DETERMINING FLOOD PRONE AREAS FOR AN UNGAUGED BASIN USING SOFT DATA AND TOPOGRAPHIC WETNESS INDEX

by

Manal Omar Aburizaiza
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Earth Systems and Geoinformation Sciences

Committee:

______________________	Dr. Paul Houser, Dissertation Director
______________________	Dr. Ruixin Yang, Committee Member
______________________	Dr. Donglian Sun, Committee Member
______________________	Dr. Celso Ferreira, Committee Member
______________________	Dr. Dieter Pfoser, Department Chairperson
______________________	Dr. Donna M. Fox, Associate Dean, Office of Student Affairs & Special Programs, College of Science
______________________	Dr. Peggy Agouris, Dean, College of Science
Date: ________________	Spring 2019 George Mason University Fairfax, VA

Determining Flood Prone Areas for an Ungauged Basin Using Soft Data and Topographic Wetness Index

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

by

Manal Omar Aburizaiza
Master of Science
Department of Computer Science at Western Michigan University, Kalamazoo MI, 2011
Bachelor of Science
Department of Statistic Computer Science at King Abdul-Aziz University, 2004

Director: Paul Houser, Professor
Department of Geography and Geoinformation Science

Spring Semester 2019
George Mason University
Fairfax, VA

DEDICATION

This is dedicated to my parents Omar and Salwa, my loving husband Wadea, my wonderful son Ahamd, my brothers Ahmad and Siraj and my sister Nawal and big thank to my advisor Prof. Houser.

ACKNOWLEDGEMENTS

I would like to thank the many friends, relatives, and supporters who have made this happen. My great parents for their support. Prof. Houser for his amazing help and support throughout my PhD journey. Drs. Ferreira, Yang and Sun, and were of invaluable help. I am deeply grateful to Yanbu University Collage Royal Commission for the scholarship. Many thanks to my father and mother in law Khaled and Umalsaad. My sincere thanks to my sisters in law Boushra and Wijdan. Big thanks to my brother Ahmad for assistance, and my colleague Eidah my best friend Nouf, my friends Yousra, and Fatimah. Finally, thanks go out to the Fenwick Library for providing a clean, quiet, and well-equipped repository in which to work. I am very grateful to my lovely husband Wadea and my son Ahmad for their tremendous love, support, and understanding.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

Data Base .... DB
Digital Elevation Mode..DEM
Geographic Information System .... GIS
Global Digital Elevation Mode..GDEM
Global Positioning System... GPS
Land use Land Cover ....LULC
Multi Flow Direction ....MFD
Multispectral Scanner System.. MSS
Open Street Map ....OSM
Participatory Geographic Information System ....PGIS
Prediction for Ungauged Basin...PUB
Quantum Geographic Information System .... QGIS
Queen Land Police Service..QLPS
Remote Sensing ....RS
SAGA Wetness Index .... SWI
Single Flow Direction .... SFD
Soil and Water Assessment Tool .... SWAT
Structured Query Language .... SQL
System for Automated Geoscientific Analyses ....SAGA
Topographic MODEL...TOPOMODEL
Topographic Wetness Index .... TWI

ABSTRACT

DETERMINING FLOOD PRONE AREAS FOR AN UNGAUGED BASIN USING SOFT DATA AND TOPOGRAPHIC WETNESS INDEX

Manal Omar Aburizaiza, Ph.D.

George Mason University, 2019

Dissertation Director: Dr. Paul Houser

The rapid urban development in the basins of the city of Jeddah, Saudi Arabia, makes the residential area in the watershed vulnerable to flood hazards. Traditional flood models rely on data calibration to provide useful runoff estimation, but such data is not available in the ungagged basins of Jeddah. Therefore, this research aims to examine the feasibility of integrating soft data and topographic data in order to determine the flood-prone areas for an ungauged basin in Jeddah. It proposes a method to extract qualitative flood information such as spatial extent and flood depth from soft data obtained from social media platforms (Twitter and YouTube) and field visits. To obtain flood information from social media, the analysis considers three kinds of social media posts: text, visual, and audio. The information obtained is validated during field visits. Next, the utility of the extracted information is examined by analyzing the spatial distribution of the soft data on the generated Topographic Wetness Index (TWI) maps. The TWI method is a

distributed method that is used to estimate the potential for water accumulation in a certain area in the catchment by estimating the hydrological slope and the upslope of the contributing catchment area. The risk area is determined based on the locations of high urban density in the watershed that are exposed to the locations with high potential for water accumulation. Finally, a flood hazard map is generated based on the risk area and the spatial distribution of the soft data. Based on the map, social media gives better results for a high-density urbanized area, while field visits give additional spatial information for lower-density and non-urbanized areas. Soft data is an important data resource in gaining flood information and determining flood-prone areas for an ungauged basin.

1. INTRODUCTION

1.1. Problem Description

Floods are naturally-occurring events that often result in human casualties and extensive property damage; floods can create a lasting impact on the social, environmental, and economic aspects of society. Jonkman and Kelman (2005) report that between 1905 and 2005, floods killed an estimated 100,000 people and affected an estimated 1.4 billion people globally. Although floods are often difficult to predict and manage, the cost of property damage and the number of human causalities can be reduced by effectively managing floods and addressing flood risks. One way of mitigating flood damage is to direct floodwater to a location where it can be stored for later use or be safely drained into the sea or a remote area.

Effective mitigation techniques are not geographically exclusive and can be used around the world. According to the Saudi Geological Survey, Saudi Arabia is a large arid country with an area of approximately 2.8 million km^2 and a population of 33,554,343. This study covers flood mitigation in the Qous basin located in Jeddah province in the Makkah Region. Jeddah province is located in the western region of Saudi Arabia; it has an area of 4,571.01 km^2 and a population of 8,293,304. Jeddah has numerous major and minor seasonal river beds; until the early 1970s, these wadis effectively served as the province's natural drainage system by channeling floodwater to its final destination (mainly the Red Sea) without barriers. In recent decades, however, parts of these wadis were converted into urban areas, and the city of Jeddah expanded to become a large city. The expansion of these urban areas occurred rapidly, without sufficient environmental planning. Commercial, industrial, and residential infrastructure blocked the wadis, channels, and streams, greatly reducing the capacity of the natural drainage system. Without a fully-functional drainage system, floodwater from heavy rains exceeds the capacity of the remaining natural drainage system, causing extensive flood damage to surrounding areas. Despite increased threats of flooding due to the reduced natural drainage system, rapid urban growth continues around the major and minor basins of Jeddah with little environmental planning. Moreover, converting rural areas to urban areas increases the runoff coefficient, with a consequent reduction in the time required to reach peak flow and a dramatic increase in the chance of flooding when heavy rain occurs.

Most hydrological and flood-prediction models require complex procedures and vast amounts of data. Such models, although effective, are inapplicable in Saudi Arabia due to the limited availability of data. Therefore, an alternative model is needed that is specific to Saudi Arabia's limited availability of data, in order to determine the spatial variability of flood-hazard zones in Jeddah province.

Flood-hazard zones are delineated based on information produced by hydraulic models and/or remote-sensing techniques, but the availability of data in real time or near real time can be very limited. In fact, numerous basins around the world are ungauged (without calibrated data), especially in developing countries. Hydrologists believe that if there is no relevant gauged basin, data can be obtained by using remote-sensing techniques, making field-work visits, and acquiring soft data from knowledge or observations of the population and recently from social media data. Blöschl et al. (2016) found that model calibrations using household flood observations improved the performance of the model of an ungauged basin with limited availability of data. Soft data have been proven to be essential auxiliary data for ungauged basins, providing detailed qualitative information from a wider perspective (Sibert & McDonnell 2015). A geographic information system (GIS), remote sensing (RS), and soft data play important roles in integrating a hydrological model by collecting, analyzing, querying, and presenting spatial or temporal data in a simple manner.

This study examines several flood factors such as land cover, land use, a digital elevation model (DEM), and drainage characteristics to generate a flood inundation map that shows the spatial extent and the flood depth of the catchment under conditions of limited data availability. A DEM provides topographic information that describe the terrain profile of the basin; the terrain profile is an essential element in directing flood water and controlling the area of accumulated water. For this study, a flood-prone area is estimated using a topographic wetness index (TWI) that interprets the effect of the topographic feature on flooding. TWI is an indicator that is assessed in determining a flood-prone area based on the topographic gradients and the upslope contributing area. Soft data will then be used to validate the resulting map.

This study also attempts to use the gathered data to reduce flooding in existing urbanized areas as well as in future developments throughout Jeddah city. Finally, the resulting flood-hazard map is evaluated using previous relevant studies, local expert knowledge, media reports, and documentation from local insurance organizations.

1.2. Research Statement

The goal of this study is to generate a flood inundation map for Qous basin, an ungauged basin in Jeddah city, and then to classify the area into different zones based on their flood-hazard level. GIS and RS techniques with the assistance of soft data are used to generate the map and to determine the spatial extent and the floodwater depth of the flooded area. To support that approach, this study examines several issues: the feasibility of extracting flood information from soft data; how such data can be utilized to perform hydrological analysis; and the extent to which the data can be used in the applicable model in order to promote the applied hydrological model.

1.3. Set of Objectives

- Delineate flood-prone areas in Qous basin with the consideration of data scarcity.
- Determine the impact of urbanization in Qous basin and how it affects the hazard level of a flood.
- Obtain the missing data from different open-source resources:
    - open-source platforms such as Open Street Map and Google Earth
    - social media data such as YouTube and Twitter
    - articles and newspapers
    - observations and knowledge from residents

    - knowledge from experts
    - field visit
- Use soft data as an additional source of data to address the dissertation objectives.
- Integrate the hard data and the soft data to produce an affective model.
- Create a mini-database for Qous basin.
- Create a flood-hazard map for Qous watershed that classifies the area into different zones based on their flood-hazard level.

2. LITERATURE REVIEW

Bronster (2003) classified floods into two main classes: extensive long-lasting floods and local sudden floods. Opolot (2013) expanded on Bronster's classification by classifying flooding based on the characteristics of the flood, the size of the affected area as a spatial element, and the duration of the triggering precipitation event as a temporal element. In another study, Berz (2000) classified floods into three types: river floods, flash floods, and storm surges. Floods have also been classified into coastal floods, flash floods, and river floods (Opolot, 2013). The aforementioned classifications demonstrate the various approaches scholars have used when studying and researching flood types and their characteristics, an understanding of which is essential for flood management.

This study focuses on flash floods, which occur suddenly after extensive rainfall, resulting in a rapid rise in water level. These floods are characterized by the speed at which they occur, making them difficult to predict or prepare for due to time constraints (Younis et al., 2008). Additionally, the high rising rate and high flow velocity make flash floods extremely dangerous to human lives (Younis et al., 2008). In fact, compared to other types of floods, flash floods have historically caused the most human casualties (Jonkman & Kelman, 2005).

Many scholars study the link between urbanization and flood risk. Liu et al., 2013) found that the degree of urbanization and the flood risk are positively correlated, and a change in land usage increases a city's vulnerability to floods. Flood management in urban areas is complex because the runoff coefficient of floodwater varies due to heterogeneous land use. In another study, Cannon (2006) argues that natural disasters are the output of natural hazards and people’s vulnerability; he believes that understanding the interaction between these two factors is much needed.

In another study, Sanyal and Lu (2005) clarify the interaction between different flood-hazard indicators that contribute to the vulnerability of human settlements, explaining that the socio-economic characteristics of a settlement highly affect its degree of vulnerability to flooding. Their approach involved estimating the vulnerability of each settlement to flooding. The results demonstrate that the most vulnerable settlements are newly built in flood-prone zones due to socio-economic conditions. Moreover; transforming land use from natural to artificial increases flood risk due to poor infiltration (Houng & Pathirana, 2013). Kia et al. (2011) state that dynamic changes inside the watershed are too difficult to cope with in some models, and therefore, understanding the physical process and having an optimization tool are needed for such a problem.

2.1. Approaches in a Flood Management System

Scholars have used different approaches to manage floods in order to minimize losses and other negative impacts. Kourgialas and Karatzas (2011) explain that a “flood management plan relies on two components: a proper flood management strategy and a determination of the flood hazard area”. A flood management strategy requires a flood protection management plan for each region based on the region's particular characteristics. For example, tanks or inhibitory dams could be built in highly vulnerable regions using telemetric meteorological stations in the basin area to provide hourly real-time data that can be used for a flood-forecast warning system, making the flood risk information available to the public. Providing emergency flood training and regulating land use also serve as flood management tools for early preparation and planning that lead to efficient responses. To determine the flood hazard area, generate a flood map that determines the spatial distribution of the flooding area, and classify the area into several zones based on their risk level (Kourgialas & Karatzas, 2011).

Due to the expected increase of flood risk in Flanders since 2000, the Flemish government changed its flood management strategy from a flood control approach to a risk-based approach, which uses probability methods to plan for protection against the consequences of floods (Kellens et al., 2013). Unlike other approaches that focus on determining the flood risk area, this approach calculates potential damages and the economic risk due flood. Damages such as casualties, production losses, and infrastructure damage are quantified in mathematical functions that are used in the damage calculations. The damage function is applied to determine the expected damages for several return periods, which makes this approach more suitable for existing urbanized areas.

2.1.1. Flood Management Using Remote Sensing and a Geographic Information System

A GIS and RS are essential sources in acquiring spatiotemporal data. The integration between these tools facilitates the integration between spatial and non-spatial data for effective flood risk management (Al-Tahir et al., 2014). Several studies use remote sensing, GIS, or their combination to assess the effect of land use on runoff and peak discharge, especially in ungauged basins (Ozdemir & Elbasi, 2015). RS data overcome part of missing data and with low cost; though RS doesn't give detailed information, it provides a wider view of the catchment and its behavior. From space, you can have a better assessment of the surrounding area under climate change and how it affects the hydrological process.

Al-Tahir et al. (2014) declare that GIS and RS can be used to generate a comprehensive flood management system. Such a system involves two components: 1) determine the flood-hazard area based on GIS and earth observations, and other flood-related data; 2) create a warning system with updated geospatial data to develop an updated evacuation plan to determine evacuation paths. Liu et al., (2013) generate a flood hazard map for an urbanized area by determining the rank and the weight of these gathered layers: the Landsat Thematic Mapper, the DEM, the river buffer, and the spatial socioeconomic distribution. The weighted value was estimated based on the effectiveness in determining flood risk. For hurricane Sandy, a flood map in New York was generated to estimate the extent of flooding in the metropolitan area (Sun et al., 2016). They used VIRS and ATMS images to determine the flood inundation area. The results indicate that VIRS can determine an inundation area only under a clear sky, but ATMS data shows better results compared to FEMA's flood map (Sun et al., 2016)

Al-Sabhan and others designed a web-based hydrological model that integrates spatial modeling and GIS environments and can obtain real-time data at no cost (Al-

Sabhan et al., 2003). It introduces a web-based real-time model for flood nowcasting, and it can be accessed through the web for an online simulation and analysis.

2.1.2. Flood management using soft data

Soft data is qualitative data that can be obtained from field work and people's observations and knowledge. Moreover, it can be obtained by extracting additional valuable information from existing data. White, Kingston, and Baker (2010) also emphasize stakeholder and public engagement in flood risk management and decision making. The researchers state that a Participatory Geographic Information System (PGIS) is a tool for encouraging community participation in decision making, judging, and examining policies and proposals without time and space constraints. From this point of view, public engagement imposes more personal responsibility in deciding where to live and where to avoid. Thus, including people from different levels improves the quality and volume of the data, to reduce uncertainty. Moreover, flood data availability increases public trust and raises awareness.

2.1.3. Flood management using social media data

Social media platforms such as Twitter, YouTube, Flickr, and Facebook provide huge amounts of user-generated real-time data. It has been used as an important contributed source of data by sharing information broadly through online platforms. Elwood, Goodchild, and Si believe that photos and videos posted on social media platforms such as YouTube, Instagram, and Facebook might contain geographic information that can be used for scientific research (Elwood et al., 2012).

Recent studies use social media for different purposes. For instance, YouTube and Twitter data were used in New York City to fill the gap in spatial and temporal coverage of the calibration data to estimate flood damage after Hurricane Sandy (Schnebele et al., 2014). Subsequently, Sun et al. (2016) assessed the accuracy of flood maps generated by remote sensing data by using Flickr data for Hurricane Sandy. Holderness and Turpin (2015) were able to determine the severity of a flood based on the number of tweets, as the density of flood-related Twitter data was used to indicate the extent of a flood in Jakarta, Indonesia. J. Fohringer et al. (2015) manually extracted flood information from tweet text and photos and combined it with a Digital Elevation Model (DEM) to estimate the water level. They also reported that social media provides extensive information for generating flood maps.

Jongman et al. (2015) examined the usability of Twitter for early flood detection in the Philippines and in Pakistan. However, they found that such processes need to be improved. Eilander et al. (2016) used Twitter data to obtain observations related to water depth and flood locations in order to estimate the flood extent in Jakarta, Indonesia. They used the collected data and the DEM to perform a flood-fill algorithm in order to generate a real-time flood map. An error of 1.72 km was estimated by McClanhan et al. (2015) while determining the location of the flood in New York City using posted tweets.

Natural hazards that represent motions are more common on the platforms for social media videos (Le Boursicaud et al., 2016); the researchers declare that the search term “flash flood” resulted in more than one million results. They also estimated discharge and flow velocity for mountain rivers in France using different images taken from YouTube videos with different resolutions. Smith et al. (2017) used data only through social media to produce a real-time modeling framework to identify areas that are vulnerable to floods in Newcastle upon Tyne in England. Scholars at Newcastle University report that during floods in Queensland in 2011, the public was urged to contribute via Twitter, and the Queensland Police Service (QPS) had the most active and visible twitter accounts throughout the disaster; this resulted in many other agencies using the @QPSMedia account as an example (Chanson, 2011).

However, the validation of social media data is critical for many reasons. Large portions of Twitter posts and Instagram and Flickr photos are not geotagged, which makes it hard to estimate the extent and the expansion of hazards from information provided during hazards. Newcastle university also developed a website that allows users to add flood-related information and upload photos directly on a map. Brouwer et al. (2017) addressed the uncertainty of social media data by comparing a generated probabilistic map based on Twitter messages with a deterministic map for a 2015 flood in the city of York in the United Kingdom. Their results illustrated that generated flood maps performed well when used in conjunction with validation data, and they proposed that this success might be related to the number of tweets within the affected area. In addition to the geotagged tweets that determined the location of the flood, Eilander et al. (2016), Brouwer et al. (2017), and Smith et al. (2017) used photos, videos, and texts to extract the location of the flood using street names, parks, or known buildings.

2.2. Predictions for Ungauged Basins (PUB)

The most accurate method for estimating runoff and other hydrological parameters is to measure them directly; however, this approach is predominantly impractical due to the high cost and amount of time involved (Bloschi, 2016). Additionally, data scarcity is an ever-present issue, and most of the catchments around the world, specifically small catchments, are ungauged and have limited data. Such basins do not adequately fit with the Empirical Hydrological Model (Hrachowitz et al., 2013) because they do not relate the catchment response to the real world, and it is difficult to understand the behavior of their hydrological processes. Moreover, most hydrological models are empirical methods based on calibration and estimation data, which increases the likelihood of uncertainties within their parameters.

Due to the aforementioned factors, the International Association of Hydrological Sciences initiated Predictions in Ungauged Basins (PUB) to improve the understanding of the hydrological process and method as a science and to address the question "whether hydrology can reduce the need for the calibration" (Hrachowitz et al p. 1231, 2013). Thus, they developed a new technique to acquire the necessary data and a new approach for developing a hydrological model and assessing uncertainties for ungauged basins. Their vision is to use an approach that relies increasingly on theoretical insight into physical processes and system understanding rather than data and calibration methods (Hrachowitz et al., 2013).

The PUB community believes that the key to understanding a catchment's hydrological function is understanding the physical characteristics of the catchment and the factors that might affect the catchment response, such as soil type, topology of the catchment, climate, and land use (Gupta et al., 2008). It aims to deal with ungauged basins and address the issue of data scarcity by generating more information from the available existing data, improving the understanding of the catchment characteristics, and finding additional sources for new data. One of PUB's primary objectives is to use the existing data from relevant gauged basins to extract additional information and transfer these hydrological parameters from gauged to ungauged basins. Such information includes catchment characteristics and parameters of the hydrological model; extrapolating such data from gauged basins to ungauged basin is based on three techniques: regression, physical similarity, and spatial proximity (Wang & Kalin, 2011). However, due to land surface heterogeneity, the spatial-temporal variability of the hydrological system decreases accuracy when transferring information from gauged to ungauged basins (Lortiz et al., 2015).

McGlynn (2012) and others debate that these techniques also require data. Additionally, choosing a suitable technique is critical because the nature of the hydrological response is nonlinear, which increases the complexity of prediction. Nevertheless; additional comparative studies between catchments are needed (McGlynn et al., 2012). From this view, PUB studies aim to find ways to reduce the uncertainty when taking advantage of available data.

PUB's objective is to develop a model to fit with ungauged basin situations, either by using new tools or by improving the existing model. Most importantly, however, PUB's goal is to assess the degree of uncertainty in the data and validate the result of the model. In many PUB cases, the strategy to validate the model is to consider a gauged basin as an ungauged basin, then use the gauged data to assess the performance of the model (Van Emmerik et al., 2015). If there is no relevant gauged basin, data could be obtained in several ways: use remote sensing techniques; make fieldwork visits; use soft data such as knowledge from experts; extrapolate information from the hydrological process; get information from the physical properties of the catchment; and use auxiliary data sources such as the population's knowledge and observations. In fact, local data gained from a hydrologist's deep understanding of the basin and its surrounding area can lead to a good model (Savenije, 2010). However, due to the lack of measurement data, the model must be constrained to limit the parameters of the model (Emmerik, 2015), which reduces the degrees of freedom and consequently increases the uncertainty.

A model can be developed even with few observations but reducing the number of observations increases the uncertainty in the model's results, emphasizing the importance of assessing the model's performance. PUB's mission is to work on creative new methods for more realistic predictions and to reduce the uncertainty of the estimated results by understanding the hydrological system of the catchment and the interaction between the hydrological system and any local or global factors that might affect the system. PUB has led hydrologists to address the hydrological problem from different disciplinary perspectives (Hrachowitz et al., 2013).

The interaction between climate, environment, and society within a hydrological system requires an integration between several disciplines: hydrology, ecology, social science, management, and climate science. Knowledge from these disciplines can clarify the links between the hydrological system and the factors that affect it. This provides a multidimensional view of the problem for an advanced understanding of the problem, the data, the model, and the sources of uncertainty (Blöschl, 2016).

Although PUB was established to estimate discharge and other hydrological parameters for an ungauged basin with limited data, it became a bigger idea for hydrology. The newly evolved methods are an inventive tool to acquire a more understandable, realistic model using qualitative information from different perspectives. It is a promising approach to get substantial instrument for solving hydrological problems for gauged and ungauged basins (Hrachowitz et al., 2013).

2.3. PUB studies

Land use land cover (LULC) change has a significant impact on the hydrological process of a watershed from both quantity and quality perspectives. From a quantity perspective, if land use changes from a rural area to an urban area, the runoff coefficient for the land in urban use can be up to several times greater than it was for the land in rural use (Ozdemir & Elbaşı, 2015). A higher runoff coefficient for urban use leads to a higher peak discharge and a shorter time of concentration, allowing less time for the peak flow to reach the outlet of the basin. From a quality standpoint, converting a barren area into an agricultural area requires fertilization, which mainly consists of a nitrogen- phosphate compound that greatly alters the quality of the floodwater.

The amount of nitrogen and phosphate depends on the type of fertilizer and the scale of the agricultural area. Moreover, if the land use is changed to an urban area, especially in a developing country, the residential wastewater is usually disposed into cesspits. This often causes floodwater and waste water to mix during floods, which causes the water quality to deteriorate (Segal et al., 2008).

The aforementioned factors create uncertainties and unfortunately, these aspects were not taken into account in developing precipitation-runoff relations. Several studies have been conducted to illustrate the relationship between LULC change and flooding. The change in LULC alters the water cycle by affecting hydrological factors such as evaporation, infiltration, and interception by vegetation. Therefore, the hydrological response of the watershed is also changed. For example, surface imperviousness due to building and road construction decreases the infiltration rate and the time of concentration (Koshak, & Dawod, 2011; Dawod et al.,2012).

Deforestation increases rainfall runoff, as there are fewer trees to intercept the water through root uptake and reduce the soil moisture. Understanding the impact of LULC change on the hydrological process can assist in urban planning to reduce potential negative impacts. Due to the nonlinear relationship between hydrological factors, understanding the relationship between the hydrological factors and the hydrological response is quite difficult. Clarifying this relationship is even more difficult in developing countries, due to the lack of data and the limited number of gauge stations, particularly in urban basins (Sikorska et al.,2012).

In PUB studies of ungauged basins, hydrologists use several methods to estimate the change in the runoff associated with an LULC change. Yu, Wang, and Kuo (2003) state that LULC change increased the peak discharge and the total runoff in the Ta-Chou ungauged basin in Taiwan. Peak discharge was estimated for different return periods. Landsat MSS and SPOT satellite images were used to classify the land use type for the time period from 1972 to 2000, to track the changes. The results show an increase in the peak discharge and the runoff total associated with the expansion of urbanization.

Similarly, Soil and Water Assessment tool (SWAT) was used to estimate the impact of LU change and peak flow for an ungauged basin in Kenya (Mango et al., 2010). The result shows that SWAT is suitable for simulating the impact of long-term and short-term LU change on peak flow, because the model accepts alternative input data due to LU change and can work with minimum input. In another study, Wang and Kalin (2011) use the Spatial Proximity Method to transfer model parameters from gauged basins to ungauged basins in Alabama in order to simulate the impact of the LULC change on streamflow. Then the model with the transferred data was integrated with the LULC map to investigate the impact on the streamflow. This shows that transferring parameters from a relevant basin assists in simulating LULC change, and it demonstrates the benefits of transferring parameters from gauged to ungauged basins.

Nagarajan and Poongothai (2012) conducted their study using only satellite images and topographic maps. The study depended on tracking the trend of LULC change and how the conversion of some land to a different use reduces the amount of water in a certain area so that the water can be reallocated to another area for human or agricultural use. Thus, management of land use, especially in heavily-populated areas, can help balance the impact on the hydrological process. However, a detailed study needs to be conducted before implementing any changes in LULC, or further expansion.

3. STUDY AREA

Wadi Qous is located in Jeddah city in Jeddah province, Makkah region, western Saudi Arabia (Figure 1). Jeddah province covers an area of 4571.01 km² and has a population of 4082184. Jeddah city is the largest city in Jeddah province, with a population of 1,992,053. It is the primary commercial city and also a major seaport and airport in Saudi Arabia. Jeddah city is only 86 km from Makkah (the holy city); about ninety percent of pilgrims reach Makkah through Jeddah.

Figure 1 Jeddah Province, the Study Area.

Jeddah province has fifteen major wadis as well as numerous minor wadis that diverge from the above-mentioned wadis. All the wadis flow towards the Red Sea, while a few of the minor wadis flow eastwards to the desert. Figure 2 depicts the fifteen wadis in the Jeddah province.

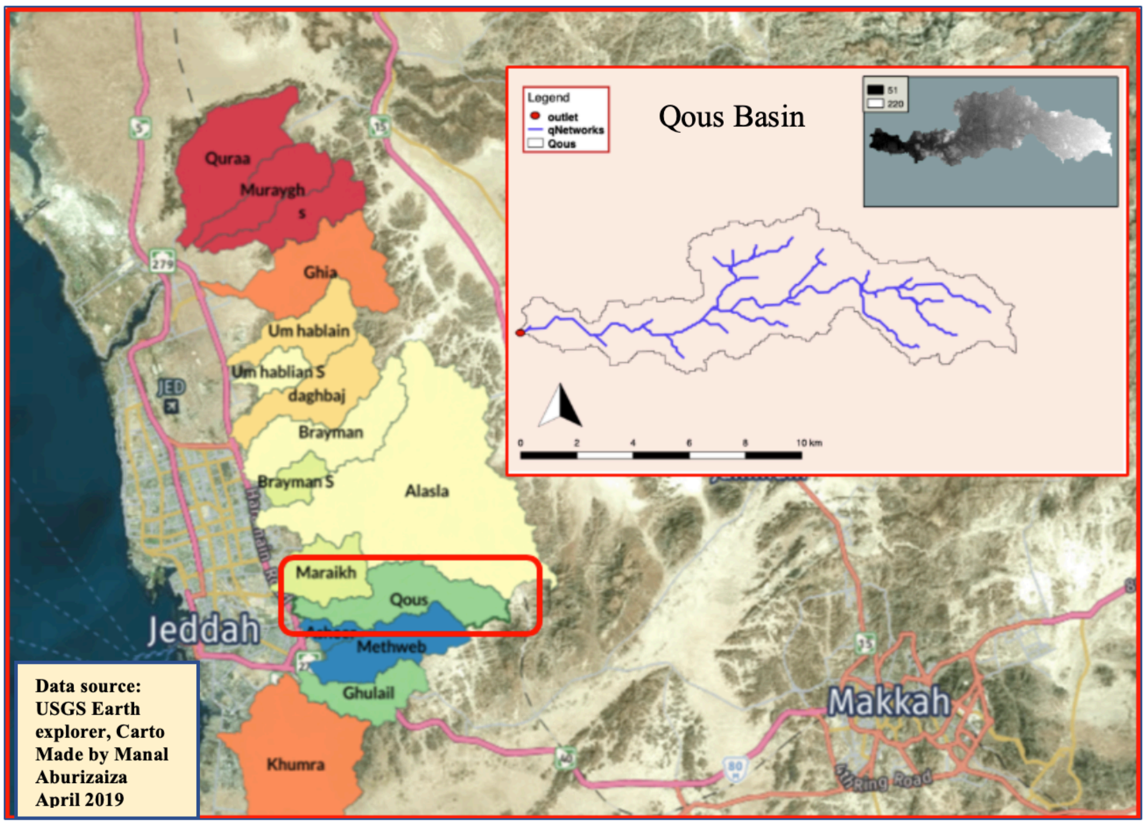


Figure 2 Major basins in the Jeddah Province.

3.1. Urban Expansion in Saudi Arabia

Until the early 1970s, the population of Saudi Arabia was about seven million, and the urban population was only about two million. In 1974, after a significant increase in the national income due to the rise of oil production and oil prices, the urban population increased by forty percent to about six million. According to the United Nation Population Division, in 2007, over eighty percent of the Saudi population lived in urban areas, and this number is expected to increase to ninety percent by 2050. Many expatriate laborers joined the development and expansion of the urban areas. Figure 3 shows the growth in the percentage of the urban population in Saudi Arabia from 1950 to about 2007, and projected to 2050 (United Nations, 2008).

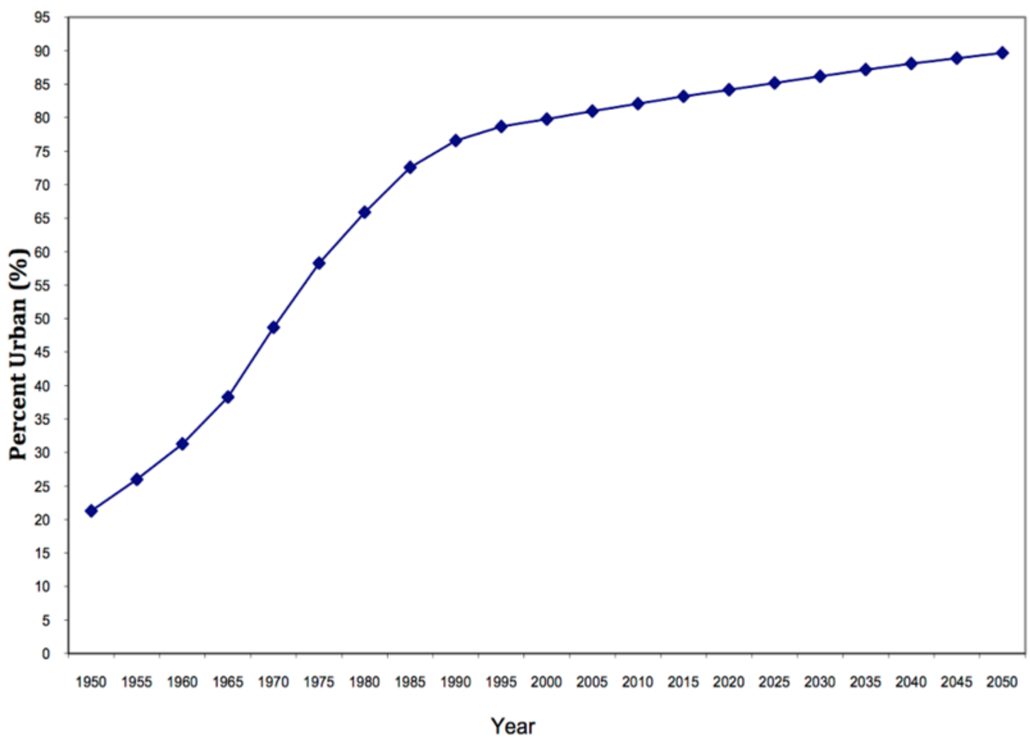


Figure 3 Percentage of urban population in Saudi Arabia (1950-2050).

Aljoufie et al (2013) also stated that Jeddah's urbanization area increased by seventy-two and a half percent between 1970 and 1980, by twenty-five percent between 1980 and 1993, and by thirty-three percent between 1993 and 2007. Unfortunately, during the expansion of these urban areas, commercial and residential infrastructures were built in the channels of the wadis (the natural drainage system), blocking the flow of floodwater to the sea and essentially creating barriers that trap and spread floodwater across the city. An adequate and efficient replacement drainage system was not built, so floodwater remains for extended periods of time, until evaporation and infiltration occur. Converting rural areas into urban areas also reduces the infiltration rate, which, in turn, increases the run-off coefficient of a flood, causing floods to last longer and cause more devastation.

The variability in rainfall patterns in the province also make the area vulnerable to abrupt flooding and adds to problems caused by the blocked wadis. Building in the middle of wadis and dry stream beds continues without adequate environmental planning. Thus, it is highly expected that flooding and its negative impacts will continue to get worse, and the cost of building a new drainage system will increase as the complexity and depth of the problem increases.

3.2. Urban Impact in Wadi Qous

Qous basin was one of the most affected basins during the floods of 2009 and 2011. The unplanned urban expansion within the area decreased the infiltration rate and increased the runoff coefficient, making it more vulnerable to flooding. Table 1 describes the morphometric characteristics of Qouas basin. One of the objectives of this study is to determine the peak discharge of Qous watershed during different time periods and at a different urbanization rate. This will assist decision makers to plan for the expansion of all cities and towns in Jeddah Province.

Table 1 Morphometric characteristics of Qous basin

Area (square kilometer)	68
Length (kilometer)	20.84
Mean elevation (kilometer)	142.305
Slope	0.037
Perimeter (kilometer)	75.75
Main flow distance (kilometer)	26.08
Main flow slope	0.0084
Main stream Distance (kilometer)	23.8
Mean stream slope	0.0066

On November 25, 2009, in the city of Jeddah, heavy rain led to a flash flood whose severity was magnified by unplanned urban development. The weather station at King Abdulaziz Airport, which is 30 km from Qous basin, reported that the precipitation value reached 70 mm with a duration of three hours. The amount of rainfall over Qous basin was estimated at 83 mm by Jeadi (2013) as the weighted average using a Precipitation Estimation from Remotely Sensed Imagery Using an Artificial Neural Networks Cloud Classification System (PERSIANN-CCS).

The flood had an extensive social and environmental impact; about 161 people lost their lives, and many others were missing. Since King Abdulaziz University (KAU) is located in the flood plain of the basin, many buildings were flooded; the flood particularly damaged equipment such as books and computers in the library, the College of Engineering, and the College of Medicine. The total losses at KAU amounted to SR 1 billion. Fortunately, the flood took place during a holiday vacation when the students were home; otherwise, the consequences of the flood would have been more devasting. Figure 4 presents photos of a flooded area during the flood in 2009.

Figure 4 Photos of flooded area in the city of Jeddah during the flood in 2009

3.3. Hypotheses of the case study

H0: Converting the nature of the Qous basin from a naturally-developed rural area into to a highly-developed urban area intensifies the peak discharge for a certain rainfall of a certain return period.

H1: Converting the nature of Qous basin from a naturally-developed rural area into to a highly-developed urban area will not intensify the peak discharge for a certain rainfall of a certain return period.

3.4. Urbanization Development in Qous Basin

Urbanization development started in Jeddah about 1973. Figure 5 displays a Google Earth historical imagery that shows the topography and urbanization development in Qous watershed at four times: 1988, 1998, 2009, and 2018. It started about 1988 within the basin's outlet area, and approximately forty percent of the area is currently urbanized.

Based on the field trip visit to Qous basin, there were several fenced lands for proposed buildings toward the east, because land in such areas is much cheaper than land in other places such as the west highway. Thus, I consider the annual average increase for the next twenty years to be almost the same as the annual average increment from 2008 – 2018: an estimate of 0.6 – 0.8. From that, it is estimated that the watershed will be fully developed by 2037. Figure 6 shows the pattern of temporal urban development in Qous basin. Table 2 shows the accumulated urban area and the annual average increment from 1988 to 2018.

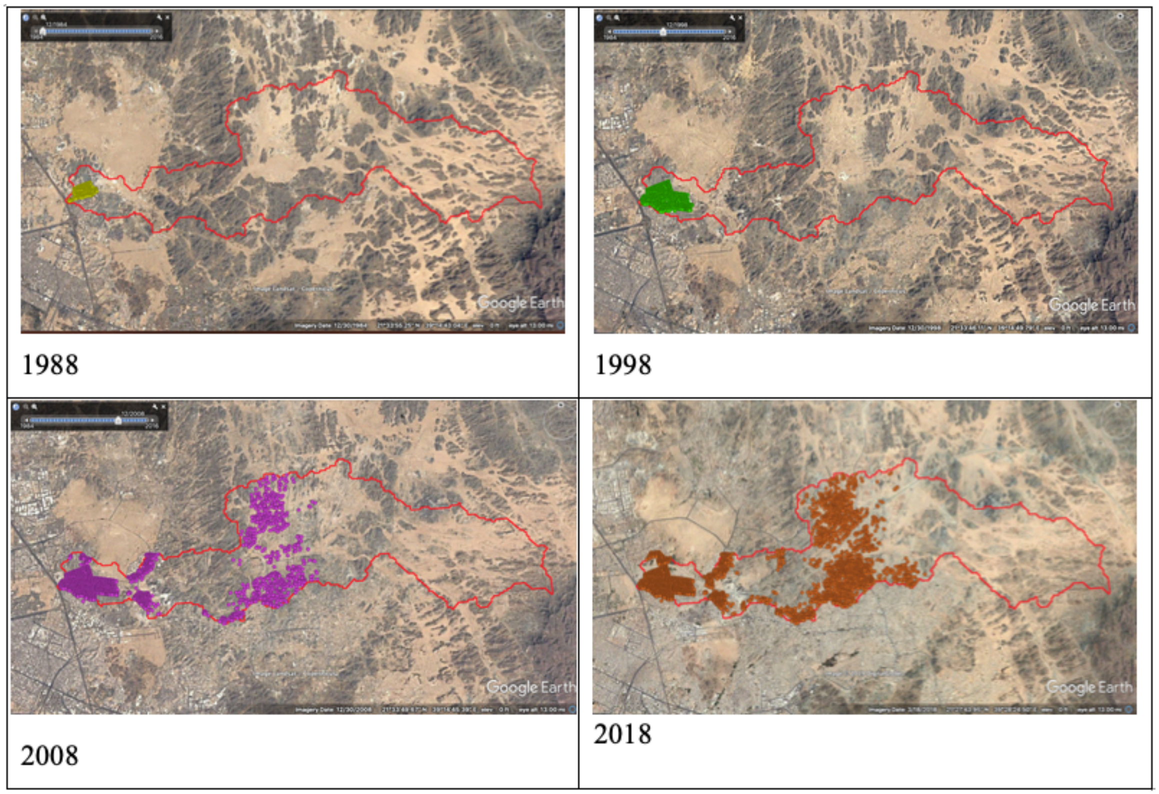


Figure 5 Urbanization development in Qous basin at four times.

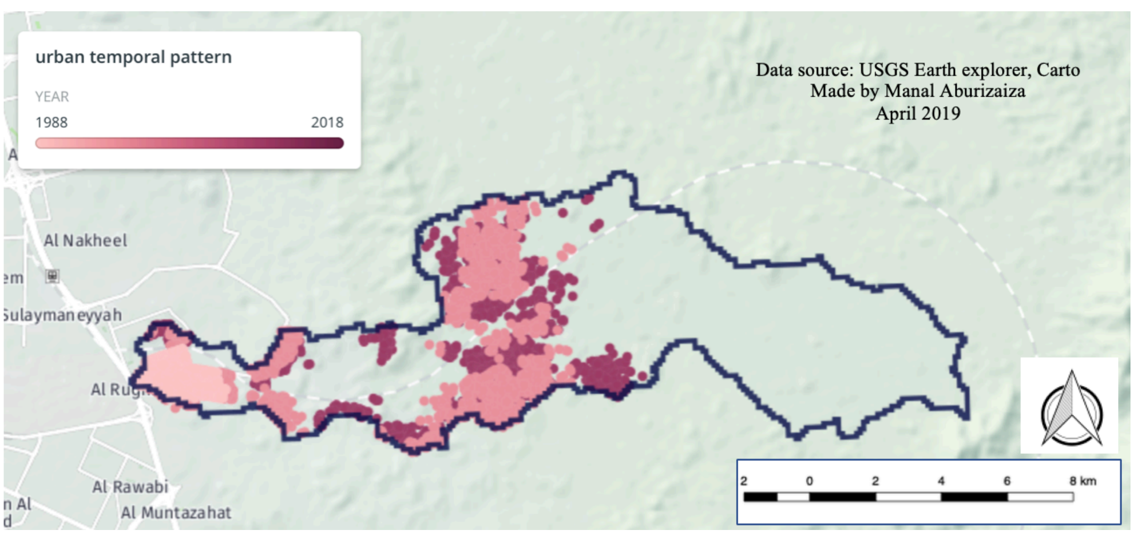


Figure 6 Urbanization development in Qous basin from 1988 – 2018.

Table 2 Urban area in Qous basin

Year	Urban Area (k^2)	Urban Area %	Annual avg Incr (k^2)
1988	0.54	0.807	--
1998	1.81	2.69	0.12
2008	12.15	18.046	1.03
2018	27.0	41.15	1.55

3.5. Estimating the Peak Discharge

There is a direct relationship between rainfall and runoff and there is a relationship between the runoff and the characteristics of the catchment. The characteristics include but are not limited to the area of the basin, its slope, length, land cover and type of soil,

The peak discharge is estimated for two cases: when it is totally rural (i.e., up to 1973) and when it is fully developed (i.e., 2037). The rational formula (Equation 1) is used to estimate the peak discharge in the Qous basin in both cases. The method was developed by Kuichling in 1889 for small watersheds in urban areas; it was selected because a fair amount of data is available. It is important to note that the rational method is used in this study only for the purpose of determining the impact of the urbanization in Qous watershed and comparing the peak discharge as a rural or urban area. However, the method is not recommended for determining the spatial flood extent of the basin because of the limitations of the following assumptions: Peak flow occurs only if the entire watershed is contributing runoff, the rainfall intensity is assumed to be uniform throughout the duration of the storm, and the rainfall is distributed uniformly over the watershed (ODOT Hydraulic Manual, 2005).

Equation 1 Rational method

$$Q = (0.0278)\ CIA$$

In this formula, Q is the peak discharge *(m3/s)*, C is the runoff coefficient *(unitless)*, I is the rainfall intensity *(mm/hectare),* and A is the basin area *(km^2).* Subsequent paragraphs explain how each of these parameters are estimated. ***A*** is estimated using QGIS. ***I*** is estimated by estimating the Time of Concentration (TC). TC is the time required for a drop of water to travel from the most remote point of the watershed to the catchment outlet. The peak discharge of any watershed takes place only if TC is equal to the time of duration, which is the interval time for the rainfall. Thus, several empirical formulas were studied and the optimum one that fairly matches the characteristics of the basin such as type of soil, depth of aquifer, slope, and degree of urbanization was selected. TC calculated using Bransby-William formula for rural (Equation 2).

Equation 2 Bransby-William equation

$$TC = 14.6\ LA^{-0.1}S^{-0.2}$$

Where:

L is the basin length (km)

A is the drainage area (km2)

S is the basin slope (m/m)

The weighted runoff coefficient ***C*** of the basin is estimated based on the value of the runoff coefficient and its corresponding area. Therefore, the basin is divided into two sub-areas (rural and urban) because each sub-area has a different value for the runoff coefficient. For example, most of the land cover of Qous basin in the developed area consists of residential detached multi-units. Based on this fact and using the Rational Method Runoff Coefficient table from The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment 1 State Water Resources Control Board 5.1.3 FS-(RC) 2011, the C value for the urban area is 0.6 and for the rural area is 0.15. The following formula is used to estimate the weighted average runoff coefficient. As an example, the weighted average runoff coefficient was estimated for 1988 using Equation 3. Table 3 and figure 7 shows the weighted average runoff coefficient values for different years in Qous basin.

Equation 3 Weighted average runoff coefficient

$$WAC_{1988} = \frac{A_1C_1 + A_2\ C_2}{A_1 + \ A_2}$$

$$WAC\ 1988\ = \frac{66.79\times0.15\ +0.54\times0.6}{66.79+0.54} = 0.15$$

Table 3 Runoff coefficient values for different years

Year	Rural Area (k2)	Urban Area (k2)	C (Weighted avg)
1988	66.79	0.54	0.15
1998	65.52	1.81	0.16
2008	55.16	14.81	0.24
2018	27.71	39.62	0.41
2037	0.00	67.33	0.6

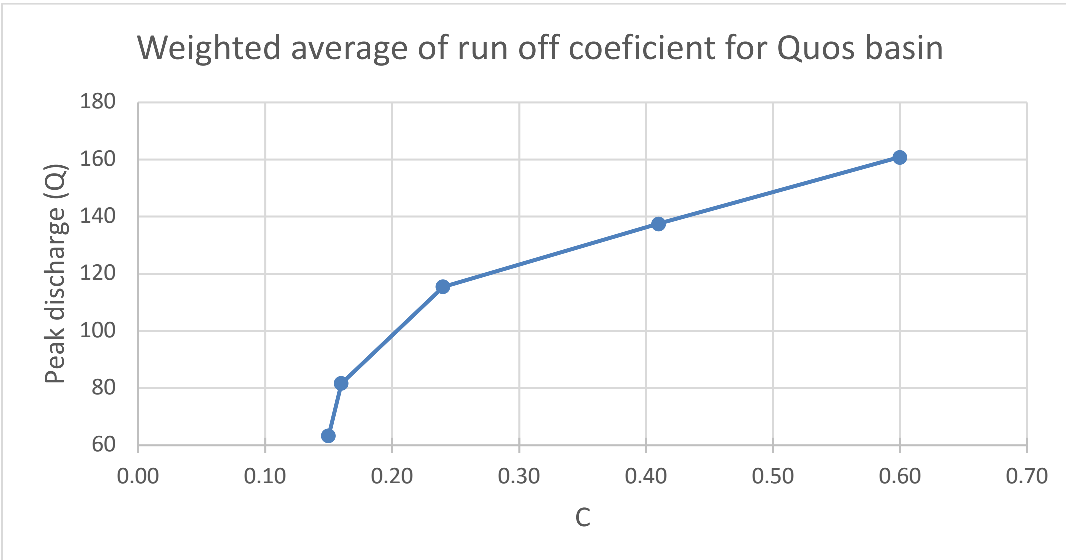


Figure 7 Weighted average runoff coefficient for Qous basin

As demonstrated in Figure 8 the time of concentration is equated to the time of duration to estimate the rainfall intensity using intensity duration frequency (IDF) curves developed for Jeddah city (Awadallah, 2015) for return periods of 10, 20, 50, 100, and 200 years. In order to estimate the rainfall intensity for a specific return period, time of concentration is equated with time of duration, which is represented on the X axis. Then, the curve for the required return period is used to find the rainfall intensity corresponding to that return period.

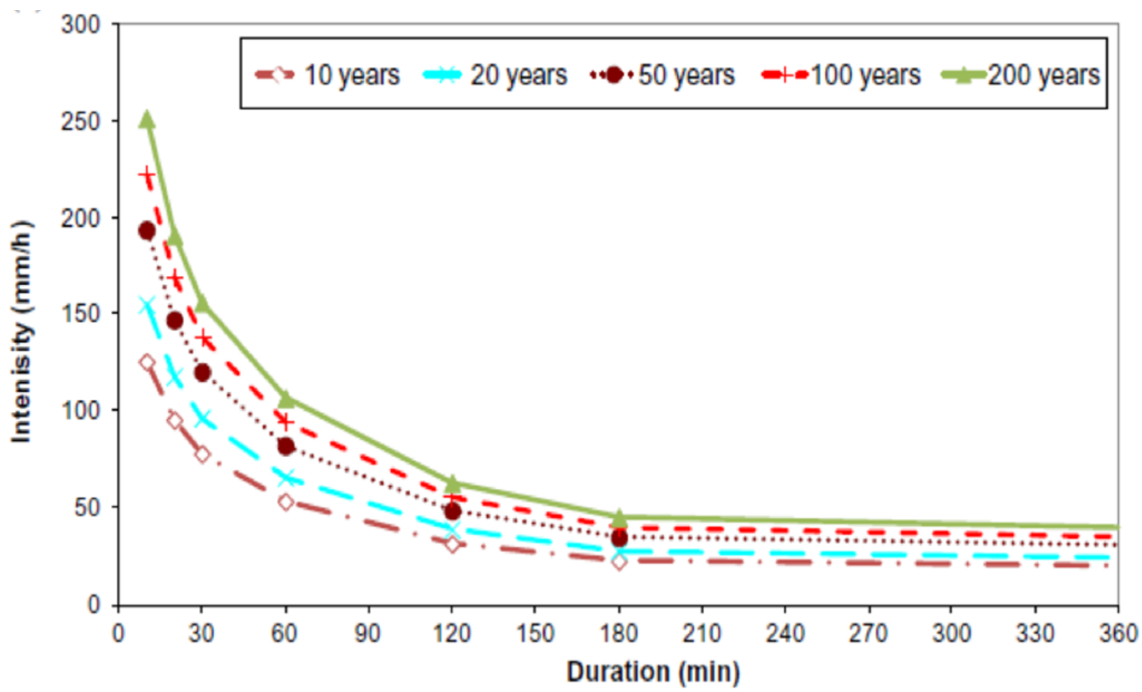


Figure 8 IDF curves for Jeddah region

To calculate the peak discharge of Qous basin for different return periods, it needs to be considered that the peak discharge is affected by the return periods. Therefore, a modifier is used to take the impact of the different return period on peak discharge. Table 4 shows the parameters' values for Rational method for rural Qous basin. Finally, the peak discharge of the Qous basin is estimated when it was totally undeveloped (before 1973) for the aforementioned return periods. Results are shown in the Table 5. Figure 9 shows the peak discharge for Qous basin (rural) for different return periods.

Table 4 Rational method parameters for Qous basin

Year	Rural Area	Urban
Peak discharge	CIA	CIA
Run-off Coefficient	0.15	0.6
Rainfall intensity	(X)mm/h	(X)mm/h
Drainage area	68 km2	68 km2

Table 5 Peak discharge for Qous basin when totally rural (Tc = 238.50 min)

Return Period	Rainfall intensity (mm/h)	Peak discharge	Modifier	Mod Q
Q 10	23	63	1.00	63
Q 20	27	74	1.10	82
Q 50	35	96	1.20	116
Q 100	40	110	1.25	138
Q 200	45	124	1.30	161

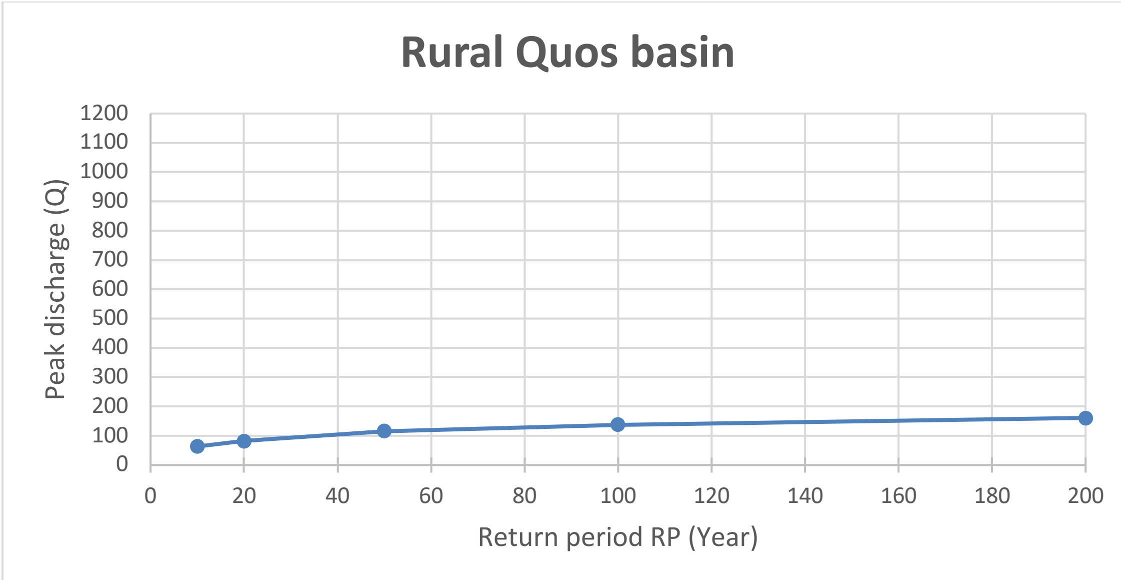


Figure 9 Peak discharge for different return periods when Qous basin is totally rural

Using the same reasoning and following the same procedure, the peak discharge of Qous basin is estimated for several return periods when the basin is totally developed. Results are shown in Table 6. Figure 10 shows the peak discharge for different return periods for Qous basin when it is totally developed. For urbanized basin, Carter formula (1961) was used to estimate time of concentration

Table 6 Peak discharge for Qous basin when totally developed (Tc = 83 min)

Return Period	Rainfall intensity (mm/h)	Peak discharge	Modifier	Mod Q
Q 10	48	520	1.00	520
Q 20	52	563	1.10	691
Q 50	68	736	1.20	883
Q 100	75	812	1.25	1015
Q 200	85	920	1.30	1196

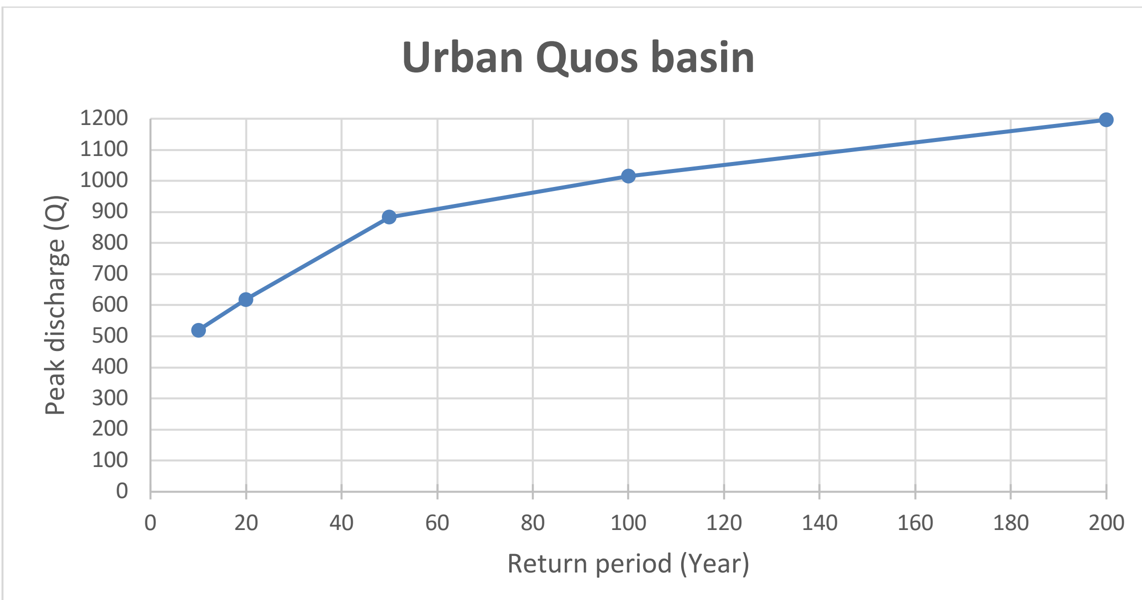


Figure 10 Peak discharge for different return periods (urban)

Table 7 Comparing peak discharge between all-rural Qous basin and all-urban Qous basin, Jeddah

	Rural	Urban
Q 10	62	520
Q 20	80	691
Q 50	114	883
Q 100	135	1015
Q 200	158	1196

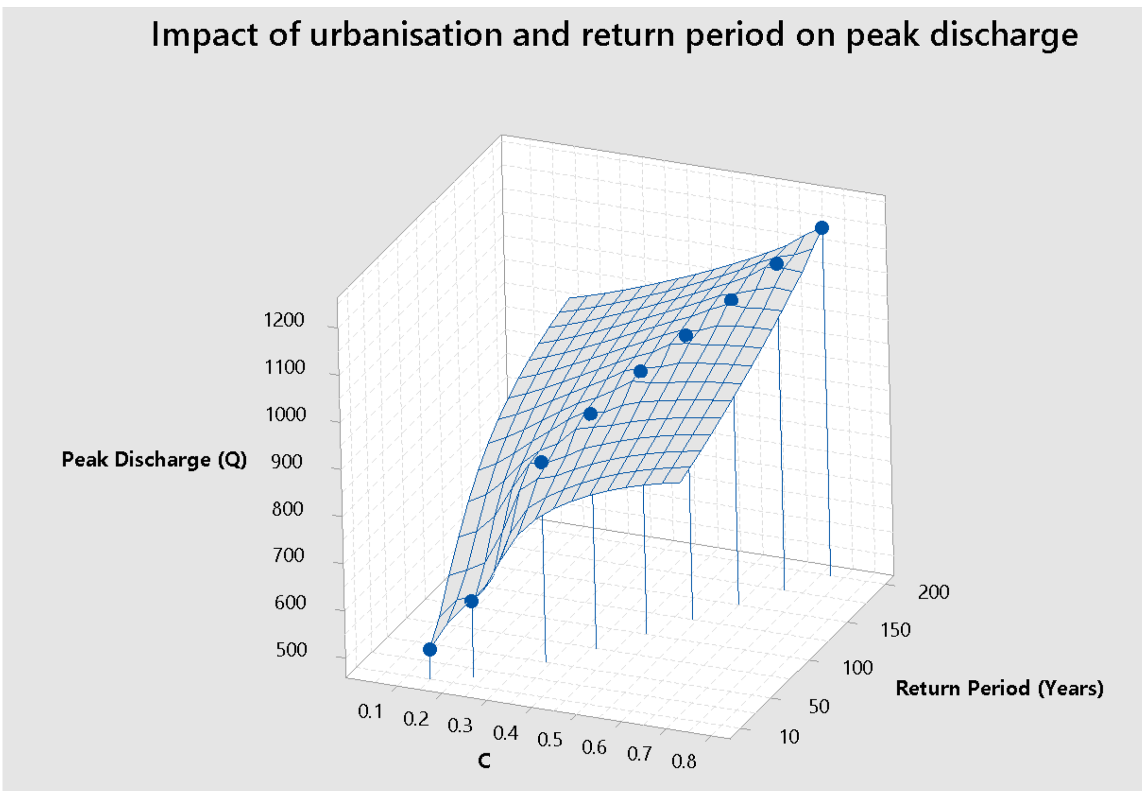


Figure 11 Impact of urbanization on Qous basin

3.6. Discussion

Table 7 shows the highly-significant difference in the peak discharge between rural and urban areas, ranging between this was a major factor in the disastrous events in 2009 and 2011. Figure 11displays the impact of urbanization on runoff coefficient and peak discharge on Qous basin for different return periods. The aforementioned results demonstrate that converting rural areas into urban areas in an unplanned and unorganized manner decreases the infiltration rate and increases the runoff coefficient within the area, which, in turn, intensifies the peak discharge for a certain rainfall. This increases the basin's vulnerability, and therefore, the planning, design, execution, operation, and maintenance of any hydraulic structure should take these changes into consideration.

4. METHDOLOGY

This chapter covers the dataset and the used methodology in this study. The first section describes the use of GIS and RS data in hydrological analysis, and the second section covers the three types of soft data: field visit, Twitter and YouTube. Topographic Wetness Index method is described in section three. To generate a flood hazard map for the Qous basin, datasets were obtained from the sources shown in Table 8.

Table 8 Data sources used for this study

Data	Source
30 m ASTER data	USGS EarthExplorer
Residential area layer	OpenStreetMap and QGIS
Road network	OpenStreetMap and QGIS
Twitter data	George Mason University
YouTube videos	YouTube web site
Photos and observation of Qous basin	Field work
Experience and knowledge	Personal communication of residents

- 30m (DEM) Digital Elevation Data Map from USGS EarthExplorer to delineate the watershed and the stream network using a QGIS hydrology tool
- Information extracted from social media platforms such as YouTube videos and Twitter text and photos to obtain flood information.
- Newspaper article and related images.

- Information from a field trip with an expert hydrologist to determine the boundaries of the basin, outlet, tributaries, dams, and the hazard area. (Especially for an ungauged basin, there is a need to link the hydrological function and the catchment properties.

4.1. GIS and RS data

Due to data limitations, land use layers (houses, buildings, and streets) were extracted as an OSM file using the OSM Downloader tool in QGIS. Next, the OSM file was imported to a DB file, then the DB file was exported in its proper topology to generate vector files. For slum areas, there was no digitized data to be exported, therefore, the topology was digitized manually using the OpenStreetMap edit tool (in-browser editor) for OSM geodata. Next, the digitized data was exported from the map as an OSM file and then converted to an Esri shape file.

In this study, the terrain data was obtained using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTERM) Global Digital Elevation Model (GDEM) with a tile size of 3601 x 3601 ($1° \, x \, 1°$) and a pixel size of 1arc-second. The DEM was re-projected to (EPSG: 20437, Ain el Abd / UTM zone 37N). QGIS with SAGA plugin was used to delineate the catchment and the streams. First, sinks were filled in the DEM raster file and the flow direction map was generated using the Fill Sink algorithm (Wang & Liu, 2006). Next, the Strahler order method was used to create the stream raster and to classify the stream raster numeric order. Finally, the Channel Network and Drainage Basins tool was used to delineate the basins of the region and its drainage.

4.2. Soft data

4.2.1. Field visits

Four field trips were undertaken to Qous basin in Jeddah Province as a partial requirement for completing the dissertation. The purpose of the trips was to generate soft data that can be obtained from field observations, to acquire information related to floods and the watershed. Google Map was used to navigate within the basin, and “My GPS Coordinate” with an accuracy of 5 meters was used to determine the spatial extent and the geolocation of each photo taken. The four trips all took place in July 2018; each trip took about 4-5 hours.

First field trip:

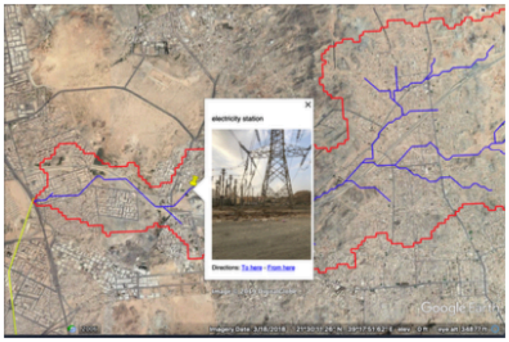
The main goal of the first field trip was to build a very general idea about Wadi Qous. On July 7, the team traveled by road, escorted by an expert in water resources who knows the area and another gentleman who has been living there for forty years. The trip started at the very upstream area and visited the main tributaries of the wadi there.

Before the trip, several maps of the area were prepared and reviewed to determine the area and understand its physical features. The oldest map was from 1988; the new one was recently taken from Google Earth Pro. Besides these maps, a literature review of several studies on the area was carried out for a wider view.

Residents told us that only Bedouins (nomads) used to live in the basin with their livestock, mainly sheep, goats, and camels. Now, a city has sprung up there, but some original semi-Bedouins still live in the upstream area, with their children getting a modern education and being urbanized. The upstream area still doesn’t have adequate modern facilities. Unfortunately, most of the houses built there look unplanned; people and animals live in proximity. Most houses were built after 1980, when residents came from nearby areas to live in the area.

Second field trip:

On July 14, the second trip was along the mainstream of the wadi as far as the main highway, the Haramain Expressway. Urbanization was found to be more concentrated in the main stream area than in the upstream area. Many facilities such as schools, mosques, and power stations were built in the middle of the Wadi, as shown in Figure 12. Geolocated photos were taken for such features to digitize them on Google Earth.



Electricity station in the main stream

High school

Elementary school

Elementary school

Figure 12 Photos from the field trips

Based on the newspaper and residents' knowledge, Jack street in Quaza was one of the areas most affected by the flood in 2009. In Quaza, there are two elementary schools, one middle school, and one high school; all are located in the same neighborhood, beside the main stream and close to the outlet, as shown in Figure 13. This makes the area highly vulnerable during floods, because of the large number of students in a small area. Moreover, the surrounding roads are narrow, which makes an evacuation difficult to perform.

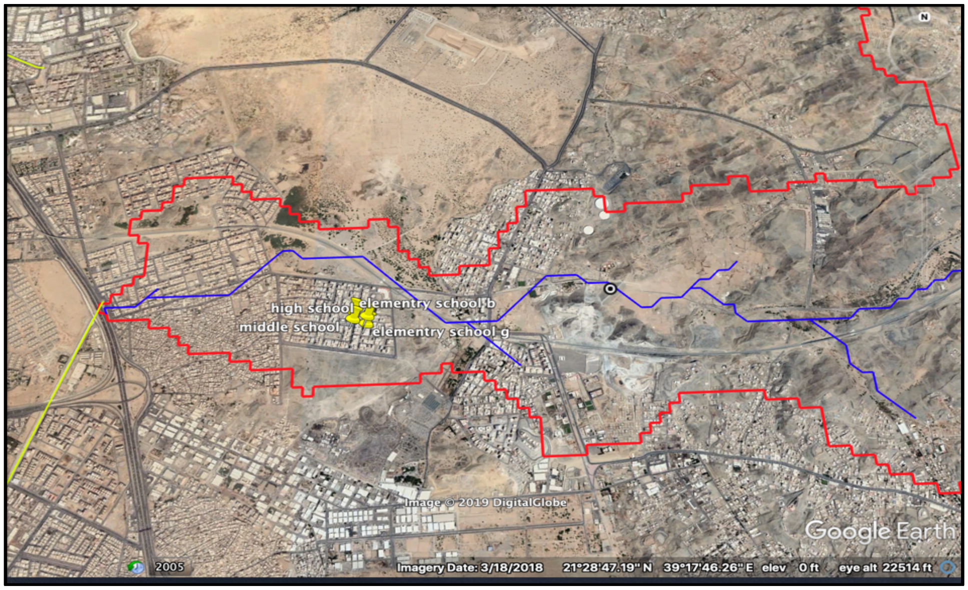


Figure 13 Four schools in the Quaza neighborhood

On the west side of that neighborhood, there are also slum-houses, mostly one-story buildings that are very close to the outlet of the watershed. The roads are non-asphalted roads (dirt roads), narrow and not easy to drive around on.

In fact, most of the residential areas in the basin are slum areas, starting from the downstream towards west to the upstream of the watershed. These buildings are exposed to flood water that naturally runs across the watershed. In November 2009, a disastrous flood hit Wadi Qous. In that flood, 110 people were killed, and more than 1000 cars were carried away and damaged. Fortunately, this took place during a holiday season; otherwise, the number of casualties would have been much higher. The Ministry of Municipality & Rural Affairs and the Ministry of Water and Agriculture took action to protect the people and their property by building three dams (one in the east side and the other two in the west side of the watershed) and canals to transfer flood water. The locations of the three dams were geotagged to define their geolocation on the map (Figure 14), and the geolocation of the dam and its outlet was digitized on Google Earth as shown in Figure 15.

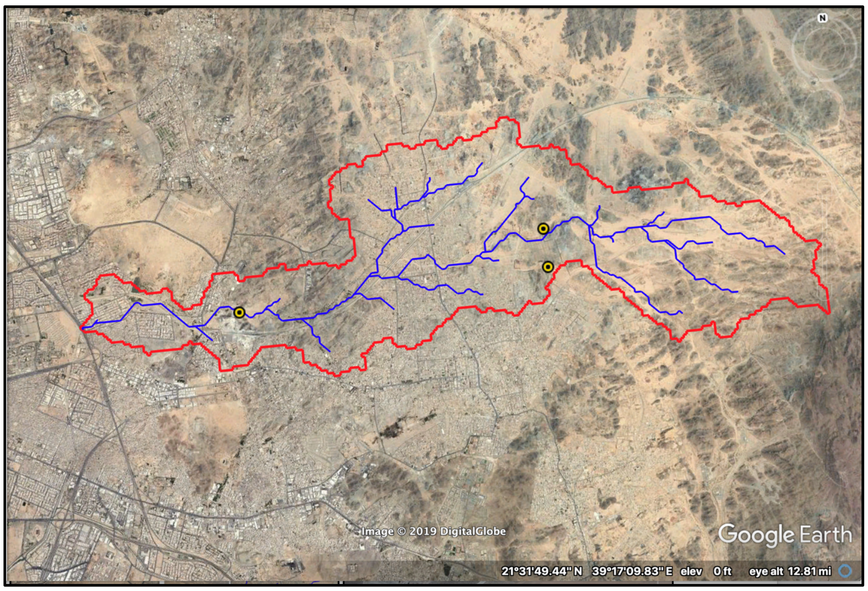
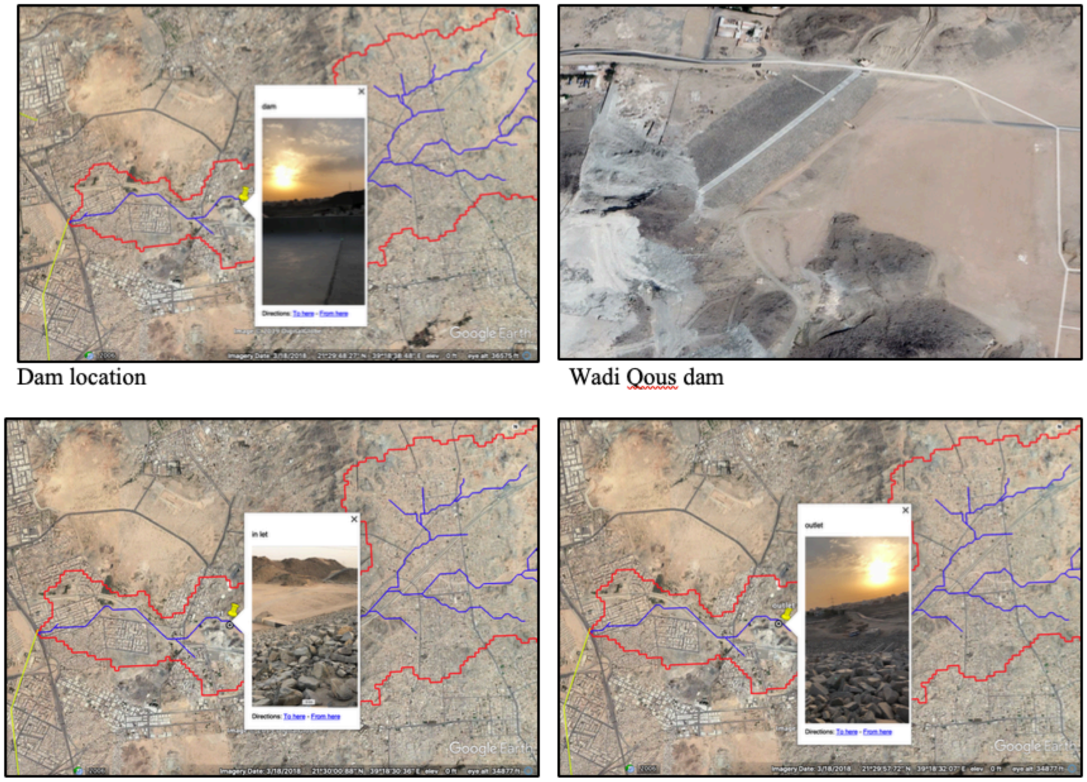


Figure 14 Geolocation of the three dams in Qous basin



Dam location Wadi Qous dam

Dam inlet Dam outlet

Figure 15 Wadi Qous dam

Third field trip:

The third visit was undertaken on July 15; it started all the way at the downstream end toward the west. In that trip, the team was looking for clues to assist with locating the spatial flood extent, determining the flooded area, and/or estimating flood inundation. The team revisited Jack street in Quaza to acquire flood-related information. The high mark of floodwater was obvious on some building walls, as shown in Figure 16. The photo shows a water mark on the wall that is an estimate of the inundation of the flood, and the geolocation of the taken photo assisted in determining the flooded area in that neighborhood.

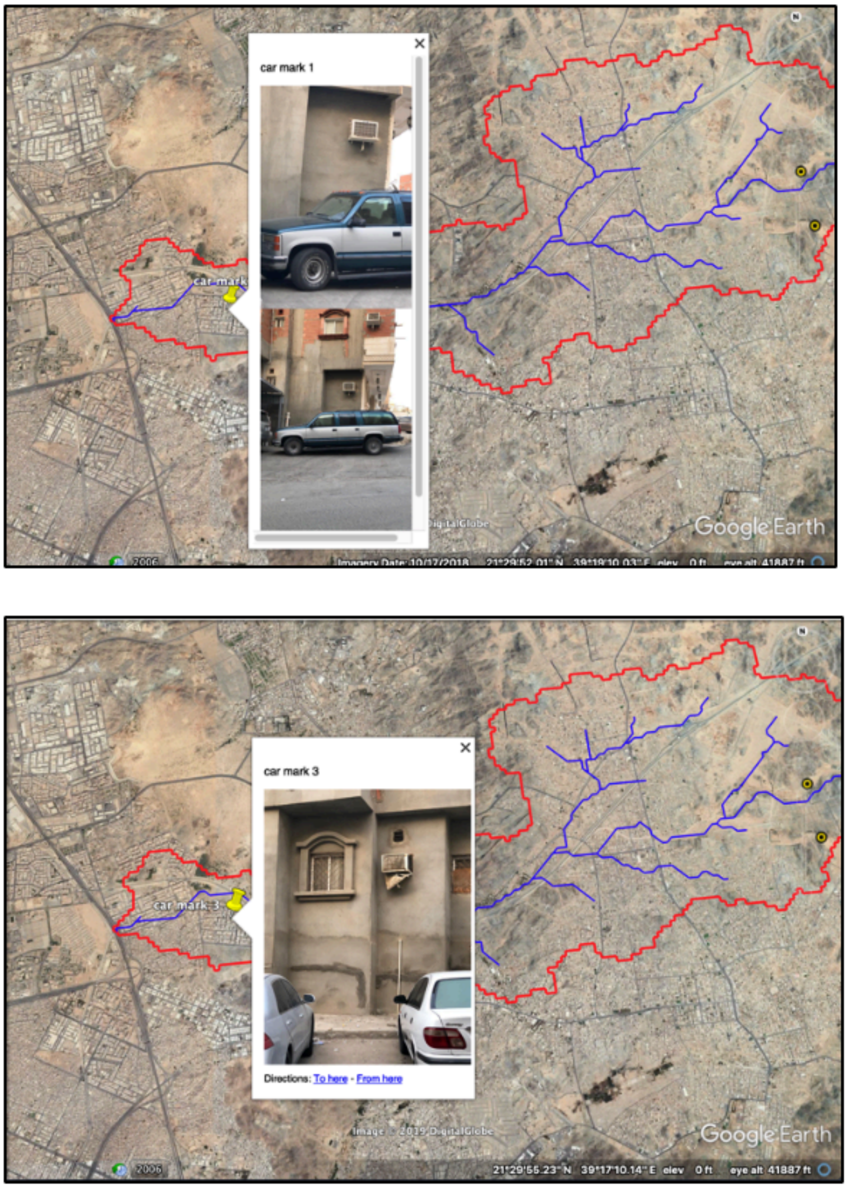
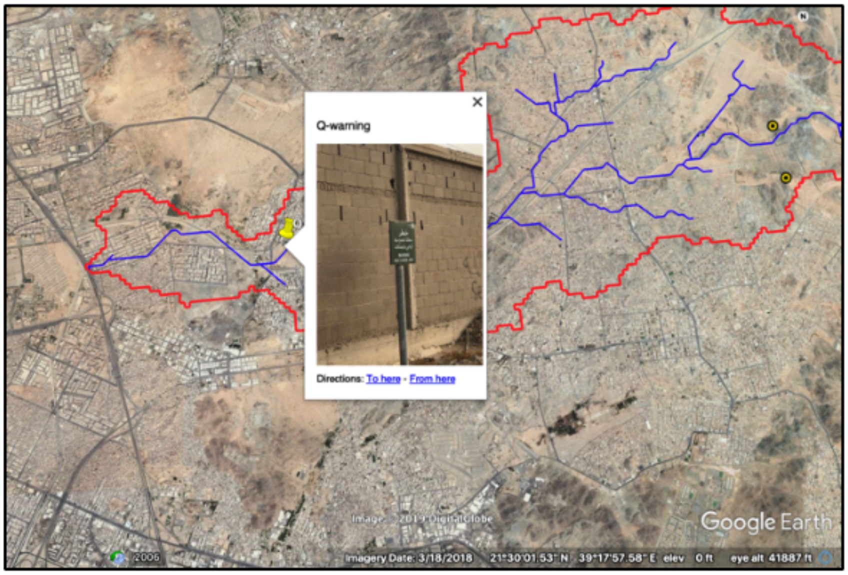


Figure 16 High mark of floodwater on Jack street

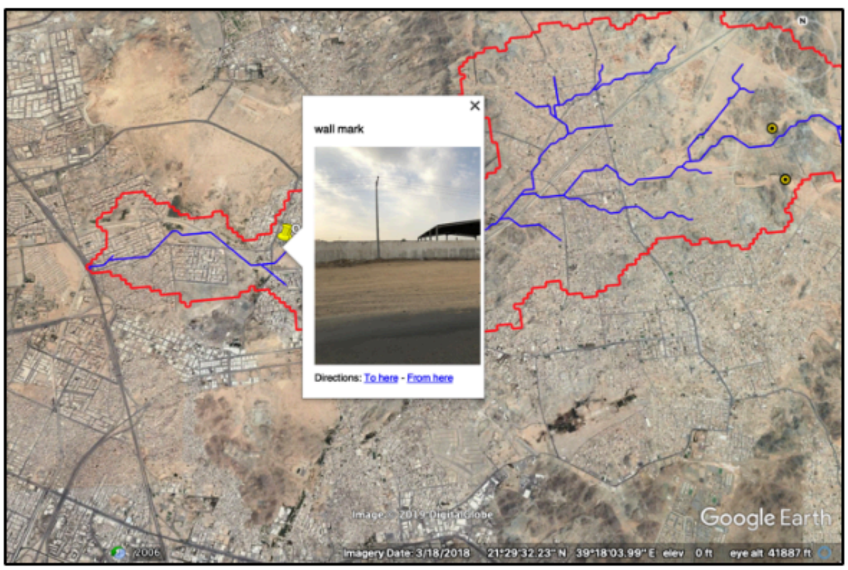
Figure 17 shows some bushes planted in a dry area in the main stream, beside the electricity station. This type of tree in this type of land gives an indication that the area was a flooded area. Moreover; a sign warning that a certain area is a flooded area also provides evidence for determining the spatial extent of the flood. Next to that sign, wall marks also support estimating the flood inundation, which also determines the spatial flood extent in the watershed (Figure 18).

As mentioned before, after the flood in 2009, the Ministry of Municipality & Rural Affairs and the Ministry of Water and Agriculture built dams and channels for flood management purposes. Two levels of water marks were found on the same wall beside the channel; based on the opinions of the expert and the resident, the upper mark estimates the flood inundation before the dams and the channels, and the lower mark estimates the flood inundation after that construction, as shown in Figure 19.

Figure 17 Flood tree beside the electricity station

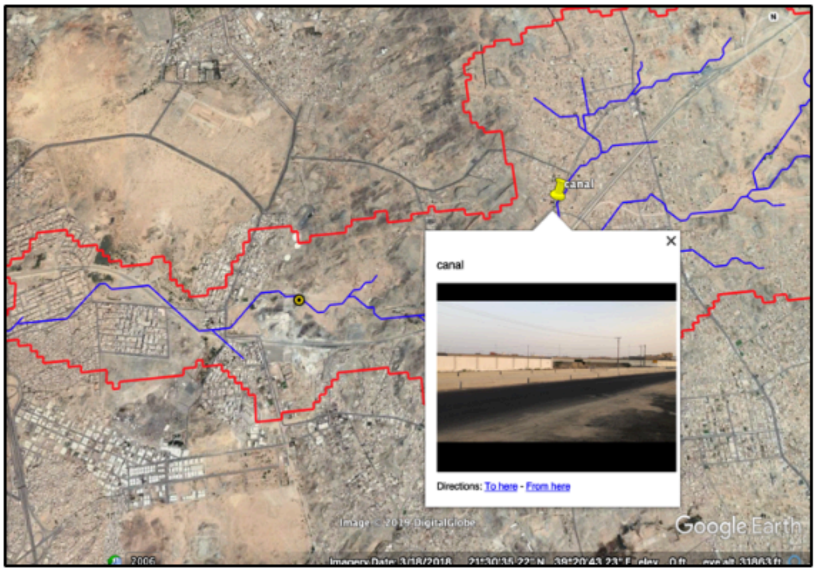


Warning sign

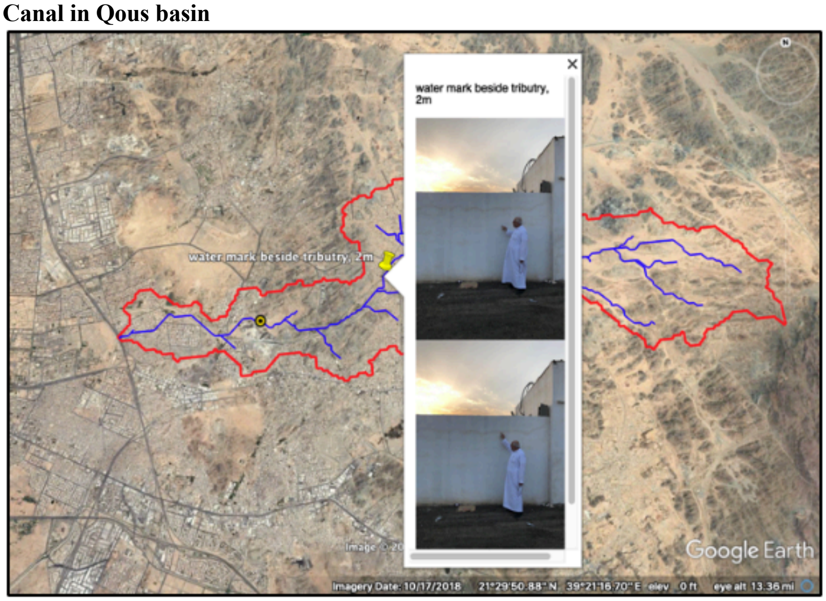


Wall mark

Figure 18 Water mark beside the warning sign



Canal in Qous basin



Water mark levels

Figure 19 Water mark level beside the canal

Fourth field trip:

In this trip, the team decided to go beyond the wadi and visited the affected area beside the overflowing area of the watershed. It started from the Haramain Expressqway and continued all the way to the sea. In fact, the Wadi used to continue all the way to the sea without obstacles, until the end of the early 1970s. In the early 1970s, several structures (public and private) started to be built. The first infrastructure built was King Abdul Aziz University. The southern part is very close to the channel of the main wadi of Qous basin. When flooding took a place in 2009, the water from Qous basin (Queza) flooded the campus, especially the southern part.

Infrastructural development has taken place from the Haramain Expressway all the way to the Red Sea. The outlet can no longer be identified; water flow spreads everywhere. Because of the new infrastructures, the natural drainage system of Qous basin and the area beyond it were highly disturbed. The buildings were built on the channel, so the natural drainage system does not exist anymore. If flooding happens, the floodwater doesn't know which way to flow. This problem will continue unless an adequate scientific solution is found to provide drainage. If an adequate drainage system was built, all these areas would not have been damaged.

The Saudi government, in an effort to avoid more such disastrous events as the 2009 floods, built a dam at Wadi Qous. The dam has gates to release water trapped behind it and direct the water into channels. The channel runs first to the south, then takes a turn to the west and discharges into the sea (Figure 20). The total length of the channel is 8.92 miles. The government initially tried to build a channel in the natural drainage passage all the way to the sea, but the channel's incredible cost to compensate property owners for land and infrastructures caused the government to abandon that plan. Again, if the natural drainage system of Wadi Qous had been respected, protected, and studied to plan a drainage system, all these development costs could have been avoided. The channel will not adequately solve the problem because floodwater may look for its natural passage.

Figure 20 Channel from Qous basin to the Red sea

Field trip conclusion:

The conversion of a rural area into an urban area has drastically changed the area in two respects: the runoff coefficient (C) of the land increased up to several fold, as shown earlier in Table 3; and the time of concentration decreased, consequently decreasing the time required to reach the peak of the flood. Compared to the area before urbanization, the impact of increases in the runoff coefficient and the time of concentration may be summarized in the following points:

1. For a given rainfall, the volume of the flood in the same area is larger.
2. The value of peak flooding for the same area is larger.
3. The time required for a flood to reach the urban area is shorter.

However; many hydraulic structures such as open channels, dikes, and dams were designed and executed when the area was rural. Thus, the design now has to be revised based on the above information, due to the conversion of the land from rural use to urban use. In addition, for the infrastructures, there are two scenarios: First, the infrastructure project that was designed but not executed should be revised and modified according to the new situation (urbanization). Second, for the infrastructure project that has been executed (the structures of the four schools mentioned), the infrastructures already built need to be modified; for example, some existing structures must be demolished and removed to avoid danger from floods.

4.2.2. Social media data

Based on Internet World Stats (2018) for Saudi Arabia, approximately 90% of the population use the Internet, 75% of the total population are active social media users, and 54% of the population use mobile devices for social media usage (Statista, 2018). Social media and technology are increasingly popular in Saudi Arabia because of the low average age of the country's population (Statista, 2018).

Social media data contains valuable information that can be utilized for hydraulic analysis. This study examines the usability of YouTube's videos and comments and Twitter's texts and photos to extract flood-related information for floods in Jeddah city. These social media platforms provide textual information from user's observations such as flood location and water depth, while videos and photos show the relationship between the water depth and part of the surrounding area (Fohringer et al., 2015). For instance, water depth can be estimated using the captured contents in an image, such as a partially submerged car or parking meter, as well as the related textual information or comments. In addition, spatial elements might be determined using the geolocation of a photo or a captured item in the photo itself, such as a street name in a road sign. In addition to that, videos might provide an audio observation that describes the situation of the hazard and its related information. Ultimately, the aforementioned information is then used to digitize photos on the map to estimate the flood's spatial extent.

4.2.2.1. Harvesting and Filtering

Twitter data were provided by George Mason University for November 21, 22, and 23, 2017, and for November 2, 3, and 4, 2018. (There were no data available from George Mason University for the floods in 2009 and 2011.) The data was filtered and harvested using keywords related to flood such as "flood", "flash flood", and "flashflood" that match the keywords with the tweet's words.

PostgreSQL (Structure Query Language), which is an open source data management system, was used to store and analyze Twitter data. Initially, all non-geotagged tweets were removed from the two datasets; geolocation information was provided in 43222 of 78885 tweets for the 2017 flood, and for 36499 of 65736 tweets for the 2018 flood. Next, the data were filtered using PostgreSQL to exclude tweets outside Saudi Arabia using the following SQL script:

```
SELECT *
        FROM development.jeddah.flood
        WHERE country ILIKE '%sa%';
```

The output table of the above script was a total of 152 tweets (see Appendix B). An SQL script was used to search for flood information within tweet texts. First, I determined the keyword that represent relevant flood information such as flood location and inundation in Arabic and English language format. For example, (قدم ,متر, meter , feet , inch…), (طريق , حي , شارع , street , road..), and (أمام, خلف , بجانب , beside, next, near …) were used to estimate the flood depth and to determine the flood extent, respectively. These keywords were searched for and compared with each word in each tweet text in the dataset, as shown in the following SQL script:

```
SELECT text, link, x, y
    FROM development.tweets
    WHERE text ILIKE '%الحي%' OR text ILIKE '%شارع%' OR text
    ILIKE '%طريق%' OR text ILIKE '%حاره%' OR
    text ILIKE '%متر%' OR text ILIKE '%قدم%' OR
    text ILIKE '%بجانب%' OR text ILIKE '%أمام%' OR text ILIKE '%خلف%'
    OR
    text ILIKE '%street%' OR text ILIKE '%road%' OR
    text ILIKE '%near%' OR text ILIKE '%next%' OR text ILIKE
    '%beside%' OR
    text ILIKE '%meter%' OR text ILIKE '%inch%' OR text ILIKE
    '%feet%';
```

Due to the limited number of tweets, there was not sufficient information related to Jeddah's flood. This was because the keywords used are in an English format, and most of the hashtags and written tweets in Saudi Arabia are in the Arabic language format because Arabic is the mother language in Saudi Arabia. Due to the aforementioned reasons, numerous tweets related to the 2009 flood were obtained manually in an Arabic language format. The search was performed using the Arabic keywords that were used during the flood: فيضانات جده ,سيول جده, سيول جده١٤٣٠ – (see Appendix B). None of the 38 tweets obtained manually were geotagged, so information was extracted from the text and the image contents if available.

Numerous YouTube videos were obtained related to the Jeddah floods. Terms in Arabic and English such as (فيضانات جده ,سيول جده (flood 2009, Jeddah flood, disaster in Jeddah, rain in Jeddah), were used to search for videos at the website www.youtube.com; 80 of 96 videos had useful related information. Three elements were considered while performing the analysis of YouTube data: videos, audio, and text. For videos, video contents were used to estimate the depth of floodwater using a nearby sign such as a traffic light or the height of a car, and the location can be determined by recognizing the location or by identifying a popular store or restaurant. For the audio element, the speaker might give an information related to flood extent or flood depth. For the text element, information can be obtained from the title itself or from watchers' comments.

4.2.2.2. Visualization

The flood information obtained from YouTube and Twitter was posted in Google Earth according to its appropriate geolocation to determine the extent of the flood and the inundation of the selected area. Photos were digitized on the map based on their geolocation (if available) or by determining the location using a street name or a recognizable feature. Extracted qualitative flood information was also used to place posts on the map based on the geolocation of the photo or the post contents. The field trip also played an important role in determining the geolocation of a photo. For example, visiting the location of a posted photo assisted in estimating the near-real geolocation of the posted photo.

Figure 21 shows the location that was extracted from the Twitter text, the Twitter title, and the photo contents of a Twitter post. This street was named after a Pakistani man who died after rescuing 14 persons (peace upon him). The government named the street after him; this street was one of the streets most affected by the 2009 flood (Asharq Al-awsat news, 2019).

Figure 21 Geolocation of a twitter post

Figure 22 represents the distribution of Twitter data related to flood information. The figure shows a retweet network that displays different tweets from different authors, but all have the same geolocation, as shown in the table in Appendix B.

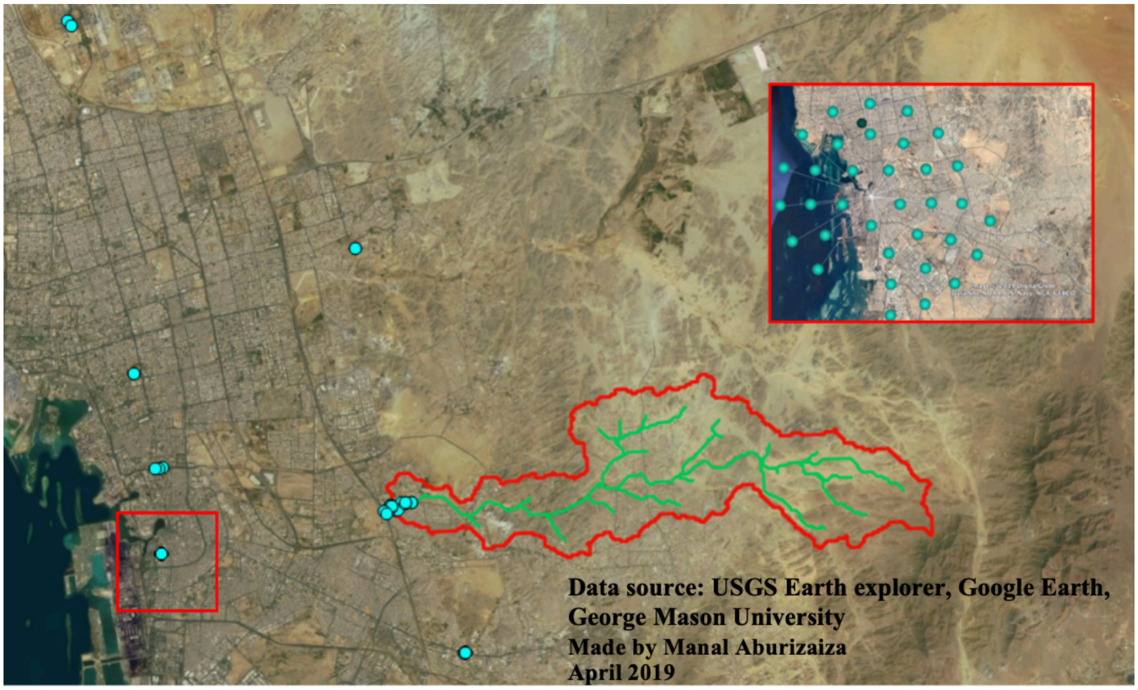


Figure 22 Distribution of flood Twitter posts in Jeddah city

For YouTube videos, contents and comments were used to determine the location of the flooded area. In Figure 23, a snapshot of a video is used to estimate the flood inundation, while the comments in Figure 24 assist with determining the location of the video's contents. Figure 25 represents the distribution of data extracted from YouTube related to flood information.

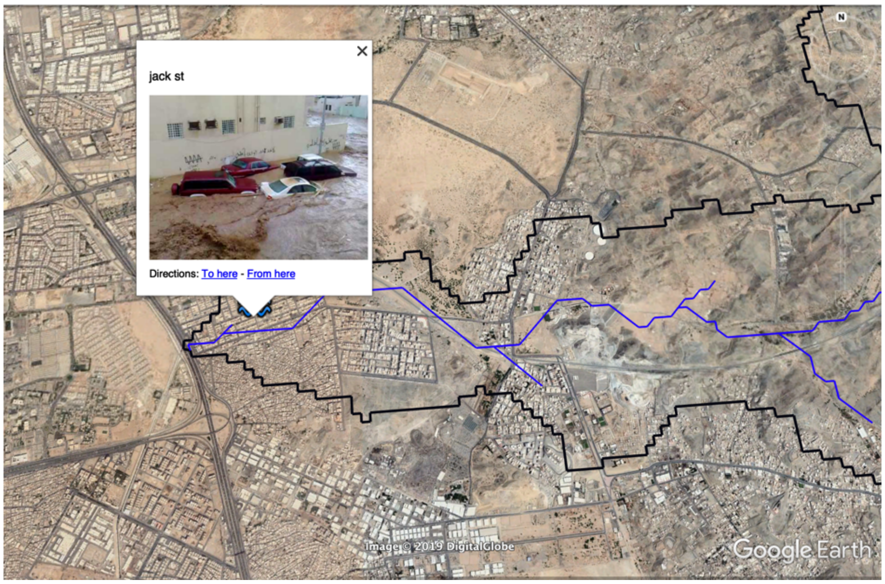


Figure 23 Geolocation of a YouTube video that provides the flood depth

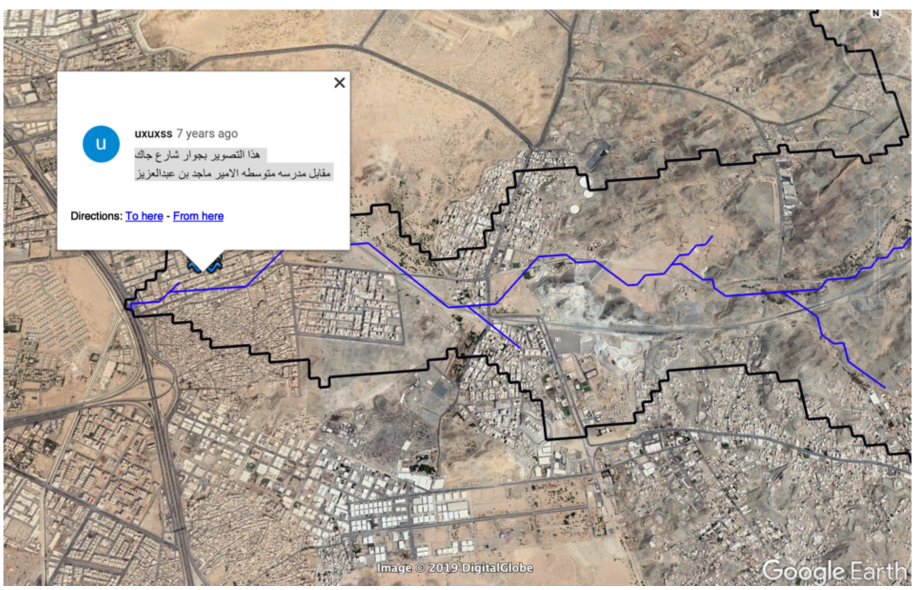


Figure 24 YouTube comment that provides the location of the video

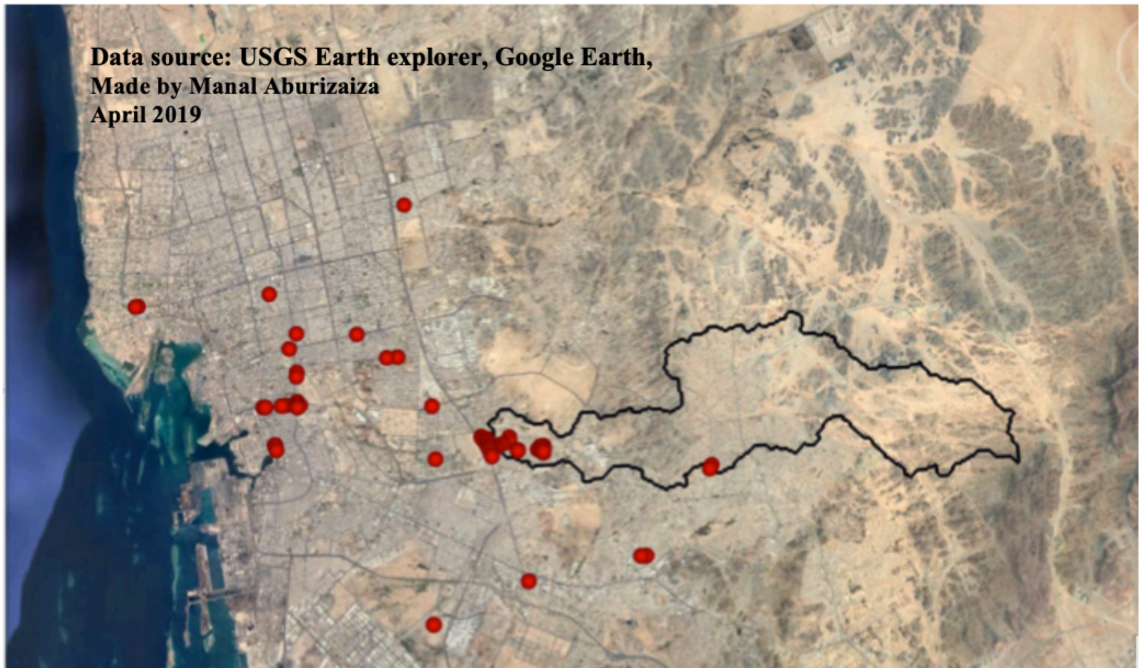


Figure 25 Distribution of YouTube data in Jeddah city

4.2.2.3. Generating a flood map based on soft data

Field trip data and social media data digitized in Google Earth was saved as a kmz file. Then, it was converted to an Esri shape file, to drive a flood extents map using QGIS and based on the three layers of soft data. The flood map based on soft data will be used to validate, compare, and improve the flood map based on the topographic wetness index method.

Figure 26 display the process of generating the data set of this study. Data set contains the vector layer of the land use (street, railway and residential area), Soft data (Twitter, YouTube and field visit) and the topographic feature of the basin obtained from DEM raster file.

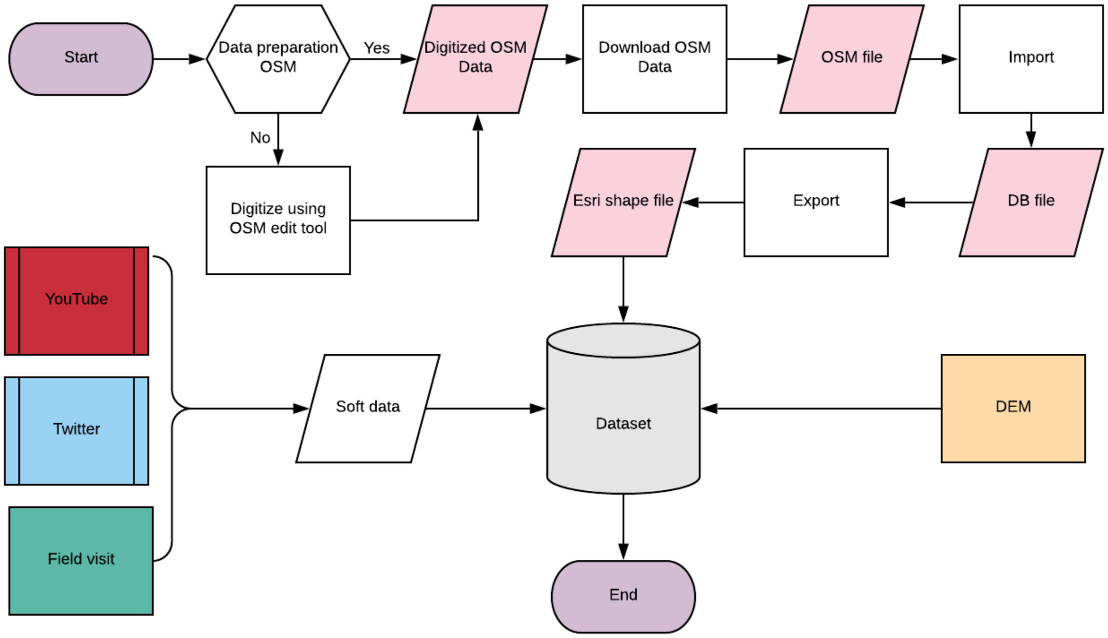


Figure 26 Data set generating process

4.3. Topographic index map

In 1979, Beven and Kirkby developed TOPMODEL, a physical base model that indicates the influence of topographic features on the hydrological response. They found a correlation between topographic parameters and the area exposed to floods (Western et al., 2002). The model has gone through improvements since 1979. Based on that model, Manfreda et al. (2008) state that the Topographic Wetness Index (TWI) relates the upslope contributing area that drains through a point and the hydrological slope at the same point. These parameters are derived from the DEM by calculating the flow direction for the hydrological gradient and the flow accumulation for the catchment area. Hence, TWI is an indicator that measures the potential on the area where water tends to accumulate to determine the areas that have more potential to be flooded. A high TWI value indicates a high potential for water to accumulate due to a low slope and/or a large upstream contributing area. A low TWI value indicates a low potential for water accumulation, due to a steep slope and/or a small contributing area.

Basically, the TWI method is used to select the optimum locations for green infrastructure. The TWI can be used to assign the area that matches a particular constraint; for instance, a city planner in Illinois uses the TWI to assign areas that need more storm water management and to re-direct flood water for groundwater recharge (Ballerine, 2017). The method also used as a preliminary study for delineation of the flood hazard area for ungauged basins. Manfreda et al. (2011) used the TWI to determine the flood hazard area in the Arno river in Italy using different DEM resolutions; they found that the performance of the method works well for a DEM with 100 m resolution or less. They also found that the method works better for basins with a high slope ratio. Moreover, a TWI map derived from high-accuracy DEM data was used with Landsat 8 and historical flood data to assign wetlands and to delineate a flood hazard area in Karawanga regency (Riadi et al., 2018). The study shows good results compared to a flood map generated by the Geospatial Information Agency in 2015. TWI is calculated using the Equation 4:

Equation 4 TWI

$$TWI = ln\ \frac{Ca}{\tan(\beta)}$$

where: Ca is the upslope contributing area per unit length of contour (catchment area divided by contour length), β is the topographic slope of the cell.

The formula is calculated based on the DEM to calculate the catchment area and curvature slope for each cell in the DEM. First, the DEM has been preprocessed by filling sinks. The catchment area is the pond area resulting from the water slides from the upslope, and the curvature slope ($tan\ \beta$) is the topographic gradient. The indicator is computed based on two mandatory parameters derived from DEM: slope and catchment area. The slope ($tan\ \beta$) is estimated using the "slope, aspect, curvature" algorithm to generate a flow direction map by determining the water direction for each cell in the DEM file. The catchment area is estimated based on the flow direction using the "catchment area recursive" algorithm, which generates a flow accumulation map that calculates the upslope contributing area. Finally, the TWI is estimated for each grid cell to generate the TWI map. Cells with similar TWI values have similar hydrological responses (Gibbs, 2017).

In this study, three flood maps were generated using the TWI method using QGIS and SAGA. First, the DEM raster file was filled, and the sinks were removed from the file. Then the three maps were created using TWI method; the first and the second TWI map was created based its flow direction method. The third map was created based on the modified catchment area method.

1. TWI map based on a single-flow direction (sfd)

   For this phase, the hydrological slope was calculated with an assumption that the water flows in one direction. Between the eight neighboring adjacent cells, the water in the cell flows toward the direction of the cell with the steepest downslope (Wolock, 1995). Therefore, the catchment area is calculated based on the D8 (deterministic eight nodes) algorithm, as water flows towards only one cell. D8 is a simple method; it does not provide an accurate image of the real flow direction, and it does not model the flow dispersion (Guang et al., 2009). Next, a TWI map is created using the Topographic Wetness Index algorithm, based on the generated flow direction map and the generated flow accumulation map.

2. TWI map based on multi-flow direction (mfd)

   For this phase, the hydrological slope is calculated with an assumption that the water flows in all directions; the slope is estimated based on the weighted average of the surrounding cells (Wolock, 1995). In this phase, the catchment area is calculated based on the MD8 (multi-flow direction) method, as the water flows from one cell to all downslope neighboring cells. This lets the accumulated area distribute from one cell to all neighboring downslope cells (Guang et al., 2009). Next, a TWI map is created using the Topographic Wetness Index algorithm based on the generated flow direction map and the generated flow accumulation map.

   Figure 27 shows the single flow direction and the multi-flow direction algorithms. Figure 28 show a TWI map for Qous basin based on single flow direction, and Figure 29 shows a TWI map based on the multi-flow direction method. The two maps represent the value of the TWI of each cell.

3. TWI map based on modified catchment area

   In this phase, a TWI map is generated using the SAGA Wetness Index (SWI), based on the modified catchment area. This algorithm is based on the multi-flow direction method; the catchment area is calculated for each cell as a function of slope β and the maximum value of the neighboring pixels in the catchment area. This smooths the value in a flat area (Böhner & Selige, 2006; Besnard et al., 2013). If the catchment area is less than the modified catchment area, then the catchment area is used, because the result is the same (Besnard et al., 2013). Figure 30 shows a topographic index map using the SAGA Wetness Index method.

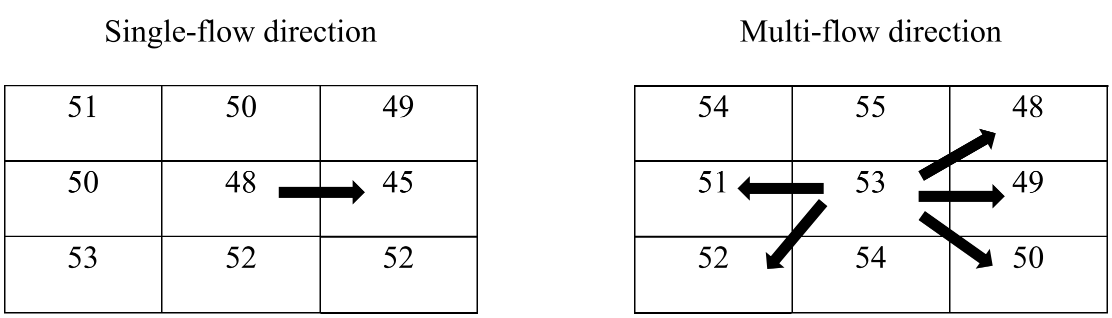


Figure 27 Single and multi-flow direction simulation

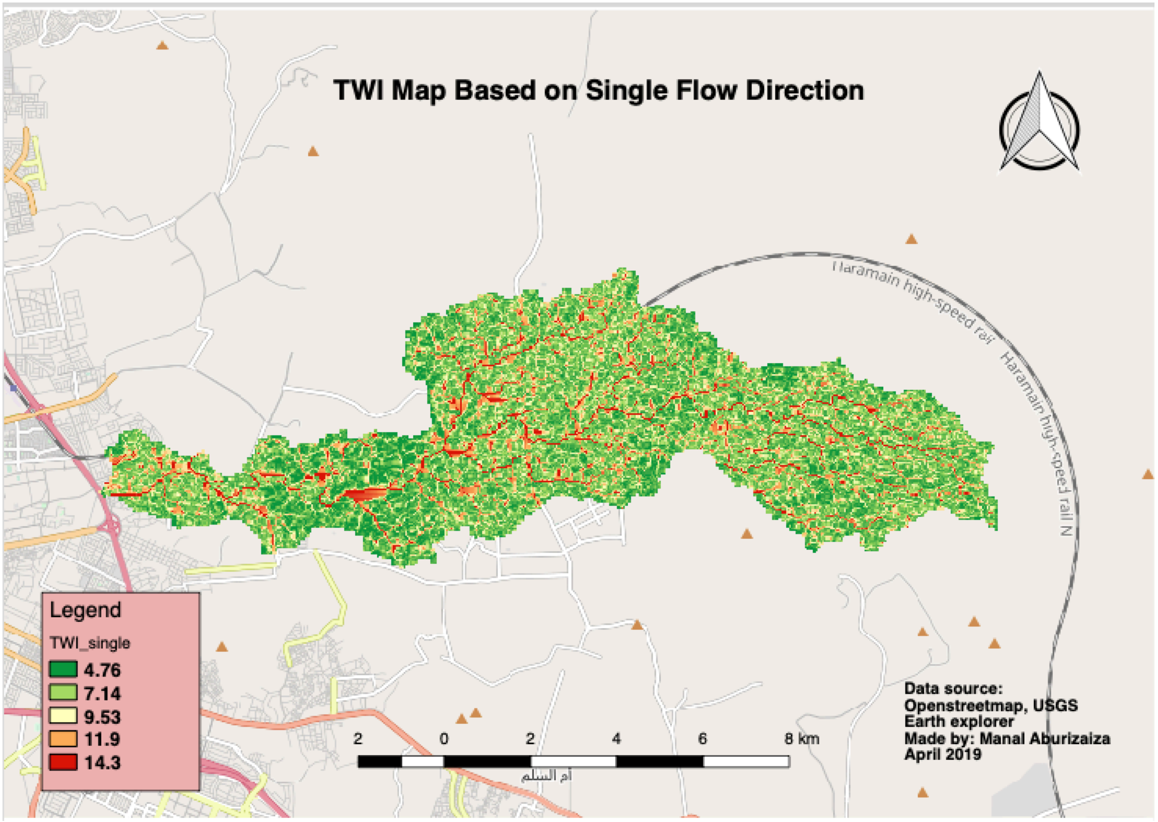


Figure 28 TWI map (single-flow direction)

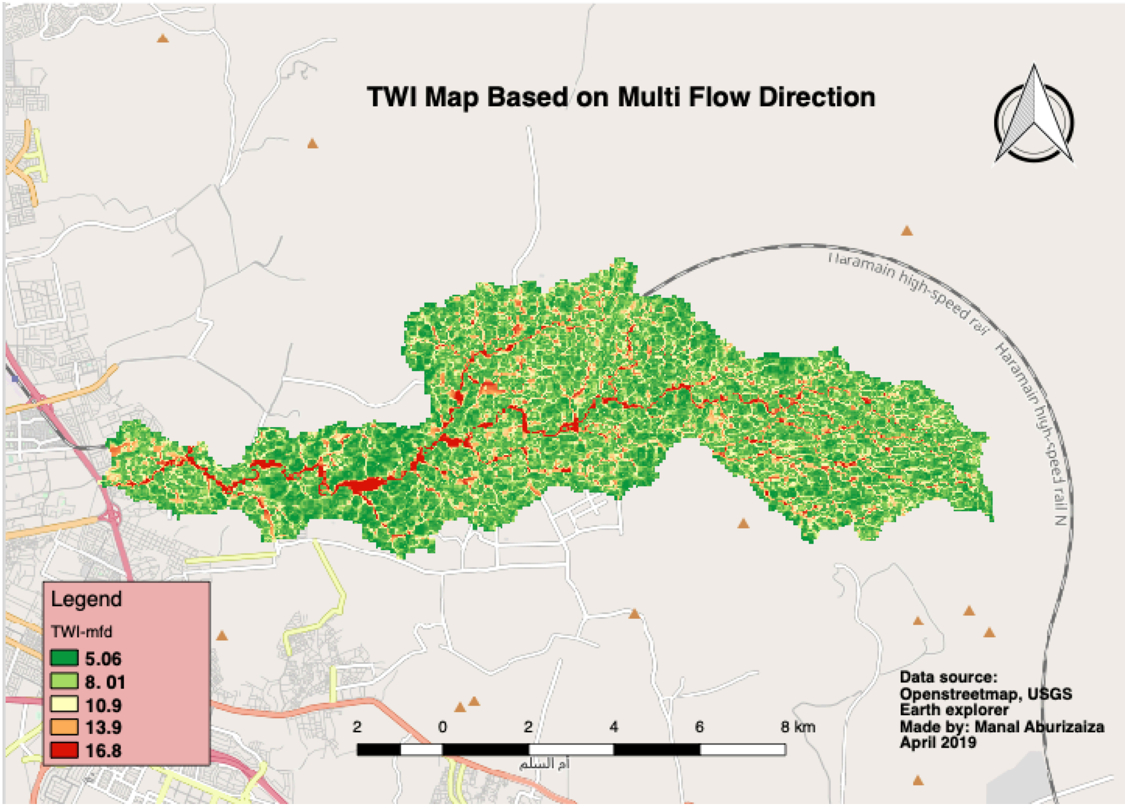


Figure 29 TWI map (multi-flow direction)

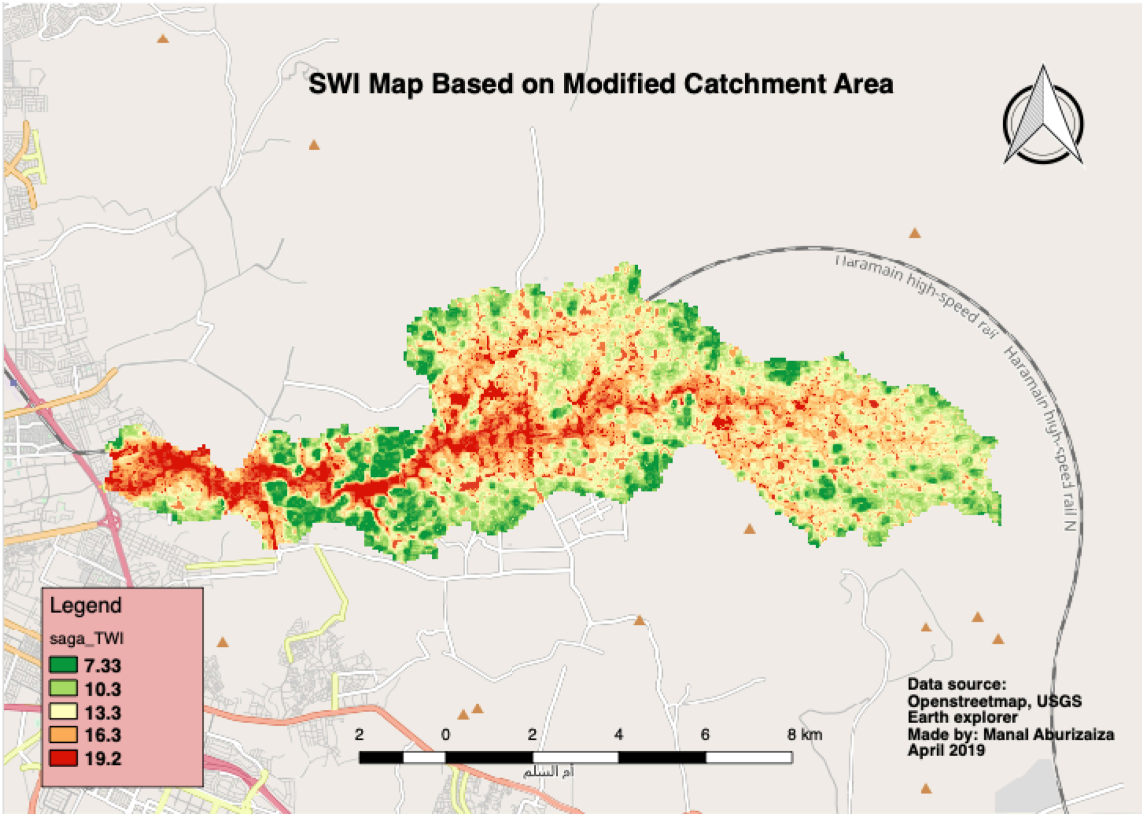


Figure 30 SWI map (modified catchment area)

Graphical modular in figure 31 describes the above TWI method. Filled DEM was used to generate the catchment area raster file based on sdf method and mfd method and to estimate the slope raster file. These files were used to generate TWI sfd and TWI mfd. The filled DEM was also used to estimate SWI based on modified catchment area. Figure 32 shows Python script for the aforementioned process.

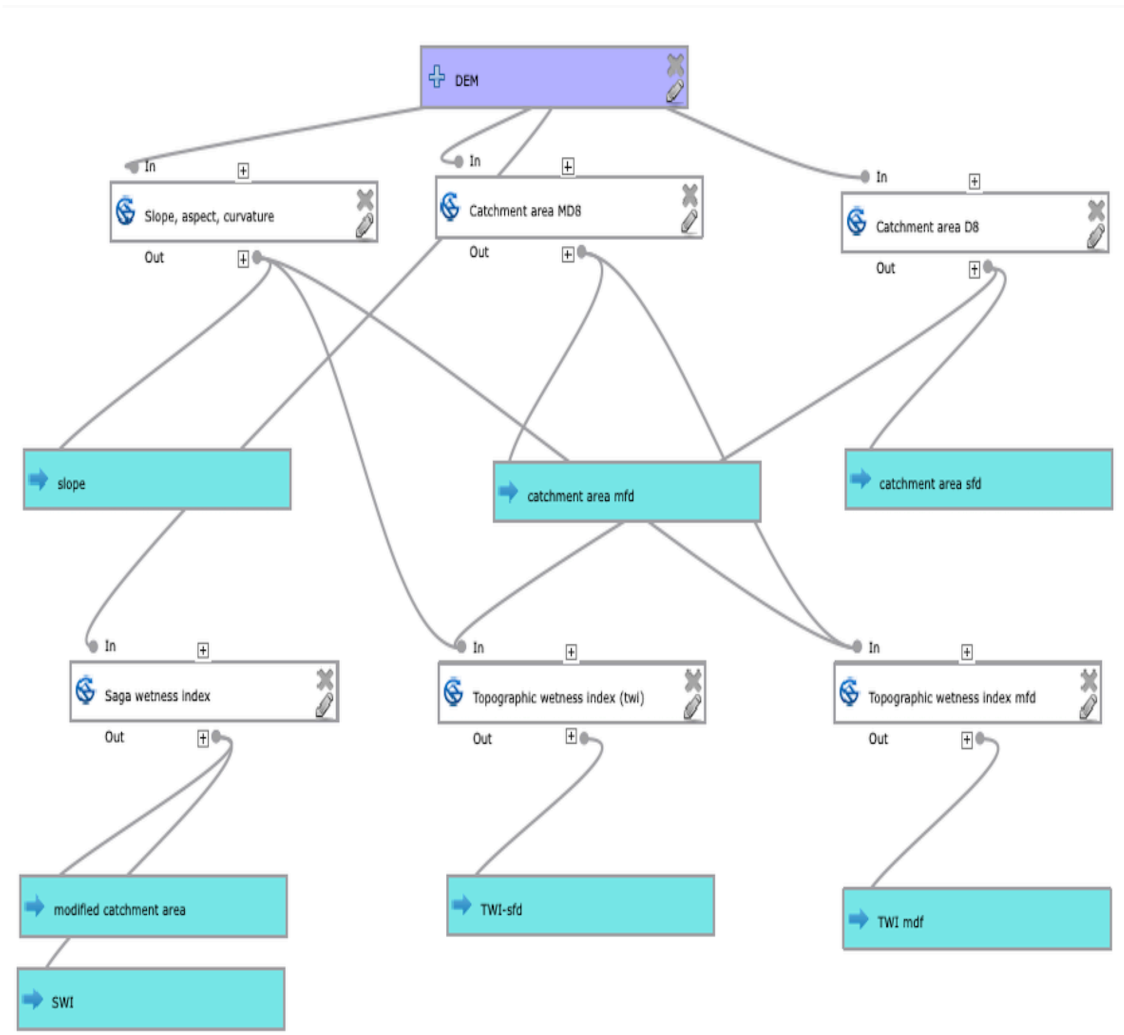


Figure 31 Graphical modeler for TWI

3TWI.py

```
##Three TWI=name
##dem=raster
##modifiedcatchmentarea=output raster
##swi=output raster
##catchmentareasfd=output raster
##twisfd=output raster
##twimdf=output raster
##catchmentareamfd=output raster
##slope=output raster
outputs_SAGASAGAWETNESSINDEX_1=processing.runalg('saga:sagawetnessindex',
    dem,10.0,0,0,0.0,0.1,1.0,3,None,None,modifiedcatchmentarea,swi)
outputs_SAGAFLOWACCUMULATIONRECURSIVE_1=processing.runalg('saga:flowaccumulationrecursive',
    dem,1,None,None,None,None,None,1.0,None,0,1.1,True,3,catchmentareasfd,None,None,None,None,None,None)
outputs_SAGAFLOWACCUMULATIONRECURSIVE_2=processing.runalg('saga:flowaccumulationrecursive',
    dem,1,None,None,None,None,None,1.0,None,3,1.1,True,3,catchmentareamfd,None,None,None,None,None,None)
outputs_SAGASLOPEASPECTCURVATURE_1=processing.runalg('saga:slopeaspectcurvature',
    dem,6,0,1,3,slope,None,None,None,None,None,None,None,None,None,None,None)
outputs_SAGATOPOGRAPHICWETNESSINDEXTWI_1=processing.runalg('saga:topographicwetnessindextwi',
    outputs_SAGASLOPEASPECTCURVATURE_1['SLOPE'],outputs_SAGAFLOWACCUMULATIONRECURSIVE_1['FLOW'],None,1,0,3,twisfd)
outputs_SAGATOPOGRAPHICWETNESSINDEXTWI_2=processing.runalg('saga:topographicwetnessindextwi',
    outputs_SAGASLOPEASPECTCURVATURE_1['SLOPE'],outputs_SAGAFLOWACCUMULATIONRECURSIVE_2['FLOW'],None,1,0,3,twimdf)
```

Figure 32 Python script

4.4. Uncertainty

Prediction in ungauged basins, especially in developing countries, is commonly associated with uncertainty. Understanding the source of uncertainty greatly assists in predicting and reducing the degree of uncertainty. The following are the expected sources of uncertainty in this study:

1. Data Uncertainty: Data has been always an issue in most research, particularly in applied research. Researchers usually face problems in obtaining the appropriate at the right time and place (Spatial and temporal). This problem occurs from three different perspectives: Availability, Accessibility, and Validity.

    1.1. *Availability*: A considerable quantity of required data for most of the research is not readily available in developing countries, which pushes researchers to look for alternative source such as the World Bank and/or United Nations and all relevant branches to obtain missing data. However, such data, rather than the actual local data, creates considerable uncertainty in the output of the model. Furthermore, if data is not even available from the World Bank or the United Nations, proxy variables where the data is available is used to represent or to replace missing variables. For example, if we assume that the Void Ratio is needed as a variable in a proposed model and adequate data about the Variable Porosity is available, the porosity could be used instead of the Void Ratio. The Void Ratio will be regressed on porosity to create a relationship between them to estimate the Void Ratio from the available data of porosity. Alternatively, this model could be used as a sub-model of the main model. Remote Sensing data can also be used to obtain missing data. In fact, the most important characteristics for a given dataset are not necessarily the quantity of available data, but the quality of available data (Sorooshian and Gupta, 1983). Therefore, the first recommendation of this study is to increase the focus on building data systems in the aforementioned countries, because, although costly, the results are invaluable.

1.2. *Accessibility*: Due to heavy regulations in aforementioned countries, required data is often inaccessible, even though it is available. However, this data is almost public data and has nothing to conceal (Hidden). For example, hydrological, meteorological, and soil data are difficult to obtain, which sometimes forces researchers to select models that fits the available data. Such a selection can create and develop uncertainty in the model output. This study recommends classifying data into different categories, and then clarifying the regulation for each category.

1.3. *Validity*: Invalid data is not uncommon in developing countries. Sometimes it even goes further as the researcher find some data are fraud (made up by human). Thus, every researcher must be very careful before using the data. Checking the validity of the data becomes a must, because invalid data will give generally invalid output. My recommendation, that agencies who are in charge of collecting, analyzing and recording data pay more attention in collecting and validating data.

2. Uncertainty Due to Spatiotemporal Heterogeneity among the Physical Characteristic of the Basin (Wadi), Landscape, and Metrology: Usually, the mean value of the aforementioned parameters are considered (used) in the proposed models, and since the variation among values of these parameters is significant, uncertainty increases. To reduce the degree of uncertainty, additional sections will be taken between reaches along the basin (wadi). Experience with the local area plays a predominant rule in assigning locations and numbers of sections along the basin, and therefore, local experts in Hydrology will be consulted to make use of their experience. Unfortunately, the high cost of this endeavor is an issue. A Benefit Cost Analysis may need to be conducted to determine the number of the sections. For example, in this study, most of the basins in Jeddah city extent to around 100 km, beginning with a highly-elevated mountainous upstream (approximately 2,000

meters). All these wadis finally discharge into the Red Sea. The slope of the mountainous area is steep, while the coastal area (plain) is flat. Similarly, in the upstream areas of the basin, the landscape is a mixture of boulders and gravel, which gradually turns into coarse sand towards the middle of the stream and a mixture of fine sand, silt, and clay in the downstream areas. Moreover, average annual precipitation in the upstream areas of these basins ranges between 250 and 350 mm, while in the downstream areas, it ranges between 50- and 80-mm. Humidity also decreases from 30 to 40 percent in upstream areas, while it increases to 90 percent in downstream areas.

3. Uncertainty Due to Human Error: Knowledge, experience, and background of researchers greatly affects the quality of work. Unfortunately, the knowledge of technicians in most developing countries is relatively low, which, consequently, decreases the quality of the output. For example, sampling and testing water from certain areas requires an experienced technician that knows precisely when, how, and where to collect, preserve, and store water samples in order to carry out the necessary tests at the laboratory to estimate values of certain parameters. Also, measurement errors increase the degree of uncertainty. In fact, the degree of uncertainty depends highly on the physical ability and experience of the technician taking the measurements. Automating some of these steps can help minimize human error in measurements. Errors also might occur from reading, rounding and/or printing.

4. Model Uncertainty: Selecting the appropriate model is sometimes not possible due to one or more of the aforementioned data deficiencies such as insufficient and/or invalid data. As previously mentioned, proxy variables for the dropped variable might be used, or a modification in the proposed model can be made to make it more applicable. Such actions, however, may create uncertainty in the model and alter the output. Moreover, sometimes multiple regression with certain variables is appropriate for a certain study, but the absence of sufficient data of certain independent variables will force the modeler to drop out that variable, creating uncertainty in the structure of the model. Another source of uncertainty occurs when the basic assumption of the regression model may not be met /valid, such as the linearity of the model. In such cases, a non-linear model may be introduced to reduce the uncertainty. Additionally, the distribution of data of certain variables does not fit a well-known distribution and forcing this data to fit a certain distribution can create a high level of uncertainty. In such cases, nonparametric tests might be used to overcome this problem, which does not assume a particular underlying theoretical population distribution.

5. Uncertainty Due to Unsuitable Regionalization: Transferring hydrological information from gauged basins with similar hydrological characteristics to ungauged basins to estimate stream flow can also create uncertainty. Even with similarities between the gauged and ungauged basins, hydrological differences such as evaporation, soil type, slope, and other factors will result in model uncertainty.

Thus, it is important to choose the suitable regionalization technique to reduce the overall degree of uncertainty.

5. RESULTS & DISCUSSION

The analysis of the soft data (Twitter posts, YouTube videos and their comments, field trip photos and observations) focuses on two main domains: identification of terms used in texts such as Twitter posts, and comments with potential semantic value related to flood information and identification of geographic locations. Semantic values are identified using the aforementioned keywords, which represent flood parameters and sign locations.

The above SQL script extracted only nine rows that contains some of the keywords. However; no textual information was obtained from the English Twitter data, because most of the tweets contain the keywords (flood, flash flood, flashflood) but not related flood information. Table 9 displays the output of the SQL script that presents the tweet's text and the post's geolocation.

Table 9 Output of Twitter SQL script

Tweets' text	Coordinate
شاركونا صور او فيديوهات 🚧🌧️. امطار_جدة | #نفق_الملك_فهد في #جدة ظهر اليوم# #الامطار مع ذكر اسم الحي اسفل هذه التغريدة. #جدة_الان https://t.co/ThQIHKQFvh	21.58110, 39.182985
RT @Saudi_Gazette: #Jeddah rains flood streets, met office near airport hit by lightning — https://t.co/cZGxQEv247 #JeddahRain…	23.917551,45.081057
RT @sadeem_wss: Flood report: peak of 20 centimeters of water in Butterfly Lane (Garden area) of @KAUST_News at 6:20 am today Novem…	21.48168, 39.18286
RT @alimhaider: @M_Bonasser We even put up signs now, wherever roads flood: Turn Around, Don't Drown. No one pays them any attention.	24.64732, 46.714581

The first tweet contains the word "neighborhood" in Arabic language format, but it doesn't give any information about the flood location, though the user encourages other twitter users to share their observations and provide spatial information. The second tweet contains the keyword "street" and the keyword "near", which estimate a zone of flood extent next to the airport northwest of Jeddah city. However; the geolocation of the re-tweet's post located in Riyadh city, which doesn't support the estimation of the flood location in Jeddah city. The third tweet gives an estimation of water depth as 20 centimeters, and the user specifies the location as Butterfly Lane, which is located in the city of Thuwal. The geolocation of the retweet posted in Jeddah city. The last tweet gives no information related to the flood, though it has the keyword street and the geolocation of the posted tweet is in Riyadh city.

It is important to notice that social media data cannot be considered as reliable information, because a user can use the same synonym for different meanings see Table 10. For example, in this case a retweet post “flood kita in any way” contains the word "flood", but the user refers to the hashtag #MissUniverse #Philippino, which is a totally different subject. For the second tweet, the user refers to another flood that occurred within the same time period in another city in Saudi Arabia.

Table 10 Unrelated flood tweets

RT @gooodviibeess: REPLY TO THIS TWEET WITH THIS: #MissUniverse #Philippines FLOOD KITA IN ANY WAY!!! https://t.co/yoRJE5Zarw
First rainy expi in Riyadh. Overwhelming indeed. No to heavy flood and traffic. □üôè□üôè Masarap sana,Ä¶ https://t.co/T3I9vIW8Kl

In this study, YouTube was more useful for gaining information than Twitter, because Twitter data was filtered and harvested using only English keywords, while YouTube was filtered and harvested using both Arabic and English keywords. Moreover; based on Statista (2017), YouTube is the second-most popular social network in Saudi Arabia with a 71% penetration rate, while Twitter has a 52% penetration rate.

For the first phase, there were 83 points for YouTube and only 42 points for Twitter. Therefore, manual search was used to obtain more Twitter data to support the resulting map. The search was mostly focused on the 2009 flood and related to the study area. Different key words were used for that, all of them in Arabic language format. In addition to that, the corresponding Islamic Hijri year of 1430 was used as a search keyword in both languages, because the Hijri calendar is used more than the Gregorian calendar in Saudi Arabia. After that manual search, the number of Twitter data increased from 42 to 87. It is important to notice that most of the new tweets were posted later than 2009, but they were related to the Jeddah flood of 2009.

In Twitter data, Abrug-Alraghamah and Quaiza were the most-mentioned neighborhoods, and Faraman and Jack Streets were the most-mentioned streets. The two streets are in proximity, and both are located in the aforementioned neighborhoods. The two neighborhoods are located in the east side of the basin, close to the outlet. The neighborhoods have a high population, and most of the people who live there are low-income people. A slum area also exists within the area, which make it more vulnerable to flooding.

The flood extent in Qous basin was obtained based on tweets' texts and Twitter-posted photo, but flood depth was not obtained, since no information related to flood depth was found in this Twitter data set. The example in Figure 33 shows a posted tweet with a photo that presents the name of the street and the neighborhoods.

Figure 33 Twitter post with flood location information

YouTube videos were used to obtain qualitative and quantitative information. Videos represent flood extent and depth by recognizing the contents of the videos, while videos' titles and comments also provide literal information for depth and location as well. It also gives an indication of the social sentiment within the area, which will not be covered in this study. It is important to notice that downloading YouTube videos is illegal, and it is only for viewing purposes. However, this might be a problem for further research, because some videos are removed by the uploader.

For example, one video's title (....... سيول جدة حي قويزة مالاتصدق.mp4) gives the name of the neighborhood (Quaza), which is located in Qous basin, and one of the comments also provides the same neighborhood name. The uploader provided audio information by specifying the location with the name of the neighborhood, and he estimated the flood depth he observed as three to four meters. The contents also give an estimation of the flood depth: some people were standing on something in the area designated to hold the air-conditioning unit for the first-floor apartment, and that gives an estimation of a depth of 1.5 meters. Figure 34 shows two snapshots from the video that show the location and the clue for estimated flood depth. The figure presents a comment that mentions the name of the neighborhood, and he also described the situation of his school on that day in the same neighborhood during the flood.

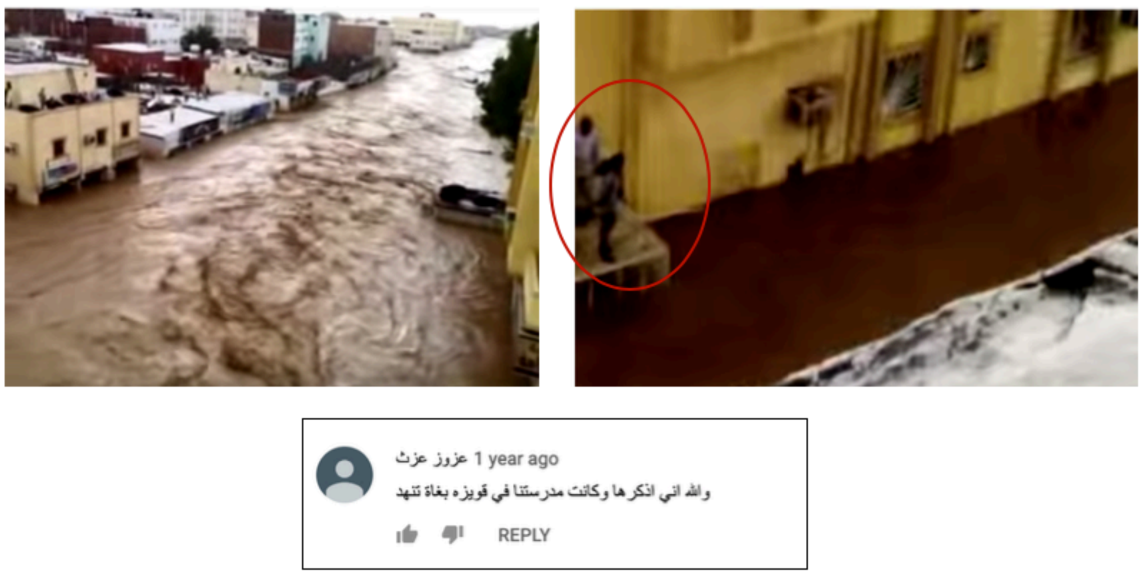


Figure 34 Flood information obtained from the contents and watchers' comments

Another YouTube video also shows a flood in Jack Street in the Quaza neighborhood, as stated by the watcher’s comments and the contents. Six comments mentioned the location of the video and three clarified that the Quaza neighborhood is located in the middle of the basin. Figure 35 shows that the comment text determined almost the exact location, as the watcher determines the location by his school name. The other comment also specifies the neighborhood, and it also explains that the problem is that the neighborhood is in the middle of Qous basin. This neighborhood was one of the areas most affected by flooding. Within this Jack street area, there are three elementary schools and one middle school; these make the area very high risk, due to the large number of children and the narraw, disorganized street. From the contents of the video, the water almost covers a Jeep car; this gives a depth estimation of 1.5 meter. During the field trip, two water marks on Jack Street also give almost the same estimation. The presenting of the schools in the video also assists with determining the flood location.

Social media information has a high probability of uncertainty. This study attempted to reduce the uncertanty of the data by visiting the locations on the videos and comparing the locations with their comments for more validation. One of the errors captured, shown in in the first tweet in Figure 35, was found when the user states that the school on the right in the video contents is Prince Majid School. During the field visit, it was found that the school is one kilometer away from the loction that is shown in the video. Figure 36 shows the geolocation of the comment’s video and a red paddle indicating the geolocation of Prince Majid School.

Figure 35 YouTube comments that determine flood location

Figure 36 The geolocation of the video and the geolocation of the school

There are also several YouTube videos related to the Jeddah flood that were frequently mentioned, but they were out of the basin's boundary, for example, the King Abdullah tunnel. The street sign in the screenshot of the YouTube video facilitates digitizing the photo to its appropriate location on the map. Moreover, comments and other textual contents regarding the video also provide information for this video. (**jeddah Rain Disaster امطار جدة - غرق نفق طريق الملك عبدالله**) provides the location of the attached video. One of the users' comments for this video also provides information regarding the location and flood depth: the comments mentioned the name of the tunnel and also describe that the tunnel is fully flooded. Based on data from the Ministry of

Transportation, the height of the tunnel is about 5.5 m, which gives an estimation of the flood inundation of that flooded area equal to 5 meters, Figure 37.

Figure 37 Flood information obtained from the video's contents

Based on the result, YouTube data was mostly clustered in the western part of Qous basin. The Quaiza and Abrug Alrughama neighborhoods, Jack street, and Al Haramain road were mostly mentioned literally and visually. There were also clustering data within King Abdullah road and tunnel, but that is beyond the boundary of the study area. Thus, the flood inundation map was derived from YouTube data that determined the Quaiza and Abrug Alrghama neighborhoods as a flooded area with an average of 1-1.5-meter water depth. However, these neighborhoods have a high-density population with unorganized urban planning and a slum area in the south of the neighborhood. The Al-Haramain road was also determined to be a flooded area, with an average flood depth of 1 meter.

All three layers of the soft data were added to the Qous basin vector layer to determine the flood extent based on qualitative information obtained from peoples' observation and knowledge. For Qous basin and from the maps that present the distribution of YouTube and Twitter data in Figure 22 and 25 in Chapter 4, there is a data clustering in the west side of the basin. It is in the downslope close to the outlet of the watershed; that makes the area have more potential for water accumulation.

The existing of social media data posting in the west side rather than the other places is because the flood happened on 2009; from Figure 5 in Chapter 3, the urbanization pattern goes from east to west, and there is more population in the east side than the west. In addition, from observations in the field visit, most of the buildings on the western side are fenced land, where a few people live with their animals; some of the existing buildings there have no residents, as these buildings are mostly used as a party hall for reservation.

Figure 38 is a map the presents the distribution of the soft data in Jeddah city and specifically in Qous basin. YouTube and Twitter data mostly match similar flood locations based on observations during flood time, while field visits added several nearby locations based on clues from observations and resident experience from the area not flooded.

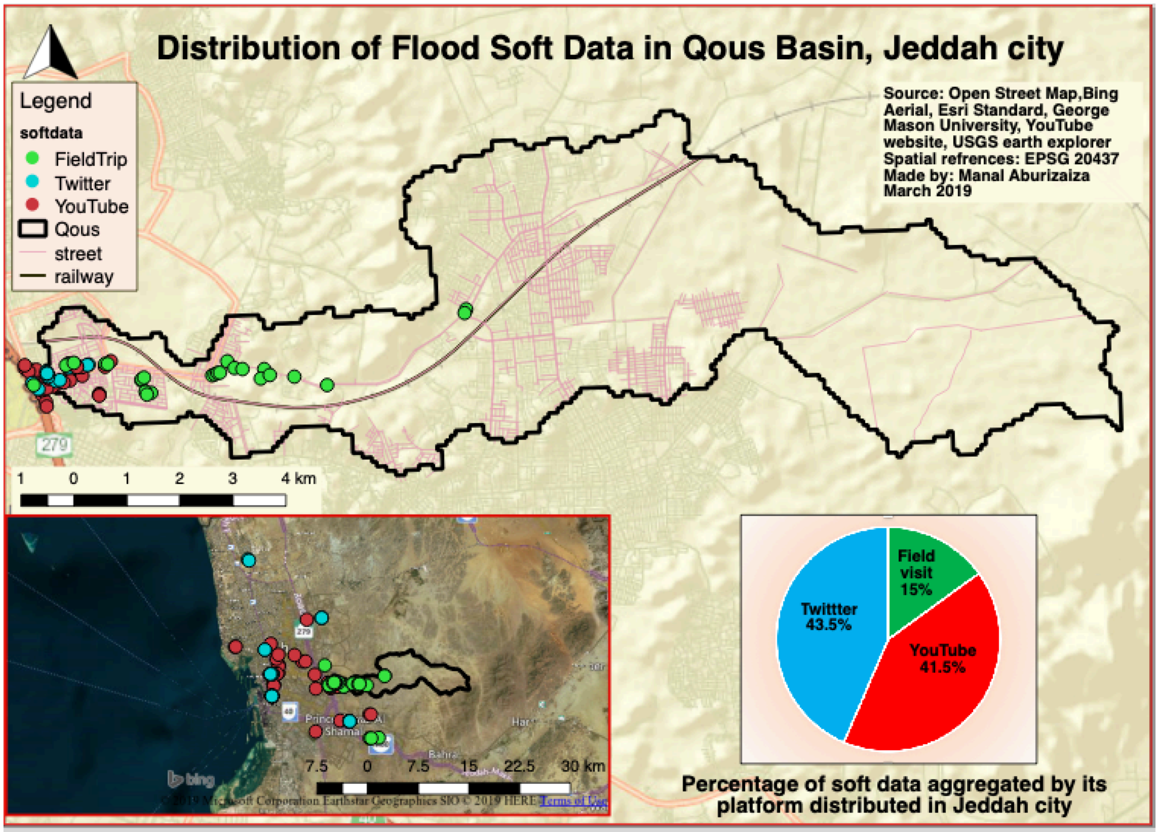


Figure 38 Distribution of soft data in Qous basin and Jeddah city

The rapid development of GIS technology enable researcher to develop distributed model rather than lumped model. Basically, it represents the spatial variation of hydrological response within the watershed with less effort (Carpenter et al.,2006). Topographic Model (TOPOMODEL) is a distributed model that uses the relationship between different points in a catchment and their hydrological similarity. The main purpose of this model is to predict the distributed response of catchment to the rainfall.

TOPOMODEL is a simple model with few parameters, this makes it easy to use and apply by engineers and planners. Other models with more parameters may provide better results but it does not fit the Saudi condition due to data limitation. However; it has three basic assumption:

1. The hydraulic gradient is approximated by the general slope of the ground surface.
2. The rate of the flow is assumed to be in a steady case through cross section of the watershed
3. The transmissivity is assumed to distribute exponentially with the depth.

In fact, soil is heterogenous throughout the basin and transmissivity is based on soil type and characteristics, and on the depth of the ground water table. This assumption can be valid only if the soil is homogenous throughout the basin. These assumptions might cause error and affect the result. However; the mis-planning in the study case disturb the natural stream and the rout of the flood as some urban area located within basin streams. The generated Topographic Wetness Index (TWI) maps display the distribution of the hydrological response before the planning. Therefore; soft data is used to support the maps and to displays the situation after the planning.

Soft data layer, street layer and railway layer were all added to each TWI map to determine the flood prone area. The three maps were compared using r.report method that generate a statistic report for each TWI raster file. The data of each raster file were classified in to four groups by its percentage value and by the accumulated area in k^2. Figure 39, 40, and 41 shows TWI Single Flow Direction (sfd), Multi Flow Direction (mfd) and SAGA Wetness Index (SWI) map respectively associated with the soft data in

Qous basin. Table 11 displays the covered area of each category and Table12 shows the percentage of the total area of the three TWI raster files.

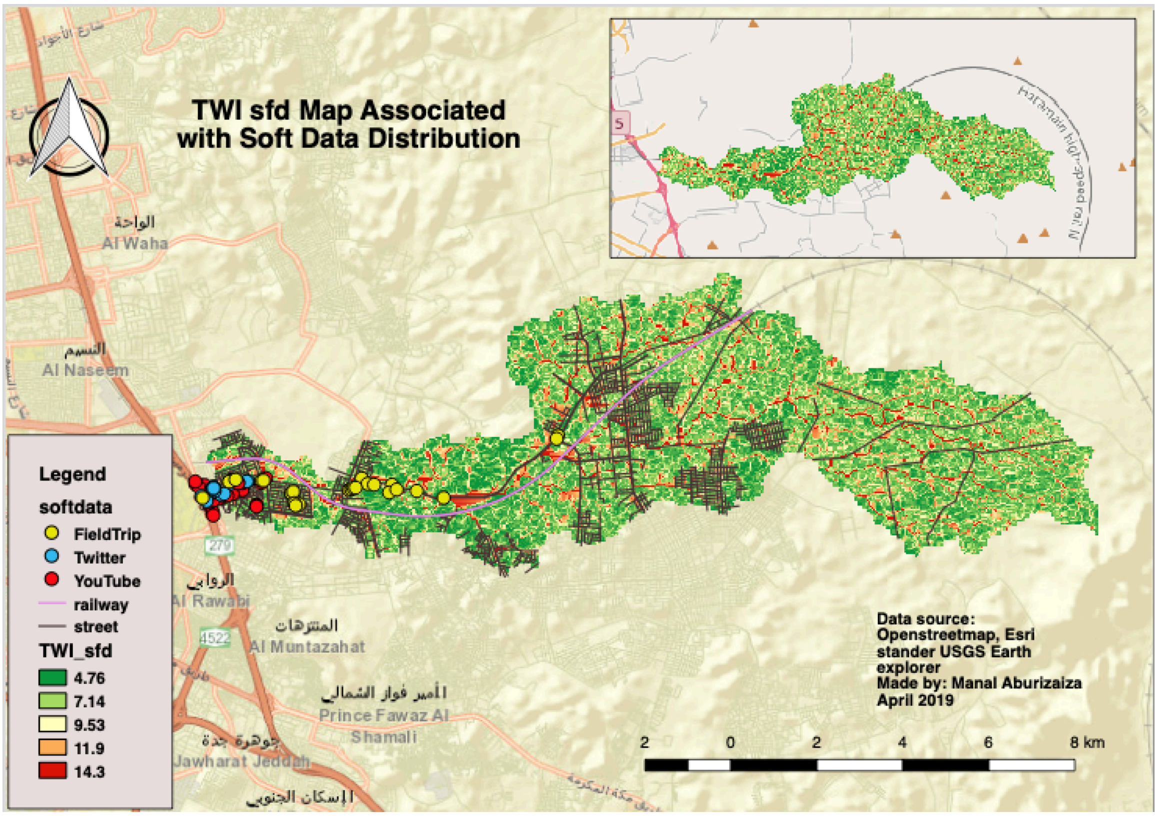


Figure 39 TWI sfd map and TWI sfd map associated with soft data distribution

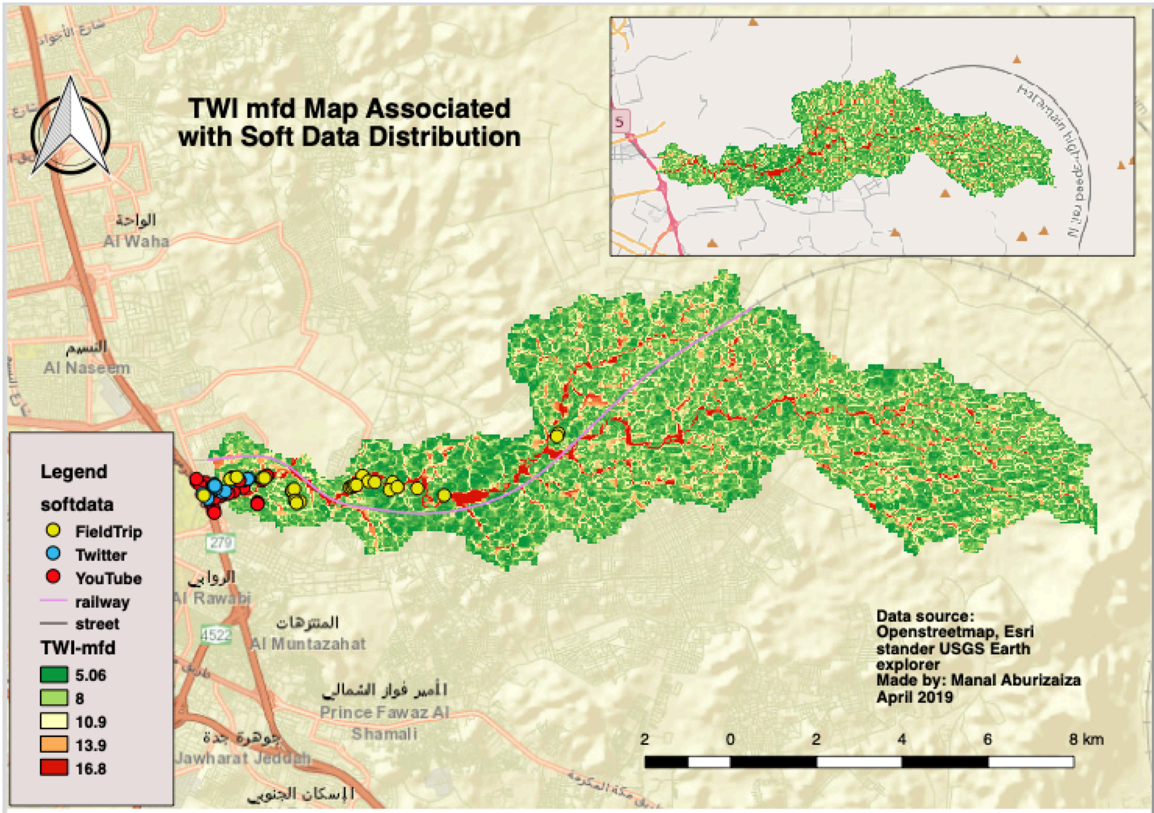


Figure 40 TWI mfd map and TWI mfd map associated with soft data distribution

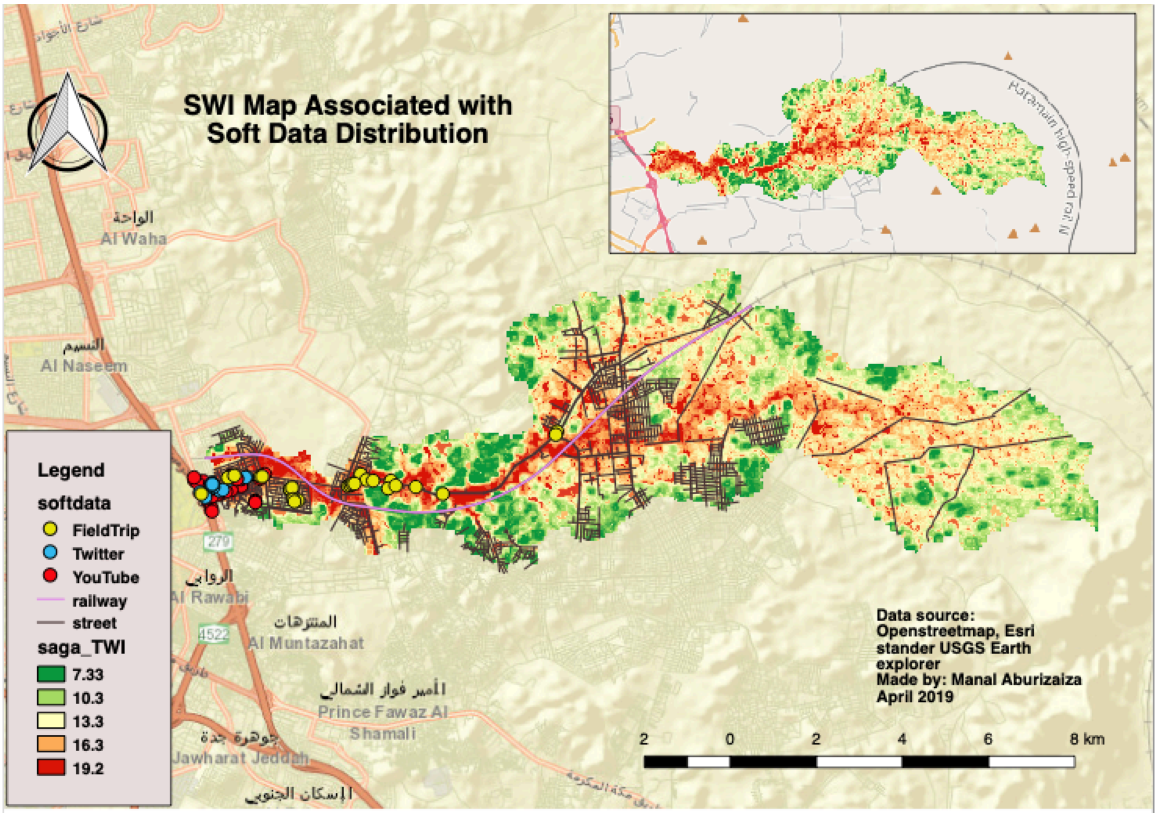


Figure 41 SWI map and SWI map associated with soft data distribution

Table 11 Area of each category in TWI maps

Category			Area/ square kilometer		
TWI sfd	TWI mfd	SWI	TWI sfd	TWI mfd	SWI
3.63– 8.04	3.74 – 8.11	5.49 - 9.68	48.704	46.102	9.171
8.04 - 12.447	8.11 - 12.48	9.68 - 13.86	14.54	14.158	27.435
12.44 - 16.58	12.48 - 16.85	13.86 - 18.04	3.966	6.217	25.414
16.58 - 21.25	16.85 - 21.22	18.04 - 22.23	0.62	1.353	5.81
Total			67.832		

Table 12 Percentage cover of each category in TWI maps

Category			Cover %		
TWI sfd	TWI mfd	SWI	TWI sfd	TWI mfd	SWI
3.63 – 8.04	3.74 – 8.11	5.49 - 9.68	71.8	67.96	13.52
8.04 - 12.447	8.11 - 12.48	9.68 - 13.86	21.44	20.87	40.45
12.44 - 16.58	12.48 - 16.85	13.86 - 18.04	5.85	9.17	37.47
16.58 - 21.25	16.85 - 21.22	18.04 - 22.23	0.91	2.00	8.57
Total			100		

The spatial distribution of the topographic index in the three TWI maps is linked to the used algorithm for estimating the flow direction and the flow accumulation. Based on the tables and the above figures, it is found that TWI sfd map gives less potential of water accumulated due to the nature of the single flow direction as the water move towards a single direction.

The highest category value of TWI covers less than 1% of the total area, it covers 71.8 % of the total area for the lowest category value of TWI. Though TWI mfd give also low potential of water accumulated, it gives higher percent in the high category value of TWI then TWI sfd. TWI sfd in the third and fourth category covers 5.85% and 0.9% respectively of the total area, while it covers 9.17% and 2% for TWI mfd for the same categories. This is due the multi flow direction method where the water flow to all downslope directions. However, the first and the second category has no significant changes between TWI sfd and TWI mfd.

The index value for TWI sfd map and TWI mfd map is associated with the Strahler topological order. Area with high index value where the area has high potential of water accumulated is associated with low tributary rank order. Area with low index value where it estimates a low potential of water accumulated is associated with high tributary rank. Figure 42 show the basin network with the TWI map.

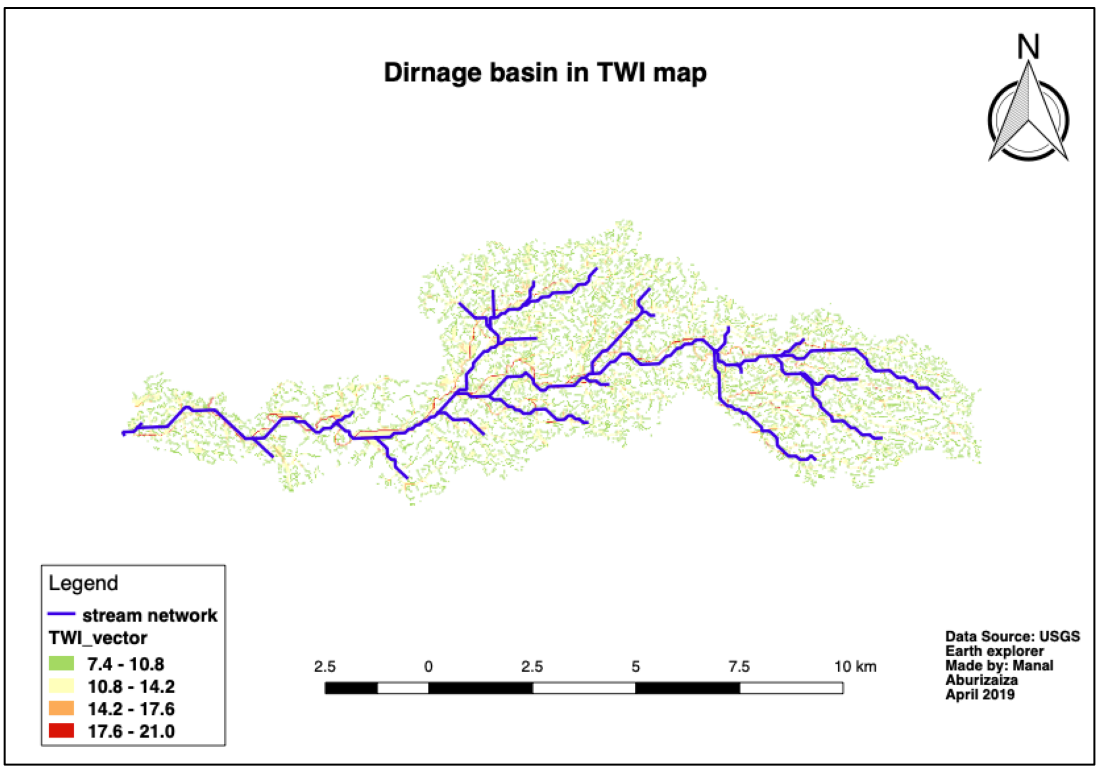


Figure 42 Basin networks in TWI map

SWI gives the highest potential of water accumulated between the three methods, it reaches 8.57% for the fourth category and 37.47 for the third category. This is due to the modified flow accumulation method.

The distribution of the soft data related to flood location in TWI sfd map and TWI mfd map doesn't highly match the distribution of the high index value especially the fourth category. For example, the index value for TWI sfd and TWI mfd map in area of Quaza neighborhood ranges between 5 and 12 with lower value, this area was highly mentioned with posts (videos and photos) in the social media data because it has three schools and people highly mentioned the danger of such situation for students. This mismatch is due to mis-planning, where this neighborhood located beside the main channel, and the urbanized area in the channel disturb the water flow.

For SWI map, the location of the posted soft data highly matches the location of the high index value within the map. For example, Faraman street which was highly affected by the flood and also was mentioned by Twitter and YouTube, has a high value index which gives a high potential of water accumulated and more potential of flooded area.

The field visit data was mostly matching the area with high potential water accumulated in the three maps, except one area. The index value of this area ranges between 5 - 14 for TWI sfd, between 6 – 14 for TWI mfd and 12 – 18 in SWI map. This area was mentioned because it has two elementary school, one middle school and one high school which should be taken in to consideration especially because it close to the outlet and 400 meters near to the main tributary.

Based on the three TWI maps and on the soft data distribution map, SWI map gives a good determination of the flood extent in Qous basin among the three TWI method. The flood extent was delinated using soft data which determines the flood area in the area with a high index value. Such method is an appropriate initial method in this study to delineates flood hazard areas for an ungauged basin with limited data source.

The distribution of the soft data about the flood has a greater concentration on the west side of the basin, where the urban area exists. Users posted their communications in areas that reflected hazard situations; such areas were more likely to be located in an urban area, as people are more likely to live there. The urban area is vulnerable to flooding due to the low infiltration rate in that area, as discussed in Chapter Three. Moreover, the urban area in the Qous basin is more vulnerable to flood damage due to several aspects of the unplanned urbanization: streets are very narrow, making them inaccessible to emergency services; streets have no sidewalks; and the elevation of the land for buildings is the same as the elevation of the street. In addition, some areas in Qous basin are slum areas, where the number of residents occupying each house exceeds the legal limit, and most of the neighborhoods are not in the sewerage system.

The above-mentioned elements make the residential area in Qous basin more vulnerable to flooding. For this study, flood-prone areas were determined for the urban area based on the urban density (exposure) and the topographic wetness index value (hazard) of the watershed. The urban density map was created based on the residential vector layer; it was generated as a heatmap to determine the urban density value in Qous basin. The urban density map and the SWI map were both normalized using the raster normalization method to have the same range of values for each map. Figure 43 and Figure 44 represents the normalized urban density heat map for Qous basin and the normalized SAGA wetness index map for Qous basin respectively.

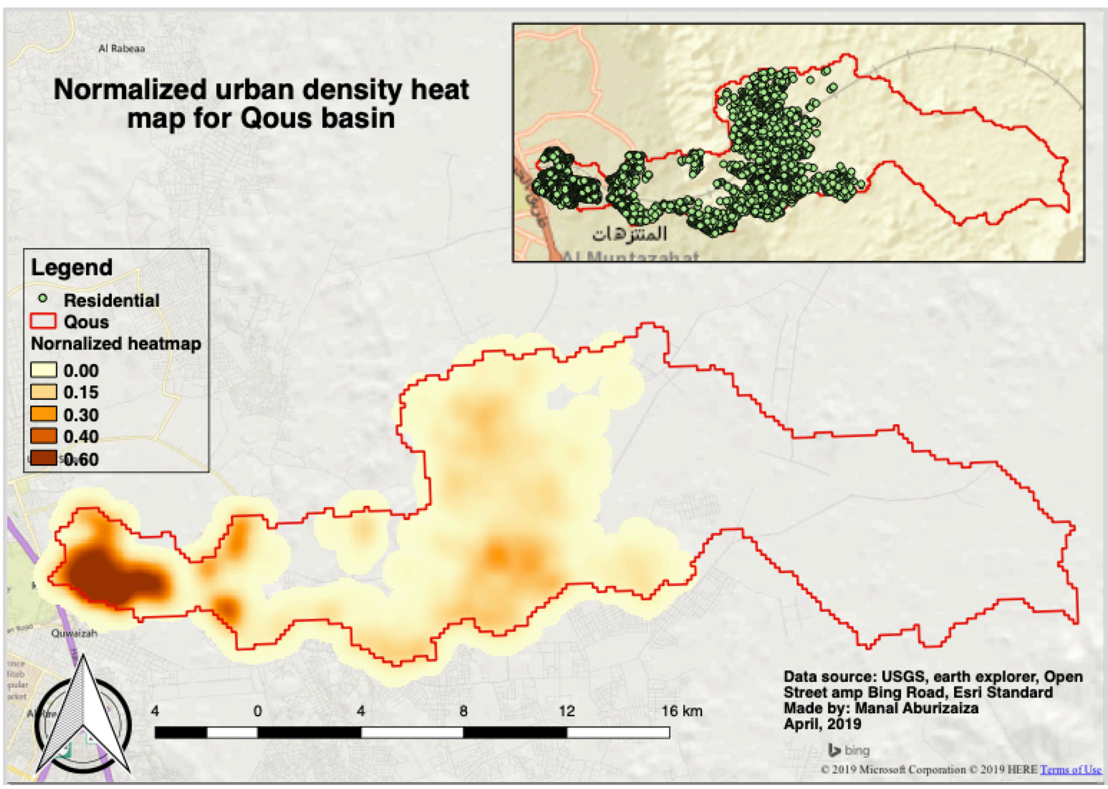


Figure 43 Normalized urban density heat map for Qous basin

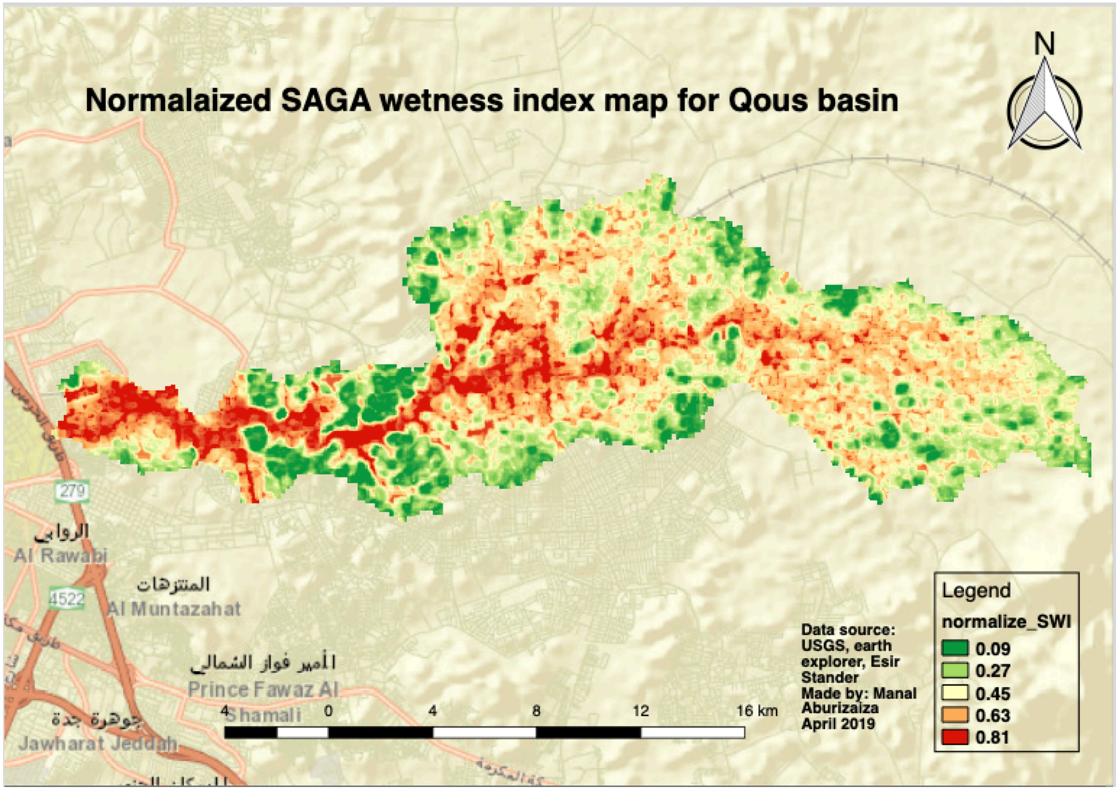


Figure 44 Normalized SAGA wetness index for Qous basin

The two maps were overlaid to create a risk map that shows the risk level; the risk level was determined by multiplying the exposure by the level of hazard. Then The soft data layer was overlaid to the risk map of the flood hazard area based on qualitative information and the flood hazard for a location was determined based on the level of risk and the interpretation of soft data information. Figure 45 represents the risk area for the urbanized area in Qous basin.

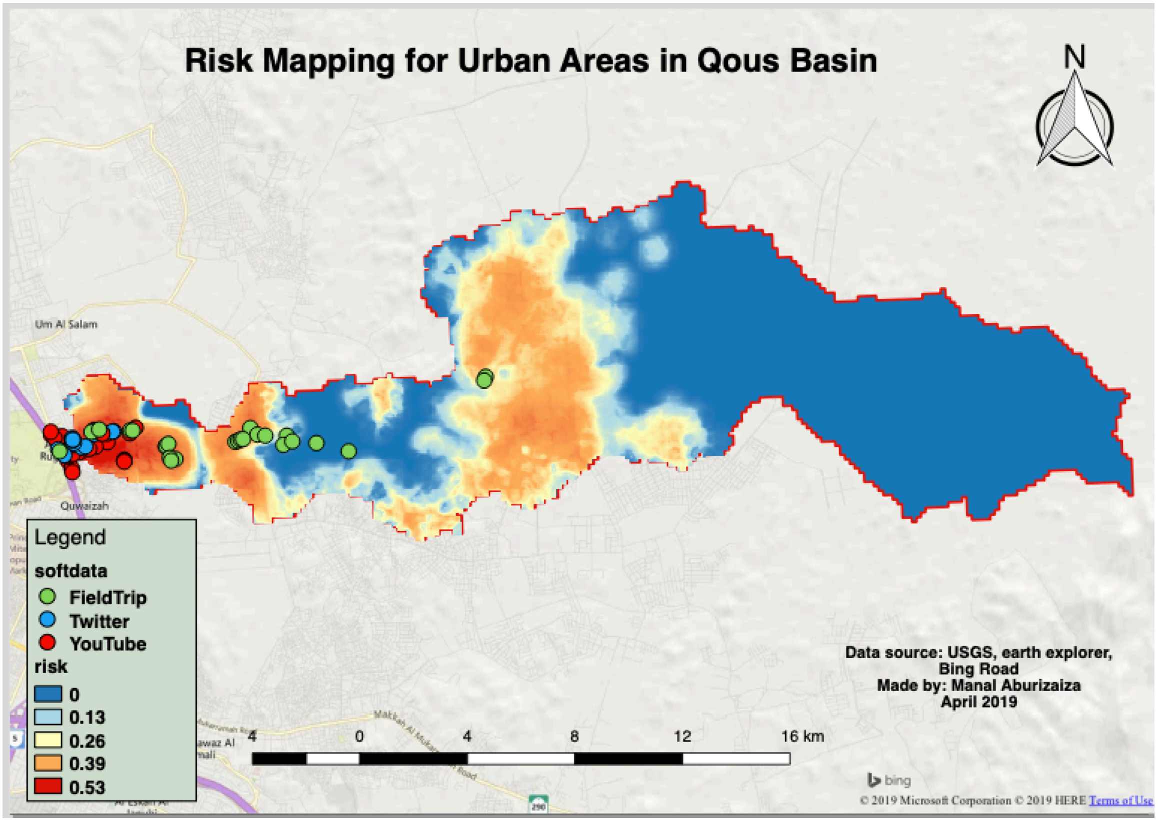


Figure 45 Risk area for the urbanized area in Qous basin

The west side of the map (red area), which has high urban density and high index values, represents a high-risk level. As the urban density and the index value decrease, the risk level also decreases. Finally, the blue area represents no risk level, because there is no urbanization in that area. The distribution of the soft data in the risk map gives a reasonable determination of the area flooded in 2009 flood. Social media data give significant results for determining the flood hazard area. The social media data are clustered in the west side of the basin, which has high urban density and a high potential for accumulation of water. These areas are the Abrug, Alrughama, and Quiza neighborhoods and Faraman and Jack Streets, which were frequently mentioned in social media posts and also by residents' experience.

It was found that some of the field visit data was located in the moderate-risk areas and the non-risk area. It needs to be considered that the flood map was generated based only on urban density, the SWI, and soft data; the risk level could be affected by other elements such as the type of building and the existence of a sewerage system, which were not included in this study. For example, the two field-visit data located in the yellow area (moderate-risk area) were a water mark on a wall that reaches two meters. The street in that area redirected the flood water and overwhelmed the area; after the 2009 flood, an artificial channel was built in that area, which assists in reducing the risk level there. The existence of the field visit in the blue area is related to the very low population density in that area, but the topographic features of the watershed direct the water through that area. Figure 46 is the final map that shows the flood hazard areas for the urbanized area in Qous basin based on soft data and Topographic Wetness Index.

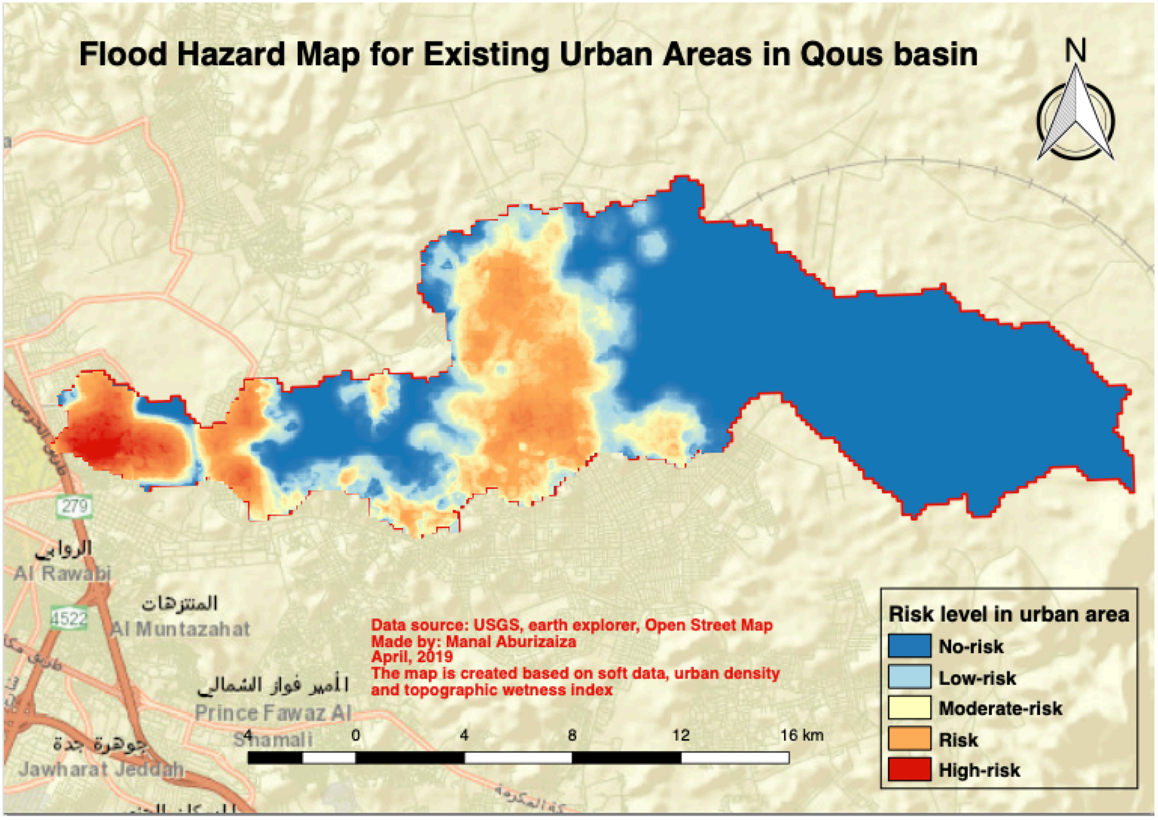


Figure 46 Flood hazard areas for the urbanized area in Qous basin

Flood hazard map for urban areas in Qous basin determines the vulnerable areas for flooding, it assess the risk for people, property and infrastructure within the watershed. The vulnerability was determined based on the population and SWI value, for that the above map delineates flood hazard areas for urban area only. Area with (No-risk) level is considered as a non-vulnerable area because it has no population, but it cannot be considered as a non-hazard area because it might have a high SWI value. Flood hazard map determines the vulnerability level for the existing urban area in the watershed, therefore, it can be used for flood emergency management plan, but it cannot be used for future planning development. The map presented in Figure 44 can be used for future planning development because it determines the flood hazard area based on the topographic features of the basin with no consideration to the population.

Soft data gives a good approximation of the extent of the flood-prone area, with the assistance of additional factors such as urban density and topographic features. The locations of the posted social media data are correlated with urban density, while the field visit considers the location of the urbanized and the non-urbanized areas that influence the flood spatial extent. The integration between the social media and the field visits gives a wider view and more understanding of the flood events.

6. CONCLUSION

6.1. Conclusion

Flood-prone areas are identified using hydrological-hydraulic simulation. Such models give significant results, but using the models is time-consuming and they require a large amount of data. The existence of ungauged basins lacking the required data due to unavailability or inaccessibility increases the need for alternatives to calibration data. This study addresses the watershed of Qous basin, an ungauged basin located in the city of Jeddah, Saudi Arabia, where calibration data is difficult to obtain.

Urban expansion in Qous basin began in 1988, starting from the west side of the watershed and moving toward the east, northeast, and southeast sides of the basin. Due to mis-planning in the urban area, buildings and roads were built in flood-prone areas, disturbing the natural drainage channels. Changes in the nature of the land use with no environmental planning decreased the infiltration rate and increased the runoff of rainfall to streams. This study aims to delineate the flood-prone areas in Qous basin using soft data as an alternative to calibration data, due to the scarcity of calibration data. Hence, qualitative information was used due to the lack of quantitative information.

Soft data is qualitative information that is generated from knowledge, opinion, assessment, and public observation. It is less reliable than hard data, as it cannot be validated because it is not comparable. It is used for gauged basins and ungauged basins, and its value increases if stream flow measurements are limited (Seibert & McDonnell, 2014). It is also used for calibration and validation (Youssef et al., 2016), but it cannot be used for uncertainty assessment (Seibert & McDonnell, 2014).

For this study, soft data consists of information from YouTube, Twitter, and field visits. The data were analyzed to extract flood-related information to assist with determining flood locations based on the population's observations and assessments. Flood-related information was extracted from social media platforms based on the posted texts, photos, and videos. YouTube videos were more useful in this study, as the information was extracted from the videos' contents, videos' titles, watchers' comments, and uploaded audio.

The extracted flood locations were validated during field visits by matching the location with a street name or a known location. During a field visit, data were also obtained from a flood wall mark indicating an inundation and from bushes in a dry area indicating soil moisture. The field visits also assisted with understanding the characteristics of the basin and its streams. Each item of soft data was digitized on the map based on its geolocation, to analyze the spatial distribution of soft data in order to generate a map of flood-prone areas in Qous basin.

Information obtained from social media data were barely sufficient for such a flood disaster. Twitter data were collected using English language keywords, while the mother language in Saudi Arabia is Arabic. Navigating through YouTube videos is time-consuming because useful data might appear at any time in a video and getting information from watchers' comments requires time and effort. It was found that social media data occurred only in the west side of the basin; for the rest of the basin, no data were obtained, because the west side is the most populated area within the basin and the east side is non urbanized area.

The residential area is an important element that affects the hazard level, and it needs to be considered as a significant factor in determining flood-prone areas. Land-use data such as road networks and residential areas were not accessible foe the study area, so an alternative source was used to obtain such data. The existence of VGI internet platforms makes geographic data accessible to the public. From this view, land use data was obtained from open source platforms such as OpenStreetMap and Google Earth, and QGIS was used to import and export the vector layers of land-use data to be used in the analysis of this study.

A map of flood-prone areas based on soft data was validated using the Topographic Wetness Index method, which is a function of the slope and the catchment area that estimates the potential for water accumulation. This method relies only on topographic data obtained from DEM that has fine resolution and is freely available to the public. It relies on the topographic features of the watershed, as the topographic features control the hydrological process in the basin. The values of the TWI were computed by estimating the flood direction to determine the hydrological gradient and by estimating the flow accumulation to determine the upslope of the contributing area.

Three TWI maps were created with different methodologies and compared to validate the flood inundation extent related to soft data. The first TWI map was generated by the Topographic Wetness Index method based on single flow direction (sfd); the resulting TWI sfd map didn't match soft data distribution. This is mostly because single flow direction doesn't reflect the reality of the flow direction, as the algorithm assumes that the water flow is only to the steepest downslope, with no involvement of other adjacent downslopes. The second map was created by the Topographic Wetness Index method based on multi-flow (mfd) direction; this improves the flow direction simulation, as the water flows in all downslope directions. The result of the TWI mfd map didn't provide a significant change from the first map.

The third map was created using the SAGA Wetness Index (SWI) method based on a modified catchment area. The SWI map provides a significant match with the map showing the distribution of flood soft data, and the SWI map showed a significant change in the index value for all categories. The SWI maps helped to validate the distribution of flood soft data in Qous basin.

The soft data flood map shows data clusters in the west side of the basin; this gives a determination of the flood-prone area based on population observations. This result works well with the SWI map, where the location of the clustering data is associated with a high index value. The Abrug Alrughamah neighborhoods, the Quaiza neighborhoods, Jack Street, Faraman Street, and the Al-Haramin highway (the area next to the Qous basin outlet) were the affected areas, with an estimation of 1- 1.5 m inundation based on flood soft data. This makes sense from the topographic perspective, because these areas are located in the downslope of the basin, near the mainstream, and beside the basin's outlet; moreover, these areas are located in the category of high-index value on the SWI map.

The final map was generated by interpreting the risk level using the spatial distribution of the soft data. Risk level was estimated based on the urban density and the value of the topographic wetness index; there are four categories of risk: high risk, moderate risk, low risk, and no risk. The final map is a flood risk map that indicate the level of the risk in the urbanized area in Qous basin. It was found that the Abrug Alrughamah neighborhoods, the Quaiza neighborhoods, Jack Street, and Faraman Street are located in the high-risk area; these locations were the locations most frequently mentioned in social-media data. These locations have a high urban density and are located in an area with high SWI value, while areas with no social-media data give low to moderate risk level and have low to no urban density. Field-visit data were distributed in urbanized and non-urbanized areas because data were obtained based on residential knowledge and field observations in the watershed. Amalgamation between social-media data and field-visit data provide a better understanding of the flood from social and topographic perspectives.

Errors in this study come from several sources. Qualitative information is usually associated with an error, because people see things from different perspectives. For social media, determining the location varied between one person and another; this will lead to some incorrect location determination. Numerous social-media data are not geolocated, and it is not guaranteed to be able to obtain the location from texts or photos. The culture and the education level play important roles in data quality; therefore, it is recommended to make people aware of the importance of social-media data and to encourage citizens to assist by providing flood-related information such as flood extent and flood depth.

Another source of error in this study is the assumptions of the use of TOPOMODEL, despite the fact that the soil and the land are not homogenous throughout the basin. The lack of calibrated data also increases the uncertainty, but this study is an initial stage to obtain data, and more research in different disciplinary areas is needed to generate a credible flood hazard area map.

In conclusion, this study aims to find an appropriate methodology to determine flood-prone areas for an ungauged basin. The objective was achieved by integrating qualitative information obtained from social-media platforms and field visits with the topographic features of the watershed obtained from DEM.

6.2. Future work:

1. The urban area in Jeddah is expanding to the north, south, and east due to active migration from the rural areas to the city. Not all the basins that originate from the Sarawat mountains, flowing toward the Red Sea, have been urbanized. The basins closest to Jeddah are expected to be urbanized in the future. The recommendation is to carry out further research to identify the flood prone areas and avoid any urban mis-planning. It should be clear that studying basins before planning will be much easier than after planning.
2. Apply the method used in this study to a gauged basin with available data to validate the framework of the method and add more parameters to the model, such as soil type and soil moisture index. Compare the results with and without the new parameters.
3. Apply more social media data using Arabic keywords to the method from other platforms such as Instagram and Snapchat to obtain rich qualitative information.
4. Collect Twitter data for each occurring disaster. “Twitter Streaming API 1%” is free and available for developers, who are allowed to obtain a 1% sample of all data related to specific parameters. Applying this method for every flood will assist with future research, because retrieving Twitter data using “Twitter Streaming API 1%” is free for only sixty days.
5. Use remote sensing data to validate the flood prone areas for non-urbanized areas where no social media is available.

APPENDIX

Appendix A:

YouTube	Link, publisher	Contents	**COMMENTS**	**TITLE**	**AUDIO**	**PUBLISHED**
سيول جدة حي .... قويزة مالاتصدق.mp4	https://www.youtube.com/watch?v=8qiTC_fZdKc Anas Ali	قويزة 2 - 3 m	قويزة	قويزة	3- 4 m	Nov 2009
Jeddah flood سيول جدة حوادث السيارات في الرعب مع الناس 2009	https://www.youtube.com/watch?v=bvCgCJCHwD4&t=19s keralaviews	Jack street Depth 1.5 – 2 m	Jack street قويزة	NA	NA	Nov 2009
تقرير مؤلم عن كارثة سيول جدة 1432 هـ (repeated)	https://www.youtube.com/watch?v=CemmfQ0eMtM Abdullah Al-Matar	Jack street Depth 1.5 – 2 m	NA	NA	NA	Nov 2011
Flood in Jeddah, Saudi Arabia 25 November 2009 (2) (repeated)	https://www.youtube.com/watch?v=bPgpe7BuDsM&t=19s FARAZ M. ISLAM	Jack street Depth 1.5 – 2 m	Medina road,Fasheliya road,Thaylia road ,Obhur road and Andulas road	NA	NA	Nov 2010
فيضانات جدة / أمطار جدة/ سيول جدة قويزة	https://www.youtube.com/watch?v=s6XAeP15Slo Ahmed Alnashmi	Jack street Depth 1.5 – 2 m	قويزة شارع فلسطين قبل كبري فلسطين مع السبعين مباشرة وانت جاي من طريق الحرمين	قويزة	NA	Nov 2009

سيول جده مقطع مرعب مصور وقت حدوث الكارثة	https://www.youtube.com/watch?v=pqQLtBISD14 Abo Rama	طريق الحرمين السريع	طريق الحرمين السريع	NA	NA	Nov 2009
Flood in Jeddah, Saudi Arabia 25 November 2009	https://www.youtube.com/watch?v=Skr5egS6Uk0 FARAZ M. ISLAM	NA	NA	NA	NA	Nov 2010
Jeddah Flood 25 Nov 2009	https://www.youtube.com/watch?v=hHdI7ForWck	قويزة Gas station	NA	NA	NA	Nov 2009
Flood In Jeddah Saudi Arabia December 2009 (repeated)	https://www.youtube.com/watch?v=ZVqbtuw9e2M Erick La-Gatta	طريق الحرمين السريع	NA	NA	NA	Nov 2016
Raining in Jeddah- 25 November 2009 1 pm	https://www.youtube.com/watch?v=TArMk8tNPe8 adi123456adi	**نفق طريق الملك** عبدالله	5 meters	NA	NA	Nov 2009
swrphome - November Rain (25 Nov 2009)	https://www.youtube.com/watch?v=tuszzZUVWsM Sophia Bernadette	KAUST 0.5 meter	NA	NA	NA	Nov 2009
Jeddah Flood Nov 25, 2009 mp4	https://www.youtube.com/watch?v=Fz7lJlP1Ttc sainumon100	0.5 meter	NA	NA	NA	Nov 2011
Jeddah Floods Nov. 25 2009 by Abu Rabee'	https://www.youtube.com/watch?v=aCv3CgE39NE Ahmed Geddy	0.5 meter	NA	NA	NA	Nov 2009
Jeddah flood	https://www.youtube.com/watch?v=SPBtjhdtDSw kmskottakkal	0.5 meter	NA	NA	NA	Nov 2009
Jeddah flood	https://www.youtube.com/watch?v=dIdIJrEMaRQ soyhunt14	0.5 meter	NA	NA	NA	Nov 2009

Rain Disaster Saudi Arabia Final	https://www.youtube.com/watch?v=rQ42Oo6WyCk Aiwaah Dot Com	Jack street, Albaik restraint حي قويزة امام محطة المساعد	NA	NA	NA	Nov 2009
سيول جدة 8-12-1430 و كارثة طريق الحرمين	https://www.youtube.com/watch?v=OkbNmxOJ2FM ab0badr	https://goo.gl/maps/VBaBHnXDEpv	NA	NA	NA	Nov 2009
flood in jeddah ksa	https://www.youtube.com/watch?v=r7jeTAFZoCM TheZerocool81	0.5 m	NA	NA	NA	Nov 2009
Jeddah Flood on 25.11.2009	https://www.youtube.com/watch?v=RaphIK5SDfQ&t=271s Mohamed Ibrahim Maricar	https://goo.gl/maps/EiLj79cAqqq https://goo.gl/maps/uf4YpBCehs72	100 or, at worst 500 year flood	NA	NA	NOV 2009
Rain in jeddah 25 Nov 2009.mp4	https://www.youtube.com/watch?v=UP6aPqLL7Tw Abid Khatib	https://goo.gl/maps/AbieWZSR31A2	NA	NA	NA	NOV 2009
flood in jeddah 25 nov 2009 bani malik dist by RASHID ALI.mp4	https://www.youtube.com/watch?v=NfZwHuU2QD4 AYTH RASHID	Bani malik 1 meter	NA	Bani malik	Bani malik	Nov 2009
Jeddah Rain Flood	https://www.youtube.com/watch?v=OIS-vEppBQE Raed J. Smadi	NA	NA	NA	NA	Nov 2009
Rain in Jeddah 25 nov 09.3gp	https://www.youtube.com/watch?v=qXl3XsfqdEs Ahmed Hussain	Non flooded area	NA	NA	NA	Nov 2009
the jeddah experience (nov. 25 2009)	https://www.youtube.com/watch?v=dfv2isgh9K0 macapagalemerson			NA	NA	Nov 2009
Jeddah Rain 1/3	https://www.youtube.com/watch?v=iSqHf295XtY Juanito Ayson	https://goo.gl/maps/drBmcQV6DrC2	NA	NA	NA	Nov 2009

Jeddah Rain 2/3	https://www.youtube.com/watch?v=OzXiY_-QKmg Juanito Ayson		NA	NA	NA	Nov 2009
Jeddah Rain 3/3	https://www.youtube.com/watch?v=OzXiY_-QKmg uanito Ayson		NA	NA	NA	Nov 2009
jeddah flood (Magrib time Nov.25,'09 Bagdadiyah area By: RELLY B. PALINO)	https://www.youtube.com/watch?v=WIbVM9OLEHo rpalino1	https://goo.gl/maps/fj753LYFi8F2 20 cm	NA	Bagdadiyah	NA	Nov 2009
jeddah flood(5+pm Nov.25,'09 Bagdadiyah area By.RELLY B.PALINO)	https://www.youtube.com/watch?v=nTbYf0UxdeQ rpalino1	https://goo.gl/maps/fj753LYFi8F2 20 cm	NA	Bagdadiyah	NA	Nov 2009
jeddah flood(by rellybpalino bagdadiyah area)	https://www.youtube.com/watch?v=qbM7qPg2a3A rpalino1	https://goo.gl/maps/fj753LYFi8F2 20 cm	NA	Bagdadiyah	NA	Nov 2009
Jeddah Rain - aslam vellur.mp4	https://www.youtube.com/watch?v=g2brwY2FnS8&t=44s aslam2100	https://goo.gl/maps/xTmzRKyUwkB2 ابرق الرغامة,	NA	NA	NA	Nov 2009
Jeddah Rain - aslam vellur- أمطار جدة سيول جدة1.mp4 (repeated)	https://www.youtube.com/watch?v=z0Sl-GUkr3Q aslam2100	Jack street Depth 1.5 - 2 m	NA	NA	NA	Nov 2009
Jeddah Rain aslam vellur أمطار جدة നിശ്ചയമായും കാണുക سيول جدة1	https://www.youtube.com/watch?v=4R2vegiBQL0 aslam2100	0.5 – 1 m	سد أم الخير	NA	NA	Nov 2009
Jeddah Rain - aslam vellur.mp4	https://www.youtube.com/watch?v=g2brwY2FnS8&t=51s aslam2100	https://goo.gl/maps/xTmzRKyUwkB2 ابرق الرغامة, 0.5 – 1 m	NA	NA	NA	Nov 2009
jeddah flood 25 nov-09.flv	https://www.youtube.com/watch?v=unEOD87Klsc mohammad naseer	https://goo.gl/maps/NdPArMWEQHE2 0.5 – 1 m	NA	NA	NA	Nov 2009

When It Rains, It Pours, Then It Floods _ Jeddah, KSA 25.Nov.09.wmv	https://www.youtube.com/watch?v=Kf2Nqse8OqI Nereus Jethro Abad			NA	NA	Nov 2009
JEDDAH FLOOD, MADARIS STREET, BUGHDADIYAH, Usman 25 NOV 09	https://www.youtube.com/watch?v=ndgX93CtfS8&t=85s usmanomi	شارع المدارس البغدادية 20 cm	NA	bughdadiyah	NA	Dec 2009
JEDDAH FLOOD,MADARIS STREET,BAGHDADIYAH,Usman 25NOV 09	https://www.youtube.com/watch?v=FI66R4GiAhw usmanomi	شارع المدارس البغدادية 20 cm		bughdadiyah	NA	Dec 2009
Jeddah on 25th Nov '09 (Live Coverage)	https://www.youtube.com/watch?v=2bFiRacNwgo Saad Patel	https://goo.gl/maps/8iBNvB7sy3o 0.5 -0.7 m	NA	NA	NA	Nov 2009
Jeddah heavy rain & flooding 25.11.2009	https://www.youtube.com/watch?v=eMNa2mO9G84 suhaibkhusro	https://goo.gl/maps/bwrLSGBktHE2 الشرفية 0.5 m	70mm 84	NA	NA	Nov 2009
Jeddah rain aftermath.mp4	https://www.youtube.com/watch?v=QcnUBIxJaas suhaibkhusro	نفق طريق الملك عبدالله	"the water level at nite at wali al ahd, reached the total height of the bridge, which is 5.5m!"	NA	NA	Nov 2009
chaos @ sitteen street.mp4	https://www.youtube.com/watch?v=awAHQJqOyTg suhaibkhusro	NA	70mm	Sitteen street	NA	Nov 2009
Jeddah rain.mp4	https://www.youtube.com/watch?v=CD4ejJTXgTg suhaibkhusro	https://goo.gl/maps/FhYTud5D88R2	70mm	NA		Nov 2009

Jeddah Under the Rain (Nov 25, '09) - Video 1	https://www.youtube.com/watch?v=hyS-iWa62oU Rakan Tarabzoni	0.5 - .08 m	NA	NA	NA	Nov 2009
worst flood in jeddah .mp4	https://www.youtube.com/watch?v=4fmBDPUyBR4&t=32s nancymarcelo	Damages one day after sale https://goo.gl/maps/2CUskbZAom72	makkah road	NA	NA	Nov 2009
jeddah Rain Disaster - امطار جدة غرق نفق طريق الملك عبدالله	https://www.youtube.com/watch?v=RBwDipU-1Ag SHaNSHooN111	https://goo.gl/maps/kgYU5ps3KaR2 4303 طريق الملك عبدالله الفرعي، البغدادية الغربية	“ نفق طريق الملك عبدالله غرقان بالكامل full”	نفق طريق الملك عبدالله	NA	Nov 2009
Jeddah rain drawns a 15 meters depth cross bridge	https://www.youtube.com/watch?v=TPzyg118EEQ&t=26s xxseliasxx	https://goo.gl/maps/kgYU5ps3KaR2	15 meters depth under bridge Total depth of 84	15 m	NA	Nov 2009
Floods in Jeddah	https://www.youtube.com/watch?v=2mhyww9Mdqs No Comment TV		NA	NA	NA	Nov 2009
Jeddah Rain Flood -3	https://www.youtube.com/watch?v=vhxHXob3cMA Raed J. Smadi	0.5 m	NA	NA	NA	Nov 2009
JEDDAH FLOOD	https://www.youtube.com/watch?v=R4Sy-IbKICY	ابرق الرغامة قويزة, https://goo.gl/maps/bjkU1LdG9rN2 https://goo.gl/maps/if9b7t7vEYN2	NA	NA	NA	Nov 2009
تقرير عن البطل الباكستاني فرمان خان الذي أنقذ 14 غريقاً	https://www.youtube.com/watch?v=SIK3A4akQ2Y Mohmmed Ayedh	الحرزات	NA	NA	NA	Dec 2009
Major flooding in the city of Jeddah in 2009	https://www.youtube.com/watch?v=nMjmJeglito Mohd Sukiman Junoh		NA	NA	NA	Feb 2014

jeddah flood.mp4	https://www.youtube.com/watch?v=f_54B8gnOWc Waqas Bashir	https://goo.gl/maps/xTmzRKyUwkB2 ابرق الرغامة,	NA	NA	حي السامر	Nov 2011
Jeddah floods Flood destroys everything	https://www.youtube.com/watch?v=9hnkBz1DHzE Al shayilat | The official channel ılıllı	Jack street Depth 1.5 - 2 m طريق الحرمين السريع	NA	NA	NA	May 2012
Jeddah flood Ali Chalil edakkaparamba (vellappokkam)	https://www.youtube.com/watch?v=uVQseYqbvnA alichalil007	0.5 – 1 m	NA	NA	NA	Nov 2009
Rain in Jeddah 25/11/2009	https://www.youtube.com/watch?v=iWQe1PBw_Rk aisallkhan12	https://goo.gl/maps/NdPArMWEQHE2 طريق الملك عبدالله، الشرفية 30 cm	NA	NA	NA	Nov 2009
Rain Central Jeddah 25-11-09.mp4	https://www.youtube.com/watch?v=Uc6o85HtAAE Mohammed Alam	20 com	bagdadiya	NA	NA	Nov 2009
Rain at Jeddah on 25.11.2009.mp4	https://www.youtube.com/watch?v=xtSUzbq2o0c Mohammed Iqbal	https://goo.gl/maps/NdPArMWEQHE2 طريق الملك عبدالله، الشرفية،	"King Abdullah Street near Hail Street"	NA	NA	Nov 2009
Jeddah Rain	https://www.youtube.com/watch?v=13crxnGlQNg Javed Iqbal	https://goo.gl/maps/fv7puVjG2e92 10 cm	NA	NA	NA	Nov 2009
rain in jeddah ksa not good	https://www.youtube.com/watch?v=2c600s9hFVk Soulkillerksa	0.5 m	NA	NA	NA	Nov 2009
JEDDAH HIGHWAY 2	https://www.youtube.com/watch?v=dBKZ_CGhzc8 Ayman Aljilani	https://goo.gl/maps/Q2xQqXnLrt52 ابرق الرغامة,	NA	NA	NA	Nov 2009
Jeddah High way Streams3 - Jeddah Flood كارثة فيضان وسيول جدة	https://www.youtube.com/watch?v=AjW9a6zm1QE amesawa	Not flooded	NA	NA	NA	Nov 2009

flood in jeddah saudi arab .mp4	https://www.youtube.com/watch?v=02M3JbIpp6g khanamir2kk	NA	NA	NA	NA	Nov 2009
Rain in Jeddah Wednesday 25 Nov. 2009	https://www.youtube.com/watch?v=gYNWwk2Wsnc Sirajuddin Ahmed	NA	NA	NA	NA	Nov 2009
JEDDAH FLOOD	https://www.youtube.com/watch?v=uIPRbBSaG8g Ahmed Hussain	https://goo.gl/maps/5Tccy8RhSXp	NA	NA	NA	Nov 2009
Video Jeddah Heavy Rain 25th Nov 09	https://www.youtube.com/watch?v=tARiE-w5CjU kasf doza	NA	NA	NA	NA	Nov 2009
Jeddah After The Rain - an exclusive rport of MR. RD	https://www.youtube.com/watch?v=biKSjgpfL6Q Roy Sto. Domingo	https://goo.gl/maps/b36f6SvzTPC2 حي السليمانية 5 -10 cm	NA	NA	NA	Nov 2009
Jeddah After The Rain - an exclusive report of aslam vellur	https://www.youtube.com/watch?v=spJzZNwCglo aslam2100	NA	NA	NA	NA	Nov 2009
Underpass after rain in Jeddah, Nov09	https://www.youtube.com/watch?v=WXDcvCTqLlU	نفق طريق الملك عبدالله	NA	NA	NA	Nov 2009
MINI ONDOY SA JEDDAH (NOV 25, 2009)	https://www.youtube.com/watch?v=dG_XJ0e6S9U qt49821	https://goo.gl/maps/TWSUCY5ogp42 20 cm	NA	NA	NA	Nov 2009
Jeddah-QUWAIZAH-2 After The Rain - an exclusive report of aslam vellur.mp4	https://www.youtube.com/watch?v=V14p8oIftc4 slam2100	QUWAIZAH after flood	NA	QUWAIZAH	NA	Nov 2009
DAMAGE CAUSED BY RAiN iN JEDDAH on 25th NOV , 2009	https://www.youtube.com/watch?v=zgL1lf-3ME0 2usman5	NA	2usman5 explain	NA	NA	Nov 2009

JEDDAH RAIN (25.11.2009)	https://www.youtube.com/watch?v=vi2b7LoMuRo kaqeel79	NA	**NA**	NA	NA	Nov 2009
flood in jeddah Malabar Bava-Kodinhi.mp4	https://www.youtube.com/watch?v=6zwek_R2kAs amaathkerala	1 – 2 m	NA	NA	NA	Nov 2009
Jeddah - A Flooded Desert	https://www.youtube.com/watch?v=GqdxmBY5jig&t=19s Roy Sto. Domingo	10 cm	NA	NA	NA	Nov 2009
Jeddah Floods Nov 2009- فياضانات شرق الخط السريع part 1	https://www.youtube.com/watch?v=w1Hyn5syI9o Sam B.	0.5 m	NA	شرق الخط السريع	NA	Nov 2009
Flooding rains in Jeddah Saudi Arabia 25-11-2009 سيول جدة 1430	https://www.youtube.com/watch?v=F_bblZ2UpuI alhlm999	قويزة, ابرق الرغامة طريق الحرمين السريع	NA	NA	NA	Nov 2009
Jeddah Rain on 25 nov 2009	https://www.youtube.com/watch?v=1LApCu2rxf0 mfkhanz	Non flooded area	NA	NA	NA	Nov 2009
jeddah after the flood disaster	https://www.youtube.com/watch?v=PIElvUwVgqc albert saranguero	2 dayss after flood	NA	NA	NA	Nov 2009
Jeddah High way Streams2 - Jeddah Flood	https://www.youtube.com/watch?v=2N6duEqi8OY amesawa	10 cm	NA	NA	NA	Nov 2009
Saudi Family drown in Jeddah's flood	https://www.youtube.com/watch?v=xrpBbz6zMLA fmansouri	0.5 m	NA	NA	NA	Dec 2009
flood in jedaah kilo03 saudi arabia	https://www.youtube.com/watch?v=xnN9rdKLF4k mikhu007	10 – 15 cm	NA	kilo03	NA	Nov 2009

Flood and streams from Jeddah سيول جدة	https://www.youtube.com/watch?v=X8TjVnTcLDQ TheSuperfaithfulgirl	https://goo.gl/maps/rWM1bEqXwt22 https://goo.gl/maps/P7CNuVBACxp طريق الحرمين السريع قويزة ابرق الرغامة	NA	NA	NA	Nov 2009
سيول و امطار جده تصوير من نافذه في حي قويزة	https://www.youtube.com/watch?v=EsFe9RsJSEE&t=111s FAIZ ALSHEHRI	Jack street 1.2 – 2 m	الجويزه هذا التصوير بجوار" شارع جاك مقابل مدرسه متوسطه الامير ماجد بن عبدالعزيز "	قويزة	NA	Nov 2009
كارثة جده انقاذ نايف عبد الرحمن معيض	https://www.youtube.com/watch?v=QZWtbNyg5zU MrAbuemad	0.5 m	**NA**	NA	NA	Nov 2009
سيول قويزة- تصوير اسامه باصهيب.mp4	https://www.youtube.com/watch?v=ijSVhXiPl1I Abdulrahman Bin rasheed		قويزة	قويزة	NA	Nov 2009
Rain Disaster Saudi Arabia Final	https://www.youtube.com/watch?v=rQ42Oo6WyCk&t=11s	https://goo.gl/maps/v8pzjZAc6zH2 https://goo.gl/maps/ibSVFgqAK2x Jack street, قويزة	قويزة	قويزة	NA	Nov 2009
Jeddah Rain 2009	https://www.youtube.com/watch?v=lD80zkTKclk 456ar	https://goo.gl/maps/D2C9mayt3Uq https://goo.gl/maps/zCf13aXKpRE2 Jack street قويزة	**NA**	NA	NA	Nov 2009
Saudi Flash floods -Amateur Video....deadly Jeddah flood	https://www.youtube.com/watch?v=PgsfPrTnV4k asif1ly		**NA**	NA	NA	Nov 2009
Jeddah Floods Nov 2009 - حصريا لم يعرض من قبل الدمار الهائل سيول جده	https://www.youtube.com/watch?v=chKOVTabCj nspire SS	https://goo.gl/maps/oR7ZrQAHqyF2 https://goo.gl/maps/axSiD7B5Run https://goo.gl/maps/YsfoDbxRFNz شارع الكليات Jack street قويزة	**NA**	NA	NA	Nov 2009

jeddah flood brave saudi saved a family	https://www.youtube.com/watch?v=TmugMfbSagI tauseef57	20 – 30 cm	**NA**	NA	NA	Nov 2009
Jeddah Raining 26th November 2009	https://www.youtube.com/watch?v=qyFChqCllwA	10 -15 cm One day after flood	**NA**	NA	NA	Nov 2009
heavy rain in jeddah on high1	https://www.youtube.com/watch?v=TQ1ytPgQFhg malikhamoud48	طريق الحرمين السريع After flood	**NA**	NA	NA	Nov 2009
flood in jeddah 25 nov 2009 bani malik dist by RASHID ALI.mp4	https://www.youtube.com/watch?v=NfZwHuU2QD4&t=2s SAYTH RASHID	0.5 m	**NA**	Bani malik	NA	Nov 2009
سيول جدة الخط السريع في 8 ذو الحجة 1430 هـ	https://www.youtube.com/watch?v=yaoXKrbTFkI zmany00	خط سريع	**NA**	الخط السريع	NA	Nov 2009
لقاء صباح العربية عن حملة فرمان - عبدالله الحمدان	https://www.youtube.com/watch?v=ZE3F0m39338 alhamdanorg	شارع الشهيد فرمان علي خان	NA	NA	شارع الشهيد فرمان علي خان	Dec 2009
فارمان فيلم عن البطل الباكستاني الشهيد فرمان علي خان	https://www.youtube.com/watch?v=_dHFeZGxVTg mbc group	أمام شركة البابطين للتجارة	NA	NA	طريق مكة كيلو ١١ أمام شركة البابطين	June 2018

Appendix B:

AUTHOR	TEXT	LANGUAGE	LINK	DATE
صحيفة سبق الإلكترونية @sabqorg	تعيد إلى أذهان أهلها ذكرى كارثة السيول عام 2009.. ومطالبات بالتحقيق	Arabic	https://twitter.com/sabqorg/status/933072015778631680	12:37 PM - 21 Nov 2017
الهواوي @huawei_34	حين تمطر في #جدة اتذكر شخص واحد؟ فرمان علي خان الذي انقذ ١٤ شخص في عام ٢٠٠٩ ثم جرفه السيول ومات-رحمه الله- اقصر قصة بطل ... #جده_تغرق	Arabic	https://twitter.com/huawei_34/status/933050337556082688	11:11 AM - 21 Nov 2017
معليش احنا بنتبهدل @MoojjEddah More	حدث لا يتكرر إلا في جدة صورتين لمكان واحد وغرق واحد الفارق بينهما الأولى 2009 والثانية 2015 تقولي مشاريع #جدة_تغرق	Arabic	https://twitter.com/MoojjEddah/status/666634137344806916	7:08 AM - 17 Nov 2015
عامر القحطاني 600K @AmerAlQa7tani	اتذكر #جدة حين تمطر في شخص واحد؟ فرمان علي خان الذي انقذ ١٤ شخص في عام ٢٠٠٩ ثم جرفه السيول ومات - رحمه الله - أقصر قصة بطل.	Arabic	https://twitter.com/AmerAlQa7tani/status/933078117463265282	1:02 PM - 21 Nov 2017
منصور العلي @maalaliz	فرمان علي #قصة_قصيرة باكستاني الجنسية مات شهيدا عام 2009 بعد انقاذ14 انسان! مات فرمان وعادت #جدة_تغرق من حديد .!	Arabic	https://twitter.com/maalaliz/status/667030491195920386	9:23 AM - 18 Nov 2015
Parody account 3@asalaswad	عام 2009 #جده_تغرق أنقذ الباكستاني"فرمان خان" 14شخص من الغرق قبل غرقه أنقذ الغريب أرواحاً بسبب فساد الأمراء غرقها:)	Arabic	https://twitter.com/3asalaswad/status/536214290965856256	9:47 AM - 22 Nov 2014
Andleeb AbbasVerified account @AndleebAbbas Feb 18	Crown Prince announces health center in KP after Farman Ali.. Nov 2009, in Jeddah flash floods Farman Ali Khan tied a rope to his waist and jumped	English	https://twitter.com/AndleebAbbas/status/1097450645546827776	2:59 AM - 18 Feb 2019

	in water to rescue people. He saved 14 lives but lost his own...#HumanityFirst #SaluteMBS #SaluteIK			
Ammar Taher @Ammar_MT	In this rare heavily raining day, we all remember Farman Khan, the hero & muslim brother from #Pakistan #Jeddah #Hero	English	https://twitter.com/Ammar_MT/status/536078879660572672	12:48 AM - 22 Nov 2014
Arab News Pakistan Verified account @arabnewspk	#Saudi #CrownPrinceinPakistanhonors 2009 #Jeddah flood hero #FarmanKhan | Here is a reminder of how he gave his life to save 14 people: https://goo.gl/vJLfp7	English	https://twitter.com/arabnewspk/status/1097424356660183041	1:15 AM - 18 Feb 2019
Bernard Koech @KoechBernard	it's now severe drought. Floods are going to follow. How is Kenya preparing? Look at this video from Jeddah, KSA. Floods can strike when and where you least expected. https://www.youtube.com/watch?v=bvCgCJCHwD4 …#JamboKenya	English	https://twitter.com/KoechBernard/status/1108638809141506048	12:57 AM - 21 Mar 2019
لثعلب السمين @pwrmez	باكستاني الجنسية توفى في عام 2009 رحمه الله عليه غرقاً بعدما أنقذ أربعة عشر شخصاً من الموت وقت سيول مدينة جدة حينما حاول إنقاذ الشخص الخامس عشر تطلب نزوله الى الماء ثم جرفه وغرق	Arabic	https://twitter.com/pwrmez/status/1109350436685922304	12:05 AM - 23 Mar 2019
جدة الآن | JeddahNow @JeddahNow	2009 غرقت #جدة 2010 مشاريع سيول 2011 مشاريع سيول 2012 مشاريع سيول 2013 مشاريع سيول 2014 مشاريع سيول 2015 مشاريع سيول 2016	Arabic	https://twitter.com/JeddahNow/status/933006480525221889	8:17 AM - 21 Nov 2017

	مشاريع سيول 2017 غرقت #جدة #جدة_الان			
صحيفة سبق الإلكترونيةVerified account @sabqorg	بالصور.. أمطار جدة تغرق حي قويزة وتعيد ذكرى سيول 2009	Arabic	https://twitter.com/sabqorg/status/536133984116166656	4:27 AM - 22 Nov 2014
حقوق الضعوف @hukusfof	#جده_الان هذا حال شارع دله .. المليارات التي رصدت لمشاريع تصريف السيول منذ كارثة سيول جدة عام 2009 أين ذهبت ؟!	Arabic	https://twitter.com/hukusfof/status/1070205494223081472	10:37 PM - 4 Dec 2018
سراج الغامدي @SerajAlghamdi	كارثة سيول جدة 2009 - - فتح ملف القضية بعد إغلاقها 2017 سيظهر الحق .. ولو بعد حين.. #الملك_يحارب_الفساد	Arabic	https://twitter.com/SerajAlghamdi/status/926914973732782080	1:52 PM - 4 Nov 2017
سعاد الشمريVerified account @SouadALshammary	#ملتقى_النخبة_الرياض العمل التطوعي فطرة #السعودية ف عام 2009 #سيول_جدة انشقت الارض وأخرجت فجأه خلال يوم 7000 شاب وشابه تقدموا للتطوع كتبت الصحافه الغربية التي كانت حاضرة للمشهد الشباب السعودي منظم للعمل التطوعي بشكل لوجستي وهو بدون تدريب لذلك اقول هي فطرة هذا الوطن د نجيب الزامل	Arabic	https://twitter.com/SouadALshammary/status/949300710683836416	7:25 AM - 5 Jan 2018
صلاح مخارشVerified account @mekarsh	سد احترازي للسيول شرق) جدة (ضمن مشروع الحلول العاجلة التي انشئت بعد سيول 2009 م في جدة ،كان دوره اليوم كبيرا #جدة	Arabic	https://twitter.com/mekarsh/status/666669219136819200	9:28 AM - 17 Nov 2015
أحمد العرفجVerified account @Arfaj1	#معلومة_من_العرفج تقرير زميلنا المتألق عزام الخديدي عن كارثة سيول جدة الاولي عام 2009لبرنامج ياهلا - YouTube	Arabic	https://twitter.com/Arfaj1/status/666667254310969346	9:20 AM - 17 Nov 2015

💎شرجاوية، @sharjah1122	يستحق الذكر والدعاء : الشهيد البطل #فرمان_خان الذي أنقذ 14 شخص من الغرق قبل وفاته في أمطار 2009 عام #جدة #سيول_جده	Arabic	https://twitter.com/sharjah1122/status/666598584234680320	4:47 AM - 17 Nov 2015
عين اليومVerified account @3alyoum	الأمطار تعيد تذكير #جدة : سكان شارع فلسطين بـ"كارثة 2009" http://www.3alyoum.com/?p=398172	Arabic	https://twitter.com/3alyoum/status/536281717091233792	2:14 PM - 22 Nov 2014
Banan Alfayez @Ban_an	سيول حايل 2009 - سيول جده 2010 - سيول جده المره 2011 ... المشكله كبيييره جداً و الفساد الإداري عندنا أكككككككبر	Arabic	https://twitter.com/Ban_an/status/31802145988681728	11:53 AM - 30 Jan 2011
sting sting @sting246810	تحقق من هذا الفيديو -- سيول جدة Jeddah flood حوادث السيارات في الرعب مع الناس 2009 http://www.youtube.com/watch?v=bvCgCJCHwD4 … via @youtube	Arabic	https://twitter.com/sting246810/status/31134414608015360	3:39 PM - 28 Jan 2011
D🕊️ @scarce987	Check this video out-- سيول جدة 2009 وصدو بيان ملكي... http://www.youtube.com/watch?v=Kw3X4rjbU9o … via @youtube	Arabic	https://twitter.com/scarce987/status/30999694842793984	6:44 AM - 28 Jan 2011
Jonathan Santiago @dagger5672	Check this video out-- فيضانات جدة / أمطار جدة/ سيول جدة قويزة http://www.youtube.com/watch?v=s6XAeP15Slo … via @youtubejeddah flood 2009 november	Arabic	https://twitter.com/dagger5672/status/30187226147061760	12:56 AM - 26 Jan 2011
AA @zahmadz_	RTصح لسانك @maghamdi 2009/11/25 كارثة سيول جدة .. تويتر يغفل عن الذكرى http://tl.gd/75gqnv	Arabic	https://twitter.com/zahmadz_/status/7908752787251200	1:29 PM - 25 Nov 2010

Jeddah Girl 7@asnaa	7asnaa سيول جدة حلقة خاصة شلتنا 22-12-2009: سيول جدة حلقة خاصة شلتنا 22-12-2009المحرر: حياتي ملكي تعلي... http://bit.ly/cQyf8X	Arabic	https://twitter.com/7asnaa/status/26263058311	5:42 AM - 3 Oct 2010
NBA Highlights @NBA_HighLightss	YouTube امطار في - جامعة الملك عبدالله سيول جدة 2009/11/25 : تغرق جامعة الملك عبدالله. 56216views. asdyoy67 · http://url4.eu/1qAFJ	Arabic	https://twitter.com/NBA_HighLightss/status/10642711802	3:52 PM - 17 Mar 2010
Syed Ali Raza AbidiVerified account @abidifacto	Aazaab-e-Ilahi for Wahabistan, Jeddah flood سيول جدة حوادث السيارات في الرعب مع الناس 2009 #pakistan#karachi #ppp... http://bit.ly/8QNGUd	Arabic	https://twitter.com/abidifactor/status/7554173808	3:09 AM - 9 Jan 2010
وسيم عبدالله @wazib	كي لا ننساهم: أسماء ضحايا سيول جدة 2009http://twitemail.com/9HE	Arabic	https://twitter.com/wazib/status/86111681700311041	9:39 AM - 29 Jun 2011
الصحافة السعودية @SaudiNpress	#Shams سد السامر.. : درع واقية تحول لخوف: أنشأت أمانة جدة سد السامر بعد سيول العام قبل الماضي «2009» لطمأنة الأها... http://bit.ly/ecbfEr	Arabic	https://twitter.com/SaudiNpress/status/32305123296280576	9:11 PM - 31 Jan 2011
الجهني @asssdk77	قول خير فياضانات جدة 2009 بالاصح ياخوي راحت فيه ارواح ان شاء الله يستمطرون بلا ضرار ويحفظ اهلها من مكروه	Arabic	https://twitter.com/asssdk77/status/1069758410143555584	5:00 PM - 3 Dec 2018
أحمد الرويجحي @ahma322	جده اغلب حالاتها القويه حدثت في نوفمبر ولا ننسى فياضانات جده الشهيره والتي حصلت في ٢٥نوفمبر ٢٠٠٩ وغيرها الكثير من الحالات المعتبره	Arabic	https://twitter.com/ahma322/status/925670037389758464	3:25 AM - 1 Nov 2017

زياد البطاح @Ziyad_A	::GReader رغم :: ٢٠٠٩: - رغم فياضانات جدة و غرق مدينة لا زالت عروس في عي... http://bit.ly/7A1MnO	Arabic	https://twitter.com/Ziyad_A/status/7255970258	6:29 PM - 31 Dec 2009
Hakeem Tarabulsi @hakeemtarabulsi	فياضانات - ليست بالفظيعة - في #إندونيسياوالشعب خرج متظاهراً، طيب تعالوا شوفوا إيش صار في #جدة عامي 2009/2011 وتهون عليكم مصيبتكم! #السعودية	Arabic	https://twitter.com/hakeemtarabulsi/status/291857919035727872	2:42 AM - 17 Jan 2013
عامر،، @bnfarhan1	ولكن في الحقيقه هو عاد بعد قضى المحاكمه بسبب فياضانات جده 2009	Arabic	https://twitter.com/bnfarhan1/status/317408629319929856	3:51 PM - 28 Mar 2013
عبدالله الغامدي @aghamdi44	وهو المتسبب في فياضانات جدة وخسارة كأس آسيا ٢٠٠٩ وأزمة الخليج	Arabic	https://twitter.com/aghamdi44/status/1062643674062950400	1:49 AM - 14 Nov 2018

REFERENCES

Al-Sabhan, W., Mulligan, M., & Blackburn, G. (2003). A real-time hydrological model for flood prediction using GIS and the WWW. Computers, Environment and Urban Systems, 27(1), 9–32. https://doi.org/10.1016/S0198-9715(01)00010-2

Ali, A. [anasali]. (2009, Nov 27)........ سيول جدة حي قويزة مالاتصدق.mp4 [Video file]. Retrieved from https://www.youtube.com/watch?v=8qiTC_fZdKc&t=2s

alimhaider. (2019, Nov 8). We even put up signs now, wherever roads flood: Turn Around, Don't Drown. No one pays them any attention [Tweet]. https://twitter.com/alimhaider/status/1058329554979295232

Aljoufie, M., Zuidgeest, M., Brussel, M., & van Maarseveen, M. (2012). Spatial–temporal analysis of urban growth and transportation in Jeddah City, Saudi Arabia. Cities, 31(C), 57–68. https://doi.org/10.1016/j.cities.2012.04.008

Al-Tahi, R., I, S., & Mahabir, R. (2014). Applications of Remote Sensing and GIS Technologies in Flood Risk Management. In J.B, Agard [Eds], (ch. 8). Flooding and Climate Change: Sectorial Impacts and Adaptation Strategies for the Caribbean. Hauppauge, NY,Nova publishers

Ammar_MT. (2014, Nov 22). He rescued 14 people from #Jeddah floods in 2009, then drowned. His name is engraved in our hearts, and in our city [Tweet]. https://twitter.com/Ammar_MT/status/536079464799555585

ArabicBest. (2016, Nov 27). شارع الشهيد فرمان خان: البطل الشاب الذي أنقذ أكثر من 14 نفس من الغرق بسيول #جدة عام 2009 قبل أن يستشهد غرقاً بسبب التعب [Tweet]. https://twitter.com/ArabicBest/status/802942692518834177

Awadallah, A. (2015). Regional intensity-duration-frequency curves for Jeddah region, Saudi Arabia, using ordinary and L-moments approaches. Journal of Flood Risk Management, 8(3), 195–207. https://doi.org/10.1111/jfr3.12085

ALSHEHRI, F. [FAIZ ALSHEHRI]. (2009, Nov 27). سيول وامطار جده تصوير من نافذه في حي قويزة [Video file]. Retrieved from https://www.youtube.com/watch?v=EsFe9RsJSEE&t=137s

Ballerine, C. (2017). Topographic Wetness Index Urban Flooding Awareness Act Action Support, Will & DuPage Counties, Illinois. Illinois State Water Survey.

Besnard, A., La Jeunesse, I., Pays, O., & Secondi, J. (2013). Topographic wetness index predicts the occurrence of bird species in floodplains. Diversity and Distributions, 19(8), 955–963. https://doi.org/10.1111/ddi.12047

Blöschl, G. (2016). Predictions in ungauged basins–where do we stand?. Proceedings of the International Association of Hydrological Sciences, 373, 57-60.

Böhner, J., & Selige, T. (2006). Spatial prediction of soil attributes using terrain analysis and climate regionalisation.

Berz, G. (2000, March). Flood disasters: lessons from the past—worries for the future. In Proceedings of the Institution of Civil Engineers-Water and Maritime Engineering (Vol. 142, No. 1, pp. 3-8). Thomas Telford Ltd.

Brenden Jongman, Jurjen Wagemaker, Beatriz Revilla Romero, & Erin Coughlan de Perez. (2015). Early Flood Detection for Rapid Humanitarian Response: Harnessing Near Real-Time Satellite and Twitter Signals. ISPRS International Journal of Geo-Information, 4(4), 2246–2266. https://doi.org/10.3390/ijgi4042246

Bronstert, A. (2003). Floods and Climate Change: Interactions and Impacts. Risk Analysis, 23(3), 545–557. https://doi.org/10.1111/1539-6924.00335

Brouwer, T., Eilander, D., Van Loenen, A., Booij, M. J., Wijnberg, K. M., Verkade, J. S., & Wagemaker, J. (2017). Probabilistic flood extent estimates from social media flood observations. Natural Hazards & Earth System Sciences, 17(5). 735–747. https://doi.org/10.5194/nhess-17-735-2017

Cannon, T. (2006). Vulnerability analysis, livelihoods and disasters. In *RISK21-Coping with Risks due to Natural Hazards in the 21st Century* (pp. 51-60). CRC Press.

Carpenter, T., & Georgakakos, K. (2006). Intercomparison of lumped versus distributed hydrologic model ensemble simulations on operational forecast scales. Journal of Hydrology, 329(1), 174–185. https://doi.org/10.1016/j.jhydrol.2006.02.013

Chanson, H. (2011). The 2010-2011 Floods in Queensland (Australia): Photographic Observations, Comments and Personal Experience.

Dawod, G., Mirza, M., & Al-Ghamdi, K. (2012). GIS-based estimation of flood hazard impacts on road network in Makkah city, Saudi Arabia. Environmental Earth Sciences, 67(8), 2205–2215. https://doi.org/10.1007/s12665-012-1660-9

De Risi, R., Jalayer, F., De Paola, F., & Lindley, S. (2018). Delineation of flooding risk hotspots based on digital elevation model, calculated and historical flooding extents: the case of Ouagadougou. Stochastic Environmental Research and Risk Assessment, 32(6), 1545–1559. https://doi.org/10.1007/s00477-017-1450-8

dionneMALIK. (2017, Nov 22) First rainy expi in Riyadh. Overwhelming indeed. No to heavy flood and traffic https://www.instagram.com/p/Bb0MWFWl0fe/ [Tweet]. https://twitter.com/dionneMALIK/status/933473257252012033

Eilander, D., Trambauer, P., Wagemaker, J., & van Loenen, A. (2016). Harvesting Social Media for Generation of Near Real-time Flood Maps. Procedia Engineering, 154, 176–183. https://doi.org/10.1016/j.proeng.2016.07.441

Elwood, S., Goodchild, M., & Sui, D. (2012). Researching Volunteered Geographic Information: Spatial Data, Geographic Research, and New Social Practice. Annals of the Association of American Geographers, 102(3), 571–590. https://doi.org/10.1080/00045608.2011.595657

gooodviibeess. (2017, Nov 23). REPLY TO THIS TWEET WITH THIS: #MissUniverse #Philippines FLOOD KITA IN ANY WAY!!! [Tweet]. https://twitter.com/gooodviibeess/status/933727774920941568/photo/1

Gupta, H., Wagener, T., & Liu, Y. (2008). Reconciling theory with observations: elements of a diagnostic approach to model evaluation. Hydrological Processes, 22(18), 3802–3813. https://doi.org/10.1002/hyp.6989

Holderness, T., & Turpin, E. (2015). From social media to geosocial intelligence: Crowdsourcing civic co-management for flood response in jakarta, indonesia. In Social media for government services (pp. 115-133). Springer, Cham.

Hrachowitz, M., Savenije, H., Blöschl, G., Mcdonnell, J., Sivapalan, M., Pomeroy, J., … Cudennec, C. (2013). A decade of Predictions in Ungauged Basins (PUB)—a review. Hydrological Sciences Journal, 58(6), 1198–1255. https://doi.org/10.1080/02626667.2013.803183 https://doi.org/10.5194/piahs-373-57-2016

Huong, H., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrology and Earth System Sciences, 17(1), 379–394. https://doi.org/10.5194/hess-17-379-2013

Jaedi, K. M. (2013). Flood Hazards Modeling in Arid Zone (Case Study in Wadi Qows Jeddah). Kin Abdulaziz University, Jeddah, Saudi Arabia.

JeddahNow. (2018, Nov 3). مع ذكر اسم الحي اسفل هذه التغريدة الامطار# شاركونا صور او فيديوهات. [Tweet] https://twitter.com/JeddahNow/status/1058686704796790785/video/1

J. Fohringer, D. Dransch, H. Kreibich, & K. Schröter. (2015). Social media as an information source for rapid flood inundation mapping. Natural Hazards and Earth System Sciences, 15(12), 2725–2738. https://doi.org/10.5194/nhess-15-2725-2015

J. Younis, S. Anquetin, & J. Thielen. (2008). The benefit of high-resolution operational weather forecasts for flash flood warning. Hydrology and Earth System Sciences, 12(4), 1039–1051. https://doi.org/10.5194/hess-12-1039-2008

Jonkman, S., & Kelman, I. (2005). An Analysis of the Causes and Circumstances of Flood Disaster Deaths. Disasters, 29(1), 75–97. https://doi.org/10.1111/j.0361-3666.2005.00275.x

Kellens, W., Vanneuville, W., Verfaillie, E., Meire, E., Deckers, P., & De Maeyer, P. (2013). Flood risk management in Flanders: past developments and future challenges. WATER RESOURCES MANAGEMENT, 27(10), 3585–3606. https://doi.org/10.1007/s11269-013-0366-4

Kia, M., Pirasteh, S., Pradhan, B., Mahmud, A., Sulaiman, W., & Moradi, A. (2012). An artificial neural network model for flood simulation using GIS: Johor River Basin, Malaysia. Environmental Earth Sciences, 67(1), 251–264. https://doi.org/10.1007/s12665-011-1504-z

Koshak, N., & Dawod, G. (2011). A GIS morphometric analysis of hydrological catchments within Makkah Metropolitan area, Saudi Arabia. International Journal of Geomatics and Geosciences, 2(2), 544.

Kourgialas, N., & Karatzas, G. (2011). Flood management and a GIS modelling method to assess flood-hazard areas—a case study. Hydrological Sciences Journal, 56(2), 212–225. https://doi.org/10.1080/02626667.2011.555836

Le Boursicaud, R., Pénard, L., Hauet, A., Thollet, F., & Le Coz, J. (2016). Gauging extreme floods on YouTube: application of LSPIV to home movies for the post-event determination of stream discharges. Hydrological Processes, 30(1), 90–105. https://doi.org/10.1002/hyp.10532

Liu, J., Zhang, X., & Wang, H. (2013). Flood Risk Mapping for Different Landuse Senarios Based on RS and GIS. Applied Mechanics and Materials, 295-298, 2415–2419. https://doi.org/10.4028/www.scientific.net/AMM.295-298.2415

Loritz, R., Weiler, M., & Seibert, S. (2015, April). Data mining methods for predicting event runoff coefficients in ungauged basins using static and dynamic catchment characteristics. In EGU General Assembly Conference Abstracts (Vol. 17).

Manfreda, S., Di Leo, M., & Sole, A. (2011). Detection of flood-prone areas using digital elevation models. Journal of Hydrologic Engineering, 16(10), 781-790.

Manfreda, S., Sole, A., & Fiorentino, M. (2008). Can the basin morphology alone provide an insight into floodplain delineation? WIT Transactions on Ecology and the Environment, 118, 47-56.

Mango, L., Melesse, A., Mcclain, M., Gann, D., & Setegn, S. (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. Hydrology and Earth System Sciences, 15(7), 2245–2258. https://doi.org/10.5194/hess-15-2245-2011

McClanahan, B., & Gokhale, S. S. (2015, August). Location inference of social media posts at hyper-local scale. In 2015 3rd International Conference on Future Internet of Things and Cloud (pp. 465-472). IEEE.

McGlynn, B. L., Blöschl, M., Borga, H., Bormann, H., Hurkmans, R., Komma, J., ... & Wagener, T. (2013). A data acquisition framework for runoff prediction in ungauged basins. In *Runoff Prediction in Ungauged Basins: Synthesis across Processes, Places and Scales* (pp. 29-52). Cambridge University Press.

Nagarajan, N., & Poongothai, S. (2012). Effect of Land Use/Land Cover change detection of ungauged watershed. *World Applied Sciences Journal*, *17*(6), 718-723.

Opolot, E. (2013). Application of remote sensing and geographical information systems in flood management : a review. RESEARCH JOURNAL OF APPLIED SCIENCES ENGINEERING AND TECHNOLOGY. Retrieved from https://biblio.ugent.be/publication/4192904

Ozdemir, H., & Elbaşı, E. (2015). Benchmarking land use change impacts on direct runoff in ungauged urban watersheds. Physics and Chemistry of the Earth, 79-82, 100–107. https://doi.org/10.1016/j.pce.2014.08.001

Riadi, B., & Suriadi, A. B. (2017, January). Identification of paddy field using Landsat image in Karawang Regency, West Java. In IOP Conference Series: Earth and Environmental Science (Vol. 54, No. 1, p. 012014). IOP Publishing.

Sadeem_wss. (2017, Nov 21). Flood report: peak of 20 centimeters of water in Butterfly Lane (Garden area) of @KAUST_News at 6:20 am today [Tweet]. https://twitter.com/search?q=Flood%20report%3A%20peak%20of%2020%20centimeters%20of%20water%20in%20Butterfly%20Lane%20(Garden%20area)&src=typd

Sanyal, J., & Lu, X. (2004). Application of Remote Sensing in Flood Management with Special Reference to Monsoon Asia: A Review. Natural Hazards, 33(2), 283–301. https://doi.org/10.1023/B:NHAZ.0000037035.65105.95

Sanyal, J., & Lu, X. (2005). Remote sensing and GIS-based flood vulnerability assessment of human settlements: a case study of Gangetic West Bengal, India. Hydrological Processes, 19(18), 3699–3716. https://doi.org/10.1002/hyp.5852

Saudi_Gezette. (2017, Nov 21). rains flood streets, met office near airport hit by lightning [Tweet]. https://t.co/cZGxQEv247 #JeddahRain

Savenije, H. (2010). HESS Opinions "Topography driven conceptual modelling (FLEX-Topo)." Hydrology and Earth System Sciences, 14(12), 2681–2692. https://doi.org/10.5194/hess-14-2681-2010

Schnebele, E., Cervon E, G., & Waters, N. (2014). Road assessment after flood events using non-authoritative data. Natural Hazards and Earth System Sciences, 14(4), 1007–1015. https://doi.org/10.5194/nhess-14-1007-2014

Segal, E., Bradford, S., Shouse, P., Lazarovitch, N., Corwin, D., & Segal, E. (2008). Integration of Hard and Soft Data to Characterize Field-Scale Hydraulic Properties for Flow and Transport Studies. Vadose Zone Journal, 7(3), 878–889. https://doi.org/10.2136/vzj2007.0090

Seibert, J., & Mcdonnell, J. (2015). Gauging the Ungauged Basin: Relative Value of Soft and Hard Data. Journal of Hydrologic Engineering, 20(1), . https://doi.org/10.1061/(ASCE)HE.1943-5584.0000861

SHaNSHooN111. (2009, Nov 26). jeddah Rain Disaster امطار جدة - غرق نفق طريق الملك عبدالله. [Video file]. Retrieved from https://www.youtube.com/watch?v=RBwDipU-1Ag

Sikorska, A., Scheidegger, A., Banasik, K., & Rieckermann, J. (2012). Bayesian uncertainty assessment of flood predictions in ungauged urban basins for conceptual rainfall-runoff models. Hydrology and Earth System Sciences, 16(4), 1221–1236. https://doi.org/10.5194/hess-16-1221-2012

Smith, L., Liang, Q., James, P., & Lin, W. (2017). Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. Journal of Flood Risk Management, 10(3), 370–380. https://doi.org/10.1111/jfr3.12154

Sorooshian, S., Gupta, V.K., and Fulton, J.L., 1983. Evaluation of maximum likelihood parameter estimation techniques for con- ceptual rainfall–runoff models: influence of calibration data variability and length on model credibility. Water Resources Research, 19 (1), 251–259.

Sun, D., Li, S., Zheng, W., Croitoru, A., Stefanidis, A., & Goldberg, M. (2016). Mapping floods due to Hurricane Sandy using NPP VIIRS and ATMS data and geotagged Flickr imagery. International Journal of Digital Earth, 9(5), 427–441. https://doi.org/10.1080/17538947.2015.1040474

Van Emmerik, T., Mulder, G., Eilander, D., Piet, M., & Savenije, H. (2015). Predicting the ungauged basin: model validation and realism assessment. *Frontiers in Earth Science*, *3*, 62. https://doi.org/10.3389/feart.2015.00062

Wang, R., & Kalin, L. (2011). Modelling effects of land use/cover changes under limited data. Ecohydrology, 4(2), 265-276.

Western, A., Grayson, R., & Bloschl, G. (2002). Scaling of soil moisture: a hydrologic perspective. Annual Review of Earth and Planetary Science, 30.

White, I., Kingston, R., & Barker, A. (2010). Participatory geographic information systems and public engagement within flood risk management. Journal of Flood Risk Management, 3(4), 337–346. https://doi.org/10.1111/j.1753-318X.2010.01083.x

Wolock, D. M., & McCabe Jr, G. J. (1995). Comparison of single and multiple flow direction algorithms for computing topographic parameters in TOPMODEL. Water Resources Research, 31(5), 1315-1324.

Yu, P., Wang, Y., Kuo, C., Yu, P., de Boer, D., Froehlich, W., … Pietroniro, A. (2003). Effects of land-use change on runoff response in the ungauged Ta-Chou basin, Taiwan. In Erosion Prediction in Ungauged Basins: Integrating Methods and Techniques (pp. 162–170). Retrieved from http://search.proquest.com/docview/1666299254/?pq-origsite=primo

BIOGRAPHY

Manal Omar Aburizaiza graduated from Dar Al-Hanan High School, Jeddah, Saudi Arabia, in 2000. She received her Bachelor of Science from King Abdul Aziz University in 2004. She was employed as a teacher assistant in Royal Commission Yanbu for four years and received her Master of Science in Computer Science from Western Michigan University in 2011.