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Using remote sensing technology in estimating flood discharge

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A S Abdullah [1], O M Moussa [1], A A Hassan [1], M Tarek [1]

[1] *Civil Engineering Department, Military Technical College, Cairo, Egypt*

E-mail: ahmedsalah5393@gmail.com

Abstract. Floods are the most natural disasters occurring on earth. Recently, Egypt has been subjected to more frequent floods due to climate change. The main objective of this paper is creating hydrological analysis and estimating water discharge due to a flood hitting a hazardous zone near Safaga city. The research is divided into four main stages; 1) Morphological study, 2) Meteorological study, 3) Losses estimation, and 4) Flood discharge estimation. First, morphological study in which watershed boundaries, main streams and morphological data are delineated using geographic information system (GIS) with the aid of Landsat-8 satellite images and 30-m resolution digital elevation model (DEM). Second, meteorological study in which conventional rainfall frequency analysis is generated to estimate rainfall depth at different return periods using 15-years rainfall historical data from weather stations. Third, losses estimation is determined by using soil conservation service-curve number method (SCS-CN). Fourth, water discharge volume is carried out through hydrological modelling using a hydrologic engineering centre model. The estimated water volume is an appropriate information for decision makers to propose the adequate protection works to mitigate flood impacts.

Keywords: Flood, remote sensing, geographic information system (GIS), hydrological modelling.

1. Introduction

Hydrologists and engineers consider flood as the dangerous surplus of surface (overland) water travels over the surface of the ground forming channel/s where it transfers to the basin outlet with a specific magnitude and frequency of flow [1]. Frequently, it is the most devastating natural hazard with high uncertainty leading to massive social and economic disruptions [2]. Various studies have shown that floods distress around 200 million people every year costing $95 billion in economic damages globally [3]. Only in 2019, the Emergency Events Database (EM-DAT) documented 396 natural disasters, with 11,755 fatalities, 95 million people impacted, and $103 billion in economic damages worldwide [4]. The previous decades many extreme rainfall events happened in arid and semi-arid regions like Egypt specially near red sea coast [5]. The Red Sea steep high terrain near Safaga city parallel to the red sea coast contains mountains such as: Abu Furad 1032m, Waira 1035m and Abu Aqarib 775m.

Many wadis cut this high land area along the Red Sea in NE-SW direction such as Wadi Safaga, Wadi Gawasis and Wadi Gasus [6]. Unplanned urbanization in low land regions which are close to wadies increase risk as these regions as they are already prone to floods due to current and forecasted extreme meteorological events [7]. The issue that makes preparing spatial analysis for floods is crucial for better and efficient flood risk management. Effective flood risk management will be derived after a better understanding of flood. The first step in a flood risk management is identification which will be achieved by hydrological analysis. Hydrological analysis for arid semi-arid regions like in Egypt should be done with respect to the behaviour of small scale watersheds using deterministic lumped conceptual models as well as choosing the suitable runoff estimation method [8].

In 1954, The first Curve Number (CN) method was illustrated by Natural Resources Conservation Service (NRCS) that was named later Soil Conservation Service (SCS) at the United States Department of Agriculture (USDA). Since then, this method became a part in every book of hydrology for losses calculation to estimate water runoff [9]. Several researches prepared hydrological analysis utilizing remote sensing technology combined with GIS and estimated water runoff of floods respect to soil losses due to infiltration parameter. For example, Dewidar used GIS technique integrated with remote sensing to analyse the morphometric parameters of the Wadi El-Gemal Basin on the red sea coast [10]. Also, Vishvam H. Pancholi carried out hydrological modelling based on SCS-CN method to estimate runoff while considering soil losses calculation [11]. Many efforts were done as Galal H. Galal who used (HEC-1) model as an efficient, and simple tool for hydrological modelling with a few inputs to estimate total water discharge volume [7]. In this research hydrological analysis watershed boundaries and streams are delineated, rainfall precipitation depth is determined by applying different statistical distributions and choosing the best to fit the dataset with 15 variable of maximum daily rainfall per year. After that, water runoff volume is then estimated taking in concern water losses due to land use/land cover (LU/LC) and soil type. At the end, obtaining appropriate results useful for making a clear vision in front of decision makers assisting in future flood risk management to control flood impacts.

2. Problem statement and research gap

Floods contribute approximately 43.5% of all fatalities resulting from natural disasters as they are the most occurring due to climate change [4]. The matter that needs an applicable identification approach of flood hazard extent to support decision makers in taking the right decisions for flood mitigation and control and also supports achieving sustainable development that takes in concern environmental, social, and economic disruptions. Several researches were done to contribute in filling this gap. However, these researches are incapable of (1) Representing a sequenced, appropriate and simple hydrological analysis and estimate water discharge volume by using up to date applicable methods and tools. (2) Applying and comparing between several statistical distributions to analyse meteorological behaviour and choose the best fit method clarifying most proper precipitation values to generate precise results of total water runoff volumes at different conventional return periods.

3. Study area

The study area is a valley lies in the eastern desert of Egypt on the red sea coast. The study area valley (Wadi Gasus) is surrounded by high sharp mountainous terrain and lies between **33°48'23.626"E, 26°26'42.696"N** and **34°2'6.037"E, 26°34'21.021"N**.

In 1994, this area exposed to extreme flood event attacked village (Old Umm Al-huwaitat) inside. Since then, it became unpopulated and mining works of phosphate and gold are stopped there causing social and economic disruptions for people and the whole country. Old Umm Al-huwaitat village is located at low land level surrounded by hilly steep heights and lies 25 Km southern west of Safaga city, 12.5 km from the red sea coast, and 60 Km from Al-Qusseir city as shown in ‘figure 1’.

Figure 1. Locating the study area’s flooded village [12].

4. Objective and research stages

The main objective of this study is to create a simple, sequenced, and appropriate hydrological analysis and estimating total volume of water runoff utilizing remote sensing technology. This research is divided into four main stages 1) Morphological study, 2) Meteorological study, 3) Losses estimation, and 4) Flood discharge estimation as shown in ‘figure 2’. The following sections describe each of these four major stages respectively all applied on a case study to explain and justify the use of it and illustrating material data used, methodologies/tools and the final output.

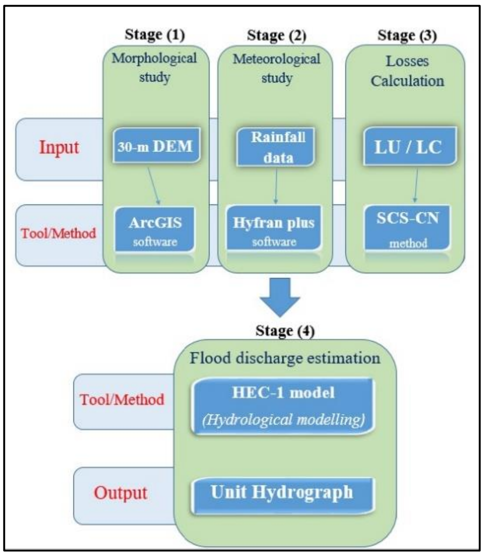


Figure 2. Research stages flow chart.

4.1 Morphological study

In this stage the morphological parameters of the study area were computed after identifying the flood catchment for Wadi Gasus basin. The basin and its data are delineated, detecting boundaries of the flood watershed as well as streams generated by ArcGIS software. ArcGIS is dependable tool for such a study Guided by universal transverse Mercator (UTM) map view and World Geodetic System (WGS) 1984 datum coordinates. This allows to be viable with various GIS topical layers and zone 36N is chosen relative to the study area location. ArcGIS simulates flood drainage network utilizing remote sensing satellite imaging integrated with a digital elevation model (DEM). DEM is a digital cartographic dataset in three dimensional coordinates (XYZ) or a computer graphic representation of elevation data that has been derived from contour lines or photogrammetric methods [13]. DEM is usually used in Ground Information System GIS to visualize the terrain of the ground surface for hydrological analysis. In this study a 30-m resolution DEM is used obtained by Shuttle Radar Topography Mission (SRTM) and satellite images are imported from different sources as Google earth pro software and United States Geological Survey (USGS) earth explorer web site with the aid of Landsat-8 Satellite. This step sends out the flood catchment streams and locates the boundaries of the basin and the disrupted village.

4.2 Meteorological study

The purpose of this section is creating frequency analysis at different return periods throughout statistical distributions. Historical rainfall data are used as input representing the maximum daily rainfall in (mm) each year gathered from Safaga weather station for 15 years (1980-1994) till flood occurrence as shown in 'figure 3'. The chronological curve indicates different observations of maximum daily rainfall each year regarding that rainfall in 1994 recorded the highest value. HYFRAN-PLUS software is a useful tool for hydrologic statistical representation as it includes a number of dominant, flexible, and accessible mathematical models that can fit for statistical analysis of extreme natural events as flood. It contains 20 statistical distributions assist to choose the most adequate distribution to fit a set of Independent and Identically Distributed (IID) data. Convenient 14 different methods were applied then compared and validated taking the most 5 fitting statistical distributions and also comparing between them again to choose the best fit by picking the lowest value for the Akaïke information criterion (AIC) and Bayesian information criterion (BIC) [14]. After that, maximum precipitation depths are estimated at different return periods of occurrence and Intensity-Duration-Frequency (IDF) curves are carried out for (2, 5, 10, 25, 50, 100) return period years.

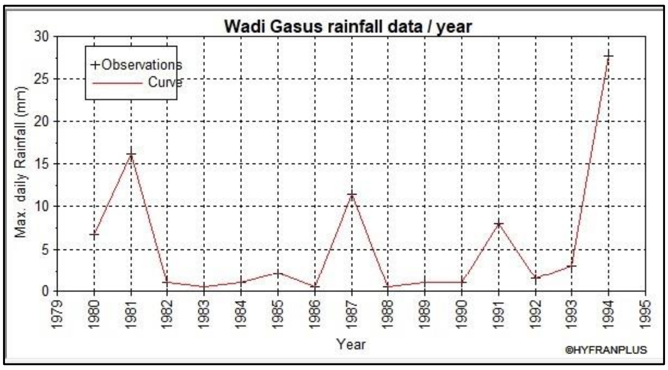


Figure 3. Rain fall data over 15 years.

4.3 Losses calculation

This part targets calculating losses of rainfall due to infiltration by SCS-CN method. The method contributes in estimating flood runoff volume. It is a simple, reliable, and stable conceptual method supported by empirical data preferably used in small watersheds. It is also chosen as compatible with HEC-1 model used for the estimation of total discharge volume in next stage. It depends on one parameter which is the curve number (CN). CN is a dimensionless number ranging (0 ~ 100) is generated with the aid of technical release 55 (TR-55) and geological data according to four considerations:

1) Hydrologic Soil Groups (HSG) are classified into A, B, C and D according to soil different types and their minimum infiltration rate.
2) Antecedent Moisture Condition (AMC) which refers to water content in soil at any given time and has three conditions (I, II, III). In this study average condition (AMC-II) is assumed.
3) Hydrologic condition which indicates the effect of land cover on infiltration and runoff, Poor hydrologic condition indicates the soil usually has high runoff potential. There are three conditions (Good, Fair, Poor). This study takes in concern hydrologic fair condition.
4) LU/LC and region type classified into four tables (Urban, Agricultural, Cultivated and Arid and semi-arid).

Geological data maps (LU/LC, soil types) were imported from (USGS) earth explorer, Food and Agriculture Organization (FAO), also hydrologic soil groups map from National Aeronautics and Space Administration (NASA) distributed active archive centre for biogeochemical dynamics [15].

Even though, SCS method is designed to be applied for watersheds up to 15 Km^2, it has been modified for larger watersheds by weighing curve numbers regarding soil type/land cover area and became as given in the following equation [11]:

$$\boldsymbol{CN_w = \frac{\sum_1^n (CN_i * A_i)}{A}}$$ where,

$\boldsymbol{CN_w}$ **:** Weighted curve number.

$\boldsymbol{CN_i}$ **:** Curve number for any given land cover/soil type (*i*), where *i*=1, 2, 3, …, n.

$\boldsymbol{A_i}$ **:** Area corresponding for any given land cover/soil type (*i*), where *i*=1, 2, 3, …, n.

$\boldsymbol{A}$ **:** Area of the whole watershed.

4.4 Flood discharge estimation

The purpose of the last stage is estimating water discharge total volume throughout hydrological modelling utilizing watershed modelling system (WMS). The Watershed Modelling System (WMS) is a graphical demonstrating simulator for analysing all phases of watershed for both hydrology and hydraulics. This system is developed by the U.S. Army Corps of Engineers/Hydrologic Engineering Centre. A special version of TOPAZ program in WMS is used to delineate the drainage system from the generated DEM and produces flow direction and flow accumulation grids. After the detection of the watershed outlet station, the basin polygon is delineated and its characteristics are defined. HEC-1 model is designed to simulate the surface runoff throughout unit hydrograph estimating water volume resulting from a rainfall storm event. After the selection of the appropriate precipitation type and inserting weighted curve number then running the HEC-1 model flood simulation, total water runoff at the outlet station of the whole basin is estimated through the unit hydrograph.

5. Results and discussion

Results for each stage are explained as follows respectively:

1) Firstly, the morphological characteristics and drainage data for the study area catchment which are major effective factors for flood runoff volume are send out by as shown in table 1.

Table 1. Morphological characteristics and drainage data.

Basin area	Basin slope	Basin length	Mean basin elevation	Minimum flow slope	Maximum stream length	Maximum stream slope
142 Km^2	0.196 m/m	26105.4 m	257.59 m	0.0142 m/m	34070.68 m	0.0102 m/m

Then, extraction of 30-m DEM map of the study area demonstrating elevations range that affects flood magnitude and direction from high to low levels indicating the highest point at 626m as shown in 'figure 4' and used for delineating the basin watershed boundary, streams with stream ordering, locating the flooded village and outlet station of the whole basin is as shown in 'figure 5'.

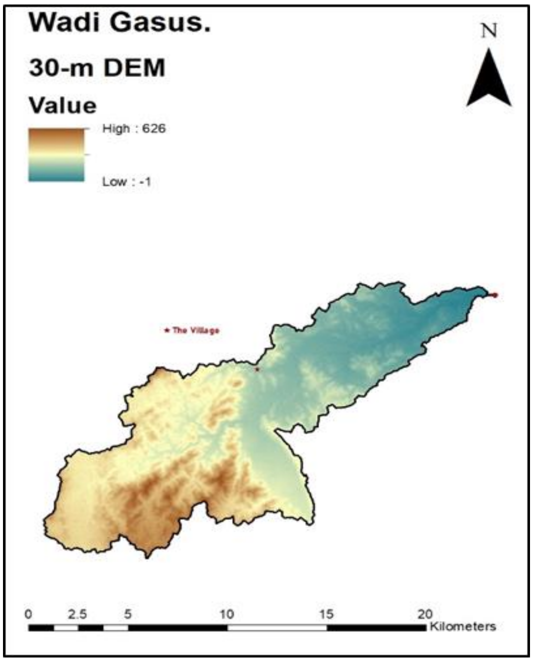


Figure 4. Wadi Gasus 30-m DEM.

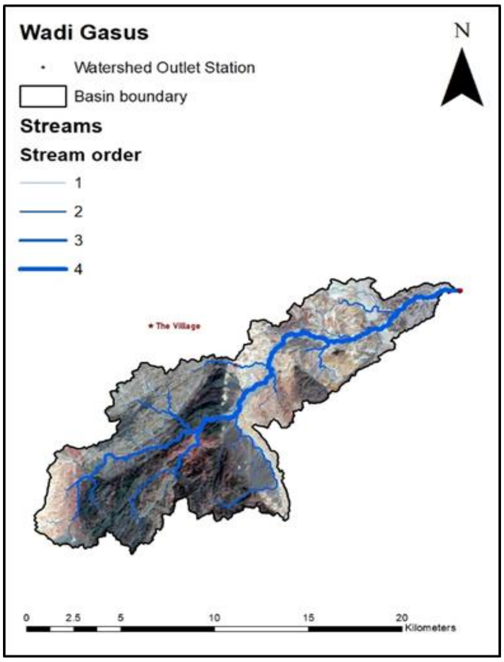


Figure 5. Wadi Gasus Watershed Delineation.

2) Secondly, statistical distributions suitable to represent this hydrological sample data in HYFRAN-PLUS were applied and the best five fitting curves are send out as shown in 'figures 6, 7, 8, 9, and 10' according to comparing AIC and BIC values and they are:

a) Weibull (method of moments).
b) Log-Pearson type 3 (Method of moments BOB, base = 10).
c) Pearson type 3 (Method of moments).
d) 3-parameter lognormal (Method of moments).
e) Compound Poisson/exponential distribution function (Method of moments).

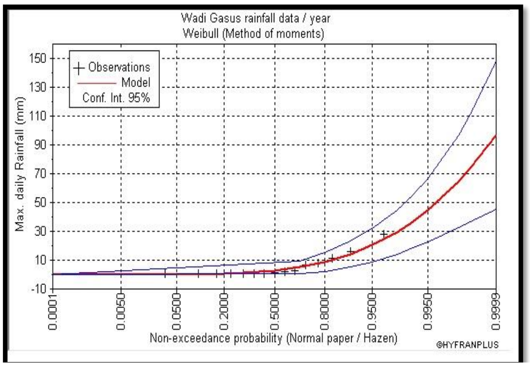


Figure 6. a) Weibull.

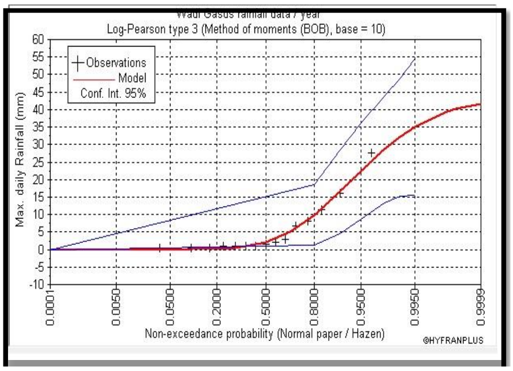


Figure 7. b) Log-Pearson type 3.

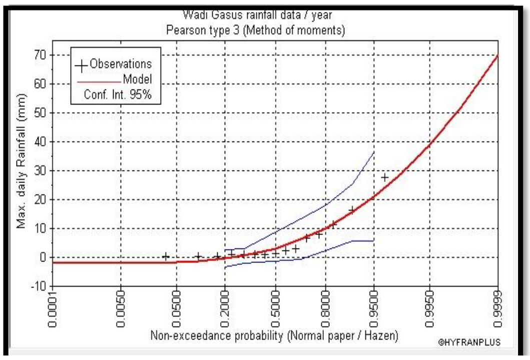


Figure 8. c) Pearson type 3.

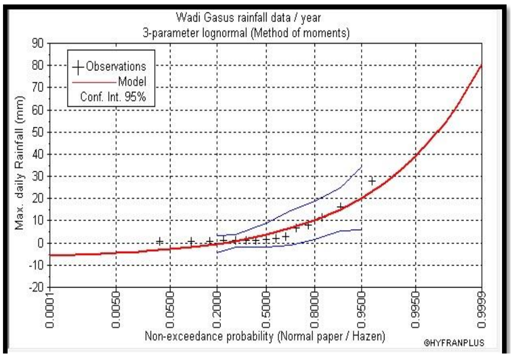


Figure 9. d) 3-parameter lognormal.

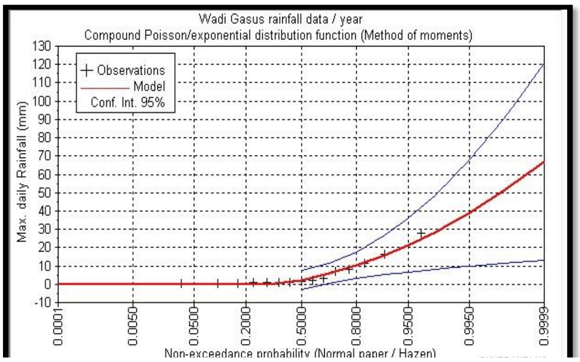


Figure 10. e) Compound distribution function.

Then, these statistical models are also compared for the second time enhancing the best fit results at 100 years return period time according to AIC and BIC values to choose Weibull (method of moments) as the best method as shown in 'figure 11' generating out the most proper prediction of rainfall depth for the specified return period years (2, 5, 10, 25, 50, and 100) as shown in table 2.

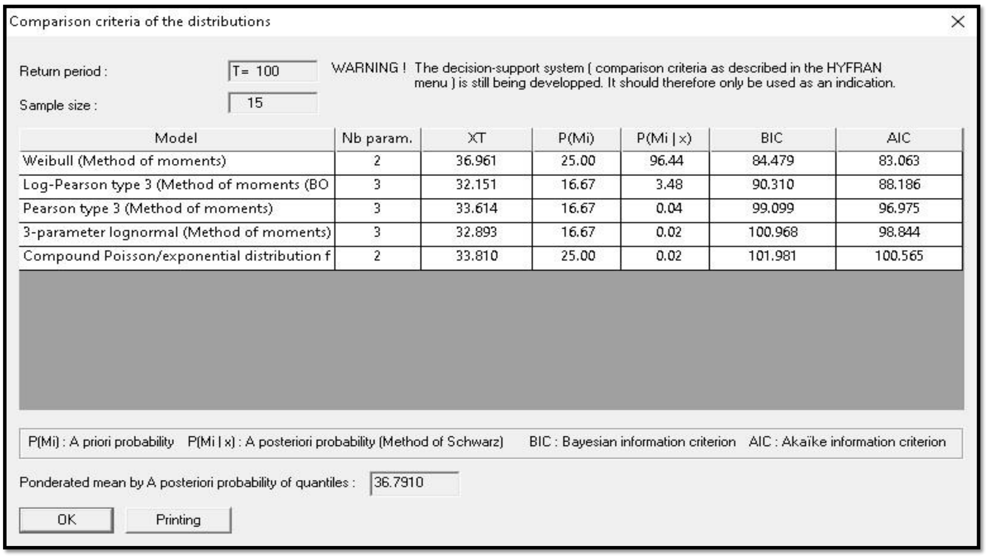
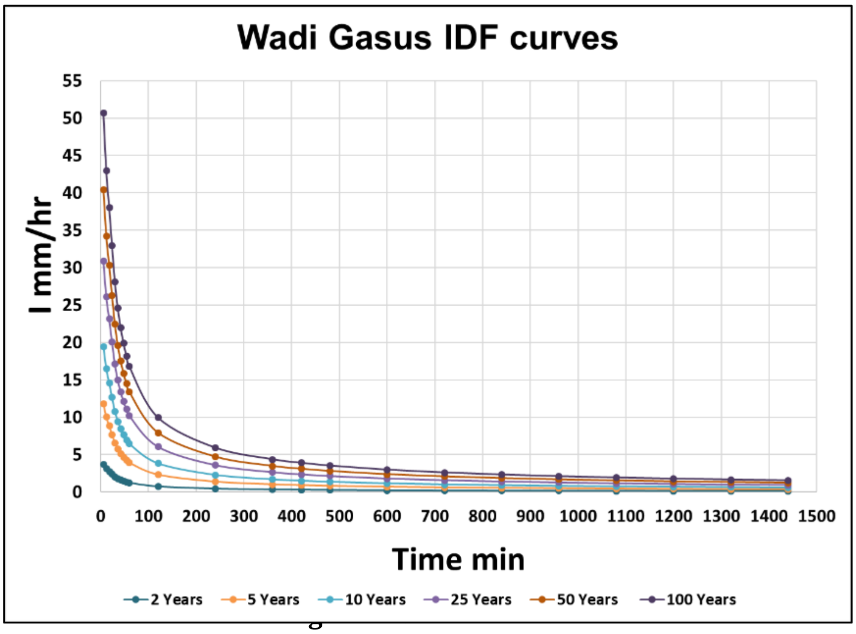


Figure 11. Comparison criteria for statistical distributions.

Table 2. Rainfall depths at different return periods according to Weibull method.

Return period (years)	2	5	10	25	50	100
Depth (mm)	2.69	8.62	14.2	22.5	29.5	37.0

After that, the IDF curves are carried out as shown in ‘figure 12’ that indicates the relationship between rainfall intensity and time at conventional return period years (2, 5, 10, 25, 50, and 100). IDF curves assist in generating precipitation at a definite computational time interval (10 minutes) which contributes in generating unit hydrograph and water discharge volume.



3) Thirdly, the losses calculation by SCS-CN method is done utilizing approximated weighted curve number (79) which is generated for Wadi Gasus basin throughout barren or sparsely vegetated land cover type and different loamy soil types map of the study area basin as shown in 'figure 13' as well as Hydrologic Soil Groups map (HSG) that indicates 3 groups of the soil types inside the study area as shown in 'figure 14'.

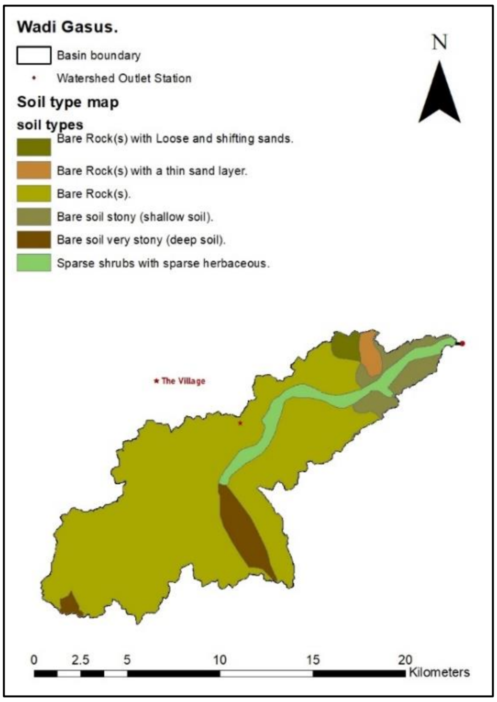


Figure 13. Soil types map.

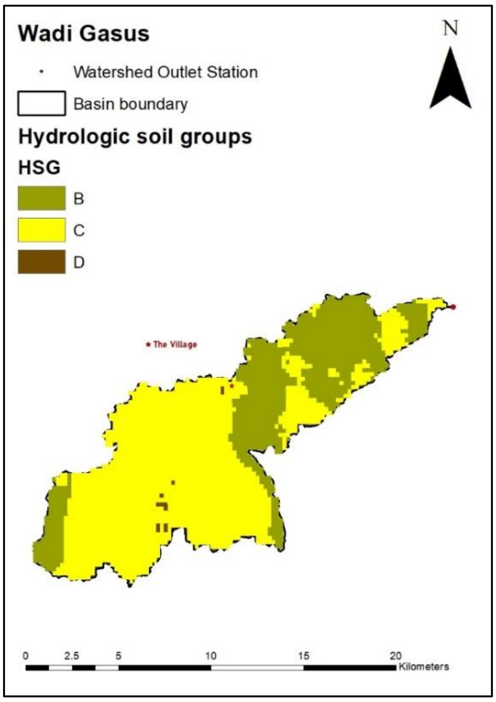


Figure 14. Hydrologic Soil Groups map.

4) Finally, by running HEC-1 model flood simulation total discharge volume is generated for the highest three values at return periods (25, 50 and 100) as well as the unit hydrograph is generated presenting the relationship between water discharge flow with respect to time and indicating time of peak in minutes, flow peak in m^3/s and total discharge volume in m^3 as shown in 'figures 15, 16, and 17'.

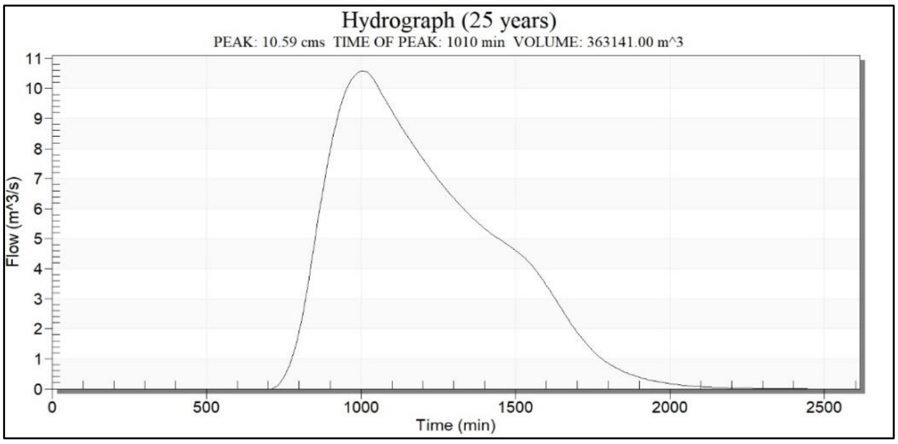


Figure 15. Unit Hydrograph for 25 years return period.

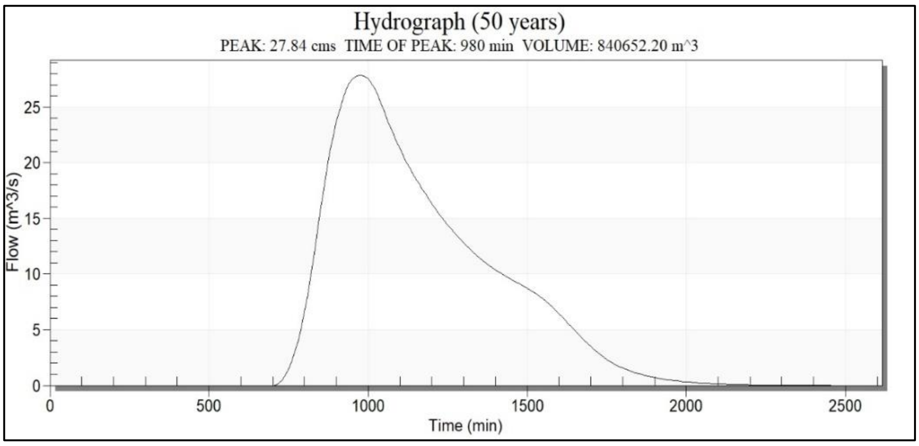


Figure 16. Unit Hydrograph for 50 years return period.

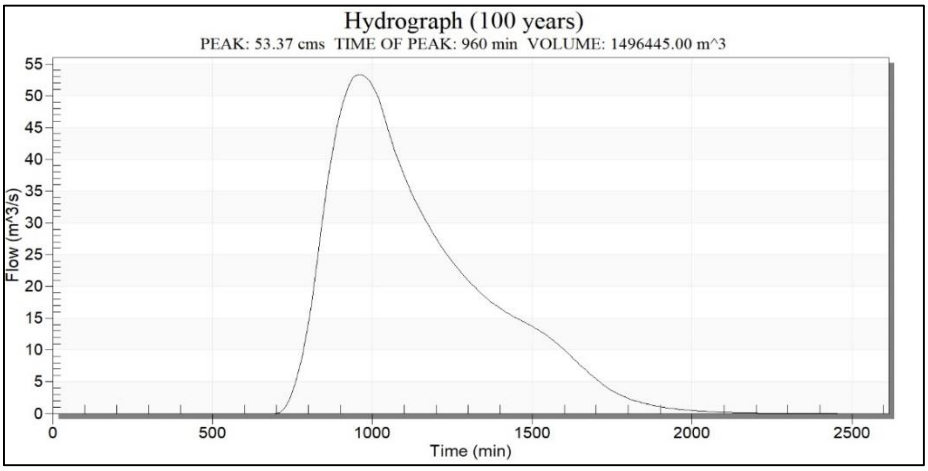


Figure 17. Unit Hydrograph for 100 years return period.

6. Conclusion

In this study, hydrological analysis and estimation of total water runoff volume were carried out through four sequenced stages engaging basically the use of GIS-based tools integrated with remote sensing technology. Wadi Gasus basin which includes the flooded village is recognized in a hot spot area prone to flood disruption impacts due to both morphological and meteorological conditions. Wadi Gasus and similar places to its nature leads urban communities involved to suffer from floods due to three main restrictions which are: morphologic factors, heavy rainfall intensity and High precipitation due to LU/LC and soil types. Some concluded remarks could be found out as follows: (1) Remote sensing technology integration with GIS data is an easy, saving time and inexpensive approach that is suitable for hydrological analysis for both small and large scale areas exposed to floods. (2) The reliable mathematical analyses of rainfall distributions lead to produce apposite precipitation values related to the conventional return periods (2, 5, 10, 25, 50, 100) in years. (3) Prediction for prevention is a useful attitude by estimating maximum precipitation and converting to water runoff discharges then estimating its total volume. (4) The proposed hydrological analysis and the obtained results are considered as an appropriate material that will support hydrologists, civil engineers and concerned decision makers as a trustworthy, sequenced flood hazard identification.

At the end, it is recommended to generate an efficient flood risk assessment as a future work next step throughout risk mapping analysing flood negative impacts to make the best use of identification platform done in this research.

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