Flood Warning And Mitigation: the Critical Issues of Water Level Forecasting

Ocheme, J. E.; Octache, M. Y.; Musa, J. J.; and Ezekiel, L. P

Department of Agricultural and Bioresources Engineering, Federal University of Technology,Minna.

ochemejohn1211@gmail.com

Abstract

Prediction of the pattern of water level is one of the benchmark in flood forecasting and analysis; this has become one of the most important issues in hydrological research. Water level is an essential component in the process of flood warning and mitigation strategies. This review revealed that water level study is an essential component in any purported flood warning and mitigation designs. Worthy of mentioning in this context is the need for effective water levelforecasting. However, the development of any forecasting system is highly fraught with encumbrances like hysteresis in the stage hydrograph due to random behaviour of river flow regime and uncertainty. Thus, within the general context of the discourse, the critical issues are the determination of appropriate forecast model, forecast lead time, and suitable water level for standby alarms and areal alert.

Keywords: Floods, flood warning, water level prediction, emerging issues

1. Introduction

Flooding is considered as one of the major threats to human civilization and is directly attributed to heavy rainfall leading to loss of human life, properties, infrastructure damage, as well as huge economic losses (Kundzewicz, 2002, Singh *et al*., 2018). Climate change, intense natural resource exploitation and inappropriate land use have altered the hydrological response of catchments (Egbenta*et al*., 2015). These factors increase the frequency and magnitude of flood events. It was estimated that Nigeria suffered combined losses of over $16.9b in damaged properties, oil production, agricultural and other losses due to flood events in 2012 alone (AmangabraandObenade, 2012, Egbenta*et al*., 2015). Similarly, a combination of an exposed, vulnerable and ill-prepared population may enhance such situations which generate additional risks. The insufficient capacity of public authorities and rescue services to act diligently in these situations also increases risks (ISDR, 2017). High population density in urban area present a higher disaster risk (Flood Warning Guide: FWG, 2010). They are expected to experience the effects of climate change with the increment of intensity and frequency of harmful events such as flash floods (Flood Early Warning System Reference Guide: FEWSRG, 2010). The flooding that affects the vast majority of the world's regions is fluvial flooding or river flooding. This type of flood occurs when the rivers overflow or burst their banks due to excessive rainfall over an extended period of time and spill onto the floodplain (Alfieri *et al*., 2018; Maggioni and Massari, 2018). Other flood that can also be experienced is pluvial flooding or surface water flooding which is a problem in many cities and occurs when there are high intensity of rainfall; here, the sewage and drainage system become overwhelmed and excess water cannot be absorbed into the soil. This also can be due to sewage and drainage blockage by human waste. This problem is enhanced in cities with insufficient or non-existent sewer systems. It suffices to note however that fluvial floods are more disastrous than pluvial flooding as they do have high return period. Pluvial floods come with less damage but, the frequency is higher and the cumulative damage over the years can be just as high as with fluvial flooding events (Jiang. *et a*l., 2018; Ten Veldhuis, 2011). Floods are among the most devastating natural disasters in the world, claiming more lives and causing more property damage than any other natural phenomena. In Nigeria, though not leading in terms of lives claimed, flood affects and displaces more people than any other disaster; it also causes more damage to properties. For instance, fluvial flood experienced in Nigeria in 2012 is the worst in living memory (Social Action, 2012). At least 20 per cent of the population is at risk from one form of flooding to another (Social Action, 2012). These losses are expected to escalate in the future due to climate change, land use change, deforestation, rising sea levels, and population growth in flood-proneareas, causing the number of people vulnerable to flood disasters globally to increase to two billion by 2050 (Bogardi, 2004, Vogogel*et al*., 2011; ICHARM, 2009).

Therefore, to avoid further disaster by flood, flood warning program must be introduced to increase lead time for watches and warnings at locations subject to flood risk. The information can be used to predict whether a flood is about to occur, when it will arrive, and how severe it will be. The warning system allows Organizations and individuals to develop their preparedness and response regimes accordingly; with this, the concomitant impacts can be mitigated.

2. Flood warning and mitigation in perspective

A flood warning is an information in the form of a prediction about a flood that is likely to happen. This information is usually targeted at and communicated to people who are in the path of the flood in advance of the flood occurring, with the intention of enabling them to avoid harm. Such information may also be communicated to infrastructure providers (e.g., electrical power companies) to enable them to take actions to avoid the disruptive effects of power outages and also to those operating flood barriers. Many population centers are protected from flooding by flood forecasting and warning systems that operate in conjunction with large-scale flood barriers that are closed when forecast thresholds are reached. Warnings are also provided for professional emergency responders so that they are alerted, for example, to evacuate people from an area likely to be flooded (Parker, 2017).

A successful flood warning system consists of several interacting components such as: continuous monitoring and forecasting of weather patterns, particularly precipitation, and water levels; detection of potentially hazardous situations; definition and implementation of rules on when, how and whom to warn in case of rising flood water levels and what to communicate in order to activate organizations in charge of civil protection as well as potentially affected people; and an adequate and effective response to the unfolding flood situation (e.g. Parker *et al*., 1994; Parker and Priest, 2012). Hence, a flood warning system is more adequately addressed as a flood-forecasting, warning and response system (FFWRS; Parker and Priest, 2012). In a FFWRS, several organizations have to collaborate and information has to be communicated, disseminated and interpreted correctly along a chain of different stakeholders, including the general public, which opens the door for many pitfalls that reduce the system's overall efficiency. Consequently, redundancies are seen as an important principle at all levels (Parker and Priest, 2012). Flood warning components in this context is as depicted by Figure 1.

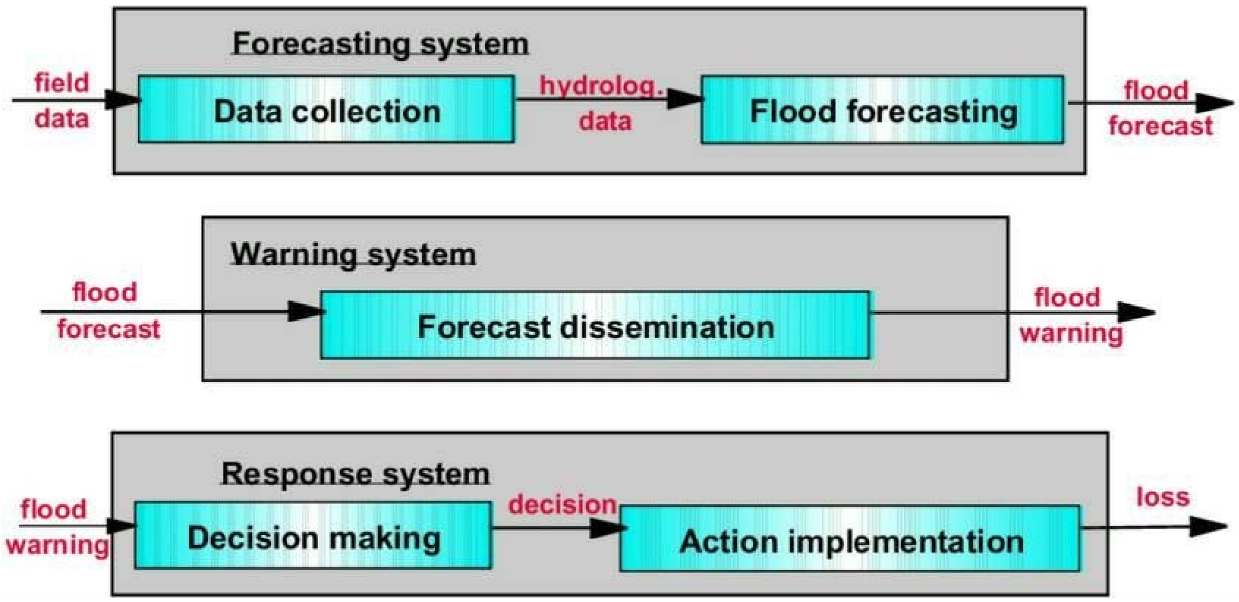

Figure 1.The flood forecasting, warning, and response system (FFWRS)

Source: (Krysztofowiczand Davis, 1983)

The components of an early warning system consists of a chain of subsystems. The first link is the forecasting system which consists of data gathering component, a component for transmission of the data to the forecasting center, and a component of forecast preparation. In the forecasting center, the data are converted into a forecast, which then is transmitted to the decision maker. The decision maker then uses the forecasts to prepare and release a warning, depending on his evaluation. Then the response system is activated. The warning is transferred to the local authorities, who have to take appropriate preventive action and pass the warning on to people in a form so that they can react (Krysztofowiczand Davis, 1983).

Therefore, for a real-time solution, an effective flood warning should be based on the regular collection of water level data, this can be done through routine monitoring in which the operating personnel make visit to stream gauging stations or hydrometric stations to collect information on temporal water levels.The objective of this is to have an idea of the transient change in the level of the river so that at critical peak flow period, warning can be issued.

3 Water level forecasting for flood and general river system management

Water level is the depth of flow above the river bed which is used to estimate the discharge; thus, because of this, water level is considered as a critical component in river flow forecasting especially water issues like hysteresis effects and uncertainty in stage-discharge relationship are taken into reckoning. River stage forecasting is crucial in water resources management and real-time prediction of extreme floods.Over any given region, the water level as well as the quantity of water flowing in streams may vary widely in both time and space. The fluctuation in discharge and water level results from variation in duration, frequency, intensity, areal cover of precipitation and variation in the catchment characteristics. Knowledge of river flow and its variability is an essential requirement for assessment, management and control of surface water resources. The basic data required for flood frequency studies, flood inundation modelling, design of flood protection and warning systems, river sediment management, water supply engineering, drought studies and geomorphologic studies are records of discharge measurement in river (WMO, 2011a).

Development of optimal flood forecasting and viable flood risk management systems have been advocated as measures of flood preparedness (Arduino*et al*., 2005, WMO, 2011a) for a variety of reasons. Due to the uncertainties surrounding the magnitude, timing and place of occurrence, geographical extent, and geophysical interactions of floods, it is often not possible to completely control them. As a result, complete protection from floods is not always considered as a viable alternative (Moore *et al*., 2005). Therefore, accurate water level forecasting that results from hydro-meteorological variations and anthropogenic disturbances are very vital for environmental protection and flood management strategy (Hofmann *et al*., 2008). During flood events, reliable water level prediction enable the use of both early warning systems to alert the population and for real time control of hydraulic structures, like diversion, gates etc., to mitigate flood effect. Water level fluctuations are dependent on diverse factors such as the spatial and temporal distribution of precipitation, topography, soil type, vegetation, land-use, catchment hydrology and the built environment, making flood forecasting a difficult exercise (White, 2001).

Therefore, Information on the flood evolution must be provided with a reasonable lead time to be effective, but this is not an easy task, particularly in Nigeria where the historical data needed for forecasting are not readily available; this situation makes real-time prediction of hydrological phenomenadifficult.Therefore, managing river systems that flow across borders is complex and multifaceted. The issue encompasses theoretical and practical debates that, in some form, have been present since the beginning of mankind, as they reflect human attitudes and values. As such, effective prediction approaches play an important role; for instance in the studies of lakes. They can be used to simulate the water level variations based upon the available measured data and predict the possible responses under different scenarios, supporting management decisions of valuable water resources.

3.1 Methods / approaches adopted for water level forecasting

The knowledge of the surface water system has a wide range of applications in life. Regular monitoring and studying of river water level behavior is important from several perspectives most especially for timely forecasting of floods and dry spells and this is exemplified by numerous references (Chinh*et al*., 2009; Koutroulis*et al*., 2010; Valle Venencio and García, 2011). In this sense, the analysis of the change in water level as well as water level forecast have been subjects of numerous research activities, though, it has been possible thus far to reliably predict water level of river a few days in advance. Hydrologists are now developing, with the aid of river level data from the last six decades, a calculation model that enable longer-term water level predictions. Therefore, In terms of forecasting techniques, it is reported that many analyses of water level forecasting approaches had been done in hydrological problems. The choice of the forecasting model is an important factor in order to improve the forecasting accuracy (Areekul*et al*., 2010).

In the last decade a new type of data-driven models, based on artificial intelligence and soft computing technique have been applied in water level forecasting. In particular, Artificial Neural Network (ANN) is one of the most widely used technique in the forecasting field (Hsu *et al*., 1995). Most applications based on these models consider the discharge as forecasting variable (Imrie*et al*., 2000; Dawson *et al*., 2002; Moradkhany*et al*., 2004), probably because of a historical contiguity with the classes of conceptual and physically based rainfall-runoff models. Such an approach requires the knowledge of the rating curve in the cross section of interest (i.e. the basin outlet) to parameterize the model. However, the knowledge of the water level is required within the framework of a flood warning system and thus the rating curve has to be used also to transform the forecasted flows into water levels.

Altunkaynak (2007)applied an artificial neural network model to accurately predict dynamic changes of surface water level in the lake. Van. Yarar*et al*. (2009) estimated level changes of Lake Beysehir in Turkey using the adaptive neuro-fuzzy inference system (ANFIS), ANN, and seasonal autoregressive integratedmoving average (SARIMA) approaches. Kisi *et al*. (2012) also forecasted daily lake levels by artificial intelligence approaches. However, detailed comparison of the time series forecasting and ANN models with the physically based models has not yet been studied in lakes.

Models based on ANN, FL, etc., and, more in general, all data-driven models, can be designed to forecast water levels directly, given their very nature. For instance, Campolo*et al*. (1999), See and Openshaw (1999), See and Openshaw (2000), Thirumalaiah and Deo (2000), Campolo*et al*. (2003), Young (2001, 2002), developed models based mainly on applications of the ANN techniques, while Krzysztofowicz (1999, 2001), Krzysztofowicz and Kelly (2000), Krzysztofowicz and Herr (2001) developed a Bayesian forecasting system which produces a short-term probabilistic river level forecast based on a probabilistic quantitative precipitation forecast.

On the other hand, physically based numerical models are constructed using a set of governing equations that address conservation laws of mass/momentum and transport processes. In contrast to a simple zero-dimensional mass balance computation for elevation and storage, these models can provide more detailed spatial-temporal patterns of water level, circulation, vertical stratification/mixing, and other aspects of lake physics (Kimura*et al*., 2012; AnyahandSemazzi, 2009). Young *et al*. (2015) used physically based hydrodynamic model to accurately predict water level fluctuations. To address these issue of water level forecasting, time series modelling has been also explored over time.

In this regard, well-known technique such as ARIMA and SARIMA are most commonly used for time series forecasting, however, they have limitations in applications due to linearity issue.Time series forecasting methods that define the trend or stochastic processes of variables have also been applied to predict water level fluctuation in lakes. One of the most commonly used approaches is the autoregressive integrated moving average (ARIMA) model, where the autoregressive and moving average filters account for systematic effects and internal shock effects in the endogenous variable, respectively. But, ARIMA models require a stationary time series without data missing (Ediger and Akar, 2007). Based on the observations time series, an identified underlying process can be constructed under the assumptions of linearity, normality, and homoscedasticity. Thus, for better prediction accuracy and variability in endogenous variables, an autoregressive moving average with exogenous (ARMAX) model includes the explanatory variables in the cause-effect technique.

One of the most common methods, based on times series analysis, are models based on the combination of autoregressive model and moving average model to increase efficiency and accuracy of water level forecasting.Therefore, the implementation of water level forecasting requires both human and computing resources. Sufficient resources must be in place to support not only the development of the system but to operate and maintain it through time. Thus, in general,water level forecasting is constrained by many issues such as the availability and types of data and their representativeness and quality. Specifically, the issues of immediate concern here are as discussed in the next section.

4.0 Emerging issues in water level forecasting

Water levels are designed to make local authority aware of the level of danger posed by the rising water level so that a necessary emergency arrangement could be initiated for the welfare of the local community affected by the river. As the water level forecasting could reduce the damage from the impact of flooding in agriculture, public uses, avoid both life and economic loss, it is therefore important to predict its fluctuation. Prediction of the pattern of water level is one of the benchmark points in the flood forecasting analysis and has been one of the most important issues in hydrological research. Water level is an essential component in the process of forecasting flood resources evaluation and is considered as a central problem in hydrology (Ekhwah*et al*., 2009).

The most critical issues involved in water level forecasting are:

a) Choice of time horizon for the practicalities of flood protection:

In general, water level changes seasonally (e.g., high in the rainy season and low in the dry season) with sharp rising/falling limbs during flood events, but not in a simple periodic mode;this give rise to hysteresis in the hydrograph with associated problem in the development of an effective rating curve for a particular river section. Therefore, it is a serious challenge to thehydrologists to decide the time suitable for flood protection especially due to the lack of the following vita information, namely:

1. Amount of rainfall occurring on a real time basis
2. The rate of change in river stage on a real time, which can help indicate the severity and immediacy of the threat.
3. Knowledge about the type of storm producing the moisture, such as duration, intensity and areal extent, which can be valuable for determining possible severity of the flooding.
4. Knowledge about the characteristics of river's drainage basin, such as soil moisture conditions, ground temperature, topography, vegetation cover, and impermeable land area, which can help to predict how extensive and damaging a flood might become.

Against this backdrop therefore, the appropriate time horizon to be chosen for flood forecasting for the practicalities of flood protection such as alerting the appropriate authorities, issuing of warnings to industries and households in the vicinity and protection of property become an issue of great concern because the catchment is not continually monitored by the agency or government institutions and bodies responsible for flood defence (Environmental Protection Agency: EPA, 2002).

b) Choice of appropriate or critical water level for the assurance of standby alarms to duty officer and area alert;

Flood response levels for Agency/ Jurisdiction will be based on river stage for a given river at a given hydrometric station so that when the water levels at the station reached the required height (m) based on historical data, the standby alarm to duty officers monitoring the catchment will be triggered. According to EPA (2002), an area alert is activated when the level reaches 3.5m and flood warning is issued as the level continues to rise but in Nigeria today, the choice of appropriate water level has been a great issue due to the fact that the agencies in charge of monitoring lack the requisite capacity to do. So, this is compounded by inadequate data on water level rises as well as absence of telemetering gauges for real-time transmission of information and corresponding analysis.

According to Sample Flood Safety Plan (2011), flood stage monitoring comprises of observing the readings from specific real-time, telemetered stream gauge that report the conditions on water courses that affect potential flooding in the area. For each gauge location on a stream or water course, stages or flows have been categorized into three levels: monitoring stage, danger stage, or flood stage but responding to these stages have been a challenging issues due to its complex nature especially due to inability of agencies shouldered with responsibility to put the necessary structures to access the real time gauge through the internet hence they cannot directly monitor the outflow at the various areas that are been affected. Thus, deciding the choice of water level remains a challenging issue especially in an area where there is no levee patrols when the elevation reaches the assumed height at the location for a named river as well as monitoring and surveillance information to decide if it is necessary to begin flood operation or direct flood fight resources to specific area where flooding is occurring or may occur soon. Concisely, lack of or improper use of technical information have been the issue; these technical information include:

1. **Radio Reporting Rain Gauges:**According to Flood Warning Systems Manual, (2012), gauges have two primary functions—sensing and communicating. Sensing involves detection of an "event", which is the smallest unit of measurement desired, such as 1 millimeter of rain, 1/100 inch of stage height, etc. Communicating involves reporting the event to a user location. For maximum flexibility, nearly all gauges are designed to allow multiple sensors at a particular site to report through a single communications platform. The gauge assigns a unique identifier to each individual sensor type (rain, stream, temperature, wind speed, etc.), and communicates both. This radio reporting rain gauge is usually needed in remote areas where commercial power is unavailable; but appropriate disseminating this information has become an issue.
2. **Stream Gauge:** In small watersheds, stream flow observations are not noted so it is difficult to calibrate watershed models and verify forecasts from models, or trigger alarms when flooding is impending or occurring. The placement of stream gauges is not usually guided by public warning requirements and forecast model requirements. Gauges used for stage alarms are at times not even located at key points of potential damage and at points that are far enough upstream to yield enough warning time for downstream locations.
3. **Communications Media:**Alert gauges and other forms of radio transmissions are susceptible to interference from man-made electrical noise, atmospheric conditions, and other transmitters on the same or adjacent frequencies. Because multiple alert transmitters share common radio frequencies, there are instances when simultaneous transmissions occur. Most VHF/UHF radio-based communications platforms do not use the alert radio transmission protocol, which transmits in real time when each sensor event occurs. Alert systems may be fast, have good resolution, and low operating costs, but they have a limited transmission range. Therefore, remote areas are at risk during flood events.

4. **Software:**The primary function of automated flood warning system (AFWS) software is to collect and interpret raw data sent from remote gauge locations. Most software also includes one or more applications that enable the user to view the data as graphical or text information, both locally and on the internet. Obviously most of the agencies in Nigeria do not have this software and even if they do, it is not properly managed. Agencies of Government like Nigerian Emergency Management Agency:NEMA and Nigerian Hydrological Services Agency: NHSA may not have been operationally organisedto technically address the issues mentioned here.

c) Data collected in terms of type, size and quality:

There are important challenges facing Federal Agencies that collect and manage hydrologic data. One of these challenges is related intrinsically to the type of problems for which hydrologic data are being used. The analysis of problems related to floods and droughts requires specific information about extreme events, which can be developed only after conducting decades or substantial period of precipitation and streamflow monitoring across a variety of different climatic and hydrologic setting. In general, the broad spectrum of present and future scientific water problems nationwide requires monitoring systems that function reliably over both large and small temporal and spatial scales. Unfortunately, the observational networks to measure various water characteristics have been in decline during the last 30 years due to political and fiscal instabilities (NRC, 1991; Entekhabi*et al*., 1999); this is basically not in term of the number of available institutions but rather the capacity and the associated service delivery.

In general, most often than not, the situation leads to imperfect characteristics of the produced data such as missing data and inconsistent value of data are therefore issues of great concern. Datapre-processing such as consistency and extension and infilling through either interpolation or extrapolation can also influence the performance of the prediction model (Zhang, 2002) because a large element of uncertainty exists in extrapolation process. It is difficult to categorically comment on the existing stations of Government Agencies to adequately handle these issues considering mal-functional nature of government agencies and interrelated problem of function duplication..

d) Choice of Model/ Model Performance:

The transformation of precipitation into channel flow by determining its depth(level) is a highly complex physical process. A common practice is to use a hydrological model to represent watershed process. Many different hydrological models have been produced by government agencies, universities, and private companies. They offer a wide range of process simulation options, differing levels of complexity and data requirements, and various degrees of technical support and training. Their application also depends on the forecasting objective, geographical and environmental factors, as well as institutional capabilities. Therefore, the selection of a "best choice" flood forecasting model needs to be based on a systematic approach (Lettenmaier and wood, 1993).

It is therefore imperative to note that Comparing Hydrological Flood Forecasting Models (HFFMs) is not a new idea, but assembling the required data for model forecasting is challenging and complex.A traditional approach is to select a gallery of models for comparison, and a watershed where models can be run. But the common data set to be assembled include meteorological data, observations of flow and stage, soil characteristics, and all other data that might be used to parameterize the models which are not readily available. Each model is configured for the watershed using the assembled data. Performance metrics are defined, and calculated for each model in the inter-comparison. The models are then ranked based on the performance metrics. This process may be repeated for a variety of different watersheds in various climates or regions of the world representing different hydro-meteorological conditions. The general idea is to select a single, most appropriate model for a particular set of hydro-meteorological and institutional conditions. Therefore, the spatial and temporal resolution of models depend on a wide range of factors. The temporal resolution depends on the frequency of input data and data assimilation as well as the forecast purpose. The spatial resolution depends on the density of the observing network, interpolation possibilities, variability of the flow conditions and the spatial characteristics of the area for which the forecast is issued (Lettenmaier and wood, 1993). But alarming in this regard is the haphazard nature of how things are being handled; institutions that are supposed to handle this critical component are not taken into proper contextual / operational reckoning.

5. Conclusion

Floods are among the most devastating natural disasters in the world, claiming more lives and causing more property damage than any other natural phenomena. Therefore to avoid further disaster by flood, flood warning program must be introduced to increase lead time for monitoring and warning at location subject to flood risk. This information can be used to predict whether a flood is about to occur, when it will arrive and how severe it will be; for real-time solution, an effective flood warning should be based on the regular but temporal collection of water level data that would allow for the fastest possible response to flood event. In this regard, effective prediction approaches play an important role in the study of river which can be used to simulate water level fluctuations. This water level forecasting is constrained by many issues such as choice of time horizon, appropriate water level for standby alert, type of model to be applied, and data availability in terms of quality and type. In general, addressing water resources concerns in the future will require increasingly substantial data base: in this regards, both Streamflow and water level data are needed to support important public policy decisions concerning towns located in the floodplains of rivers.

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