FLASH FLOOD MODELLING OF UNGAGGED WATERSHED BASED ON GEOMORPHOLOGY AND KINEMATIC WAVE: CASE STUDY OF BILLI DRAINAGE BASIN, EGYPT

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ABSTRACT

Billi is one of the ungagged drainage basins in the Eastern desert of Egypt and characterized by drought and rare precipitation. However, events of heavy rain are occuring increasingly leading to repetitive flash flood events that extend to Red sea coast casing damages for human and infrastructures. El-Gouna is a touristic urban area locates in the valley's delta, which is not prepared with protection structures and depends on desalination of salt groundwater as the main source for fresh water. Due to the lack of historical data and the availability of non reliable data for the flash flood event of 09th March 2014, this paper adapts the KW-GIUH model to investigate the hydrological response of Billi drainage basin and to model the rainfall-runoff process based on the basin's geomorphological characteristics and kinematic-wave equations. The sensitivity analysis showed a significant effect of rainfall intensity, the overland and channel roughness coefficients, and the sub catchment contributing area over the peak discharge and time to peak. The simulated hydrograph looks more reasonable and within the acceptable limits with the analytical solution comparing with the field measurement, where the peaks occurred almost in the same time and an error of peak discharge by -19% and runoff volume error of -7.69%. The differences attributed to the limited difference in the estimated effective precipitation with -1%, which is responsible for an error of -10.29% in the peak value, and -8.71% in water volume. The results of KW-GIUH model are promising and could be used as a reliable input to another robust shallow water model to examine the effects of flash flood events over urban areas located in the deltas of ungagged watersheds. This will reduce the amount of required data, computational efforts, and provide reliable results that could be used for protection and rain water harvesting applications.

Keywords: Kinematic Wave, Geomorphological Instantaneous Unit Hydrograph, Ungauged Watershed, Billi Drainage Basin, Egypt.

1 INTRODUCTION

The Eastern Desert of Egypt is characterized by drought and rarely precipitation. However, events of heavy rain occur increasingly in yearly frequency. Flash floods resulting due to many of valley systems in the region, which extend to either Red sea coast or Nile river. Many of urban areas are located in the catchments and valley's delta, and most of the settlement aren't prepared with protection structures (Tügel, et al., 2018). Many of reports refered to human and infrastructure damages over the area during the last decades (Bauer, et al.). These damages are likelihood to be maximized due to the effects of climate change effects in term of sharp drought and precipitation (Tügel, et al., 2018).

Billi drainage basin sit in the Eastern Desert of Egypt, and extends from the Red Sea Hills at the western part to El-Gouna coastal plain in the east; and bounded by the coordinates 33° 12' 33" to 33° 40' 18" E and 26° 57' 56" to 27° 28' 20" N. Its area about 878.7 km^2 and elevated from 0 to 2126 m. The basin is surrounded by Wadi Umm Masaad in the north borders, Wadi Umm Diheis in the south, drainage basins of the Nile river in west, and the Red Sea to the East. Five main morphological features are included in the basin, from west to east, that have specific features: high mountains, Abu Sha'ar plateau, wadi Billi, coastal ridge of Esh Al-Mellaha, and a coastal plain (Bauer, et al.).

A selected event of flash flood flow coming from Billi drainage basin to El-Gouna town on 09th March 2014 is measured in the field using a mobile electromagnetic flow rate measurement device at the end of Billi canyon and published in the PhD thesis of (Hadidi, 2016). The results showed around 35 million m^3 precipitated during this event, and almost one million cubic meters passed through the Billi Canyon and continued towards the sea causing damages to the asphalt roads and infrastructure in El-Gouna.

The recorded values are unreliable as the measurements number is limited and nonuniform temporally with 6 values over 18 hrs; and done only in one point of shallow water due to the hard accessibility. Thus, the resulted hydrographs can't be used to calibrate the results of KW-GIUH model. However, it's could be used as an indication for the hydrograph shape, minimum water volume and main inflection points.

Later, (Elsisi, et al., 2018) modelled the same event analytically using Flood-Plain method and got a results of double peak value with almost 80 m^3/s and almost tribble of water volume of (Hadidi, 2016).

Figure 1. Collapse of infrastructure due to the scour effect: main road (left), bank protection (middle), and cutting lines of electricity, internet and phone (right) (Helal, 2014)

(Tügel, et al., 2018) used the recorded hydrograph of (Hadidi, 2016) as an input to solve the shallow water equations and simulate the flow propagation process over the basin's delta. In spite of the needing of detailed hydrological data and applied high computational efforts for relatively small area. However, the results included not only a unit hydrograph, but also the flow evolution, water depths and flow velocities in the whole simulated domain and for any time. Hence, a wide range of applications may be developed in term of managing the flooded water.

The validity of (Tügel, et al., 2018) results is depending to a large extend on the availability and reliability of the input hydrograph, which is not available for most of the drainage basins in the area.

The same flash flood event will be modelled again using the Kinematic Wave Geomorphic Instantaneous Unit Hydrograph (KW-GIUH) model (Lee, 1997) and based on only the excess rainfall and limited morphometric data that can be derived using GIS techniques. The resulted hydrograph will be compared with the results of (Hadidi, 2016) and (Elsisi, et al., 2018) and analysed to examine the applicability of KW-GIUH to predict the hydrological response and modelling the rainfall-runoff process for ungagged drainage basins over the Eastern Desert of Egypt.

The KW-GIUH proved its validity in modelling flash floods within humid zones as shown in (Lee & Yen, 1997) and (Lee, et al., 2009); and within arid zones as in (Jarrar, et al., 2007) and (Shadeed, et al., 2007), where sufficient high accuracy results and stable values of the calibrated parameters is achieved.

2 KW-GIUH MODEL

The Kinematic Wave based on Geomorphic Instantaneous Unit Hydrograph (KW-GIUH) model was developed by Prof. Kwan Tun Lee, Watershed Hydrology and Hydraulics Laboratory, Department of River and Harbour Engineering, National Taiwan Ocean University. The KW-GIUH model used for modelling surface runoff in ungauged catchments. The idea based on integrating the precipitation data with watershed hydraulic response to predict the rainfall-runoff process (Taiwan Typhoon and Flood Research Institute, 2018).

2.1 Runoff Simulation

The overland flow over a permeable soil surface can occur, when the rainfall rate is greater than the infiltration rate, or when the soil surface near the stream is saturated (Shadeed, et al., 2007). (Lee & Yen, 1997) considered the unit depth of excess rain falls uniformly and instantaneously over a drainage basin, and assumed to be consisted of large number of independent and noninteraction raindrops. Thus, the process of rainfall-runoff can be represented by tracing the excess rainwater, which moving along different paths towards the watershed outlet to produce the outflow hydrograph.

According to (Strahler, 1952) the drainage basin order **Ω** can be divided into different states. The x_{oi} denote of ith-order overland areas and x_i ith-order channel, where i = 1,2, …, Ω.

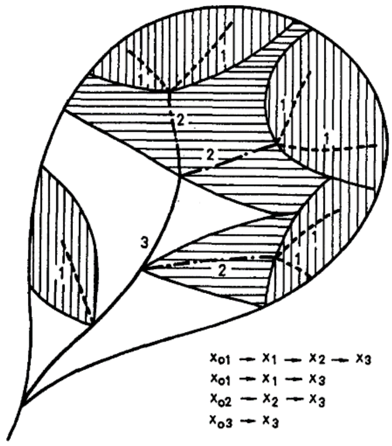

Figure 2. Drainage basin of third order main stream according to Strahler ordering system (Lee & Yen, 1997)

Figure 2 shows the possible travel paths for excess raindrops over the drainage basin. Starting from overland region to the channel of low order then traverse to channel of higher order until they reached to the output. If *w* denotes a specific path $x_{oi} \to x_i \to x_j \to \ldots \to x_\Omega$, the probability of excess raindrop to adopt this path is:

$$P(w) = P_{OA_i} P_{X_{oi} x_i} \cdots P_{X_i x_j} \cdots P_{X_k x_\Omega} \tag{1}$$

where, P_{OA_i} = ratio of ith-order overland area to the total watershed area; $P_{X_{oi} x_i}$ = transition probability of raindrops moving from ith-order overland area to ith-order channel = unity by definition; and $P_{X_i x_j}$ = transition probability of raindrops moving from ith-order channel to jth-order channel.

The total travel time for excess raindrops moving along path *w:*

$$T_w = T_{X_{oi}} + T_{X_i} + T_{X_j} + \cdots + T_{X_\Omega} \tag{2}$$

The IUH can be represented by the convolution of two groups of probability density functions:

$$u(t) = \sum_{w \in W} \left[\left(f_{x_{oi}}(t). f_{x_{ri}}(t). f_{x_{rj}}(t). \dots . f_{x_{r\Omega}}(t) \right) . \left(f_{x_{ci}}(t). f_{x_{cj}}(t). \dots . f_{x_{c\Omega}}(t) \right) \right] . P(w) \tag{3}$$

The travel time for overland flow area and for storage component of a channel is assumed to follow an exponential distribution, but the translation component of a channel is assumed to follow a uniform distribution. Therefore, the hydrological response of a drainage basin can be considered conceptually as a combination of linear reservoirs and linear channels in series and/or in parallel.

2.2 Travel Time Estimation

Lee & Yen (1997) considered a sub-basin as it consists of two identical rectangular overland flow planes. Each one of them contribute by lateral discharge into the channel, which has a constant cross-section and slope. By means of the following equations the travel time for different order sub-basins can be estimated from overland and channel hydraulics.

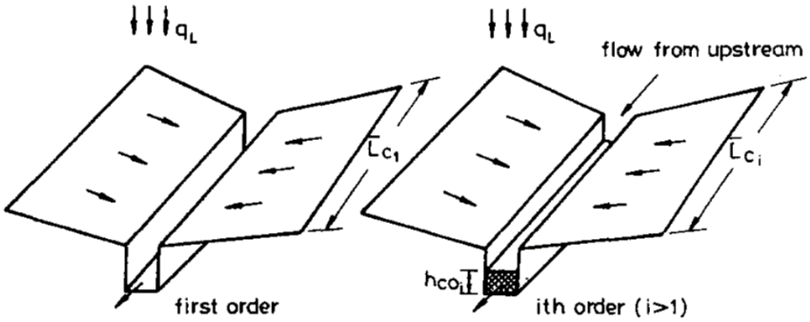

Figure 3. Sub-basin as V-Shape (Lee & Yen, 1997)

The travel time for ith-order overland plane can be obtained using kinematic-wave approximation as:

$$T_{x_{oi}} = \frac{h_{osi}}{q_l} = \left(\frac{n_o \, \overline{L_{oi}}}{\bar{S}_{oi}^{0.5} \, {q_l}^{m-1}} \right)^{\frac{1}{m}} \tag{4}$$

where $\bar{S}_{oi}$ the mean ith-order overland slope; n_o the effective roughness coefficient for the overland planes; m = constant and recognized as 5/3 from Manning's equation.

The travel time for an ith-order channel:

$$T_{x_i} = \frac{B_i}{2 \; q_l \, \overline{L_{oi}}} \left(h_{csi} - \; h_{coi} \right) = \frac{B_i}{2 \; q_l \, \overline{L_{oi}}} \left[\left(h_{coi}^m + \frac{2 \; q_l \, \overline{L_{oi}} \, L_{ci} \, n_c}{B_i \, \bar{S}_{ci}^{0.5}} \right)^{\frac{1}{m}} - h_{coi} \right] \tag{5}$$

where $\bar{S}_{ci}$ the mean slope of ith-order *channel*; n_c the effective roughness coefficient for the *channel* flow; and B_i the width of ith-order channel.

h_{coi} = the inflow depth of ith-order channel due to water transported from upstream reaches. So, it's equal zero for the first order because no channel flow is transported from upstream. However, for 1 < i < Ω it can be can expressed by:

$$h_{coi} = \left[\frac{q_l\, n_c\, (N_i\, \bar{A}_i - A\, P_{OAi})}{N_i\, B_i\, \bar{S}_{ci}^{0.5}}\right]^{\frac{1}{m}} \tag{6}$$

where: N_i = number of *i*th-order channels; and $\bar{A}_i$ = mean of drainage area of order *i*.

3 INPUT PARAMETERS

3.1 Morphological Parameters of Billi Drainage Basin

The author analysed the Digital Elevation Model (DEM) of 1° x 1°, released in November 2011 under the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) program (Meti & Nasa, 2011) using Esri ArcMap 10.5 to re-delineate Billi drainage basin, where the pour point moved to the same point of measurements done by (Hadidi, 2016).

The values of drainage basin area *A*, the stream order numbers N_i, average length of stream order $\overline{L_{ci}}$, the mean channel gradient $\overline{S_{ci}}$, and the gradient of overland regions $\overline{S_{oi}}$ were derived using GIS techniques, Table 1. Other parameters are calculated using the following equations that developed by (Lee & Yen, 1997):

The transition probability of raindrops moving from *i*th-order *channel* to *j*th-order *channel* can computed as:

$$P_{X_i x_j} = \frac{N_{i,j}}{N_i} \tag{7}$$

where: N_i = number of *i*th-order channels; and $N_{i,j}$ = number of *i*th-order channels that contribute to *j*th-order channel.

The mean of drainage area of order *i*. Can calculated as:

$$\bar{A}_i = \frac{1}{N_i}\sum_{j=1}^{N_i} A_{ji} \tag{8}$$

where, A_{ji} = denotes the area of *overland* flow regions that drain directly into *j*th *channel* of order *i*, and overland areas drained into the lower order channels tributary to this *j*th channel of order *i*.

The ratio of ith-order overland areas to the total drainage basin area, can obtained as:

$$P_{OA_i} = \frac{1}{A}\left(N_i\, \bar{A}_i - \sum_{i=1}^{i-1} N_i\, \bar{A}_i\, P_{X_i x_j}\right) \tag{9}$$

where, *A* = total area of the watershed.

The mean length of ith-order V-shape *overland* flow planes:

$$\overline{L_{oi}} = \frac{A\, P_{OAi}}{2\, N_i\, \overline{L_{ci}}} \tag{10}$$

In addition to limited field investigation to measure the width of main channel at the outlet point. (Lee & Yen, 1997) suggest a linear variation of channel widths to simplify the field investigation work:

$$B_i = \frac{B_\Omega \sum_{i=1}^{i} \bar{L}_{ci}}{\sum_{i=1}^{\Omega} \bar{L}_{ci}} \tag{11}$$

where, B_Ω = denotes the channel width at the watershed outlet.

The element-based method cited by (Arcement, et al., 1989) has been applied to estimate the channel roughness coefficient, and the adjusted equation to derive the overland roughness value:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_s \tag{12}$$

where n_0 is relating a straight, uniform or smooth channel; n_1 is a value added to correct the effect of surface irregularities; n_2 is a value added to correct the effect of the shape and size of the channel cross section; n_3 a value for obstructions; n_4 a value for vegetation and flow conditions; and m_s is a correction factor for meandering the channel.

The related parameters are determined by inspection of photographs and the aerial photography of study area using (Google LLC., 2018). A weighted value has been derived for both the stream network and overland roughness for practical application.

Table 1. Geomorphological Parameters of Billi drainage basin.

Parameters		**Stream Order**					
Description	**Symbol**	**1**	**2**	**3**	**4**	**5**	**6**
ith-order stream number	Ni	2426	523	129	28	5	1
Mean ith-order stream length (km)	$\bar{L}$ci	0.4436	1.0997	2.3262	4.3113	18.4621	49.2184
ith-order sub catchment contributing area (km^2)	$\bar{A}$i	0.14	0.95	3.17	19.12	120.55	813.961
ratio of the ith-order overland area to the catchment area	PoA$_i$	0.417268	0.298643	0.000188	0.209952	0.032032	0.041918
Mean ith-order overland slope (m/m)	$\bar{S}$oi	0.1648	0.1459	0.1506	0.1460	0.1505	0.1338
Mean ith-order channel slope (m/m)	$\bar{S}$ci	0.1188	0.0467	0.0262	0.0165	0.0127	0.0072
total area of	A	813.9610					

the Sub-catchment (km^2)		
Channel width at catchment outlet (m)	B_Ω	23.6
Overland flow roughness	n_o	0.15
Channel flow roughness	n_c	0.04

Table 2. Transition probabilities ($P_{xi,xj}$) of stream network for Billi drainage basin.

$P_{1,2}$	$P_{1,3}$	$P_{1,4}$	$P_{1,5}$	$P_{1,6}$	$P_{2,3}$	$P_{2,4}$	$P_{2,5}$
1810/2426	358/2426	75/2426	120/2426	63/2426	378/523	69/523	53/523
0.746084	0.147568	0.030915	0.049464	0.025969	0.722753	0.131931	0.101338
$P_{2,6}$	$P_{3,4}$	$P_{3,5}$	$P_{3,6}$	$P_{4,5}$	$P_{4,6}$	$P_{5,6}$	---
23/523	91/129	28/129	10/129	22/28	6/28	5/5	---
0.043977	0.705426	0.217054	0.077519	0.786	0.214	1	---

3.2 Hydrological Parameters of 09th March 2014 Event

The weather parameters of 09th March 2014 has been recorded using Vaisala® Weather Transmitter WXT520 sensor and published by Hadid (2016). A value of uncertainty is expected in the records as there is only one-point station to cover the large extends of Billi drainage basin and the variation of the morphometric features.

The accumulated rainfall depth reached to 32.82 mm over 10 hrs. It's worth to mention that the area is exposed to a very light rain event on 8th March with 0.92 mm over 5 hrs. Due to the small-time scale of heavy precipitation in combination with the cloudiness, decreasing of temperature, and no vegetation; the losses of water due to the evapotranspiration process during the storm event is insignificant. While the infiltration process has a strong effect on the surface runoff behaviour.

The infiltration losses determined empirically using the Soil Conservation Service Curve Number (SCS-CN) method (Mishra & Singh, 2003).Two hydrological soil types are identified using the geological map of Billi drainage basin, Figure 4. The first one classified as type A and extends over the desert plateau of Abu Sha'ar and Wadi Billi, while the other one is type D and covers all the rocky areas.

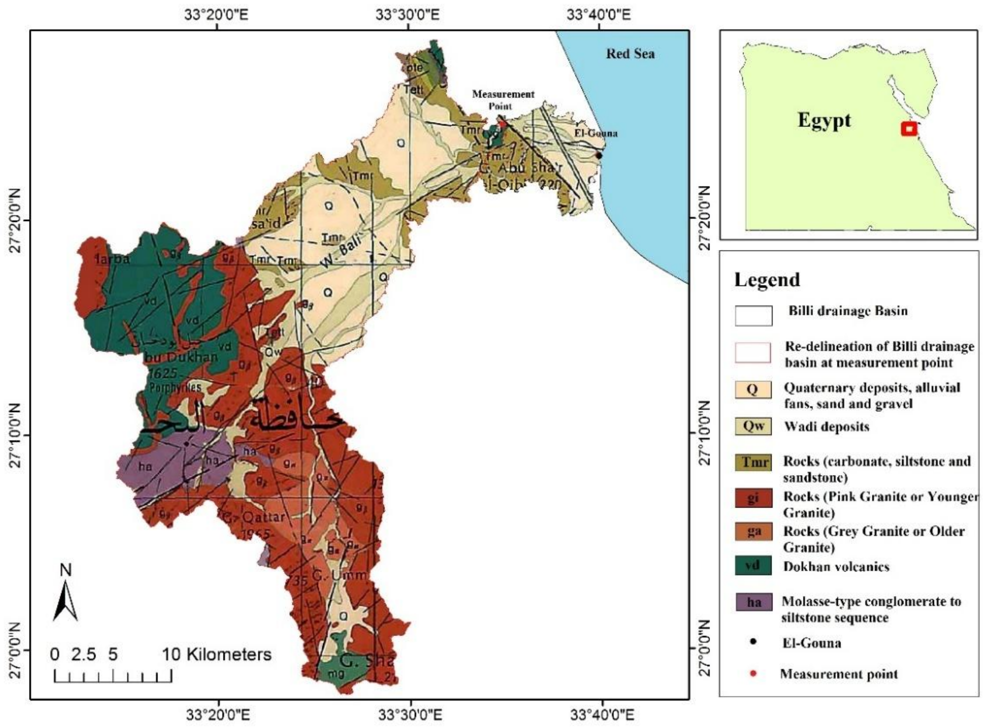

Figure 4. Geological Map of Billi drainage basin, modified after (The Egyptian General Petroleum Corporation, 1986)

The rainfall events over the previous 5 days didn't exceed the defined threshold of the antecedent soil moisture conditions (AMC). Therefore, the values of CN are revised to follow the dry condition of AMC-I. The value of the effective rainfall depth is weighted and calculated as the following:

$$S = \left(\frac{1000}{CN} - 10\right) * 25.4 \tag{13}$$

where, S is the potential maximum retintion or infiltration (mm).

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{14}$$

where, Q is the effective rainfall depth (mm), and P is the total rainfall depth (mm).

$$Q_{\text{weighted}} = \frac{Q.\,Area\%}{100} \tag{15}$$

where, Q_{weighted} is the weighted arithmetic mean of the effective rainfall depth over Billi drainage basin

Thus, the percentage of effective precipitation Ø estimated as 9% and calculated as:

$$\emptyset = \frac{\sum Q_{\text{weighted}}}{P} \tag{16}$$

Table 3: Parameters of Curve Number method for Billi drainage basin.

soil-vegetation-land use complex	Land Use description	Hydrological soil type	Area	Area	CN (II)	Revised CN (I)	S	Q	Q-Weighted	Effective Precipitation Ø
SVL	**----**	**----**	**km2**	**%**	**----**	**----**	**mm**	**mm**	**mm**	**%**
Sand	Natural desert landscaping	A	247.2	30.37	63	43	336.7	3.96	1.20	9%
Rock		D	566.7	69.63	88	75	84.67	2.49	1.73	
Sum	----	----	**813.9**	----	----	----	----	----	**2.94**	----

The resulted excess rainfall estimated as 2.94 mm over 10 hrs and assumed to be distributed uniformly over Billi drainage basin area.

It's worth to mention that (Elsisi, et al., 2018) used only one average value of CN for the whole watershed area, and didn't revise it to AMC-I. Thus, a difference of -1% in estimation of the effective precipitation existed. This will be explained later the limited difference in the simulated and calculated hydrographs.

4 SENSITIVITY ANALYSIS

The sensitivity analysis has been applied for all input parameters in the model equations to examine the effect of each parameter on the unit hydrograph shape and to determine the most sensitive ones. The applied range of values for each parameter estimated according to the possible range of mistake.

Generally, a significant impact is noticed for overland and channel roughness on IUHs, where the overland roughness was examined for no = 0.1 to 0.5, and the channel roughness for nc = 0.01 to 0.05. The results shown an inverse relation for both of channel and overland roughness with the peak value and have a little effect on the time to peak, where increasing the value of no and nc delaying the time to peak.

As the main channel width is the only parameter measured in the field, so it's important to test the sensitivity on IUH. The values of $B\Omega \pm 25\%$ were tested, and the resulted hydrographs in Figure 5 illustrates a minor effect of the channel width on the discharge peak with no observed effect on time to peak.

For each of the morphometric parameters derived using GIS techniques: ith-order stream number N_i, Mean ith-order stream length $\bar{L}_{ci}$, ith-order sub catchment contributing area $\bar{A}_i$, Mean ith-order overland slope $\bar{S}_{oi}$, and Mean ith-order channel slope $\bar{S}_{ci}$, the range of values were tested for the actual values ± 10% due to the accuracy in measurements. The results showing limited change in peak value for all parameters except for the sub catchment contributing area $\bar{A}_i$ where it's increased up to 10.4%, with no observed effect of them on time to peak.

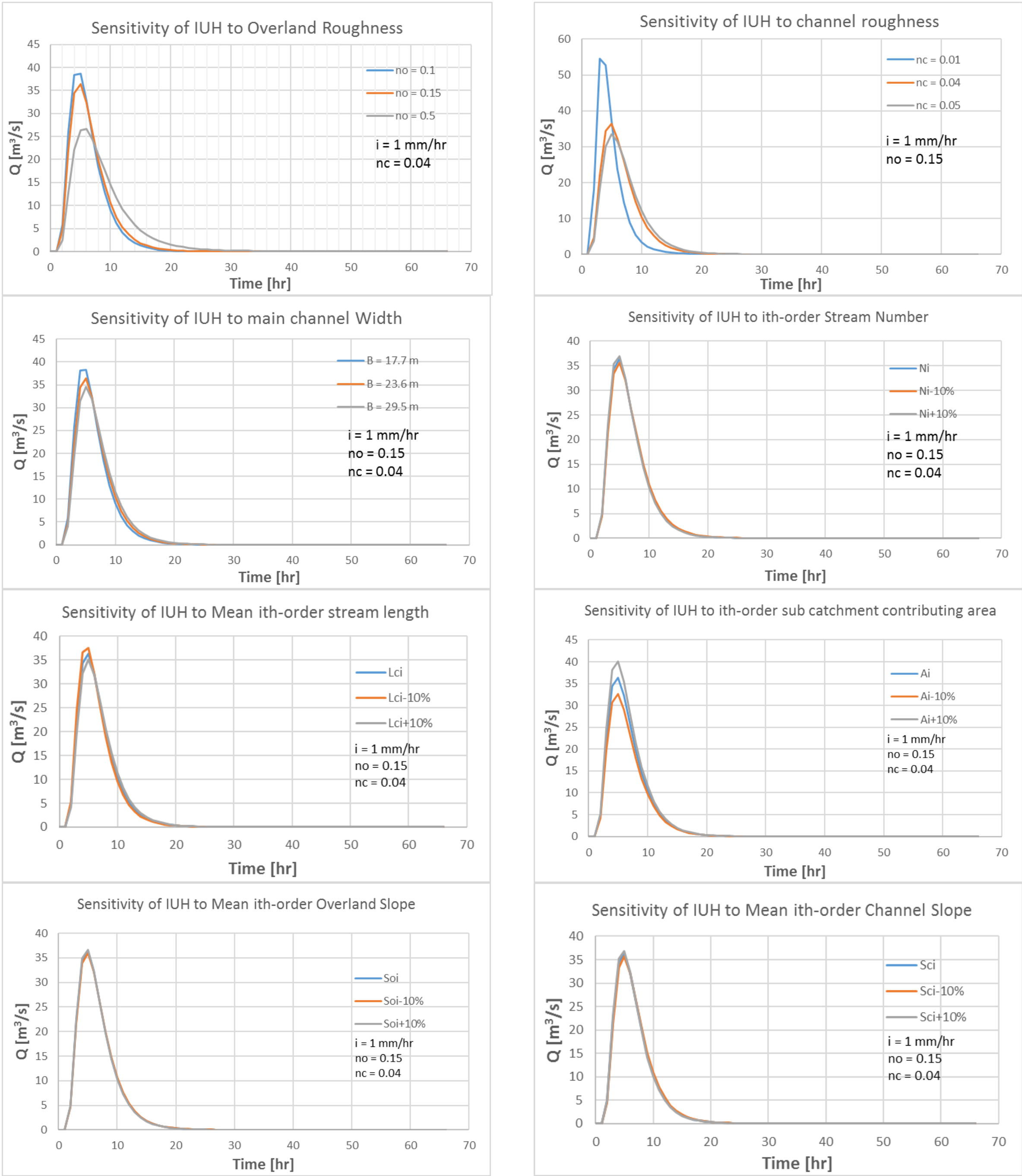

Figure 5. Sensitivity Analysis of IUH to Morphometric Parameters

The order of main stream reduced by one order from 6^{th} to 5^{th} to investigate the effect of the drainage basin order on the IUH of KW-GIUH model. The result shows high sensitivity, where the discharge peak value decreased by 63.7% and the time to peak reduced by 3-time steps. It's worth to mention that KW-GIUH model considers all the stream network including the permanent and the intermittent lines.

5 RESULTS AND DISCUSSION

5.1 GIUH Generation

To understand the hydrological response of Billi drainage basin, the author examined the effect of different values of excess rainfall intensity (i = 1, 5 & 10 mm/hr) on the GIUH generation. The results showed that the forming of GIUH is a function of the excess rainfall, and with increasing the intensity of excess rainfall the peak value will increases, and the time to peak decrease. Also, it's reasonable to expect that the form of GIUH is varying from each sub-basin to another within Billi drainage basin due to the variation in the morphometric features.

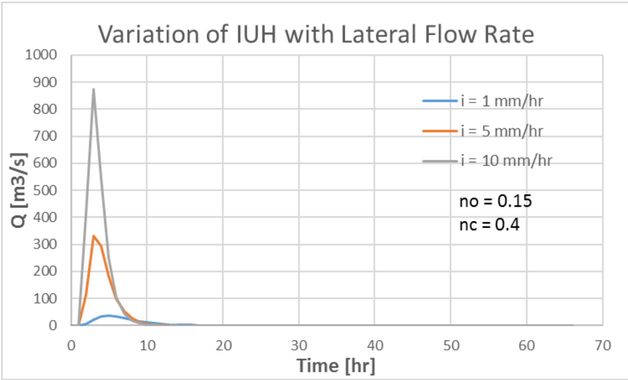

Figure 6. Variation of GIUH with lateral flow rate at Billi drainage basin

5.2 Event of 09th March 2014

On 09th March 2014, a rain storm event was recorded with a single peak, and the hyetograph of excess rainfall determined as 2.94 mm over 10 hrs.

The resulted hydrograph, Figure 7, shows a peak value of 65.33 m^3/s at 07 PM, and water volume of 2,405,700 m^3. It's worth to mention that the main flood period extends from 11 am of 09th March to 05 pm of 10th March with almost 30 hrs, then it continues with very limited discharge value for another 15 hrs.

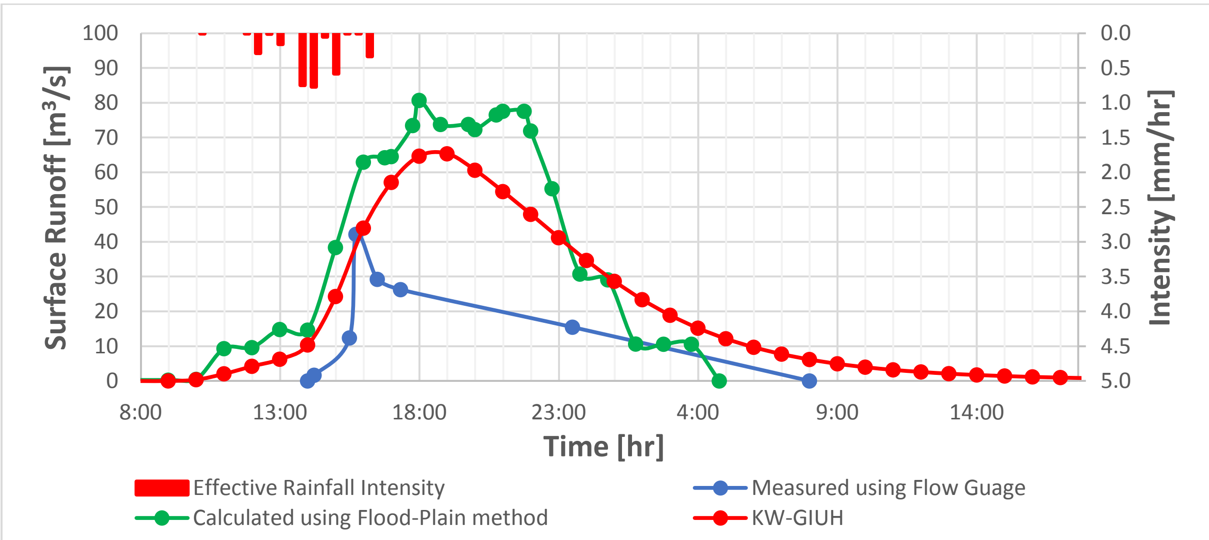

Figure 7. Simulated hydrograph of Billi drainage basin compared with measured *(Hadidi, 2016)* **and calculated** *(Elsisi, et al., 2018)* **hydrographs, event of 09th March 2014**

5.3 Model Verification

The resulted IUH of KW-GIUH model is verified by comparing with the analytical solution of (Elsisi, et al., 2018) and the field measurement of Hadid (2016), where, three selected criteria is examined to analyse the goodness of fitting degree (Huang, et al., 2012):

The error of peak discharge $EQ_p(\%)$:

$$EQ_p(\%) = \frac{Q_{p,est} - Q_{p,obs}}{Q_{p,obs}} \times 100 \quad (17)$$

where, $Q_{p,est}$ denotes the peak discharge of the simulated hydrograph [m^3/s], and $Q_{p,obs}$ represents the peak discharge for the observed hydrograph [m^3/s].

The error of the time to peak ET_p:

$$ET_p = T_{p,est} - T_{p,obs} \quad (18)$$

where, $T_{p,est}$ is the time for the peak arrival for the simulated hydrograph [hr], and $T_{p,obs}$ is the time for the peak arrival for the observed hydrographs [hr].

The runoff volume error EQ_V (%):

$$EQ_V(\%) = \frac{Q_{V,est} - Q_{V,obs}}{Q_{V,obs}} \times 100 \quad (19)$$

where, $Q_{V,est}$ denotes the runoff volume of the simulated hydrograph [m^3], and $Q_{V,obs}$ is the runoff volume of the observed hydrographs [m3].

As shown in Figure 7 and Table 4, the simulated, measured and calculated peaks occurred almost in the same time. A significant difference exists in the values of peak discharge and runoff volume between the result of KW-GIUH model and the field measurement of Hadid (2016). While, it looks more reasonable and within the acceptable limits with the analytical solution of (Elsisi, et al., 2018). The differences here attributed to the limited difference in the estimated effective precipitation with -1%, which is responsible for an error of -10.29% in the peak value, and -8.71% in water volume. Thus, the final errors minimized to -8.75% for the peak value and +1.02% for the water volume.

The results indicate the applicability of KW-GIUH model for reliable simulation of the rainfall-runoff process for Billi drainage basin. Thus, for the ungagged watersheds of the Eastern Desert of Egypt.

Table 4. The goodness of fitting degree of the simulated hydrograph with the analytical solution and field measurement hydrographs for Billi drainage basin, event of 09th March 2014.

Criteria	With field measurement of (Hadidi)	With analytical solution of (ElSisi, et al.)
Error of peak discharge $EQ_p(\%)$	+ 54.95	- 19.03
Error of time to peak discharge ET_p (hr)	+ 3	+ 1
Runoff volume error EQ_V (%)	+ 140.57	- 7.69

6 CONCLUSION AND RECOMMENDATIONS

This paper adapts the KW-GIUH model to estimate the travel time for the excess raindrops and generates the Instantaneous Unit Hydrograph for the flash flood event of 09^{th} March 2014 in Billi drainage basin, Egypt.

Even the recorded hydrograph is doubtful as the measurements number is limited, nonuniform temporally with 6 values over 18 hrs, and done only in one point of shallow water due to the hard accessibility. However, the simulated hydrograph shows relative similarity with the main changes in the shape and the time to peak.

The simulated and the analytical solution hydrographs shown relative matching and within the acceptable limits, where the peaks occurred almost in the same time with an error of peak discharge by 19% and runoff volume error of 7.69%. The differences here attributed to the limited difference in the estimated effective precipitation with -1%, which is responsible for an error of -10.29% in the peak value, and -8.71% in water volume. Thus, the final errors minimized to -8.75% for the peak value and +1.02% for the water volume.

The results of the KW-GIUH model proved its validity with GIS techniques as the main tool to investigate the hydrological response of the ungagged watersheds in the Eastern Desert of Egypt without needing to historical rainfall-runoff data.

It's recommended to analyse statistically the correlation between the hydrological and the morphological parameters to determine the weight of each morphometric parameter that contribute to flash flood hydrograph. This approach will develop deep understanding of the hydrogeomorphological processes within Billi drainage basin.

Also, the resulted hydrograph of KW-GIUH model may be used as a reliable input to another robust shallow water model to simulate in detail the effects of flash flood events over the urban areas located in the deltas of ungagged watersheds. This will reduce the amount of required data, computational efforts, and provide reliable results that could be used for future planning of protection and rainwater harvesting applications.

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ACKNOWLEDGEMENT

This work couldn't be accomplished without the kind support of Prof. Kwan Tun Lee Director of Geographic Information System Research Center, National Taiwan Ocean University by providing us with KW-GIUH model. Also, the first author gratefully acknowledges the fruitful discussions with Dr. A. Adel Saleh from the Water Resources Research Institute (WRRI), Egypt.