A Model to Identify Expeditiously During Storm to Enable Effective Responses to Flood Threat

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Summary
In recent years, hazardous flash flooding has caused deaths and damage to infrastructure in Saudi Arabia. In this paper, our aim is to assess patterns and trends in climate means and extremes affecting flash flood hazards and water resources in Saudi Arabia for the purpose to improve risk assessment for forecast capacity. We would like to examine temperature, precipitation climatology and trend magnitudes at surface stations in Saudi Arabia. Based on the assessment climate patterns maps and trends are accurately used to identify synoptic situations and tele-connections associated with flash flood risk. We also study local and regional changes in hydro-meteorological extremes over recent decades through new applications of statistical methods to weather station data and remote sensing based precipitation products; and develop remote sensing based high-resolution precipitation products that can aid to develop flash flood guidance system for the flood-prone areas.

A dataset of extreme events has been developed using the multi-decadal station data, the statistical analysis has been performed to identify tele-connection indices, pressure and sea surface temperature patterns most predictive to heavy rainfall. It has been combined with time trends in extreme value occurrence to improve the potential for predicting and rapidly detecting storms. A methodology and algorithms has been developed for providing a well-calibrated precipitation product that can be used in the early warning systems for elevated risk of floods.

***Key words*:**
Satellite Remote Sensing, Climate, Hazards, Weather, Flooding.

1. Introduction

Climate change and variability increases the probability of frequency, timing, intensity, and duration of flood events. The frequency of extreme weather events is expected to increase under a warming climate, which is regarded as a consequence of anthropogenically elevated concentrations of carbon dioxides in the atmosphere. While a connection between the first signs of climate change and recent severe extreme weather events, such as floods in Saudi Arabia is debated in the scientific literature, accelerated population growth and development in disaster-prone areas are already responsible for rapidly increasing damages, property loss, and fatalities. Floods are among the deadliest disasters along with earthquakes and windstorms. The magnitudes of these catastrophes are often ascribed to a combination of event severity and faulty management practices [2, 3].

The climate of the Arabian Peninsula is critical for several sectors including water resources, agriculture, power generation, biodiversity, migration and food security. The near real time weather and climatic information enhances the effectiveness of any assessments for climate impact studies, especially in relation to global warming and changes in climate (IPCC, 2007). The climate of Saudi Arabia tends to be hot, sometimes extremely hot during summers and mild to warm winters. Semi-arid climates receive precipitation below potential evaporation, rainfalls are little and erratic whereas precipitations exhibit strong spatial and temporal variability [4]. The largest rainfall in the Saudi Arabia occurs in the western and south-western region. Rainfall occurs during the wet season that spans November through April, although sporadic rainfall events are observed in the transition months of October and May. Most of the annual rainfall is typically received in the form of a few intense thunderstorm events of relatively short duration during the wet season. The annual precipitation is reported as about 52.5 mm/year, with a maximum rainfall of 284 mm occurred in 1996.

The damages resulted through flash floods related to the geomorphological conditions of the area. Some of the most affected areas are located immediately after the narrow parts of the valleys, where the speed and power of the runoff increased, and the water level rose. Other factors that have a big influence on these flash floods problems are related to the anthropogenic activities. These factors include man-made earth dykes. Water can collect behind them, as soon as the water pressure increased on these dykes; they break down, causing catastrophic floods. Most of the urban areas have been built haphazardly within the lowest points of the valleys flood plains which were strongly affected [9]. This is

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because a small increase in water level in these areas was enough to cause serious damage to buildings and infrastructures in the area. Other factors that are related to drainage basins and networks, rainfall distribution and values, and climatic changes and their influence on rainfall values change in the future [10].

The present-day climate of the desert and semi-desert areas is known to have changed on various temporal (inter-annual, inter-decadal, multi-decadal and inter-seasonal) and spatial scales (particularly for rainfall), which represents a major challenge for the climate forecasting and modeling of these climatic variables in these areas Good source on climate of Saudi [14, 15].

2. Background and Literature Review

For the Arabian region, water availability and precipitation are critical for agriculture, water supplies, power, migration, food availability, biodiversity, and other aspects. Saudi Arabia is semi-arid country with long-term annual precipitation averaging 70 mm/year. Precipitation varies widely throughout the country, and tends to be higher in mountainous areas of the west and southwest. In most places, the majority of annual precipitation arrives in no more than a few days of intense storms. The total amount of water input also varies widely from year to year. The wet season is November to April in the northern part, but more affected by a summer monsoon in the southern part. Despite the overall dry conditions, flash floods can be devastating and regularly cause loss of life and property, as seen particularly in the past ten years. Flash flood damage is often related to dry ephemeral stream channels (valleys) that concentrate very large amounts of water from storm rainfall events. The urban infrastructure is built in valleys that are vulnerable to flooding during extreme rain events. Saudi Arabia has approximately 450 dams that store water along valleys, but these can also fail under the pressure of water from intense storms, resulting in water rushing downstream as they drain catastrophically. The magnitude of impacts and loss of life from the worst of such catastrophes can be ascribed to a combination of severity and faulty management practices [11, 12].

The frequency of heavy rainfall events is expected to increase under a climate changing to warmer conditions, which is regarded as a consequence of anthropogenically elevated concentrations in the atmosphere of carbon dioxide and other greenhouse gases. Climate change and variability increases the probability of frequency, timing, intensity, and duration of flood events. Near real time weather and climatic information enhances the effectiveness of any climate impact assessments for adaptation programs, which are expected to become increasingly necessary in relation to climate changes and global warming (IPCC, 2007). Whether there is, so far, firm attribution of the many recent severe extreme weather events, such as floods in Saudi Arabia, to climate change continues to be debated in the scientific literature, particularly given the extreme level of background inter-annual hydrologic variability in arid areas [15, 21]. In any case, accelerated population growth and development in disaster-prone areas are also and already clearly responsible for rapidly increasing damages, property loss, and fatalities.

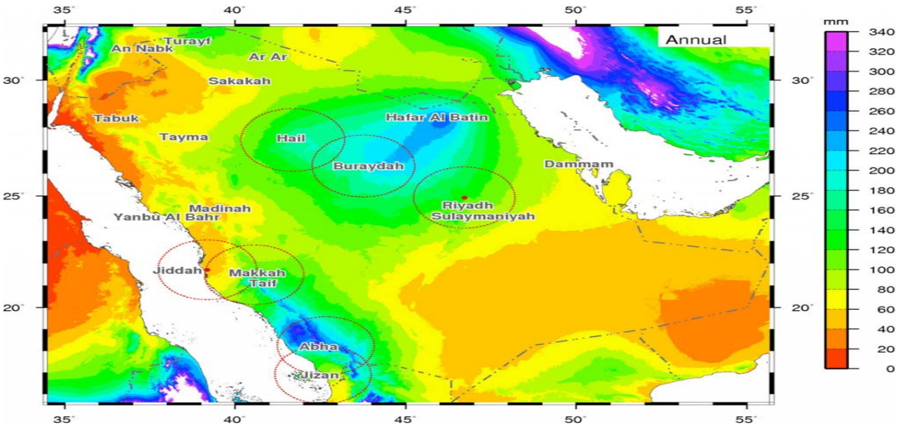

Fig 1: Rainfall distribution in KSA (Courtesy the National Center for Atmospheric Research)

Floods are the deadliest disasters worldwide. Anthropogenic climate change is expected to lead to more intense heavy precipitation, even where the mean precipitation stays the same or decreases, as has been the case in much of southwest Asia. Thus, climate change is expected to substantially increase vulnerability to these disasters [22]. There is evidence that heavy precipitation events have indeed already become more intense in most regions for which there are good weather observations, but few analyses are available so far for Saudi Arabia specifically. In addition, global and large-scale climate fluctuations are known to occur on yearly, decadal, and longer timescales that can greatly affect the hydrological conditions and risk for extreme events, fluctuations to which arid areas like Saudi Arabia are seen to be particularly sensitive. It is not yet clear to what extent these fluctuations, as they affect Saudi Arabia and particularly for the risk for heavy precipitation that can induce flooding, can be modeled, predicted, and monitored to provide early warning of heightened risks [23].

Despite many research works focusing on rainfall and temperature patterns and monitoring in different regions and some case studies of flooding, no comprehensive study is available for vulnerable regions and/or areas [17, 25]. Better understanding of the effects of climate change is necessary in planning for civic preparedness, agriculture, industry, and water policy. To provide a better understanding with respect to climate change and flood prediction, this study will perform an assessment of risk factors and trends for heavy precipitation extremes and the development of a precipitation product and flood hazard mapping for the Kingdom of Saudi Arabia [13].

The Kingdom of Saudi Arabia is located in an arid region (Latitude: 16.5°N–32.5°N; Longitude: 33.75°E–56.25°E). The rainfall in the northern area varies between 100-200 mm with average 70.1mm per year, although 500mm per year in southern region with average 265m per year roughly 60% of the total runoff which covers only 10% of the land area [20, 22]. The 40% of remaining runoff happens in the far south western coast (Tahama), which covers 2% of land area [21]. The region of southwestern is bit complex in term of terrain and rain fall distribution as it contains Red Sea Coast, plain lands, valleys, lowlands and mountains. Fig 2 shows the precipitation and rainfall history in Saudi Arabia. There are few parts, which get most of the rainfall, while the rest of the country is dry throughout the year. The cities where hazardous flooding conditions have been experienced are circled in Fig 2. In recent year's incidents of flash flooding happened in various major cities (Jeddah, Riyadh and Dammam) since 2013.The Kingdom has constructed a total of 450 dams to control flash floods, store surface runoff and recharge, supply drinking water and provide irrigation waters. Approximately 2.02 billion m^3 (BM^3) of runoff could be collected and/or stored in these dams [17]. 89 out of 450 dams in Saudi Arabia are located in southwestern area with 600 million m3 (Mm3) water collection per year [18]. However, Al-Zahrani et al. [7] showed that the surface runoff was significantly higher than the collected runoff in this southwestern region. There is 100, 10 and 7 deaths due to flood in 2009, 2011 and 2013 respectively [6, 8, 9], which supported the idea that capacities of the dams and/or drainage systems were susceptible. In April 2017, the King Fahd dam had to release approximately 40 Mm^3 of water due to exceeding the safety level [6]. In regions of Red Sea Coast, Al-Baha, Jazan and Asir, runoff is much higher than the capacities as 30-425, 32-443, 53-738 and 88-1230 Mm3 per year respectively. Consequently, significant fractions of runoff were lost and the populations living in the valley routes were vulnerable to the flash floods.

In the recent years, [7] predicted the increase in temperature of 1.8–4.1°C in different regions by 2050. They predicted an increase in rainfall by 15-25 mm/year in the central, western and eastern regions of Saudi Arabia in 2050. Another study predicted an increase in rainfall by 26–35 mm/year in these regions during 2070-2100 [1]. For the southwest region, [1] projected an increase in rainfall in this region by 96.7 mm/year during 2070-2100. For different emission scenarios, [23] predicted positive trends for temperature increase in the central, north and southwest regions while for rainfall, positive trends were reported in the southwestern regions. In addition, higher levels of variability in rainfall were anticipated in different regions [24].

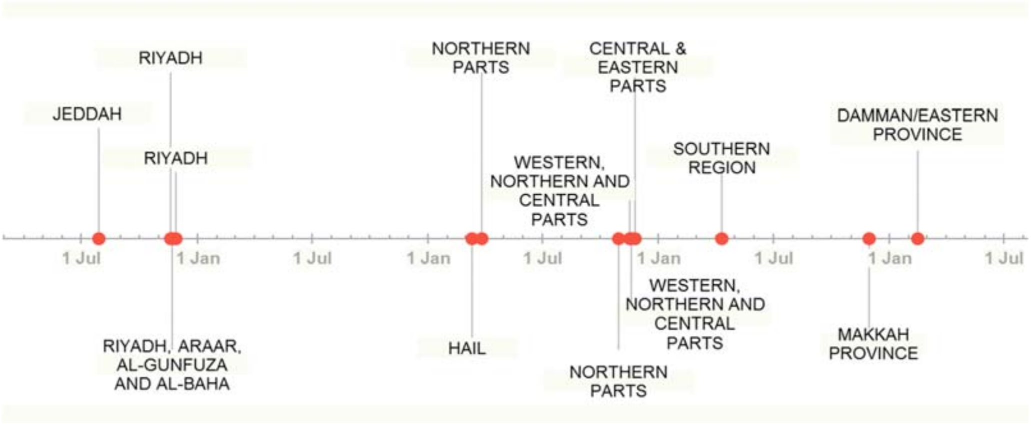

Fig 2: Shows major rainfall with flash flooding since 2013 to 2017 in KSA

Different regions have different seasons for the peak rainfall and temperature [7]. Past studies have modeled floods in Saudi Arabia through the applying the WMS software system [5, 16]. The HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) hydrologic model was used in the main channel of Valley Fatimah watershed in western Saudi Arabia to monitor hydrologic responses [6]. Another flood simulation study was performed using the WMS software for several return periods in the Almisk Lake stretched along the Wadi Bani Malek in Jeddah [19]. For the Valley Qanunah basin in the southwestern coast of Makkah, flash flood hazard was analyzed through dividing the basin into 13 sub-basins using the WMS software. Total volume of discharge in the sub-basins was predicted to be in the ranges of 66 - 138 MCM [25].

3. Methodology

1. Assessment of risk factors for heavy precipitation events

We propose a refined systematic approach to identifying risk factors for heavy rainfall. Firstly, we compare station records with available gridded products and re-analyses to determine how to best identify heavy rainfall events. Secondly, we identify that the tele-connection indices, pressure and sea surface temperature patterns that are most predictive of heavy rainfall. Analysis of the time trends in extreme values will determine if such trends can be attributed to changes in background atmospheric and ocean properties. The results from this phase of the study will quantify the potential for predicting and detecting storms with the potential to result in damaging floods.

Weather station data obtained from the SA Presidency of Meteorology and Environment network, (approximately 30 sites over the past 30 years). Based on such data together with analysis of case studies of past destructive floods, an appropriate quantitative threshold has been defined for the extreme rainfall to be assessed, which may take into account both intensity and storm duration.

This stage will characterize trends in heavy precipitation and their possible causes in terms of both climate change and variability in tele-connection modes. The main aim is to determine which meteorological factors, operating at different timescales and thus amenable to short- or long-term prediction, can potentially aid now casting and prediction of heavy precipitation throughout SA.

2. Data Model for Heavy Rainfall Prediction

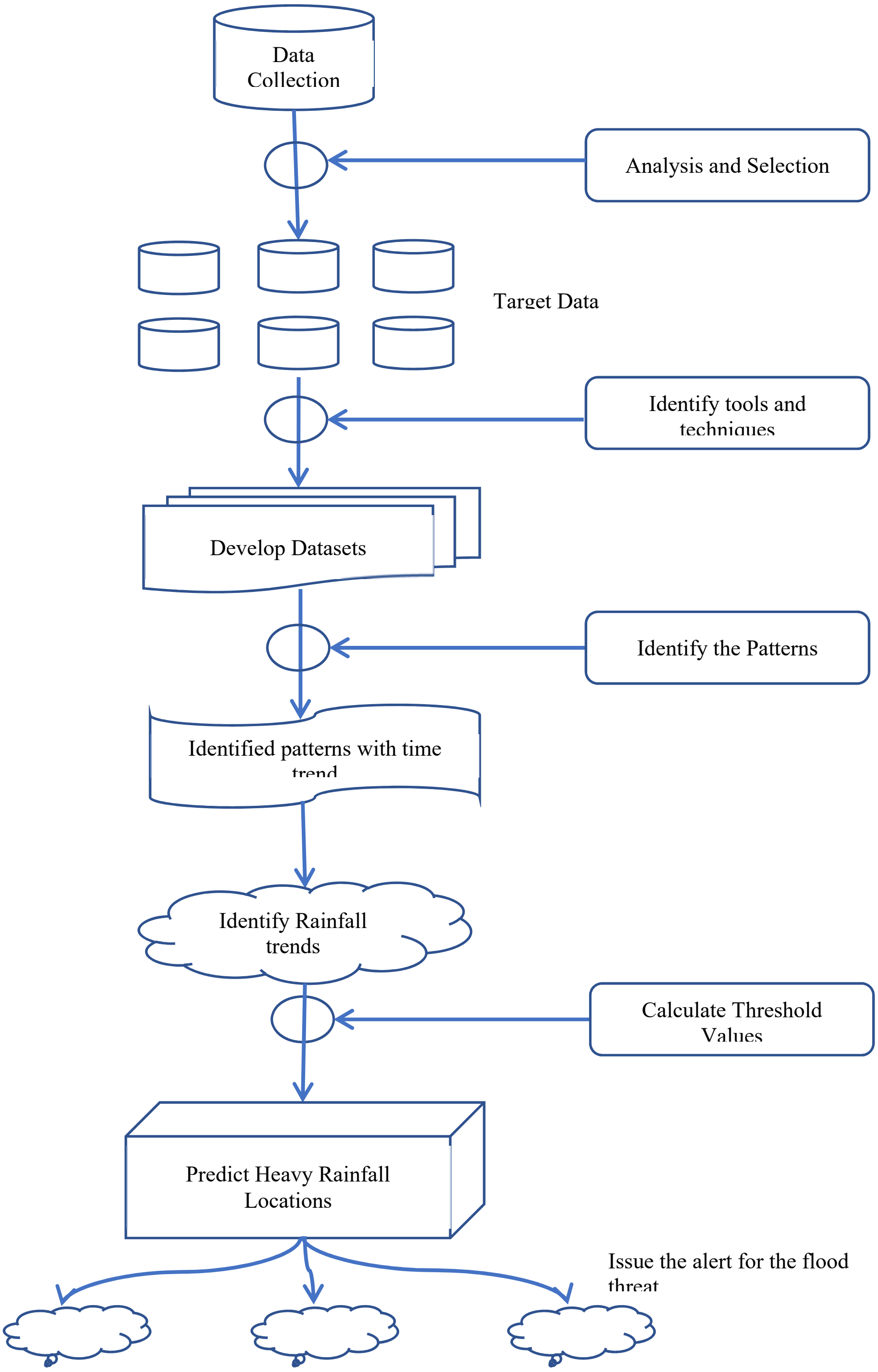

Fig 3: General Data Model for Heavy Rainfall prediction

First we gather the historical weather data and used for analysis. The data collection was obtained from multiple sources, and the regular dew point temperature (Celsius), relative humidity, wind speed (KM/H), station level pressure, mean sea level, wind speed, pressure and observation of rainfall are all characteristics of the data obtained. Creating a target data set selecting a data set or concentrates on a subset of variables or data samples on which discovery is to be performed. Then the crucial move is to identify patterns with time trend and the rainfall trends. One of the challenges that face the knowledge discovery process in meteorological data is poor data quality. For this purpose, to achieve detailed and accurate information, we try to prepare our data carefully. We first choose the most related attributes to our mining task. We ignore the path of the wind for this reason. Then the missed value records are deleted, and then helpful features are found to represent the data based on the task's purpose.

After identifying the patterns with time trend and the rainfall trends selecting the data mining task i.e. classification, regression and decision tree. Then various data mining techniques are applied like- K-NN, Naïve Bayesian, Multiple Regression and ID3 on weather data set and makes the rainfall prediction that is Rainfall Category or No Rainfall Category and onto the basis of that the alert issued for the flood threat.

3. Developing a precipitation product and flood hazard mapping

The Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis products have been found to be comparable to station-measured precipitation in SA and in the United Arab Emirates. However, these studies also found biases in the remote sensing products, such as overestimation of mean precipitation and underestimation of heavy precipitation. As well, studies have used the TMPA research product, which is only released about a month after the fact and thus not useful for responding quickly to storm hazards. Thus, we propose to develop a calibrated precipitation product at 0.25°, 3 hour resolution over SA based on the TMPA real-time product, typically available with only a 3-hour lag time and the newer Global Precipitation Mission (GPM) Integrated Multi-satellite Retrievals (IMERG) early-run product available at half-hourly resolution and 6-hour lag time.

Algorithm 1

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Step 1- Data collection
Step 2- Comparative analysis with various existing models
Step 3- Identify tools and techniques to predict rainfall events.
Step 4- Develop datasets
Step 5- Based on the dataset identify the patterns
Step 6- Combine identified pattern with the time trend
Step 7- Identify rainfall trends
Step 8- Calculate threshold values
Step 9- Predict heavy rain locations based on developed model
Step 10- Issue the alert for the flood threat
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The statistical methodology was developed by team members and successfully applied to climatically diverse. Precipitation occurrence and amount conditional on occurrence are modeled using separate parametric models, which together output the risk of exceeding any flood threshold of interest. Predictors may include season, spatial location, information from satellite precipitation products, synoptic information, and available nearby station data. The developed model will allow locations of enhanced hazard for heavy precipitation to be identified expeditiously during storm events, enabling effective responses to flood threat. The relationship between remote sensing based precipitation values and station-measured precipitation will be quantified at timescales from sub-daily to annual across percentiles of the precipitation intensity distribution. Precipitation occurrence probability will be modeled using logistic regression. A nonlinear transfer function from satellite to station precipitation quintile, conditional on occurrence, has been developed using flexible probability distributions. Efficient methods for fitting a hyper exponential distribution with arbitrary number of components to precipitation data have been developed by our team. For better interpretability, the same predictors can be used for both the precipitation amount and occurrence models. Stepwise addition of predictors keeps only terms that enhance the final model's fidelity compared to observations.

The developed probabilistic product has been verified for suitability and reliability in identifying heavy precipitation events, including consistency with observed probabilities across a wide range of precipitation intensities. A testing period withheld from the training data set and including several flood events will confirm that the model satisfactorily represents floods. Information metrics and conventional meteorological skill scores quantify the product skill and the benefit gained by using remote sensing products.

Thus, this will result in a well calibrated precipitation product customized to delineate, in near real time, heavy precipitation events that have potential for causing damaging floods over SA. The developed and validated now cast product will be highly beneficial as part of an operational disaster response system. A similar statistical model may also run in forecast mode to provide warning of elevated risk for flood events in the coming days to months, using numerical weather predictions and the synoptic and tele-connection predictors identified in this paper.

4. Conclusion

Due to flash flooding in recent years in Saudi Arabia damages to infrastructure and death are recorded and government took actions to handle this type of situation in future. In this research work, a model is proposed to assess the pattern and trends in climate means and extremes affecting the flash flood hazards and water resources in Saudi Arabia to improve the risk assessment for forecasting the weather conditions. We examined temperature, precipitation climatology and trend magnitudes at surface stations in Saudi Arabia to propose the model to generate alert in the treads areas. Based on the assessment climate patterns maps and trends are accurately used to identify synoptic situations and tele-connections associated with flash flood risk. We develop the model based on the local and regional changes in hydro-meteorological extremes over recent decades through new applications of statistical methods. The developed model considered the multi-decadal dataset of extreme events based statistical analysis in connection with pressure and sea surface temperature patterns most predictive to heavy rainfall. An algorithm has been developed for providing a well-calibrated precipitation product that can be used in the early warning systems for elevated risk of floods. The developed model allows locations of enhanced hazard for heavy precipitation to be identified expeditiously during storm events, enabling effective responses to flood threat.

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