BEST: International Journal of Management, Information Technology and Engineering (BEST: IJMITE)
ISSN 2348-0513
Vol. 2, Issue 7, Jul 2014, 45-58

DERIVATION OF SPATIALLY DISTRIBUTED UNIT HYDROGRAPH FOR BALISAN VALLEY WATERSHED USING GIS AND REMOTE SENSING TECHNIQUES

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ABSTRACT

Spatially distributed unit hydrograph bad been derived for ungauged Balisan valley watershed using GIS and remotely sensed satellite image. Field observations were made regarding to land cover for better comprehension of the watershed characteristic and to increase accuracy degree of classification. Five major types of land covers were recognized and represented in the form of raster images of 50*50m resolution namely: exposed rocks 24%, woods and pasture 42%, pasture and grassland 7%, close seeded 21%, and bare soil 2%. Experimental work includes analyzing of 45 soil samples for different locations at Balisan Valley watershed. ArcGISsoftware was used to assign specific curve number (CN) value to each grid cell depending on both Hydrologic soil group and land cover. Arc GIS was also used for watershed delineation, display of results, and performance of analytical calculation.

The drainage basin was divided in to two systems for the purpose of travel time estimation; they were storage, and conveyance system. Storage system was dealt according to SCS Curve Number algorithm to subtract losses from total precipitation to find excess rainfall. The conveyance system was divided into two flow regimes, overland and channel flow. Special FORTRAN code was written to rout excess rainfall cell by cell to the catchment's outlet to allow the generation of successive isochrones. Time of concentration for the watershed was found to be 8.91 hr.

KEYWORDS: GIS, Remote Sensing, Watershed Area, Peak Flow

INTRODUCTION

The watershed modeling by GIS and remote sensing was carried out by many researches [1, 2, 3, 4, 5, 6, 7]. The spatially distributed unit hydrograph model was applied for Balisan Valley watershed of 217km2, located on north west of Sulaimani governorate near Ranya town between (360o 17' 0"-360 28' 0'') N and (440o 28' 0''-440 41' 0'') E according to WGS (Figure 1). The landscape of the region mostly distinguished for its mountainous nature with steep slope up hills and average watershed slope of 30%. The elevation changes very dramatically from (650-2200mamsl). The most of the land left without treatment. The river in the watershed was of ephemeral type that wasabout 25 km length.

Remote Sensing

Remote Sensing was the science and art of obtaining useful information about an object. Area or phenomenon through the analysis of data acquired by a device that was not in contact with the object, Area, or phenomenon under investigation [8].The satellite image for Balisan Valley was from landsat-7 ETM, 2/3/2003, colored and corrected with 14.25m resolution [9]. The subsequent image processing and display was carried out by using ERDAS IMAGINE 8.7 (see Figure 2) and ArcMap.

ERDAS program was used to perform both supervised and unsupervised classification, while ArcMap program was used for registration and assigning specific coordinate system to the image for proper display and measurement purposes. Unsupervised classification was computer-automated process to uncover the statistical patterns inherent in the image. Cells of the same spectral characteristic were collected in clusters, the cells were statistically similar inside each cluster while different from the cells of another cluster, the program adopt ISODATA algorithm to perform unsupervised classification, ISODATA referred to (Iterative Self Organized Data Analysis), The ISODATA clustering method used the minimum spectral distance formula to form clusters. It began with either arbitrary cluster means or means of an existing signature set. Each time the clustering repeats, the means of these clusters were recalculated. The new cluster means were used for the next iteration. The ISODATA utility repeats either the clustering of the image until a maximum number of iterations had been performed, or a maximum percentage of unchanged pixel assignments had been reached between two iterations [10].

Supervised Classification of Balisan Valley

The result of supervised classification was checked against observed samples recorded previously through field visits, it showed acceptable agreement, except for wood and close seeded cover, that the former was over estimated. Many trials of selecting AOIs were repeated until the achievement reached the limits of acceptability. The over estimation of close seeded cover over wood cause by healthiness of vegetation in both cases that look like similar cover for the observer. Figure (3) shows the spatial curve number percentage for Balisan Valley.

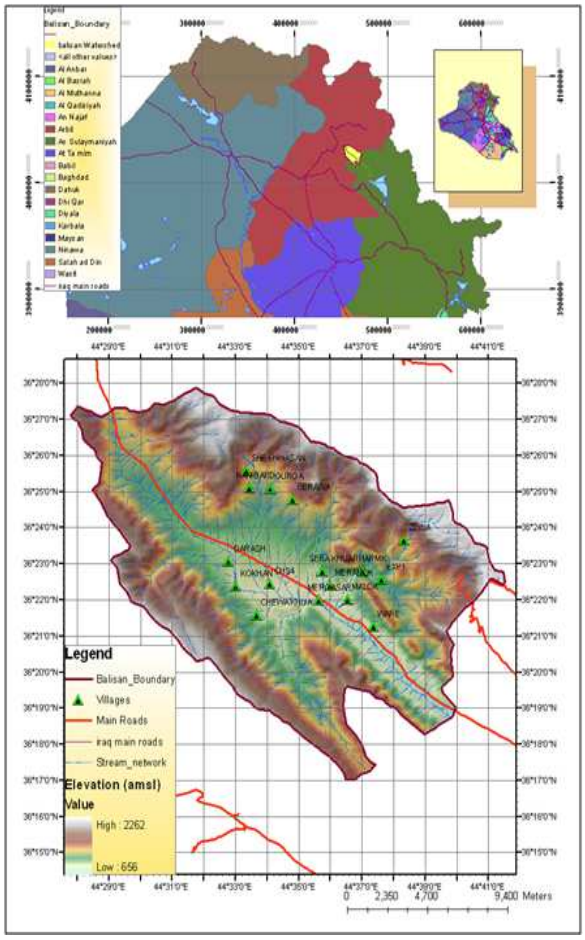

Figure 1: Location of Balisan Valley

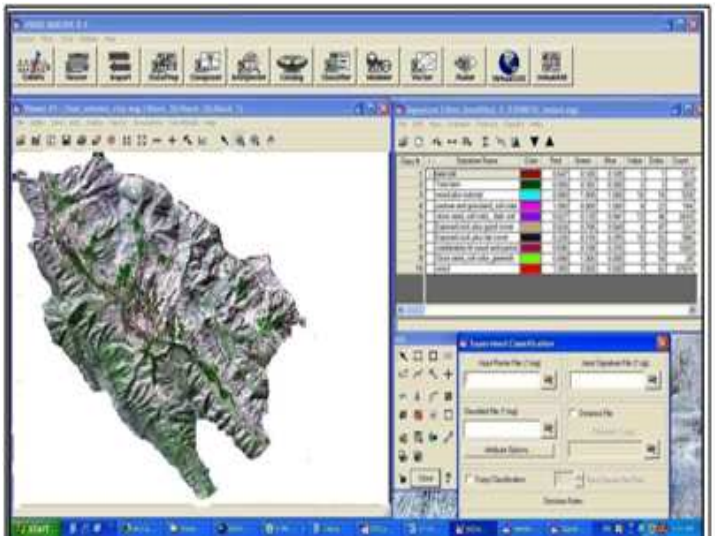

Figure 2: ERDAS IMAGINE Preview

GIS was used to reclassify Landuse\Landcover image for assignment of new pixel value representing (CN) values (Figure 4). Unclassified means pixel with no data values, and that was common in each satellite image, however ERDAS IMAGINE optionally asks if you classify zero data pixels or not. The data in Table (1) further processed by using EXCEL spreadsheet to yield for weighted curve number. ArcGIS used to create image raster representing weighted curve number (CN_w).

Methodology and Model Application

The basic purpose of this research was to utilize a conceptual method of deriving unit hydrograph depending on ArcMap's computational, storage, and management power. ArcMap (See Figure 6) software was developed by ESRI (Environmental System Research Institute). It provides flexible and powerful GIS platform to display and analyze any data inherent in raster images. ArcMap utilization was made at different stage of model development, starting with recognizing and assigning data value to particular cell and inventing specific name to comply for its curve number (CN) value.

Raster Calculator option inside Surface Analysis drop down list used to subtract amount of losses from total runoff. Functional power of ArcMap used to create flow accumulation and flow direction raster, which they represent key raster input to any spatial models. The process of abstracting losses from total rainfall, calculating travel time for each cell, and routing it to the watershed outlet, were all simulated in model builder environment. Model Builder Window (see Figure 7) provide unique environment for arranging and combination various readily available, and user defined functions in Tool Boxes. Once the model created in model builder, it can be stored, edited, and rerun in any time. Two FORTRAN code elaborated to satisfy the needs that was not possible to be met by ArcMap software only. The first FORTRAN code was written to find the depth of flow for each cell depending on channel section in the cell and upstream coming discharge. The second FORTRAN code was written to track the path (i.e. cells) that water passes through it and summing its corresponding travel time until it reaches the outlet, the result of this program will be accumulated travel time data file.

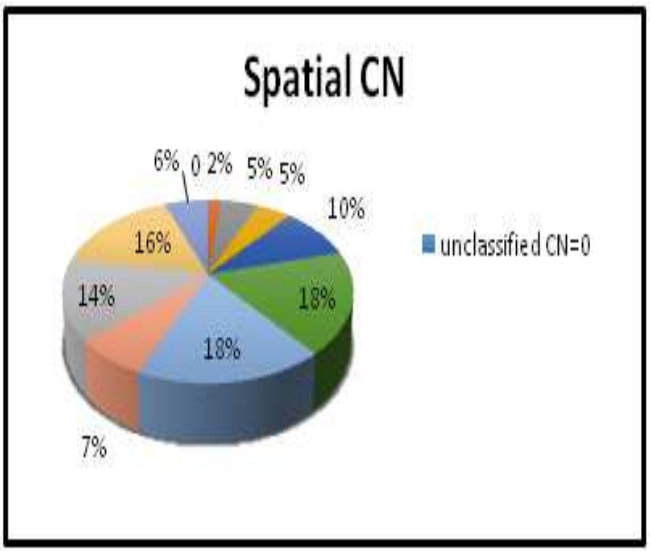

Figure 3: Spatial Curve Number Percentages

Single Cell Travel Time and Accumulated Travel Time

Single Cell Travel Time (SCTT) means the time that water needs to travel across every single cell along the flow path according to the flow direction until it reaches the edge of the cell, while Accumulated Travel Time (T_c) is the time that water needs to reach outlet beginning in the location it starts to move toward the outlet. T_c is computed by summing all travel time of consecutive component of drainage conveyance system. ArcGIS software is not capable to perform this task, for this purpose a FORTRAN code was written to account for T_c for each single cell within the catchment. Flow direction, and SCTT raster data set were converted to ASCII form. These files were used as read file (input file).

The FORTRAN code was trained to track the flow path starting from each single cell until it reaches the final sink cell that represent the outlet of the watershed summing the elapsed time for the runoff to move across each cell. Hence, the accumulative travel time (T_c) for that cell was calculated and stored in separate ASCII file. The resulted (T_c) converted to raster form using *conversion*toolbox and displayed in ArcGIS environment. Figure (5) shows typical accumulated travel time of raster image classified for 30 minutes time interval.

Table 1: Distributed Curve Number (CN)

No.	Classes	% Area	CN
1	Bare Soil: Area left unseeded after plowing CN=83	2%	83
2	Tree Farm CN=65	5%	65
3	Close seeded: Area treated mechanically. soil color (greenish)CN=65	5%	65
4	Exposed Rock: good cover condition CN=70	10%	70
5	combination between wood and pasture CN=60	18%	60
6	Wood CN=55	18%	55
7	Pasture and Grass land. soil color (greenish) CN=61	7%	61
8	Exposed Rock: fair cover condition CN=90	14%	90
9	Close seeded: dark soil CN=72	16%	72
10	Woods: outcrop projected from ground surface CN=65	6%	65
	Weighted Curve Number (CN_w)		*68*

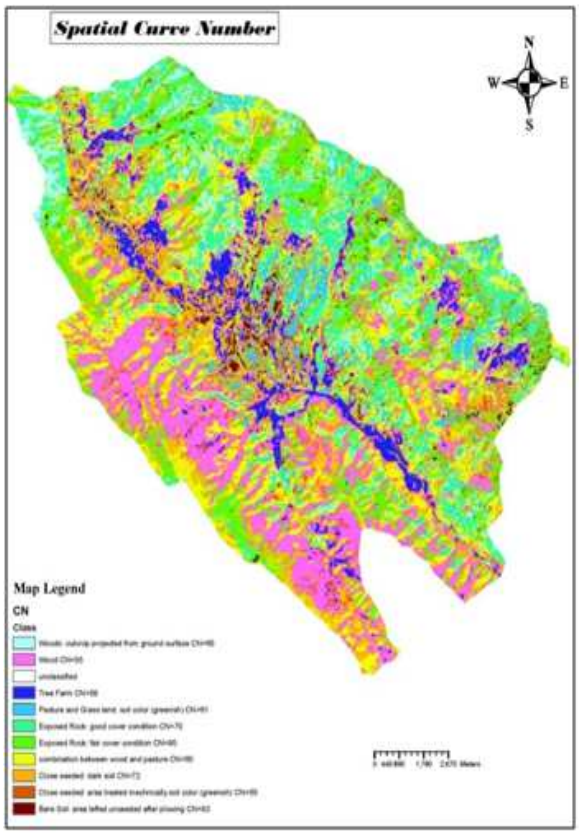

Figure 4: Spatially Distributed Curve Number

RESULT AND DISCUSSIONS

Model #1

The first attempt of direct runoff hydrograph (DRH) derivation was based on the approach of using TR_55 equation for overland flow, Manning formula for equilibrium flow velocity, and averaged CN (see table (2)).

According to Manning's equation, the travel time is directly proportional to roughness coefficient and inversely changes with discharge and ground slope. However, there is no basic procedure be used for the assignment of Manning's roughness (n) to particular parcel of land, it depends on the experience and personal judgment, same explanation is true for channel section geometry. Using constant CN results in generation of uniform rainfall distribution, however this condition cannot be approved in nature, because of variation in aerial distribution of rainfall while dealing with large area. This assumption can also be criticized for various response of soil type and soil surface cover to rainfall, which they enroll in determining temporal and quantitative variation of effective rainfall during rainfall duration. The amount of abstraction represented by CN only account for quantity of rainfall excess regardless of starting time and how long was it lasting (i.e. temporal variation). The hydrograph predicted based on the previously described approach satisfy expected general basic properties of hydrographs regarding shape and base time division between rising and falling limp.

The model derived unit hydrograph in figure (8) successfully predicted the bill shape of the unit hydrograph and counted for recession period which is always longer than rising period. Figure (5) is a raster image represents accumulated travel time for model#1, it is obvious how did the model detect the differential response of the watershed conveyance system to translate water from the places where essentially generated to the outlet. The figure (5) illustrates also close correlation between watershed drainage pattern and travel time variation.

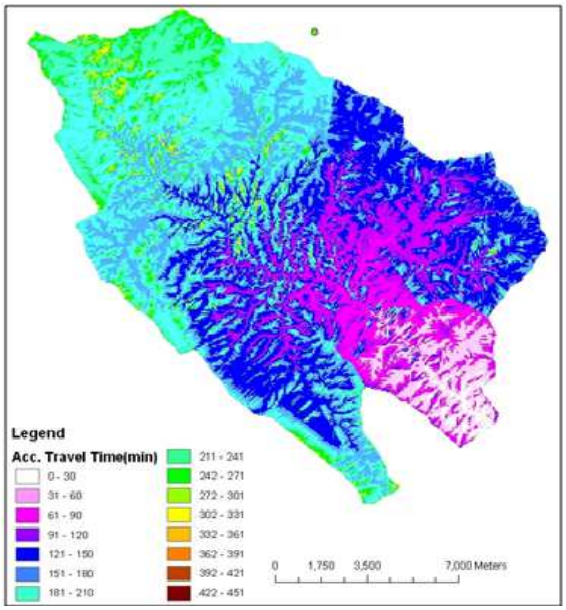

Figure 5: Image Raster of Accumulative Travel Time

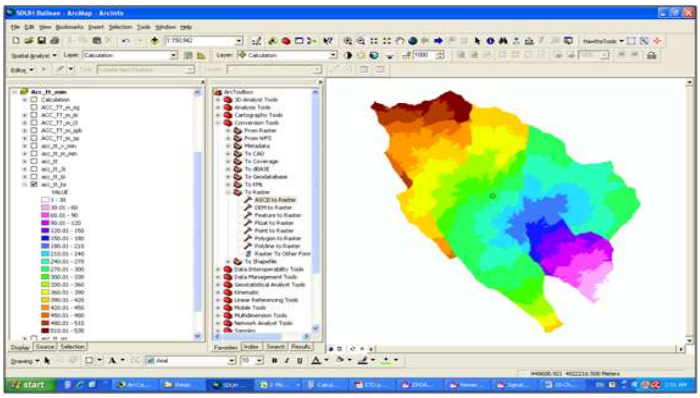

Figure 6: Arcmap Preview

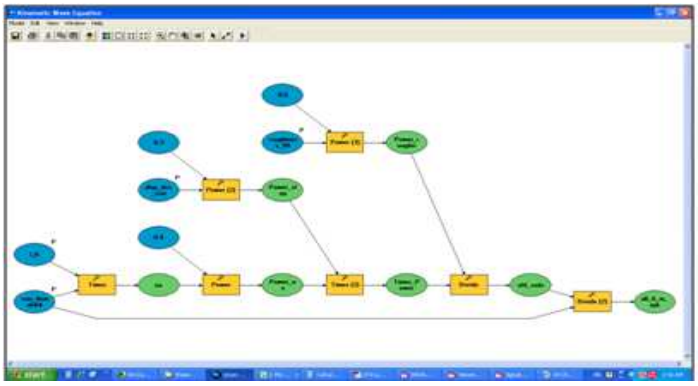

Figure 7: Model Builder Preview

Table 2: Basic Parameter and Output Result for Model#1

Model Parameter		Output	
Resolution	50*50 m	Base Time (hr)	7.6
Weighted CN_w	68	Time to peak (hr)	2.5
Effective rainfall intensity	1.35 mm/hr		
Overland travel time equation	TR_55	Peak flow rate (m^2/s.m)	29105
Channel flow	Manning formula		

Model Evaluation

To ensure the correctness of calculation and avoiding any conceptual mistake, the result of the model tested against the concept of mass conservation. Since direct runoff hydrograph represent time increment change of rainfall excess volume, the area under the hydrograph curve must be equal to effective rainfall volume essentially generated over the watershed area for a particular period. For this purpose, effective rainfall volumecalculated using the following equations:

$$P_e = \frac{(P-I_a)^2}{(P-I_a)+S}$$

$$S = \frac{25400}{CN} - 254$$

Where:

P_e = *accumulated direct runoff in (mm)*

P = *accumulated rainfall in (mm)*

I_a= *initial abstraction in (mm)*

S= *maximum potential retention in (mm)*

CN= SCS Curve Number

Table (3) shows numerical representation of time-area histogram shown in Figure (9).

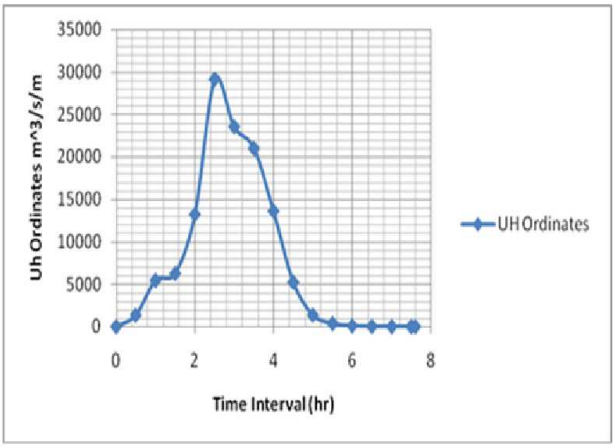

Figure 8: UH Ordinates for Average CN and Uniform Rainfall Intensity

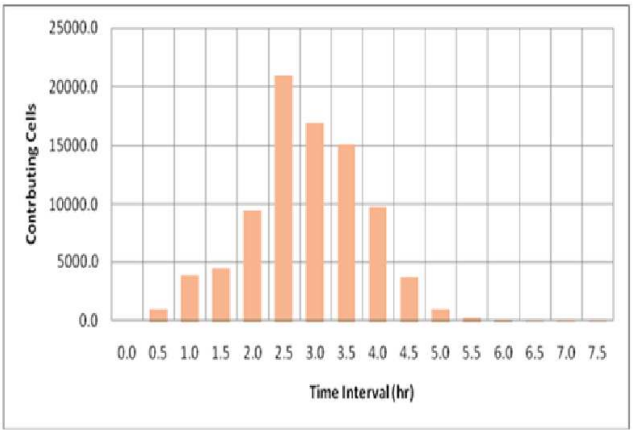

Figure 9: (30 min) Time-Area Based on Average CN and Uniform Rainfall Intensity

Table 3: Detail of Model Verification

#	Time Interval (hr)	No. Cells	Area (m^2)	Volume (m^3)
1.0	0.0	0.0	0	0.0
2.0	1.0	4890.0	12225000	122250.0
3.0	2.0	14002.0	35005000	350050.0
4.0	3.0	37892.0	94730000	947300.0
5.0	4.0	24900.0	62250000	622500.0
6.0	5.0	4744.0	11860000	118600.0
7.0	6.0	338.0	845000	8450.0
8.0	7.0	30.0	75000	750.0
9.0	7.5	4.0	10000	100.0
Total		**86800.0**	**217000000**	**2170000.0**

Model #2

The objective of the model#2 scenario is to demonstrate the effect of spatially distributed CN, and thus varied excess rainfall intensity, that was considered to be the amount of excess rainfall depth generated in each cell divided by total rainfall duration (Table 4).Model #2 simulated upon the same concept of Model#1except of using spatially varied CN instead of averaged one. In this respect, the effective rainfall intensity is not uniform anymore; this is in contrast to traditional method of deriving unit hydrograph which always being derived uponuniform rainfall intensity assumption.

The time-area histogram for model#2 in figure (10) exported to EXCEL workbook to yield for further processing and graph drawing. From result analysis and visual comparison of thetwo models, no quantitative decrease in peak discharge or variation in time to peak and base time was observed (see Figure 11). This may happen because the amount of rainfall excess increasesfor any pixel may counter balanced by a decrease in excess rainfall depth for another cell located on the flow path of runoff, and finally the flow rate unaffected.

Table 4: Basic Parameter and Output Result for Model#2

Model Parameter		Output	
Resolution	50*50 m	Base Time (hr)	7.5
Spatial CN	Variable	Time to peak (hr)	2.5
Effective rainfall intensity	Not uniform		
Overland travel time equation	TR_55	Peak flow rate (m^2/s.m)	28913
Channel flow	Manning formula		

Model #3

Model#3 demonstrates the effect of CN adjustment for slope factor. One limitations of SCS CN methods is that, the values of CN in standard tables derived for watersheds with average land slope of 5%. In the most research following equationsarranged to account for slope effect on curve number [11]:

$$CN_s = CN_2 * K_s$$

$$K_s = \frac{322.79+15.63(s)}{s+323.52}$$

Where:

CN_2= standard curve number for AMC II

CN_s= adjusted CN

K_s=adjustment factor

s= Slope (m/m)

In general, the observed hydrograph in figure (11) is similar to that obtained for averaged CN in model#1. Adjusting curve number (CN) for slope may counterbalance the sudden change of CN and reduce the impact of CN on excess rainfall intensity, in return the dramatic change of flow velocity will reduce. Adjusting CN for slope improves homogeneity of the CN surface input to the model, thus it is logical to be identical to the hydrograph for model#1.

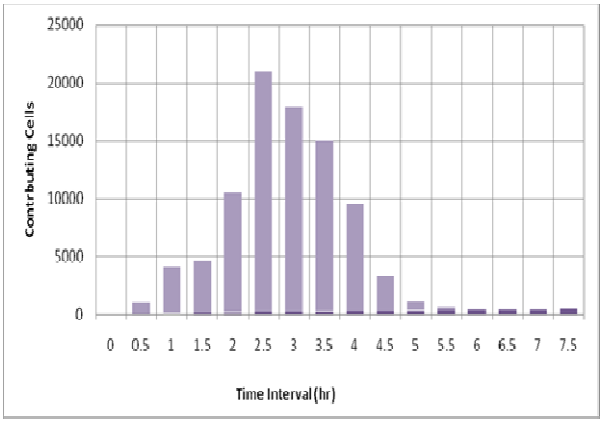

Figure 10: 30min Time-Area Based on Spatial CN and Uniform Rainfall Intensity

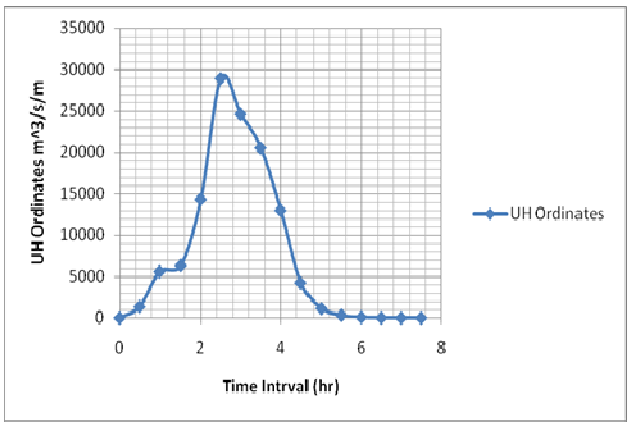

Figure 11: UH Ordinates Based on Spatial CN and Non-Uniform Rainfall Intensity

Spatial CN and Uniform Rainfall Intensity CN and Non-Uniform Rainfall Intensity

In the previous demonstration of the models, the effect of different use of CN only limited on that part of conveyance system which is being governed by channel flow. The travel time for threshold remains unchanged because the overland flow travel time was computed upon equation of TR-55, which is CN independent; therefore, the absence of differences observed for each model may be reasoned for this factor. In figure (12), the hydrograph for the three models packed together for better comprehension of the results.

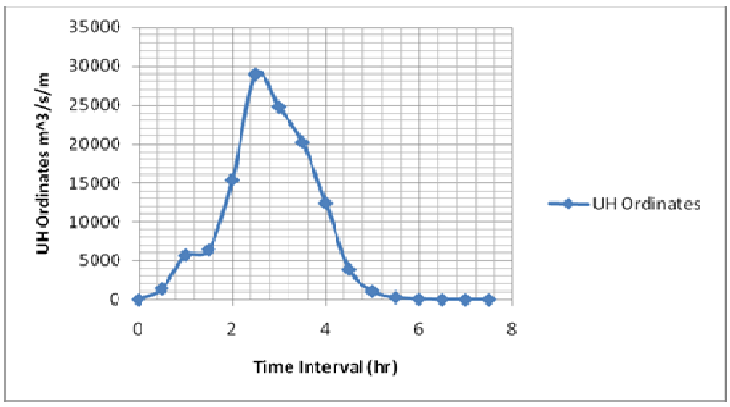

Figure 12: UH Ordinates Based on Slope Adjusted CN and Non-Uniform Rainfall Intensity

Sensitivity Analysis

In order to evaluate the sensitivity of the SDUH model responds to different input parameters, a series of analyses were performed. The 'base' values that were used in this study were presented in Table (5).

Channel Flow Segmentation

Channel section properties changes dramatically with the rate of flow, gradient slope, and coefficient of roughness. Roughness coefficient and gradient slope can be dealt with spatially, but concerning channel section it impossible to assign each single cell its channel section description properties. In this sensitivity analysis for channels where flow controlled by Manning's formula and assumed to have trapezoidal section, were divided into different segments. Each segment recognized for particular bottom width and stream length. Figure (14) shows the effect of channel segmentation for Model#1.

Table 5: Basic Parameter and Output Result for Model#2

Model Parameter		Output	
Resolution	50*50 m	Base Time (hr)	7.5
Spatially Adjusted CN for Slope	Variable	Time to peak (hr)	2.5
Effective rainfall intensity	Not uniform		
Overland travel time equation	TR_55	Peak flow rate (m^2/s/m)	28937
Channel flow	Manning formula		

Sensitivity Analysis for Rainfall Intensity

The rate of runoff discharge was directly proportional to the intensity of effective rainfall. The base intensity shown in table (5) was increased by 1, 3, and 6 times its base value. Figure (15) shows comparison of unit hydrograph for different intensities.

It is obviously seen that as much as intensity increases the unit hydrograph curve will shift to the left and peak discharge increases and occurs earlier. The base time of the unit hydrograph remain unchanged, this proves the stability of the model for base time estimation.

Implementation of Kinematic Wave Equation for Overland Flow

The point of interest in any spatial model is to magnify the impact of various runoff_rainfall related features on the runoff hydrograph. TR-55 equation cannot comply for full spatial model,because once the equation arranged for its parameters, it will show no response for different rainfall depth and duration. The objective of this study is to derive unit hydrograph for ungauged watershed and to reduce the risk and uncertainty, which arise while using lumped methods, for this purpose Kinematic Wave equation was also implemented, and the result discussed and compared thoroughly.

Model#4

The parameter (i_e) in kinematic wave equation is a relationship constituent between rainfall and travel time. In previously discussed models the effect of rainfall intensity limited on that part of conveyance system that governed by channel flow, here after this effect extended even to the threshold cells that governed by overland flow. In the same procedure described for model#1, 2,and 3, unit hydrograph derived for averaged (constant) CN, spatially varied CN, and spatially varied CN adjusted for slope effect. The hydrographs were drawn and compared, the following observation were taken (see Table 6).

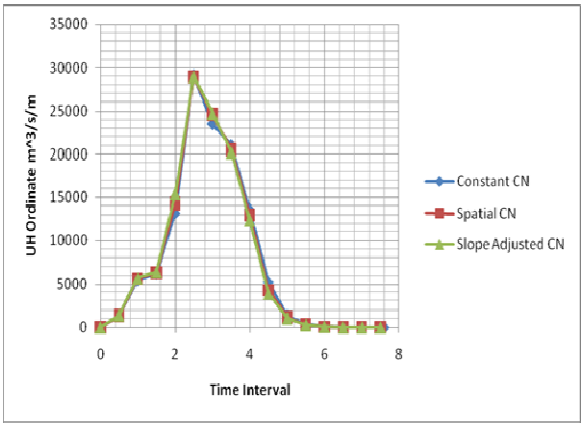

Figure 13: Direct Runoff Ordinates

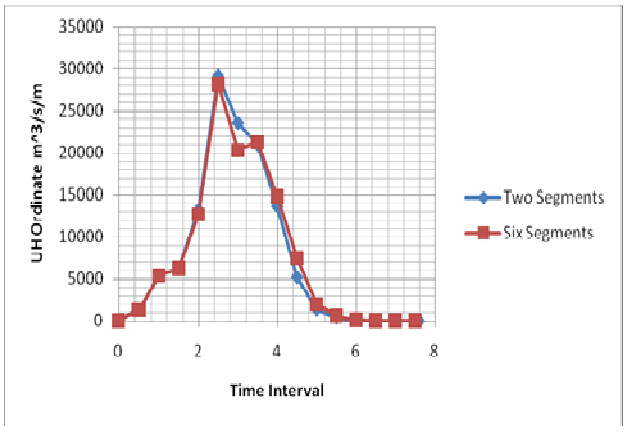

Figure 14: Sensitivity Analysis for Different Use of CN for Channel Segmentation

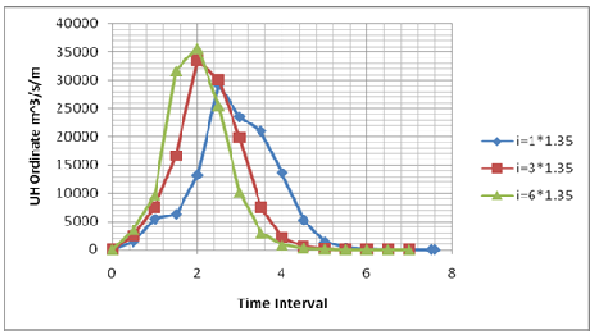

Figure 15: Comparison Unit

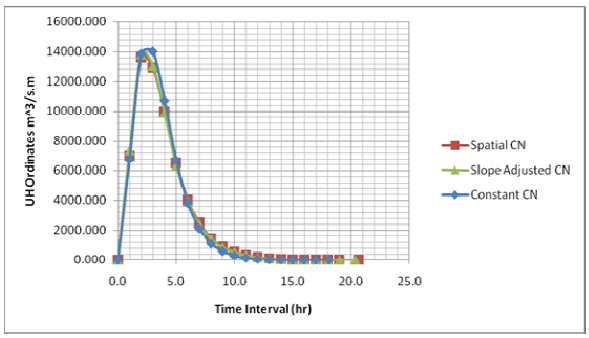

Figure 16: Graphical Representation Hydrograph for Different Intensities of Model#4

Table 6: Basic Parameter and Output Result for Model#4

Model Description	Base Time (Hr)	Time to Peak (Hr)	Peak Flow Rate (M^2/S)
Averaged CN	18.1	3	14037
Spatial CN	20.7	2	13679
Slope Adjusted	20.4	2	13845

In general, an increase in base time and decrease in peak flow rate for the hydrographs was observed compared to these of models#1, 2, and 3, but again no significant differences observed for various use of CN. Base time duration determined by the implementation of kinematic wave equation may reflect more realistic base time duration for watershed hydrograph, because it accounts for variation in rainfall intensity. Figure (16) shows graphical representation of model#4.

Sensitivity Analysis

Sensitivity analysis is the models response for specific parameter while the other held constant. Sensitivity analysis was performed against different effective rainfall intensity and dividing of channel to several segments, each segment assigned with specific length and width. In contrast to models, prediction based on TR_55 an increase or decrease of intensity will also increase and decrease base time and peak flow rate of the unit hydrograph (see Figure 17). This situation satisfy theoretical expectation of experts that claim that the time to peak and base time duration of hydrographs are not unique and depend on characteristic of rainfall. In this respect, the concepts of superposition that comply for lumped methods no anymore valid. Figure (17) shows the effect of rainfall intensity on unit hydrograph.

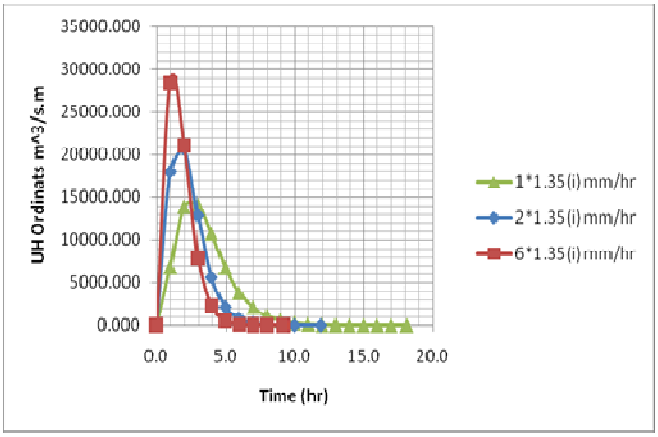

Figure 17: Effect of Rainfall Intensity on Unit Hydrograph

SCS Unit Hydrograph

The drainage pattern in the watershed divided into three classes, each class correlated to its coefficient of velocity represented in table (7). Figure (18) shows flow type classification between channel flow and swale flow, the rest of the watershed flow type controlled by overland flow. Separate raster prepared for each flow type to determinetheir flow velocity (See Figure 18). The three raster representing each flow type was mosaicked to one raster representing the velocity value for each cell within the watershed. Its velocity to yield for travel time divided the flow path distance for each cell. The travel time raster was converted to ASCII form, and then used as input data file for FORTRAN code to perform the routing. The concept of determining unit hydrograph is lumped but the procedure of estimating time of concentration was spatial, in a way the model may be described as semi-spatial model.

The following are the basic parameters for SCS unit hydrograph [12].

$T_c=8.91hr$

For 1-hr rainfall duration D=1 hr

$T_p= t_r /2+t_p, q_p=C\ A/T_p$

$t_l=0.6T_c \rightarrow t_l =5.346\ hr$

$T_p=5.846\ hr,$

$q_p=(2.08)217/5.846=77.208\ m^3/sec.cm$

The ratio of q/q_p and t/T_p was used to derive curvilinear unit hydrograph shown in figure (19).

Table 7: Coefficients of Velocity (fps) Versus Slope (%) Relationship for Estimating Travel Velocities [13]

Flow Type	K
Small Tributary - Permanent or intermittent streams which appear as solid or dashed blue lines on USGS topographic maps.	2.1
Waterway - Any overland flow route, which is a well-defined swale by elevation contours, but is not a stream section as defined above.	1.2
Sheet Flow - Any other overland flow path, which does not conform to the definition of a waterway.	0.48

Snyder's Unit Hydrograph

In previously described models two approaches were illustrated, they may be abbreviated with spatial model and semi-spatial. In spatial model hydrograph, elements were estimated fairly depending on spatial model implementation. In semi-spatial predefined velocity values integrated with GIS capability for spatial implementation of these values. Moreover, Snyder's synthetic approach in contrast to spatial approach it was fairly lumped method; the three graphs for the approach were represented in figure (20).

Unfortunately, there was no nearby similargauged watershed for which the values of both C_p(storage factor) and C_t(local coefficient account for the effect of slope and storage) can be able to estimate, therefor the representative values was used depending subject related literatures. The Snyder's hydrograph was comparably similar to SCS hydrograph, but this similarity is not consistent because self-judgment enroll in assigning specific value for either C_t and C_p, and factorizing lag time t_l to determine hydrograph base time. Figure (21) shows an illustration graph for Snyder's synthetic unit hydrograph derived for (C_p=0.6, Ct=1.2, and $t_b=4t_e$').

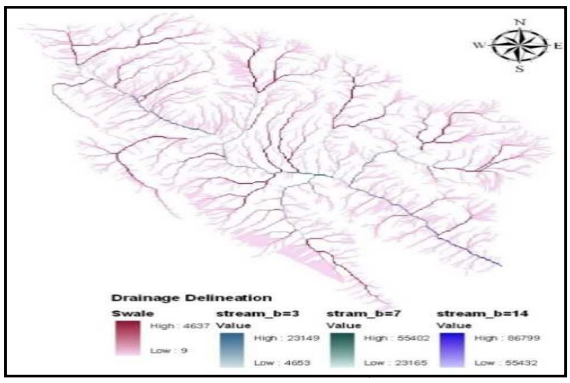

Figure 18: Drainage Delineation for Flow Types

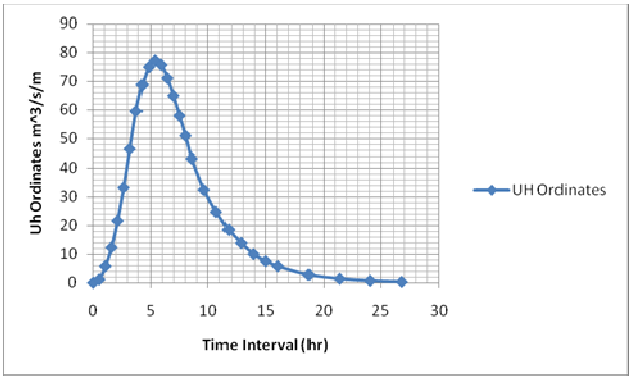

Figure 19: SCS Unit Hydrograph

CONCLUSIONS

The conclusions throughout this research can be summarized in the following items:

- Remotely sensed image can be used to uncover various features within large area, while using traditional methods are costly and time consuming.
- Spatial models can account for complexity in the watershed regarding landscape and soil cover condition, for which using lumped methods is uncertain.
- Spatially distributed unit hydrograph predicts hydrograph shape well, but base time duration, time to peak, and quantitative evaluation of peak flow rate may needs calibration to best fits observed unit hydrograph if exist.
- Spatial models capable to implement different approaches to derive unit hydrograph, depending on suitability of each approach for specific condition.
- Using spatial models reduce uncertainty in estimating direct runoff, because the user can apply for any specific rainfall-runoff related factor.
- Spatial models may be used to estimate subjective parameters of lumped methods, because sometimes the equations related to lumped methods are limited for specific condition.

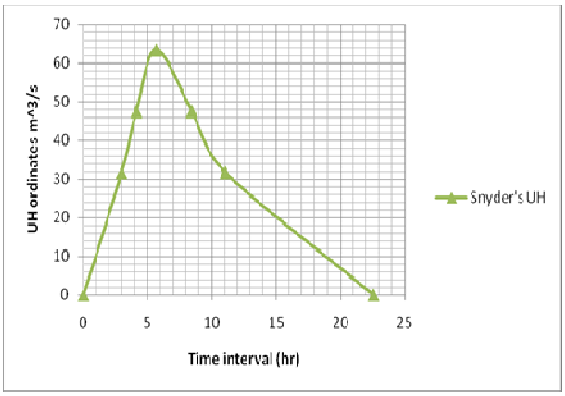

Figure 20: Comparison between Spatial Semi-Spatial and Lumped Method

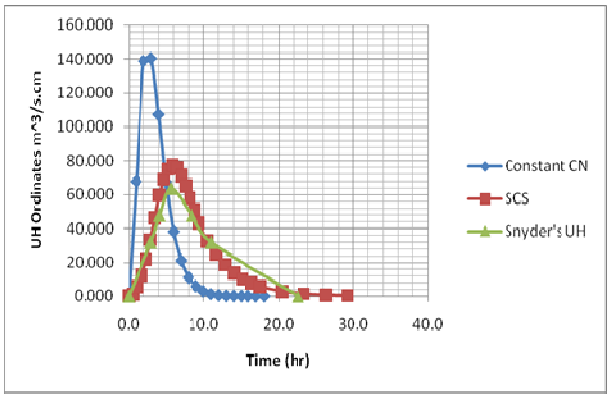

Figure 21: Snyder's Unit Hydrograph

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