfall Measurement Systems

The sound produced by huge raindrops is highly associated with rainfall rate and can be used to sense and measure rainfall rate according to a paper presented. An algorithm about the acoustical rainfall rate is proposed in their study for intense rainfall. This algorithm is susceptible to the relative proportion of large raindrop sizes within the raindrop size distribution [18]. A paper has presented an integrated methodology using C-band polarimetric radar measurements which can obtain the best estimate of rainfall. The methodology exploits the collaboration of reflectivity factor, differential reflectivity, and specific differential phase radar measurements. This contributes to the principle of self-consistency of radar polarimetric measurements in rain [19]. The products of Rain Gauge which are manual, semi-automatic or use data from loggers are still unable to accurately measure rainfall. This is therefore improved through development research on rain gauge, which reads using Bluetooth and RF-FSK modems simply and promptly [20]. The behavior of the tipping bucket rain gauge in various rain intensities, from light rain to extreme rain was described in a certain study. The authors also identified the problem that ordinary tipping bucket rain gauge suffers, the calibration and how to improve the accuracy in the lab and its results. The modified tipping bucket rain gauge (TBRG) has proven to be an effective method for minimizing these errors. A new TBRG with an obstacle sheet modified gives better accuracy than the original one with a little modified [21]. In another paper, the weather natural disaster prevention for quantitative daily rainfall forecasting derived from the weather pattern SACZ-ULCV is presented using intertwined statistical downscaling (SD) and soft computing (SC) approaches. Results showed that the FSD and the NSD are possible alternatives to achieving communication on the daily rainfall variable from meteorological and thermo-dynamic variables [22].

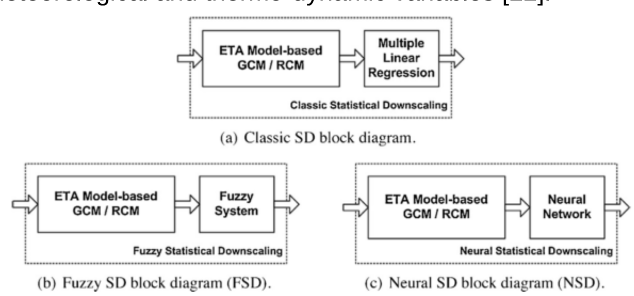

Fig. 5. *The classic downscaling diagram (adapted from [22])*

A study was also developed to assess the effects of 23 mother wavelet functions on the function of the rainfall-runoff models of the hybrid wavelet-based ANN. In this study, the hybrid Multilayer Perceptron Neural Network (MLPNN models) ans the Radial Basis Function Neural Network (RBFNN) were developed using both the discrete wavelet and the types of continual wavelet transformation [23]. A study aims to explore the efficacy of multiple rainfall sources (gage measurement, and radar and satellite products) for assimilation-based multi-sensor precipitation estimates and to make multi-step-ahead precipitation predictions based on assimilation. The results of the forecast obtained are very valuable information for the flood warning during typhoon periods in the study watershed [24]. In another study, a Vantage-Vue Integrated Sensors Suite (ISS) weather station was used to measure rainfall intensities of one-minute integration time from June 2013 to February

2014. The study examines the pattern of rainfall distribution, temporal and cumulative rain rate distribution, and their contribution to total rainfall [25]. Another paper presented a cheap and efficient rain gage tipping bucket with an internet-enabled data logger for rainfall measurements. The data logger posts the rainfall data via a microcontroller interfaced with a GSM / GPRS module [26] to a SQL database located on our server. In another paper, a hybrid wavelet neural network (HWNN) model is developed by incorporating multi-resolution analysis (MRA), mutual information (MI), and particle swarm optimization (PSO) into artificial neural network (ANN) models to effectively forecast monthly rainfall from preceding monthly rainfall and climate indices. The results show that the HWNN model improves the predictive accuracy of the monthly rainfall over Australia compared to the reference models, and the improvement is more significant for the inland stations in south-east Australia and stations in Western Australia [27]. Another work aimed at detecting and calculating the sources of ambiguity present in interpolated maps of rainfall from the depths of the link precipitation. This study also tested the actual and optimal performance of one of the cellular providers in the Netherlands on one commercial microwave network [28]. A previous study also found out that the flood prediction can be determined if convective rains happen continuously beyond 9 hours [29]. Figure 6 shows the size distribution of drop-downs.

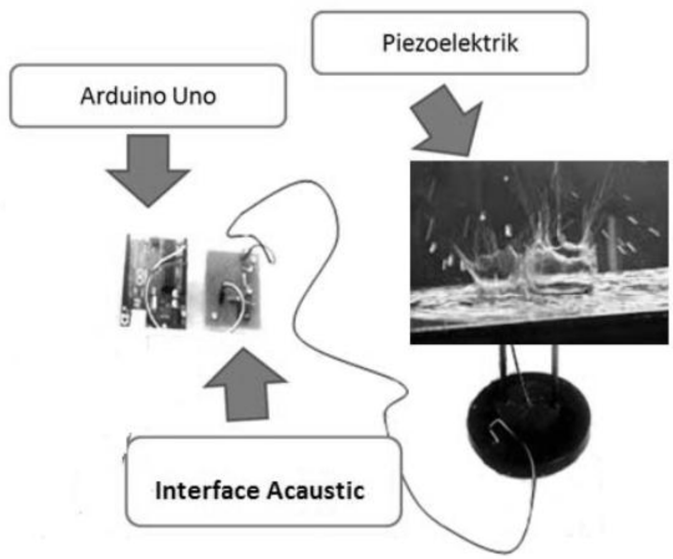

***Fig. 6**. Measurement of the drop size distribution (adapted from [29])*

2.3 Flood Warning Systems

The two models which can be applied for flood monitoring were the HBV and DUFLOW. The HBV model was utilized to recreate the catchment release hydrograph saw at the station in Montalban. The DUFLOW model, separately, was utilized to proliferate the flood wave from Montalban to station Mangahan. The two models have been confirmed to be compelling for application as proven by Kobold's test that the HBV model can be utilized for pre-notice streak flooding by utilizing hourly information [30] contrasted with Badilla's investigation that pre-owned everyday information. Likewise, the DUFLOW model is an administration apparatus fit for reenacting framework conduct because of entryway or dam tasks, flood waves, tsunamis, and water system and waste framework activities [31]. Moreover in Honduras, the location framework was planned to supply a viable arrangement to provide individuals sufficient time to take off and secure their property by caution approaching surge communities. As outlined in figure 7, this extends employments an idealized sensor organize comprising of two communication levels. The ranges comprise of 144 MHz for office and community hubs and 900 MHz for mode sensors [32].

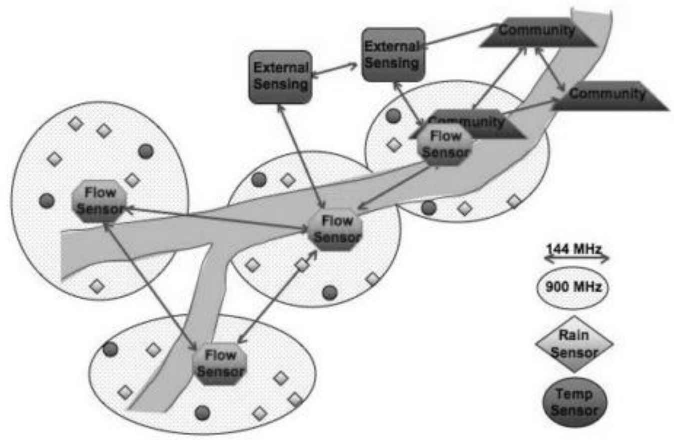

***Fig. 7**. Idealize sensor network (adapted from [32])*

Other remote sensor hubs have been utilized for surge checking and alert framework. It includes the grid-based savvy and versatile approach. It was examined within the paper that this framework can too finish on-site surge modeling, separated from joining farther fixed-network for computationally-intensive surge modeling focuses. The paper points to boost the sensors to lattice objects of the most elevated quality. It bolsters adjustment to WSN and makes a difference make strides the tangible modalities [33]. In another paper, the artificial intelligence model was established to determine the water level at short notice. The water level was predicted using the artificial neural networks (ANN), the support vector machine (SVM) and the adaptive neuro-fuzzy inference system (ANFIS). This study shed some light on the best practices in using different artificial intelligent methods for hourly water level prediction with different model settings. Further studies with the availability of short-term [34] were desired to issue an early warning. In a paper comprised of the battery as its power source, a receiver, and a transmitter, the flash flood warning system was introduced. For the upstream, the transmitter has a data logger, water level gauge sensors, a rain gauge and a device with warning alarm and SMS transmitter. The receiver, on the other hand, is downstream and is composed of an SMS receiver and an alarm system [35]. Polarization Ratio temporal trends at some AMSR-E bands (C, X, and Ka) were studied to demonstrate their potential in flood and rainfall monitoring. End ground truth data were used for rainfall and water level measurements in Argentina's lower Bermejo Basin, and a general correlation between variations of the polarization ratio and ground parameters was found at the different AMSR-E frequencies [36]. The level of rainfall can be predicted through a neural backpropagation network which was used as a technique in another study to determine the water level to improve the prediction technique. In this study, a novel Extended Kalman Filter (EKF) optimization algorithm was used to overcome the nonlinearity problem and to come out with an optimal ANN for flood water level prediction 3 hours in advance [37]. This study has a BPN model for the prediction of the floodwater level, as shown in Figure 8.

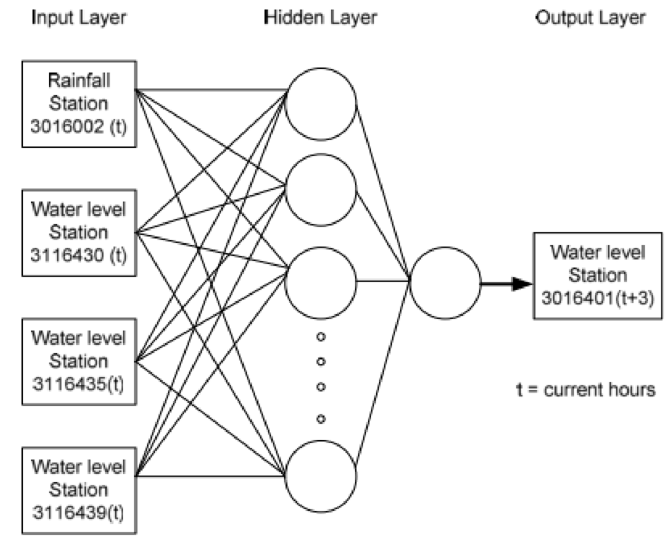

Fig. 8. *BPN Model for flood water level prediction (adapted from [37])*

A combination of Kalman filter and BPN can enhance flood performance and prediction [38],[37]. The introduction of the extended Kalman filter at the BPN output shows significant improvement in predicting and tracking the actual flood water level performance. Figure 9 shows the artificial neural network structure used in this study, whereby BPN is the most popular supervised ANN model.

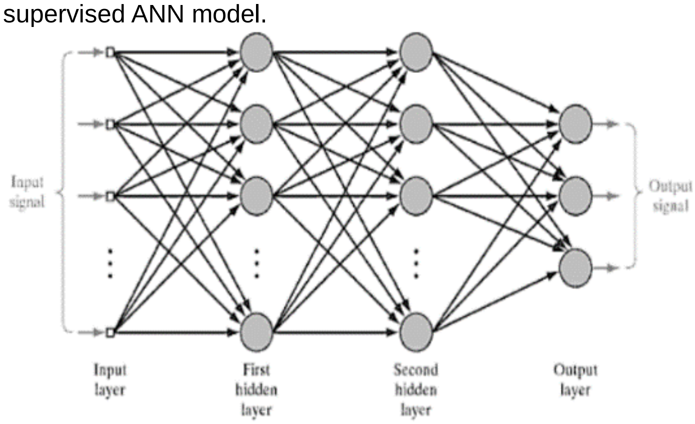

Fig. 9. *Structure of artificial neural network (adapted from [38]).*

A real-time measuring system can be employed for energy-efficient, with vigorous communication potential [39]. This study is a real-time flood surveillance measurement system. Its deployment is in Southern Spain, in a flash-flood prone to 650 km of the semi-arid watershed. DatalogV1A, a low-power, and long-range communication device developed to deliver automatic data collection and reliable communication. A new model has been developed for a flood warning system using an Artificial Neural Network (ANN) and Wireless Sensor Nodes (WSN). It includes six (6) hydrological factors, such as variation in water speed, air moisture, atmospheric pressure, rainfall, wind speed, and water level. The WSN measures these parameters. These vectors are verified and tested in theoretical terms [40]. Figure 10 shows the ANN model used in that study.

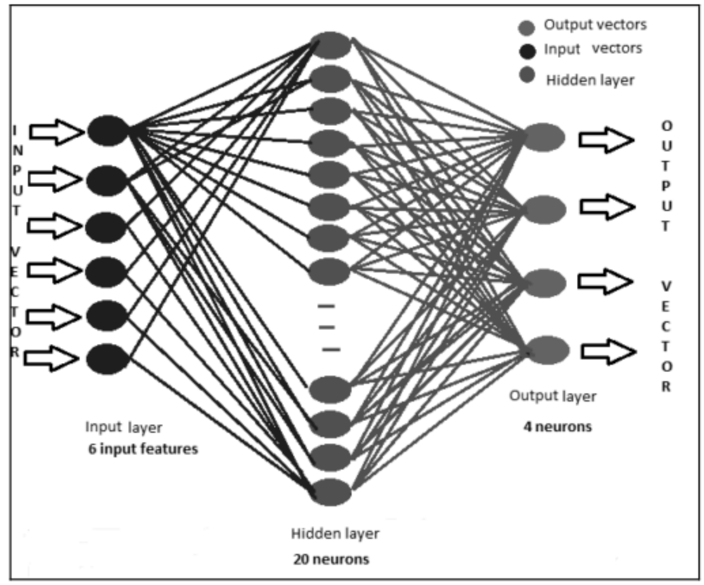

Fig. 10. *Basic ANN model used for simulation (adapted from [40])*

Warning transmitters and flood detection systems can be combined with electrical cabling, and flood prediction can also be designed for the common residential building's electrical system [41]. This study relates to the safety of people at risk of electrical shock caused by floods. In Figure 11 the system explains.

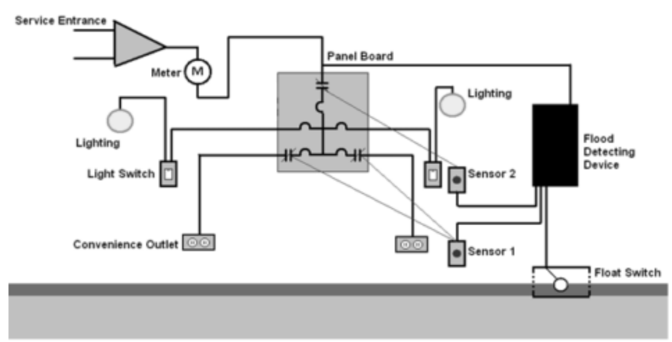

Fig. 11. *Flood Detection System (adapted from [41])*

Also integrated with an early flood warning system was SMS technology via SIM300 GSM Modem. The system is capable of predicting the time a flood happens in advance. The system can determine three types of water level or flood level, low tide level, and early flood level. In three conditions it transmits out three warning or notification messages thru SMS. The system used a stand-alone PVC pipe, used for 24 hours, and may be requested for the statues of water level [42]. Figure 12 shows the principal design used in this study.

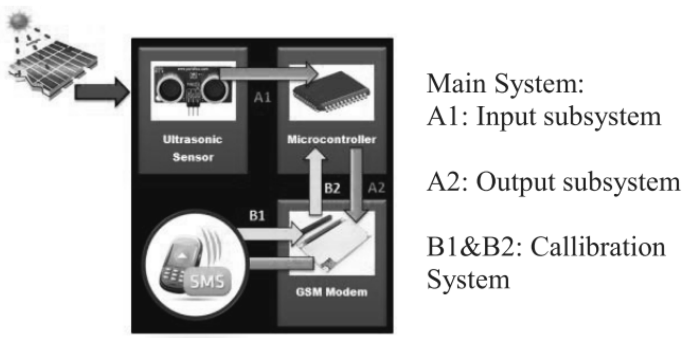

Fig. 12*. The main design of the early flood alert system (adapted from [42]).*

The research focused on calculating the water-courses unpredictable water level and flow rate. There are several sensors installed along the watercourse from the upper stream into the village area. IT uses the SCADA (Supervisory Control and Data Acquisition) industrial control system to function as a central flood warning system control program. There is an HMI (Human Machine Interface) designed based on the focused area contour map [43]. The authors proposed a flood alerting system based on neuro-fuzzy (NF). The input data was gathered via a Wireless Sensor Network (WSN). The proposed model has gathered input parameters from a specific site, such as rainfall, river water level, and river water flow, and sent the data to the decentralized node. The flood possibility index [44] has been determined by the Adaptive Neuro-Fuzzy Inference System (ANFIS) model based on the inputs. Computer and mobile networks also served as instruments for the design and development of a flood warning system in an area. The water level, rainfall quantity, and image data were gathered and sent to a server using mobile data networks through the internet. These data are then processed for flood warnings and can be determined. The system uses mobile and web systems to view the measured data and to inform warning messages for the flood possibility [45]. Figure 13 shows the system architecture for this study.

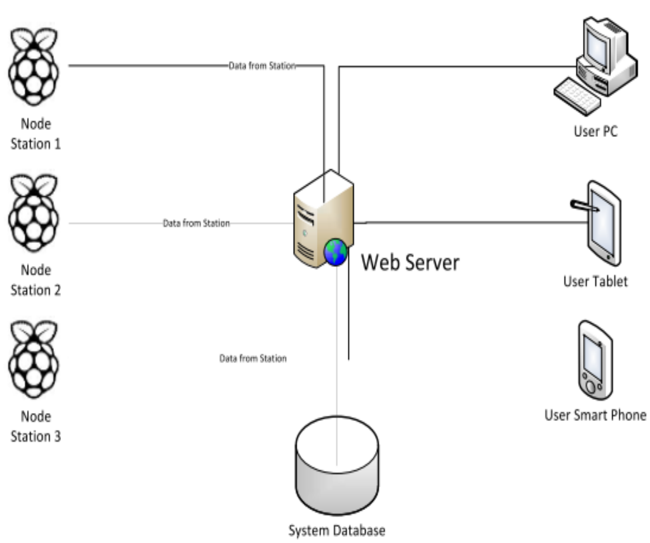

Fig. 13*. System architecture (adapted from [45])*

An easy method to automatically monitor a specific area's flood object, based on the currently widely used remote cyber-surveillance systems and image processing methods to get instant feedback from flooding and waterlogging events. In this study, in which a flood is considered a possible object of invasion, the mode of intrusion detection of these surveillance systems is used. Automatic flood risk-level monitoring of specific river segments, as well as automatic urban flood detection, has become possible through the detection and verification of flood objects [46]. NASA developed the use of a technology called SensorWeb which leverages Open Geospatial Consortium (OGC) Sensor Web Enabling (SWE) standards to facilitate the interoperability of different satellite and ground sensors. This is for the rapid collection and dissemination of both space- and ground sensor data and flood disaster management data products [47]. A flood monitoring system in real-time was implemented in two streets near España Boulevard to give visual data and actual flood information through web services and mobile phones. The system is consists of a rain gage and ground-based pressure sensor connected via the GPRS network to a locally planned data logger with telemetry capabilities. A TCP server receives data from the stations and is processed through mobile and web services to provide an update on real-time flood as well as its graphical information. An early flood estimation system was implemented using a Random Forest algorithm to give motorists and system users an early warning advisory [48]

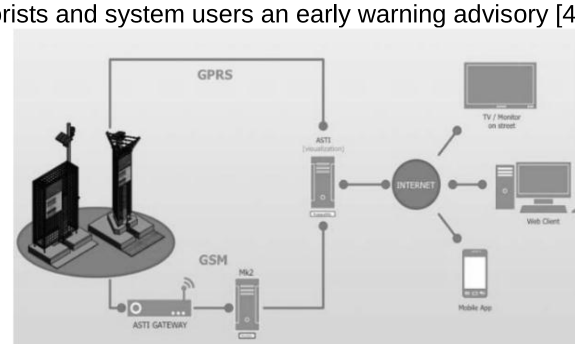

Fig. 14. *Urban Flood Monitoring System (adapted from [48])*

Back Propagation Neural Network (BPN) was also implemented to predict the level of water in which the result based on a study is high precision. Relative Absolute Error and Mean Square Error were used to measure the prediction model's accuracy between the actual water level and the water level predicted [49]. In mobile areas, another paper presented the automated wireless flood warning system for informing people during floods. The level of floodwater was measured using a wireless sensor. Using RF signals, the data was sent to the raspberry pi microcontroller. Once the water level reaches its threshold, an ad hoc network, a set of mobile devices is created. This network can be embedded in smartphones that are used to transmit flood warning messages as a device [50]. The wireless water level sensor is positioned on the measuring scale that is used to measure the water level. The measured water levels are continuously transmitted to this microcontroller through the XRF Module Transceiver, using Radio Frequency signals. The Department of Science and Technology (DOST)-Advanced DOST-Advanced Science and Technology Institute has installed various hydro-meteorological devices throughout the Philippines, including Automated Rain Gauge (ARG), Tandem Stations and Water Level Monitoring Stations (WLMS). This paper addresses the need for the development of a predictive model that provides a water level for an early nowcasting system. This also includes flood hazards providing the local communities with a decision support tool. The model was able to deliver an accurate and early prediction of the water height or level without depending on the rainfall-runoff models [51]. To measure the water level changes in a river for this technology, an additional ultrasonic sensor is integrated with the system. Figure 15 shows the system layout.

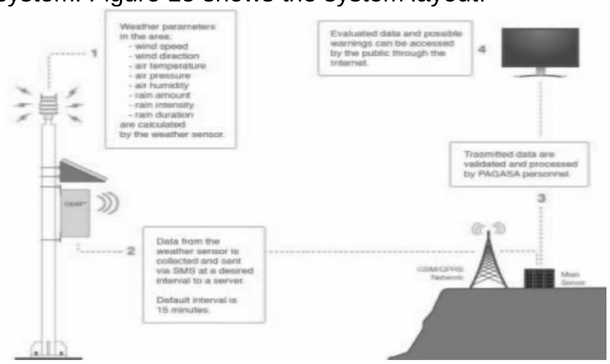

Fig. 15. *Remote River Nowcasting system in Cagayan, Philippines (adapted from [51])*

Another research paper that is based on the E-Noe project has demonstrated a flood warning system for the dangerous areas. The system monitors the water level of a runway or river. If the height is at the alert level, it notifies the authorities through text messages and phone calls. Microcontroller and Sonar systems are used. The microcontroller manages the data that will then be stored via cloud computing [52]. Figure 16 shows the study's system flow.

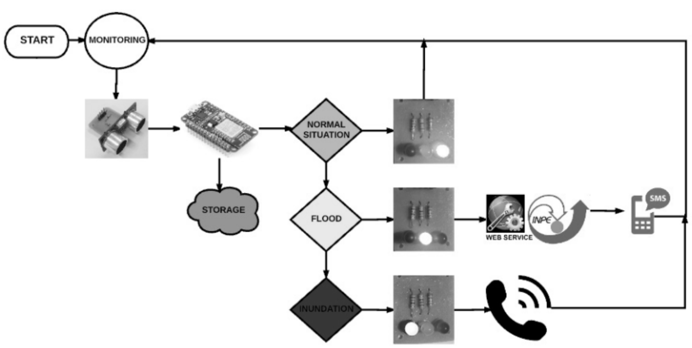

Fig. 16. *System flow (adapted from [52])*

A flood warning system for Korea's Muslin Stream Watershed has also been developed. The project employed smart technology to send early flood warnings to end-users. The model used HEC-HEM which provides a forecast for floods. The aim of the server-client based program used in this study is to predict the flooding situation in real-time [53]. The detail of the system configuration for the flash flood guidance (FFG) was explained in figure 17.

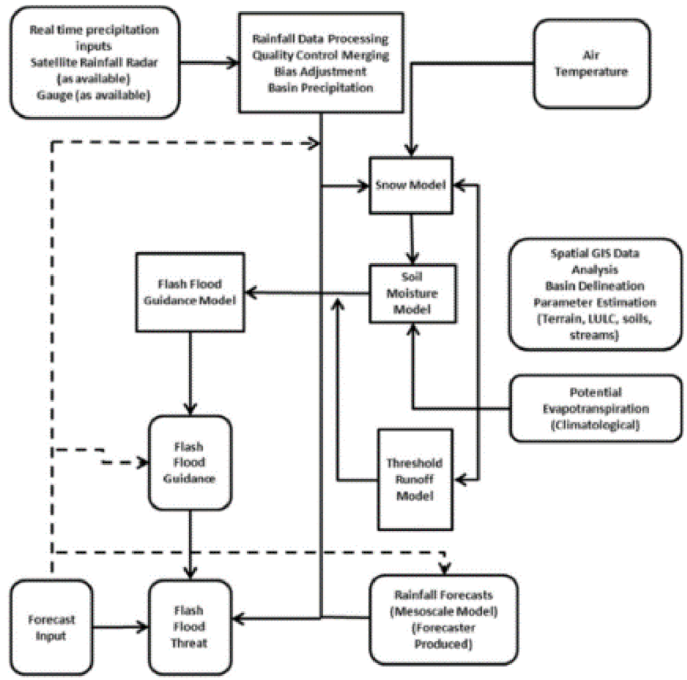

Fig. 17. *FFG System Configuration (adapted from [53])*

2.4 Systems employing Rainfall measurement and Flood warning

A prediction of rainfall may also be based on linear stochastic auto-regressive moving average (ARMA) models, artificial neural networks (ANN), and the non-parametric nearest neighboring method whereby the results emphasized that the time series analysis methods offered a significant development in flood projection accuracy contrasted to simple rainfall prediction approaches of an experimental nature [54] Multi-sensor data rainfall inputs from the geostationary meteorological satellite, Doppler weather radar, and numerical weather prediction (NWP) models [55] were used to develop a new technique in rainfall prediction and flood control. This research study also investigated the relationship between visible and infrared geostationary meteorological satellite (metsat) images to rainfall depth, and developed a rainfall estimate based on satellite. There has been a proposal for an original early alert system for heavy rainfall in Europe in which its goal is to identify projections of tremendous accumulations of rainfall over a short period of time and in small catchments that is risky to flash flooding. This is based on the recently developed European Precipitation Index based on Simulated Climatology (EPIC), which is measured using weather forecasts from the COSMO-LEPS joint and then suited with gamma distributions at each time step of the forecast horizon [56]. A paper examines the applicability of the Numerical Weather Prediction (NWP) model for flood prediction ensemble forecasts. In this study, the hydrological model used a 10-km-resolution rainfall forecast and its downscaled 2km-resolution forecasts as input data for flood forecasting and early warning application [57].

3 SUMMARY OF RESULTS

All studies discussed in this research paper are related to the prediction or forecasting of rainfall, flood detection, and prediction of rainfall. Others comprised of discussion of rain gauges for measuring rainfall, real-time flood detection devices or sensors. These studies or articles have provided the researcher with enough knowledge and information pertaining to rainfall measurement and predictive sequence modeling. The next tables illustrate and summarize the outcome of several patents and articles reviewed:

TABLE IA
Patented Flood Warning Devices

No.	Title of patent	Year patented or applied	Functions or Methods	System type
1.	Early Flood Warning System	1979	Used electronic circuit to provide flood or flash flood warning to individuals in threatened areas.	Flood Warning System
2.	Water level detector alarm device	1998	Alarm device for detecting predetermined water level	Flood Warning System
3.	Water level calculator and water level forecasting system and method	2001	Forecasting of water level of a river with a limited volume of calculation and at a high accuracy by numerical calculation	Flood Warning System
4.	Alarm-reporting system	2002	An alarm automatic reporting system for the users of a cellular phone and a mobile terminal about danger of flood or the like.	Flood Warning System
5.	Quantitative precipitation prediction method	2003	It allows the user to see how much precipitation is expected to occur over the target point or area.	Rainfall Measurement System
6.	Evacuation guiding system for water disaster	2003	This system selects an optimum evacuation guiding route map from the region to an evacuation site.	Flood Warning System
7.	Simplified rainfall alarm	2006	A simplified rainfall alarm which can simply and easily measure a cumulative rainfall, readily inform residents of the rainfall.	Rainfall Measurement System
8.	Nationwide combined radar rainfall information providing system	2006	Continuous rainfall can be precisely determined using radar	Rainfall Measurement System
9.	Method and system for automated location-dependent recognition of flood risks	2008	A method and system for automated location-dependent recognition of flood risks, flood states being measured and location-dependent probability values being determined.	Flood Warning System
10.	Water level observation system by image processing	2008	A water level device for measuring the water level by image processing.	Flood Warning System
11.	Concentrated heavy rainfall prediction system	2010	A concentrated heavy rainfall prediction system through an insolation amount meter installed at such points	Rainfall Measurement System
12.	Sudden flood risk avoidance system and method	2012	A flood detection device was installed on a road on which a vehicle passes is configured to measure the water level of a flood on the road.	Flood Warning System

TABLE II
Rainfall Measurement Systems

No.	Title of study	Year published	Functions or Methods	System type
1.	Rainfall Measurement using Passive Underwater Acoustical Remote Sensing	1982	An acoustical rainfall rate algorithm is used in this for heavy rainfall. This algorithm is sensitive to the relative proportion of large raindrop sizes within the rain drop size distribution	Rainfall Measurement System
2.	An integrated procedure for rainfall estimation using C-band dual-polarization weather radars	2008	An integrated methodology which, starting from C-band polarimetric radar measurements that allows to obtain the best rainfall estimation.	Rainfall Measurement System
3.	Rain gauge development employing bluetooth and RF modem	2011	A rain gauge that easily and promptly measure rainfall intensity using Bluetooth and modem RF-FSK.	Rainfall Measurement System
4.	High accuracy tipping bucket rain gauge	2012	This is the modified tipping bucket rain gauge (TBRG) that has proven to be an effective method for minimizing error from the previous tipping bucket rain gauge.	Rainfall Measurement System
5.	Neural network and fuzzy logic statistical downscaling of atmospheric circulation-type specific weather pattern for rainfall forecasting	2014	The weather natural disaster prevention for quantitative daily rainfall forecasting derived from the SACZ- ULCV weather pattern was used as a method.	Rainfall Measurement System
6.	Comparative study of different wavelet based neural network models for rainfall-runoff modeling	2014	It uses the hybrid Multilayer Perceptron Neural Network (MLPNN) and the Radial Basis Function Neural Network (RBFNN) models.	Rainfall Measurement System
7.	Watershed rainfall forecasting using neuro-fuzzy networks with the assimilation of multi-sensor information	2014	It uses gauge measurement, radar and satellite products to explore the effectiveness of multiple rainfall sources.	Rainfall Measurement System
8.	Study and Characterization of Rainfall Intensities in Akure , Southwestern Nigeria	2014	Rainfall intensities of one-minute integration time were measured using a Vantage-Vue Integrated Sensors Suite (ISS) weather station.	Rainfall Measurement System
9.	Internet enabled tipping bucket rain gauge	2014	A cheap and efficient tipping bucket rain gauge with an internet enabled data logger to measure rainfall.	Rainfall Measurement System
10.	A hybrid wavelet neural network model with mutual information and particle swarm optimization for forecasting monthly rainfall	2015	A hybrid wavelet neural network (HWNN) model for effectively forecasting monthly rainfall.	Rainfall Measurement System
11.	Measurement and interpolation uncertainties in rainfall maps from cellular communication networks	2015	It uses commercial microwave network from one of the cellular providers to quantify the sources of rainfall	Rainfall Measurement System
12.	Measurement of Drop Size Distribution Rain in Mataram Utilize Disdrometer Acoustic For Flood Prediction	2016	I uses disdrometer that has the ability to check the large and long rains with better quality forwards. Signals triggered by rain can be classified to be processed into the rain.	Rainfall Measurement System

TABLE IIIA
Flood Warning Systems (Part 1)

No.	Title of study	Year published	Functions or Methods	System type
1.	The use of HBV model for flash flood forecasting	2006	The HBV and DUFLOW were the two models are applied for flood monitoring.	Flood Warning System
2.	Design of early warning flood detection systems for developing countries	2007	This project uses idealized sensor network consisting of two communication tiers	Flood Warning System
3.	Flood Modelling in Pasig-Marikina River Basin	2008	DUFLOW model was used as a management tool capable of simulating the system behavior due to operations of gates or dams, flood waves, tidal wave and operation of irrigation and drainage systems	Flood Warning System
4.	An Intelligent and Adaptable Grid-based Flood Monitoring and Warning System	2008	It involves intelligent and adaptable grid-based system.	Flood Warning System
5.	Short-term Water Level Prediction using Different Artificial Intelligent Models	2009	Artificial intelligence model was established in this study to determine the short-term water level	Flood Warning System
6.	Flash flood warning system in risky area	2011	It is a Flash flood warning system that is composed of battery as its power source, a transmitter and a receiver.	Flood Warning System
7.	Monitoring flood in the lower bermejo river basin using multifrequency microwave signatures	2011	It uses the temporal trends of Polarization Ratio at some AMSR-E bands (C, X, and Ka) in order to show its potential in flood and rainfall monitoring.	Flood Warning System
8.	Artificial neural network modelling and flood water level prediction using extended Kalman filter	2012	Back propagation neural network was employed as a technique in determining the water level to improve the prediction technique. A novel Extended Kalman Filter (EKF) optimization algorithm was employed in this study.	Flood Warning System
9.	Flood water level modelling and prediction using artificial neural network: Case study of Sungai Batu Pahat in Johor	2012	Combination of BPN and Kalman filter	Flood Warning System
10.	A real-time measurement system for long-life flood monitoring and warning applications	2012	A developed low-power and long-range communication device, so-called DatalogV1, was used to provide automatic data gathering and reliable transmission.	Flood Warning System
11.	An improved flood warning system using WSN and artificial neural network	2012	It uses wireless sensor nodes (WSN) and artificial neural network (ANN).	Flood Warning System
12.	Design of Flood Detection System With Automatic Branch Circuit Cut-Off Capabilities and Sms-Based	2013	Flood detection system and warning transmitter are joined together with the electrical wiring and electrical system of a common residential building for flood prediction	Flood Warning System

TABLE IIIB
Flood Warning Systems (part II)

No.	Title of study	Year published	Functions or Methods	System type
13.	Design and Construction of Early flood warning system through SMS based on SIM300C GSM modem	2013	SMS technology through SIM300 GSM Modem was used for flood warning system. The system can identify three water level types –flood level, early flood, and low tide level. It sends three warning messages via SMS in three conditions.	Flood Warning System
14.	Flash flood warning system using SCADA system: Laboratory level	2014	The industrial control system SCADA (Supervisory Control and Data Acquisition) system is selected to work as a central control program of the warning system.	Flood Warning System
15.	Neuro-fuzzy(NF)-based adaptive flood warning system for Bangladesh	2014	A neuro-fuzzy (NF) based flood warning system. The input data have been collected using wireless sensor network (WSN).	Flood Warning System
16.	Design and Development of a Flood Warning System via Mobile and Computer Networks	2015	Mobile and computer networks served as tools for the generation of data about rainfall amount and water level.	Flood Warning System
17.	Cyber surveillance for flood disasters	2015	Automatically monitors the flood object of a specific area, based on widely used remote cyber surveillance systems and image processing methods in order to obtain instant flooding and waterlogging event feedback.	Flood Warning System
18.	Flood sensing framework by Arduino and Wireless Sensor Network in Rural-Rwanda	2015	It uses SensorWeb at NASA which leverages Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) standards for the purpose of flood disaster management	Flood Warning System
19.	A real time urban flood monitoring system for metro Manila	2016	The system consists of a ground-based pressure sensor and a rain gauge connected to a locally designed data logger with telemetry capabilites using GPRS network.	Flood Warning System
20.	Water Level Prediction Model Using Back Propagation Neural Network Case study : The Lower of Chao Phraya Basin	2016	Aside from Back Propagation Neural Network (BPN), Mean Square Error and Relative Absolute Error were used to measure the accuracy of the prediction model	Flood Warning System
21.	Automated wireless flood warning system in remote areas	2016	A wireless sensor was used to measure the level of flood water. The data will then be sent to the raspberry pi with the aid of RF signals.	Flood Warning System
22.	Development of a predictive model for on-demand remote river level nowcasting: Case study in Cagayan River Basin, Philippines	2017	A predictive model that can provide an ahead of time nowcasting system for water level and flood hazard to provide a decision support tool for the local communities. A data driven approach using machine learning is implemented to generate ahead-of-time water level estimation. An additional ultrasonic sensor is integrated in the system to measure the water level changes in a river for this technology	Flood Warning System
23.	A flood warning system to critical region	2017	The system checks the water level of a river or a runway. it warns the authorities through phone calls and text messages. It uses sonar and microcontroller.	Flood Warning System
24.	Development of flood alert application in Mushim stream watershed Korea	2017	The system used smart technology to send end users for early flood warnings. The model used is HEC-HEM which provides flood forecasting.	Flood Warning System

TABLE IV

Systems employing Rainfall measurement and Flood warning

No.	Title of study	Year published	Functions or Methods	System type
1.	Comparison of short-term rainfall prediction models for real-time flood forecasting	2000	Artificial neural networks (ANN), linear stochastic auto-regressive moving average (ARMA) models and the nonparametric nearest neighbour method were used.	Both
2.	Multi-sensor data inputs rainfall estimation for flood simulation and forecasting	2012	A rainfall forecasting and flood monitoring using multi-sensor data rainfall inputs from the Doppler weather radar, geostationary meteorological satellite and numerical weather prediction (NWP) models.	Both
3.	A European precipitation index for extreme rain-storm and flash flood early warning	2015	It uses European Precipitation Index based on simulated Climatology (EPIC), which is calculated using COSMO-LEPS ensemble weather forecasts and subsequently fitted with gamma distributions at each time step of the forecast horizon to provide early warning system for heavy precipitation	Both
4.	Flood Forecast and Early Warning with High-Resolution Ensemble Rainfall from Numerical Weather Prediction Model	2016	Numerical weather prediction (NWP) model was used for flood forecasting.	Both

4 CONCLUSIONS

This paper has reviewed patented and articles about rainfall measurement and flood warning systems. The review is categorized based on patented flood warning devices, published papers about technologies in rainfall calculation and flood forecasting. Some papers include both rainfall measurement systems and flood warning systems. Those studies and patents are arranged chronologically. The review finds out that several methods or algorithms were used based on the purpose and location. Most of the patents involve an alarm device as a sign that a predetermined level of water has reached. As early as 1979, there is already a flood warning system but it only involves conventional electronic board. Today, micro boards are widely used to replace this. There are also several rainfall measurement systems presented and published in different proceedings and journals. One study used an acoustic rainfall rate algorithm while others used several models in measuring the rainfall size. Flood warning technologies have emerged from 2006 to present. Several algorithms and models were established and presented. It is found out in this review that is still technologies that can be applied in measuring the rainfall size and forecasting the flood level. One emerging technology is through the application of predictive modeling used in python programming in a raspberry pi platform. Since the raspberry pi microcontroller is compatible with many applications, web service application systems can be integrated as one of the features of the flood warning system.

5 REFERENCES

[1] D. B. Zoleta-Nantes, “Flood hazards in Metro Manila: Recognizing commonalities, differences and courses of action,” Soc. Sci. Diliman, vol. 1, no. 1, pp. 60–105, 2000.

[2] R.. Badilla et al., “Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for the Greater Metro Manila Area,” Flood Risk Anal., pp. 1–7, 2014.

[3] A. P. Guide, “Flash floods and floods : The Awesome Power of flooding can occur nationwide : A Preparedness Guide,” U.S. Dep. Commer. Natl. Ocean. Atmos. Adm., no. July 1992, pp. 1–12, 1992.

[4] M. Pollock, M. Dutton, P. Quinn, E. O. Connell, M. Wilkinson, and M. Colli, “Accurate Rainfall Measurement: The Neglected Achilles Heel of Hydro-Meteorology,” no. 1, pp. 1–7, 1998.

[5] K. P. Pornasdoro, L. C. Silva, M. L. T. Munárriz, B. A. Estepa, and C. A. Capaque, “Flood Risk of Metro Manila Barangays : A GIS-Based Risk Assessment Using Multi-Criteria Techniques,” J. Urban Reg. Plan., pp. 51–72, 2014.

[6] A. R. Permut, A. A. Permut, and R. M. Permut, “Early Flood Warning System,” US Pat. 4153881, pp. 1–16, 1979.

[7] Rish and L. Thomas, “Water level detector alarm device,” US Pat. 5781117, pp. 1–13, 1998.

[8] H. Kunio, “Water level calculator and water level forecasting system and method,” Espac. Bibliogr. data JP2001215119 — 2001-08-10 WATER, p. 1, 2001.

[9] I. Shigeru, “Alarm-reporting system,” Espac. Bibliogr. data JP2002350559 — 2002-12-04 Alarm., pp. 5–6, 2002.

[10] M. R. Smith, “Quantitative precipitation prediction method,” US Pat. 6581009, pp. 1–12, 2003.

[11] S. Akihiko and M. Tetsuo, “Evacuation guiding system for water disaster,” Espac. Bibliogr. data JP2003162785 — 2003-06-06, pp. 5–6, 2003.

[12] O. Makiko, “Simplified Rainfall Alarm,” Espac. Bibliogr. data JP2006258577 — 2006-09-28, pp. 5–6, 2006.

[13] F. Chikao, “Nationwide Combined Radar Rainfall Information Providing System,” Espac. Bibliogr. data JP2006030013 — 2006-02-02, pp. 5–6, 2006.

[14] H. Feyen, J. Mehlhorn, and C. Oehy, “Method and system for automated location-dependent recognition of flood risks,” US Pat. 7395157, pp. 1–25, 2008.

[15] S. Kenichi, Y. Yoshiki, and H. Umio, “Water Level Observation System By Image Processing,” Espac. Bibliogr. data JP2008057994 — 2008-03-13, pp. 5–6, 2008.

[16] M. Yasuhiro, “Concentrated Heavy Rainfall Prediction System,” Espac. Bibliogr. data JP2010286458 — 2010-12-24 Conc., pp. 5–6, 2010.

[17] T. Takeshi, S. Masahiro, and O. Hiroki, “Sudden Flood Risk Avoidance System And Method,” Espac. Bibliogr. data JP2012141840 — 2012-07-26, pp. 5–6, 2012.

[18] J. A. Nystuen, “Rainfall Measurement using Passive Underwater Acoustical Remote Sensing,” no. October, pp. 508–513, 1982.

[19] L. Baldini, E. Gorgucci, and V. Romaniello, “An integrated procedure for rainfall estimation using C-band dual-polarization weather radars,” 2008 IEEE Radar Conf. RADAR 2008, no. 1, pp. 1–4, 2008.

[20] T. Yuwono, Ruzardi, and M. Ismail, “Rain gauge development employing Bluetooth and RF modem,” 2011 IEEE Int. Conf. Sp. Sci. Commun. “Towards Explore. Equatorial Phenomena”, Iconsp. 2011 - Proc., no. July, pp. 320–323, 2011.

[21] U. Lewlomphaisarl and P. Saengsatcha, “High accuracy tipping bucket rain gauge,” SICE Annu. Conf., pp. 372–375, 2012.

[22] M. C. Valverde, E. Araujo, and H. Campos Velho, “Neural network and fuzzy logic statistical downscaling of atmospheric circulation-type specific weather pattern for rainfall forecasting,” Appl. Soft Comput. J., 2014.

[23] M. Shoaib, A. Y. Shamseldin, and B. W. Melville, “Comparative study of different wavelet-based neural network models for rainfall-runoff modeling,” J. Hydrol., 2014.

[24] F. J. Chang, Y. M. Chiang, M. J. Tsai, M. C. Shieh, K. L. Hsu, and S. Sorooshian, “Watershed rainfall forecasting using neuro-fuzzy networks with the assimilation of multi-sensor information,” J. Hydrol., 2014.
[25] O. M. M. O. Ajewole and A. T. Adediji, “Study and Characterization of Rainfall Intensities in Akure, Southwestern Nigeria,” IEEE, pp. 4–7, 2014.
[26] T. K. V. Raghava and S. P. Wani, “Internet enabled tipping bucket rain gauge,” 2014 Int. Conf. Comput. Commun. Informatics Ushering Technol. Tomorrow, Today, ICCCI 2014, pp. 1–5, 2014.
[27] X. He, H. Guan, and J. Qin, “A hybrid wavelet neural network model with mutual information and particle swarm optimization for forecasting monthly rainfall,” J. Hydrol., 2015.
[28] M. F. Rios Gaona, A. Overeem, H. Leijnse, and R. Uijlenhoet, “Measurement and interpolation uncertainties in rainfall maps from cellular communication networks,” Hydrol. Earth Syst. Sci., 2015.
[29] Y. MS and S. IW, “Measurement of Drop Size Distribution Rain in Mataram Utilize Disdrometer Acoustic For Flood Prediction,” Int. Semin. Intell. Technology Its Appl., pp. 107–110, 2016.
[30] M. Kobold and M. Brilly, “The use of HBV model for flash flood forecasting,” Nat. Hazards Earth Syst. Sci., vol. 6, no. 3, pp. 407–417, 2006.
[31] R. A. Badilla, “Flood Modelling in Pasig-Marikina River Basin,” Mod. Appl. Sci., vol. 8, no. 5, pp. 1–73, 2008.
[32] E. Basha and D. Rus, “Design of early warning flood detection systems for developing countries,” 2007 Int. Conf. Inf. Commun. Technol. Dev., pp. 1–10, 2007.
[33] D. Hughes et al., “An Intelligent and Adaptable Grid-based Flood Monitoring and Warning System,” 2008.
[34] L. Lu, S. Zhang, J. Yu, and H. Zhou, “Short-term Water Level Prediction using Different Artificial Intelligent Models,” 2009.
[35] Y. Chonbodeechalermroong and S. Chuenchooklin, “Flash flood warning system in a risky area,” in ECTI-CON 2011 - 8th Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand - Conference 2011, 2011, pp. 133–136.
[36] B. Aires, “Monitoring flood in the lower Bermejo river basin using multifrequency microwave signatures,” no. 1, pp. 3–6, 2011.
[37] R. Adnan, F. A. Ruslan, A. M. Samad, and Z. M. Zain, “Artificial neural network modeling and flood water level prediction using extended Kalman filter,” 2012 IEEE Int. Conf. Control Syst. Comput. Eng., vol. 4, no. Cascade, pp. 535–538, 2012.
[38] R. Adnan, F. A. Ruslan, A. M. Samad, and Z. Md Zain, “Floodwater level modeling and prediction using artificial neural network: a Case study of Sungai Batu Pahat in Johor,” 2012 IEEE Control Syst. Grad. Res. Colloq., no. Icsgrc, pp. 22–25, 2012.
[39] R. Marin-Perez, J. García-Pintado, and A. S. Gómez, “A real-time measurement system for long-life flood monitoring and warning applications,” Sensors, vol. 12, no. 4, pp. 4213–4236, 2012.
[40] J. K. Roy, D. Gupta, and S. Goswami, “An improved flood warning system using WSN and artificial neural network,” in 2012 Annual IEEE India Conference, INDICON 2012, 2012.
[41] R. R. Caubalejo, J. Manansala, G. H. Manuel, and D. B. Oriño, “Design of Flood Detection System With Automatic Branch Circuit Cut-Off Capabilities and Sms-Based,” Unpubl. Thesis, no. September 2013.
[42] E. Kuantama, P. Mardjoko, and M. A. Saraswati, “Design and Construction of Early flood warning system through SMS based on SIM300C GSM modem,” in Proc. of 2013 3rd Int. Conf. on Instrumentation, Communications, Information Technol., and Biomedical Engineering: Science and Technol. for Improvement of Health, Safety, and Environ., ICICI-BME 2013, 2013, pp. 115–119.
[43] K. Achawakorn, K. Raksa, and N. Kongkalai, “Flash flood warning system using SCADA system: Laboratory level,” in 2014 International Electrical Engineering Congress, iEECON 2014, 2014.
[44] M. E. Hossain, T. N. Turna, S. J. Soheli, and M. S. Kaiser, “Neuro-fuzzy(NF)-based adaptive flood warning system for Bangladesh,” in 2014 International Conference on Informatics, Electronics, and Vision, ICIEV 2014, 2014.
[45] A. Dersingh, “Design and Development of a Flood Warning System via Mobile and Computer Networks,” 2015.
[46] S. W. Lo, J. H. Wu, F. P. Lin, and C. H. Hsu, “Cyber surveillance for flood disasters,” Sensors (Switzerland), 2015.
[47] V. Vunabandi, R. Matsunaga, S. Markon, and N. Willy, “Flood sensing framework by Arduino and Wireless Sensor Network in Rural-Rwanda,” in 2015 IEEE/ACIS 16th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, SNPD 2015 - Proceedings, 2015.
[48] F. C. C. Garcia, A. E. Retamar, and J. C. Javier, “A real-time urban flood monitoring system for Metro Manila,” IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON, vol. 2016–Janua, pp. 3–7, 2016.
[49] P. Truatmoraka, N. Waraporn, and D. Suphachotiwatana, “Water Level Prediction Model Using Back Propagation Neural Network Case study : The Lower of Chao Phraya Basin,” 4th Int. Symp. Computational Bus. Intelligence, pp. 200–205, 2016.
[50] C. Srihari, S. Prashanthi, V. Sriranjani, and S. S. Ahila, “Automated wireless flood warning system in remote areas,” in Proceedings - 2016 IEEE International Conference on Technological Innovations in ICT for Agriculture and Rural Development, TIAR 2016, 2016, pp. 181–187.
[51] F. C. C. Garcia, A. E. Retamar, and J. C. Javier, “Development of a predictive model for on-demand remote river level nowcasting: a Case study in Cagayan River Basin, Philippines,” IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON, pp. 3275–3279, 2017.
[52] A. Silva Souza, A. M. De Lima Curvello, F. L. D. S. De Souza, and H. J. Da Silva, “A flood warning system to critical region,” in Procedia Computer Science, 2017.
[53] M. Azam, H. S. Kim, and S. J. Maeng, “Development of flood alert application in Mushim stream watershed

Korea," Int. J. Disaster Risk Reduct., pp. 11–26, 2017.
[54] E. Toth, A. Brath, and A. Montanari, "Comparison of short-term rainfall prediction models for real-time flood forecasting," J. Hydrol., vol. 239, no. 1–4, pp. 132–147, 2000.
[55] T. Wardah, R. Suzana, S. Y. S. N. Huda, and A. A. Kamil, "Multi-sensor data inputs rainfall estimation for flood simulation and forecasting," CHUSER 2012 - 2012 IEEE Colloq. Humanit. Sci. Eng. Res., no. Chuser, pp. 374–379, 2012.
[56] L. Alfieri and J. Thielen, "A European precipitation index for extreme rain-storm and flash flood early warning," Meteorol. Appl., 2015.
[57] W. Yu, E. Nakakita, and K. Jung, "Flood Forecast and Early Warning with High-Resolution Ensemble Rainfall from Numerical Weather Prediction Model," in Procedia Engineering, 2016.