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Advance Ensemble Flood Warning System: A Case Study for Nullah Lai †

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Abstract: River flow forecasting is an essential tool to manage the floods in current era especially for flash flooding scenarios in urban areas. This study focuses the flash flooding scenario on basin of Nullah Lai basin which comprises of twin cities of Islamabad & Rawalpindi. Steep slopes in Margalla hills & Islamabad creates high flash floods in lower reaches of Rawalpindi which are densely populated. High intensity rainfall when occurs in steep slopes of Margalla and Islamabad pour down high floods with high velocity which instantaneously reaches the Rawalpindi less sloppy regions in which causes raising of water level in the stream and flooding occurs. Nullah Lai Rawalpindi reach starting from Qatarian bridge to Gawalmandi bridge has always faced the flash flooding over the time. In the period of few hours the water level reaches the several fts level in the nullah that is why it is not possible to timely alert the people living on the banks that problem always ask for the need of forecasting system at Nullah Lai. In current research china metrological agency forecast center (CMA) ensemble forecast data has been utilized to get the forecasted stage in the Nullah Lai. For this purpose, two initial objectives were set to achieve which basic needs to process the data available in grib format at data centers. The digital model of Nullah Lai was made using hydrology tools available in ArcGIS 10.3. The digital equation was obtained from gene expression modeling (GEP) which was later used to generate the ensemble stage forecast against the ensemble rainfall forecast. The results obtained shows that the flash flooding phenomenon in Nullah Lai can be with some uncertainty be predicted well before time. Using 3 days ahead forecast data from CMA same floods were predicted 3-days before the happening of event. This research also provides the procedure to use the ensemble forecast data in developing the automated model to generate the ensemble stage forecast against coming events. This study will help the administrative authorities to better manage the upcoming floods and save live and capital cost lost in flash flooding phenomenon which continuously happen in the basin of Nullah Lai.

Keywords: ensemble; flash flooding; Nullah Lai; Flood forecasting; catchment; gene expression modeling; THORPEX; Tiggi; CMA; Arcgis

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1. Introduction

The development and implementation of policies and procedures related to water management and transportation are influenced by climate forecasts. These forecasts can help decision-makers in various areas, such as farming, urban flooding, and transportation. In addition to helping manage the flow of water, they can also help disaster administration and supervisors keep track of the allocation of water to diverse users [1]. The occurrence of flash flooding is a major concern for scientists in normal risks and hydrologic studies due to its top-positioning in various categories of disasters [2]. In the event of a flash flood, people should anticipate the coming surges and prepare for the secure passage of the water flow. This is done through the process of de-terminating the stream flow. It is additionally essential for monitoring the water supplies for various purposes, such as the water system, route, mechanical and hydroelectric utilization, and natural watering [3]. The use of climate models is currently scheduled for various global forecasting centers. These models are utilized for the prediction of atmospheric and climate conditions [4]. The NWP system uses the laws of Thermodynamics and Material science to predict the long-term state of the climate by taking into account the various factors that affect its development. The EPS system is a collection of expectations that are generated by the model. These expectations are then used to generate forecasts [5–9]. A collection of realizations known as individuals' members in an ensemble forecast is composed of various arrangements of similar parameter types. One of the most common realizations is the control estimate, which is based on the best available conditions in the atmosphere. This allows for a more reasonable depiction of the demonstrate. An ensemble framework is a representation of the vulnerability of the forecast [10].

As TIGGE (THORPEX Interactive Grand Global Ensemble) network [11,12] was established in 2005 to create strategies that combine different weather forecasting frameworks. Through its data ac-cumulation centers, the public can access worldwide weather forecasts that are issued by various weather forecasting organizations. The different frameworks utilized by different forecasting centers vary in their approach to forecasting. For instance, the Nullah Lai center is located in the twin cities of Islamabad and Rawalpindi. This region has been featured in hydrological modeling before [13]. During the monsoon season, heavy rainfalls can cause flash flooding in low-lying areas of the city of Rawalpindi. It is very difficult to remove the people from these areas due to the growing urban population. The penalty for forecasting high-climate events is based on their ability to predict such situations. Despite the increasing number of end users for weather forecasts, the majority of them are not focused on forecasting the exact weather conditions for the upcoming season [14].

This study was conducted to find out what kind of work needs to be done to improve the prediction capabilities of Nullah Lai. There is currently no system that can precisely forecast the likelihood of a certain event happening. This study aims to provide a comprehensive analysis of the various aspects of the river's flow and its development.

2. Procedural Background

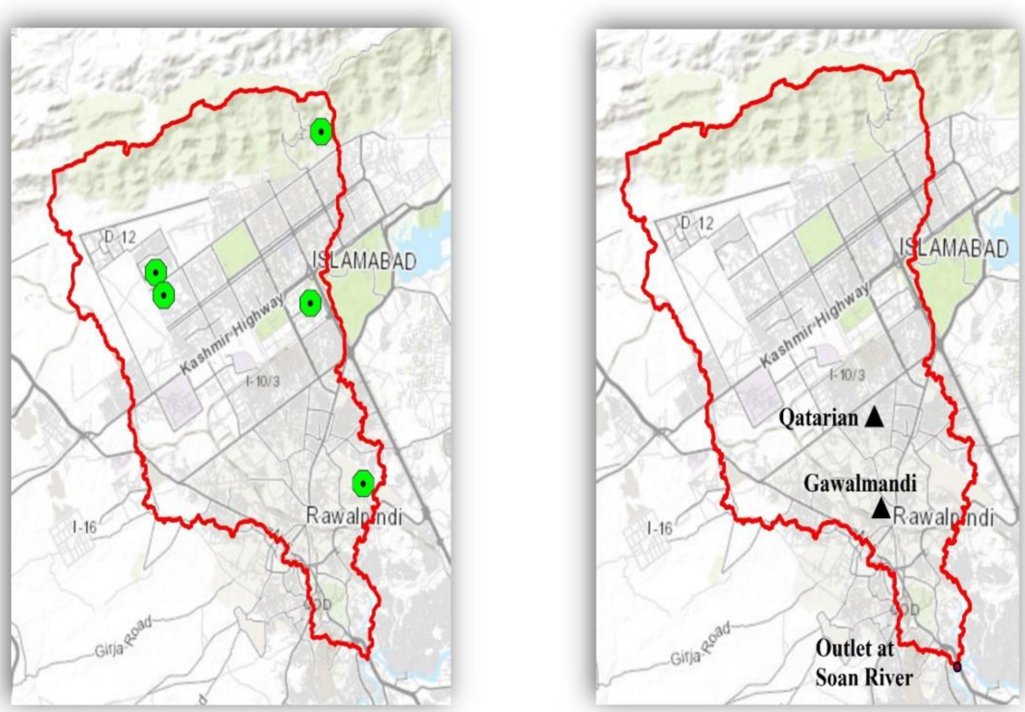
The research was based on statistical and digital modeling of Nullah Lai which was then utilized in process of ensemble prediction. The first step for the modeling was to gather data from different data providers. The research was conducted using large datasets to establish a relationship between the rainfall and the stage at Nullah Lai in the first phase. In the second phase, the data collected from different stations were linked to form a comprehensive analysis.

2.1. Forecast Data

Researchers use different models to predict the amount of rainfall that will occur in a given area. The predictions are then analyzed using data collected by the China Metrological Agency. For the study, the agency's data was used to forecast the flow of water in the Nullah Lai stream. Over 500 forecasts have been made regarding the rainfall that will happen in the watershed of Nullah Lai. These predictions were made using a format known as the GRIB, which is a representation of the latitude and longitude network. Data on the precipitation was collected from the data center of the China Metrological Agency from 2017 to 2019. The data collected during the study was gathered by researchers using grib files, which were collected monthly. They only used this method for the predictions since they were only focused on extreme weather events that usually occur during the monsoon season. Each file was analyzed separately and used for forecasting the rainfall. Two separate files containing 48 h′ and 72 h′ worth of rainfall data were downloaded. These were then split into two grib files, one containing a forecast and the other a plot of the accumulated rainfall. The grib files were then processed using a utility known as wgrib2. The NetCDF file was then processed using the ARC-GIS 10.3 platform. This method generated a total of 48 h′ worth of forecast data. After that, a table extract tool was used to extract the data into a format that can be used to display the forecast. All the 12 evets′ data were then analyzed and processed in order to produce a graphical representation of the data.

2.2. Rainfall and Stage Data

The data collected by PMD included the daily total rainfall from various gauge stations located in Chaklala, Bokra, Golra, RAMC, Saidpur, and PMD. These measurements were taken from 2010 to 2020.



(**a**) (**b**)

Figure 1. (**a**) Rain Gauging Station; (**b**) Stage Measuring Stations (right-2) Position.

2.3. Digital Modelling of Nullah Lai Catchment

A catchment area is a region of land where rain falls and flows toward a common outlet. Without a digital modeling process, the drawing of a watershed area can be very time-consuming and challenging. This process can be done with the help of tools such as the ArcGIS software.

The following describes the steps in the process of digital modeling of Nullah Lai′s catchment area. After downloading the data from the USGS website, using the DEM format, the area′s digital elevation can be marked with the coordinates of its source. In addition, using the spatial analytic tool, you can apply a ′′fill′′ tool to the area.

You can use the ′′flow direction′′ tool to obtain a view of the flow directions in the water. You can also use the ′′basin tool′′ to delineate the various drainage basins. The conversion tool for the Raster to Polygon and Raster to Polygons can be used to convert the image into a polygon. Finally, you can use the ''clip tool'' to clip the watershed from other areas.

The ''flow accumulation'' tool can be used to create a file that contains the water flow data. You can then use the ''Raster Calculator'' tool to make a water stream network. In the conversion segment, the ''Raster'' tool can be used to transform the streams into polygons. Finally, the ''clip'' tool can be used to clip the steam lines from other areas.

The input outlet point coordinates can be used to draw the catchment area to a specific point. The ''pour point'' tool can also be used to create a watershed area that is respected by each outlet point. Finally, the "Theisen Polygons" tool can be used to create a representation of the rain gauge's polygons.

2.4. Observed Rainfall—Stage Modelling

After collecting data about the rainfall and runoff in the area, a model was developed using the DTREG numerical modeling software. This tool was used to create a Gene Expression Program, which was able to mimic the biological process of developing a phenomenon. The process of gene expression programming involves developing various types of systems, such as decision trees and networks of neural and polynomial concepts. In DTREG, this type of programming is referred to as symbolic regression.

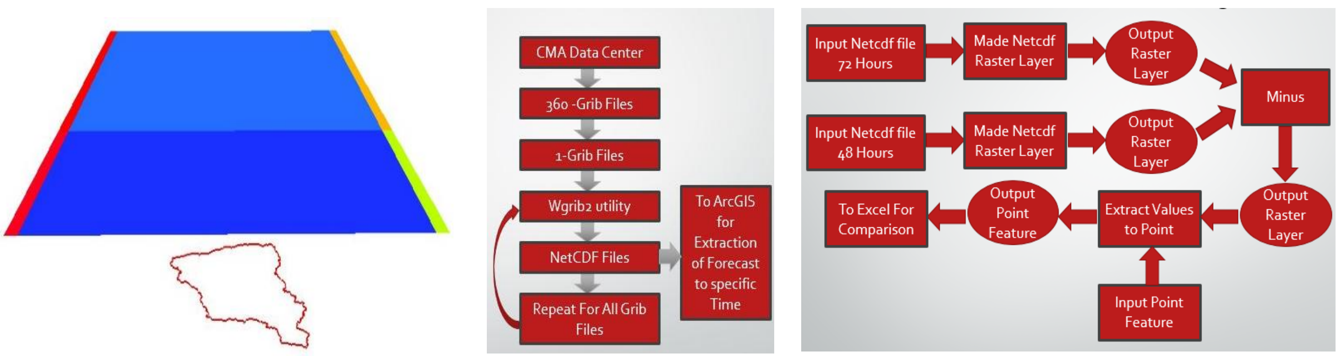
Following Relation was obtained by analyzing the 7 years of rainfall and stage data.

$$S = \mathrm{Sqrt}(P - 6.2275699) + ((-26.983058)/P) + 1.8792162 + \mathrm{Sqrt}(\mathrm{Sqrt}P) \quad (1)$$

Stage is denoted as "S"
Basin Mean of Rainfall is denoted as "P"

3. Materials and Methods

The research utilizes statistical and digital modeling techniques to develop a model of Nullah-La-Catchment shown in Figure 2. The data collected from various sources, such as TIGGI and PMD, were then processed using wgrib2, DTREG, MS Excel, and ArcGIS. The main objective of this study was to create a statistical model of the rainfall-runoff event and to relate this to the data collected by the CMA ensemble.



(**a**) (**b**) (**c**)

Figure 2. (**a**) Raster layer over Nullah Lai catchment; (**b**) CMA data processing; (**c**) Extracting forecast using ArcGIS.

4. Results and Analysis

The results of this study are compared with the actual runoff and rainfall produced by the different ensembles. The twelve extreme events that occurred during the 2017 to 2019 monsoon season are discussed here to highlight the significant run-off in the Nullah Lai. Re-searchers are more likely to focus on the ensemble forecast due to the varying atmospheric conditions. Due to the varying topography and flow conditions of the Nullah Lai catchment area, it is difficult to predict the exact amount of rainfall that will occur.

This section aims to provide a comprehensive analysis of the rainfall run-off and provides a comparison with the ensemble forecast.

Ensemble Predicted Stage vs. Actual Stage

The section compares the ensemble stage, forecasted stage, and actual observed data from the obtained results. It also provides a range of possible outcomes for a given event. Figures 3 and 4. graphically explains the twelve (12) extreme events from 2017 to 2019.

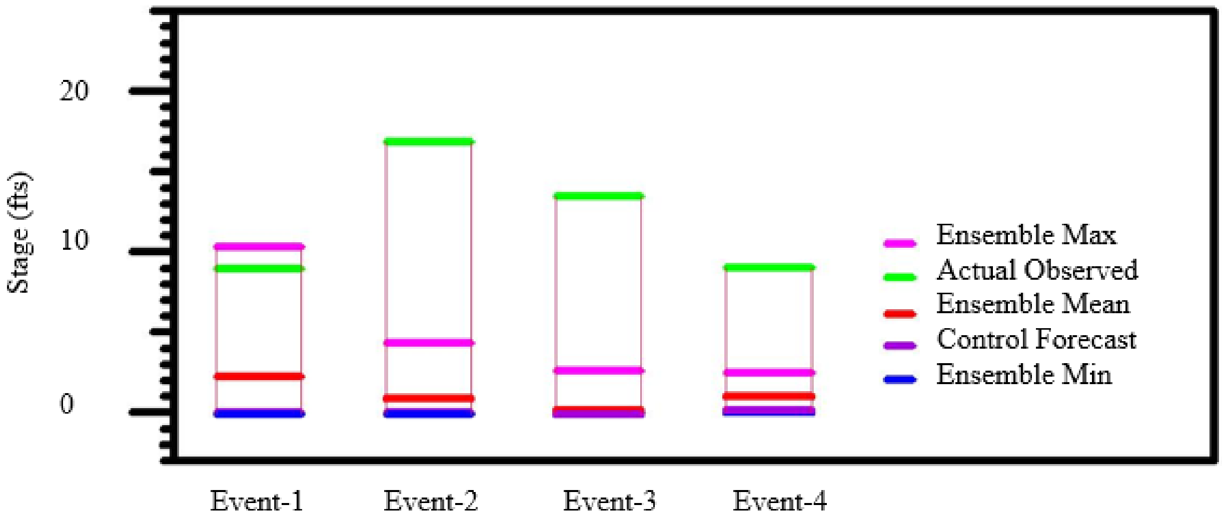


Figure 3. Event 1,2,3 &4 Stage graphical representation.

The predicted outcome of a controlled forecast is 16.67%. This means that it only made two out of 12 predictions that were carried out correctly. It can be concluded that the forecast is misleading and cannot take into account other factors that can affect the prediction.

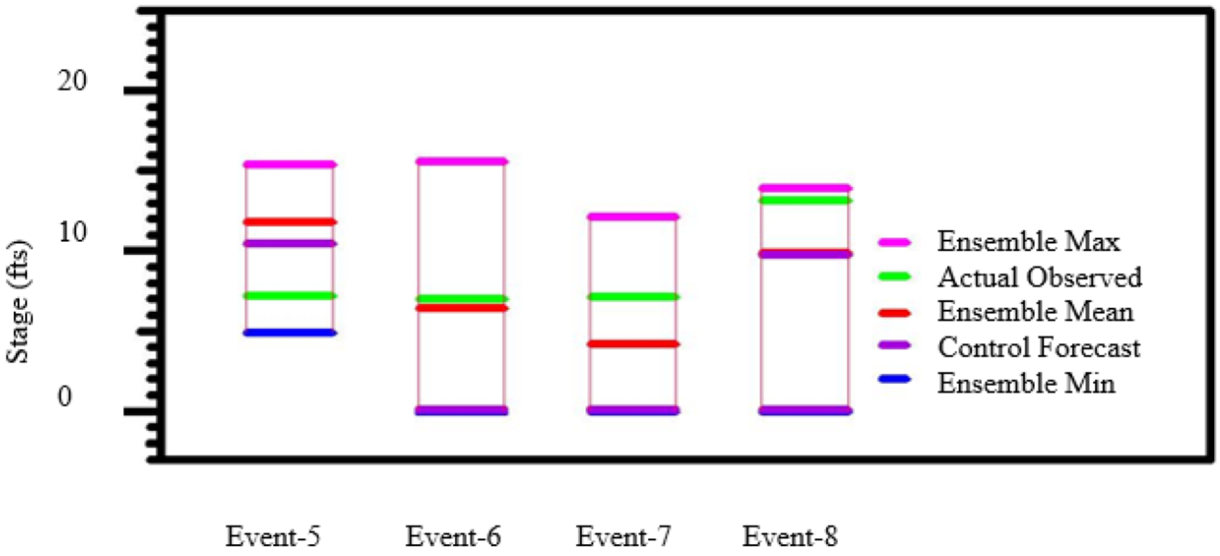


Figure 4. Event 5,6,7 &8 Stage graphical representation.

The ensemble prediction system was able to provide a precise estimate of the flow's expected range.

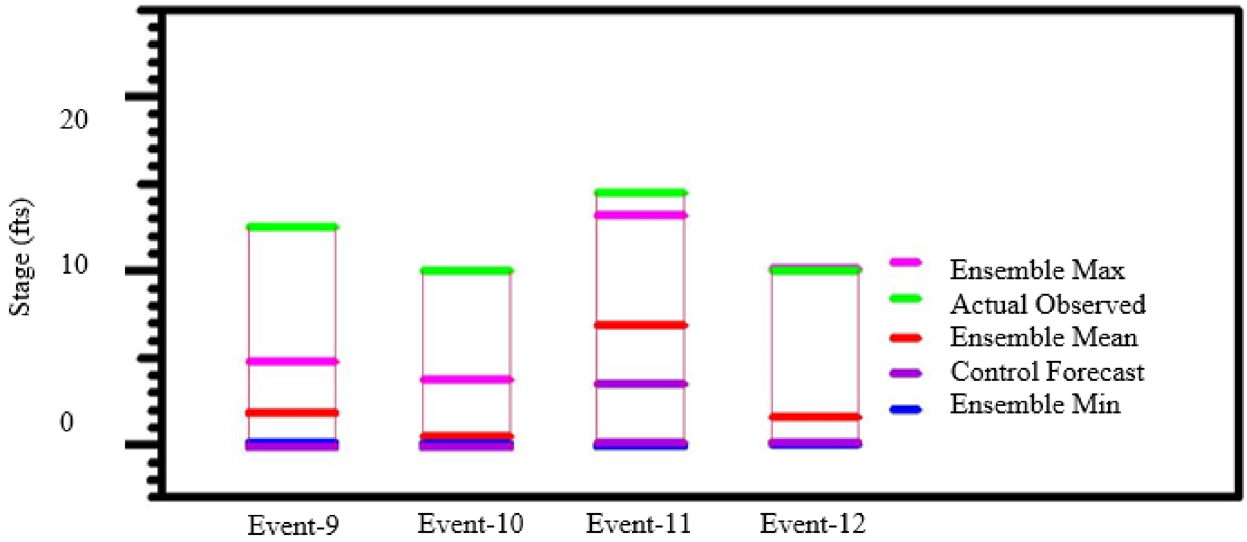


Figure 5. Event 9,10,11 &12 Stage graphical representation.

The accuracy rate of forecasting an event out of 12 events was 7 out of 12. This means that the predicted outcome is 58.33% accurate. The advantage of using an ensemble forecast is that it gives a better idea of the likelihood of an extreme event happening within the next 3 days.

5. Conclusions

Following conclusions can be drawn from the conducted study:

1. The Nullah Lai watershed was digitally modelled using the latest version of ArcGIS 10.3.1. This model was made using the most accurate digital elevation data from the USGS.
2. The model was able to produce a root mean square of 77% and a correlation coefficient of 0.88. The data collected during the period indicated that the model is very accurate.
3. The fore-casting system was used to study 12 extreme events that occurred from 2017 to 2019. Out of these, seven events were within the range of the ensemble forecast. The results show that the ensemble forecast is more accurate than the control forecast when it comes to forecasting events.

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