A GIS- Independent method for ~~Prediction of~~ Stream-Order-Law Ra Prediction in ~~geomorphologic parameters of catchment~~ Catchment ~~wi~~ ~~GIS to~~for Runoff ~~estimate~~ Estimation ~~runoff using~~ using GIUH ~~model~~]

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Abstract:

Estimation of ~~flood~~ direct runoff in ungauged catchments has great importance in the d hydraulic structures. The geomorphologic instantaneous unit hydrograph (GIUH) techni geomorphologic parameters to estimate catchment runoff. In this research, regression e were developed based on morphometric~~geometrical~~ characteristics of ~~nine~~ some catchme as area, length and slope of the main river to estimate stream-order-law rat geomorphologic ~~data~~ charactristics of other catchments with no need for GIS anc elevation model. These equations were verified ~~used for verification of stream-order-la as well as geomorphologic parameters corresponding to~~ in the Gagas, Heng-Chi and catchments. In this study, the effect of stream-order-law ratios on the rate of runoff in catchment was examined, and the sensitivity of runoff rate to each ratio was analyz GIUH model was assessed in two cases of GIS-supported and ~~GIS unsupported~~p method. The mean errors of the regression equations in estimation of ratios R_B, R_L, R_A R_{SO} in three study catchments were 4.7%, 23.5%, 7.1%, 41.3%, and 22.9%, respectiv

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Formatted: Font: (Default) +Headings CS, 12 pt, Complex Script Font: +Headings CS, 12 pt direct runoff hydrograph for the Heng-Chi and the Kasilian catchments were computed b model and compared with observed direct runoff. According to the results, the errors discharge for four rainfall-runoff events in ~~GIS-unsupported~~proposed method case w average, 10% more than the error in the case of GIS-supported GIUH. The results of G the two cases are very close to each other. The mean coefficient of efficiency of the mo computed as 0.87.

Key words: GIUH, GIS, Stream-order-law ratios, Geomorphologic parameters, Runoff

1. Introduction

Estimation of design flood in catchments is a vital issue in design of flood control st Most catchments of the world are ungauged and the statistical methods which srongly rainfall-runoff data are not efficient, hence the rainfall-runoff models are employed to runoff. GIUH is a rainfall-runoff model for estimating runoff in ungauged catchmen ~~their~~based on geomorphologic parameters (GP) of catchment.

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~~Studies on streams orderings of catchments were first introduced by Horton (1932, 1945 modifications were made on Horton's method by Strahler (1952, 1957, 1964) leading t method of ordering.~~

The idea of GIUH was introduced by Rodriguez-Iturbe and Valdes (1979). They sugg instantaneous unit hydrograph (IUH) model in which time to peak and peak flow catchment were functions of geomorphologic features. ~~The geomorphologic parameter catchments are calculated by GIS software such as ArcGis and hydrologic extensions ArcHydro. For this purpose, DEM of the catchment is necessary. First, stream netw delineated and, GP such as the number of streams, lengths, slopes, and drainage areas order of streams is carried out based on stream orderings (Horton-Strahler method).~~
GIUH model was extended and used by other scientists in different catchments (e.g. Gu 1980; Rodriguez-Iturbeet al. 1982; Lee and Yen 1997 and Kumar and Kumar 2008, S and Norouzpoor 2014).
An alternative approach was provided by Lee and Yen (1997). The travel times for orders of overland areas and channels were derived using the kinematic-wave theory a

substituted into the GIUH model to develop a kinematic wave-based GIUH model for w runoff simulation.

Lee and Chang (2005) offered a GIUH model to estimate surface and subsurface catchments. In their research, special importance was given to separation of surface flo subsurface flow in catchments. Sabzevari et al. (2013) modified the model presented by Chang (2005) for estimation of surface and subsurface flow of Kasilian catchment. ~~Th also given a saturation model for separation of saturated and unsaturated zones of regions.~~

~~Sabzevari and Norouzpoor (2014) suggested a GIUH model which is capable of taki shape and profile curvature in complex hillslopes in computation of surface and subsurfa time. Also, the effect of geometry of complex hillslopes on the runoff in sub-catchment of Walnut Gulch was investigated.~~

~~Kumar et al. (2004, 2007) rendered the runoff estimation of ungauged catchments by the GIUH-based Nash and Clark models. They used stream ratios to estimate Nash and parameters. Kumar and Kumar (2008) focused on estimation of runoff in Ramganga cat India, applying GIUH based on kinematic wave theory. The model was used in the case the inputs were geomorphologic parameters and stream-order-law ratios. Travel time streams and overland regions in the two above cases were given as analytic equations b Horton-Strahler stream-ordering system.~~

~~Choi et al. (2011) used a concept of geomorphologic dispersion to estimate Nash parameters from spatial heterogeneity of flow path within a catchment.~~

The geomorphologic parameters of the catchments are calculated by GIS softwares ArcGis and hydrologic extensions such as ArcHydro. For this purpose, digital elevatio (DEM) of the catchment is necessary. Stream networks are delineated and, GP such number of streams, lengths, slopes, and drainage areas in each order of streams are based on stream orderings.

The stream-order-law ratios (SOLR) are calculated based on geomorphologic informat vice versa. The equations governing the GIUH model can be developed based on SOL (Kumar & Kumar, 2008).

~~Based on GP of catchment, stream-order-law ratios such as bifurcation ratio (R_B), stream- ratio (R_L), stream-area ratio (R_A), and stream-slope (R_S) ratio could be computed.~~ According to the GIUH offered by Yen and Lee (1997), the travel times of overland regio stream could be worked out regarding stream-order-law ratios prior to IUH estimation.

Studies on streams orderings of catchments were first introduced by Horton (1932, 1945 modifications were made on Horton's method by Strahler (1952, 1957, 1964) leading t method of ordering.

Sherve (1966) concluded that the Stahler stream numbers generally gave a better fit for stram networks than did the Horton stream numbers.

Horton-Strahler's laws were extensively used in geomorphological applications to class systems [e.g., Raff et al., 2003; Reis, 2006], to establish relations with the fractal nature of network as detailed by Rodríguez-Iturbe and Rinaldo [1997] [e.g., Beer and Borgas, 1993; La and Roth, 1994; Rodríguez-Iturbe et al., 1994], and to characterize scale properties [Claps et a Peckham and Gupta, 1999; Veitzer and Gupta, 2000; Dodds and Rothman, 1999, 2001].

~~Based on GP of catchment, stream-order-law ratios such as bifurcation ratio (R_B), strear ratio (R_L), stream-area ratio (R_A), and stream-slope (R_S) ratio could be computed. Acco the GIUH offered by Yen and Lee (1997), the travel times of overland region and strea be worked out regarding stream-order-law ratios prior to IUH estimation.~~

~~Due to the lack of topographic map and DEM for most of the catchments, application based GIUH models is practically useless. One goal of this research is to provide a techn which one could compute geomorphologic parameters without the need for GIS. Calcula GP by means of GIS is costly and takes a long time. For example, extensions such as Ar though capable of calculating the number, length, and slope of streams at any order, pro information about overland surface slopes or drainage area at any order which oug calculated manually by GIS specialists which is time consuming. For this purpose, GP o catchments of various sizes with diverse stream networks were collected. The values of order-law ratios and the actual GP of the catchments obtained from GIS were derived.~~

Using GIS tool is one of best ways of calculating the geomorphologic parameters (Sarang al.2003; Obi Reddyet al.2004; Valeriano et al. 2006; Ozdemir and Bird, 2009)

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The high resolution of DEM results in a more accurate prediction of GP and runoff using models. Although, today the whole world's DEM is prepared by the Shuttle Radar Topog Mission, but some of the hydrologists due to their little familiarity with GIS, do not like u GIUH methods because extracting the GP requires a lot of time and they apply simpler n of rainfall-runoff. In this research, based on geomorphological information of a number o catchment a set of equations is provided whose SOLR and GP geomorphologic paramete be calculated based on parameters such as catchment's area and main river length. These used as input parameters of GIUH model and is used for predicting the surface and subsu runoff of the catchment.

~~To study the relation between data, linear and nonlinear regressions were used using tl software. In general, length and slope of the main stream and area of the catchment ar the geometric parameters that are easily computable for every catchment. It is also imp present empirical equations which could predict all stream-order-law ratios based geometrical catchment information.~~

The important aims of this research are:

(1) to present equations which can predict, ~~without the use of GIS and DEM of the ca~~ the stream-order-law ratios of catchment on the basis of length, slope of the main stre area of catchment ~~(geometrical features)~~.

~~(2) to analyze sensitivity of stream ratios and its effect on direct runoff hydrograph (DRH~~

(~~3~~2) Apply of predicted stream-order-law ratios to estimate direct runoff of ungauged cat by means of GIUH ~~without the use of GIS~~method.

2. GIUH model

Surface runoff of the overland regions moves, through stream networks, to the c catchment. If a catchment is ordered via Strahler ordering scheme, the water travel pat the overland regions to the outlet are specified. Each flow path is comprised of differer the first of which is the overland region and the others are the streams. The probability motion in a certain path $w: x_{o_i} \rightarrow x_i \rightarrow x_j \rightarrow \ldots \rightarrow x_\Omega$ is expressed as:

$$P(w) = P_{OA_i} P_{x_{oi}x_i} P_{x_i x_j} \ldots P_{x_k x_\Omega}$$

where P_{OA_i} is the initial state probability of rain drop moving from *i*th order overland r the *i*th order stream, which can be approximated as the ratio of *i*th order overland area to catchment area; $P_{x_{oi}x_i}$ which is the probability of raindrop moving from *i*th order overlan (x_{o_i}) to *i*th order stream equals one; and $P_{x_i x_j}$ is the transitional probability of rain drop from *i*th order stream (x_i) to *j*th order channel (x_j).

The number of streams at each order and how they are connected to each other spe probabilities in Eq. (1).

The value of IUH of a watershed comprising different runoff paths is given by (Rodriguez-Iturbe and Valdes 1979).

$$u(t) = \sum_{w \in W} [\, f_{x_{o_i}}(t) * f_{x_i}(t) * f_{x_j}(t) * .... * f_{x_\Omega}(t)]_w \times P(w)$$

where $f_{x_k}(t)$ denotes the travel time probability density function (PDF) in state x_k with travel time value (T_{x_k}) and the function f is indeed the IUH of any state x_k calculatec formula $f(t) = (1/T_{x_k})\exp(-t/T_{x_k})$. The PDF is a function of the travel time of each sta overland regions and streams. Asterisk (*) denotes a convolution integral. $w \in W$, \ $W = \langle x_{o_i}, x_i, x_j, ..., x_\Omega \rangle$, i = 1, 2, 3, . . . , Ω and t is the time.

To solve Eq. (2), one could resort to the Laplace transformations. In the process o derivation, computation of travel time is the most intricate part of the work because i depends on GP of the catchment.

The ordinates of DRH for the catchment were estimated by convoluting the effective hyetograph with the derived IUH.

The equation for estimation of DRH is:

$$Q(t) = \int_0^t u(t-\tau) I_e(\tau) d\tau \qquad (\text{:}$$

where I_e is the excess rainfall and $u(t)$ is the catchment IUH.

2.1. Travel time of overland planes and streams

According to the kinematic wave theory, the travel time of an overland plane depend length, slope, Manning coefficient, and excess rainfall intensity. Eq. (4) which is due to Lee (1997) gives the travel time of the *i*th overland plane.

$$T_{X_{oi}} = \left(\frac{n_0 A P_{OA_i} \sum_{i=1}^{\Omega} R_L^{i-\Omega}}{2a^{1/2} S_{c_\Omega}^{b/2} L q_L^{m-1} R_B^{\Omega-i} R_L^{i-\Omega} R_S^{b(i-\Omega)/2}} \right)^{1/m}$$

where R_B, R_L, R_A, and R_S are bifurcation ratio, stream-length ratio, stream-area ratio, and slope ratio, respectively; A is the area of the catchment; a and b are 5.463 anc respectively; q_L is the excess rainfall intensity; n_0 is the Manning's roughness coeffic overland flow; $S_{c\Omega}$ is slope of the highest order stream; the constant m can be recognize from Manning's equation and L is sum of mean length of the streams of different orders. The travel time of the *i*th-order channel in each path is obtained, based on its GP, througl (Yen and Lee 1997):

$$T_{X_i} = \frac{B_\Omega L R_L^{i-\Omega} R_B^{\Omega-i} \sum_{i=1}^{i} R_L^{i-\Omega}}{q_L A P_{OA_i} (\sum_{i=1}^{\Omega} R_L^{i-\Omega})^2} \left[\left(h_{co_i}^m + \frac{q_L A P_{OA_i} n_c \sum_{i=1}^{\Omega} R_L^{i-\Omega}}{B_\Omega S_{c_\Omega}^{1/2} R_S^{(i-\Omega)/2} R_B^{\Omega-i} \sum_{i=1}^{i} R_L^{i-\Omega}} \right)^{1/m} - h_{co_i} \right]$$

where h_{co_i} is the inflow depth of the *i*th-order channel due to water transported from ι reaches, is given as:

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$$h_{co_i} = \left(\frac{q_L n_c A(R_B^{\Omega-i} R_A^{i-\Omega} - P_{OA_i}) \sum_{i=1}^{\Omega} R_L^{i-\Omega}}{S_{c_\Omega}^{1/2} B_\Omega R_S^{(i-\Omega)/2} R_B^{\Omega-i} \sum_{i=1}^{i} R_L^{i-\Omega}} \right)^{1/m} \qquad (6)$$

Where n_c is the Manning coefficient of stream, B_Ω is the width of the stream. The value equal to zero for i=1.

3. ~~Geomorphologic parameters (GP)~~ Horton-Strahler stream-order-law ratios

As observed in the Eqs. (5) and (6), the stream-order-law ratios particularly, R_S, R_A, R_L, I high importance. These affect the travel time, IUH, and DRH; also, they are computed ac to the GP. For this purpose, the stream network is delineated by means of GIS. In the streams are ordered via Horton-Strahler method, and the number, length, and slope streams are calculated at each order.

In order to calculate the coefficients R_S, R_A, R_L, R_B coefficients the provided equations acc to Table (1) are used.

Tab1e1: The Equations related to Horton-Strahler stream-order-law ratios

Equation Number	Equation	Description
(7)	$R_B = N_{i-1} / N_i$	N_i : Number of ith-order channels
(8)	$R_L = \overline{L_{c_i}} / \overline{L_{c_{i-1}}}$	$\overline{L_{c_i}}$ ~~is the mean~~ :~~L~~length of ith-order channels
(9)	$R_A = \overline{A_i} / \overline{A_{i-1}}$	$\overline{A_i}$:~~is the m~~Mean area of catchment of order i
(10)	$R_S = \overline{S_{c_i}} / \overline{S_{c_{i-1}}}$	$\overline{S_{c_i}}$:Mean slope of the ith-order streams

The value of R_B is given by the following equation regarding the number of stream seg each order:

$$R_B = N_{i-1} / N_i \quad , i = 2, 3, \ldots, \Omega$$

N_i denotes the number of ith-order channels. The length ratio (R_L) is:

$$R_L = \overline{L_{c_i}} / \overline{L_{c_{i-1}}} \qquad , i = 2, 3, \ldots, \Omega$$

$\overline{L_{c_i}}$ is the mean length of ith-order channels. Eq. (9) yields the value of R_A:

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$$R_A = \overline{A_i} / \overline{A_{i-1}}$$

where $\overline{A_i}$ is the mean area of catchment of order i. It should be noted that the mean a given stream segment is, in fact, a cumulative value, for example, the area of a thi catchment is a sum of the areas of the first, second and third-order streams. Computation not so easy a task for the GIS users.

The value of R_S depends on the streams slope and is obtained by Eq. (10):

$$R_S = \overline{S_{c_i}} / \overline{S_{c_{i-1}}} \; , i = 2, 3, \ldots, \Omega$$

where $\overline{S_{c_i}}$ is the mean slope of the ith-order streams.

As a result of experiments in the natural catchments, the following ranges are ol $3 \le R_B \le 5$ and $1.5 \le R_L \le 3.5$. Slope of the streams and overland planes for different cat at each order are different. The mean values of these slopes at each order take a cons time to compute by GIS, especially in large catchments.

In this research, a new slope ratio named the overland slope ratio (R_{SO}) is introduced that in terms of the mean slope of the overland plane by:

$$R_{SO} = \overline{S_{o_{i-1}}} / \overline{S_{o_i}} \tag{11}$$

where $\overline{S_{o_i}}$ is the mean slope of the ith-order overland plane.

In this research we intend to find the relationship between R_{SO} and the other stream-o ratios.

Herein, a way for computing GP via regression equations is sought. These equations att regression methods work through statistical analysis of the information of catchments po geomorphologic attributes. The way these equations perform computations will be expl the next sections.

4. Case Study

To study the relationship between geomorphologic parametersstream-order-law ratios(knowledge of the GIS based GP SOLR (i.e the GP SOLR derived from GIS) of some catchments is required. This research uses information received from twelve catchn different countries. Table (1) shows the GIS based GP SOLR along with stream order the case study catchments. The catchments Long chi (Shuyou et al. 2010); Long men (Sh al. 2010); Chaukhutia (Kumar 2014); Al-Malaqi (Shadeed et al. 2007); Debarwa (Alemn Mathur 2014); Gherghera (Alemngus and Mathur 2014); San-Hsia (Chang and Lee 20 Badan (Shadeed et al. 2007); Al-Faria (Shadeed et al. 2007) were used for train estimation of regression equations, and the Gagas (Kumar and Kumar 2008), Heng-Chi (Chang 2005) and Kasilian (Sabzevari et al 2013) catchments were used for verificatio suggested equations.

The columns Table (12) (from left to right) illustrate, respectively, the catchment na reference, stream order (i), number of streams, mean stream length, mean stream are stream slope, mean overland slope, R_B, R_L, R_A, R_S, and R_{SO}.

The Heng-Chi catchment is located in northern Taiwan and has an area of 53 km^2 (Le The Gagas catchment lies in the middle and outer range of the Himalayas in Uttarakhand India and has an area of 506 km^2 (Kumar and Kumar 2008). The Kasilian Catchment is between 53° 18' E and 53° 30' E longitudes and 35° 58' N to 36° 7' N latitudes in the nort and has an area of 67.8 km^2. Figure (1) shows the Gagas and , Kasilian and H catchments.

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Table ~~1~~2. ~~GP~~ Geomorphologic characteristics of twelve case study catchments

Catchment Name	Geomorphologic parameters										
	Order	N_i	$\overline{L_i}$	$\overline{A_i}$	$\overline{S_c}$	$\overline{S_o}$	R_B	R_L	R_A	R_S	R_{SO}
1. Gagas	1	121	1.74	3.02	0.172	0.810	4.8	2.4	5.4	0.4	2.6
Kumar and Kumar 2008)	2	23	3.04	18.58	0.141	0.655					
	3	6	7.63	79.22	0.041	0.172					
	4	1	23.4	506	0.017	0.065					
2. Heng-Chi	1	30	0.66	1.043	0.087	0.450	3.3	2.6	4	0.6	1.1
	2	6	2.74	6.919	0.050	0.419					
(Lee and Chang 2005)	3	2	1.6	19.9	0.012	0.349					
	4	1	4.97	53.23	0.012	0.347					
3. Kasilian	1	42	1.6	0.915	0.241	0.345	3.5	1.5	4.3	0.4	1.1
	2	11	1.79	4.813	0.070	0.297					
(Sabzevari et al 2013)	3	3	2.45	20.75	0.047	0.263					
	4	1	4.65	67.8	0.008	0.261					
4. San-Hsia	1	69	0.92	1.15	0.161	0.314	4.2	2.9	5	0.4	1.1
	2	16	2.08	4.99	0.092	0.203					
(Chang and Lee 2008)	3	3	3.88	18.15	0.037	0.364					
	4	1	17.8	125.9	0.013	0.293					
5. Al-Badan	1	41	1.38	1.37	0.170	0.140	4	1.5	4.5	1	1.7
	2	6	3.2	10.12	0.092	0.062					
(Shadeed et al. 2007)	3	2	5.03	40.73	0.140	0.051					
	4	1	3.17	85	0.135	0.029					
6. Al-Faria	1	49	1.03	0.937	0.154	0.117	4	1.5	4.3	1.1	1.6
	2	8	2.12	6	0.085	0.058					
(Shadeed et al. 2007)	3	3	3.5	19.4	0.161	0.033					
	4	1	2.62	64	0.125	0.031					
7. Al-Malaqi	1	62	1.92	1.81	0.146	0.140	9	1.3	17	0.8	4.3
	2	16	2.61	5.83	0.122	0.063					
(Shadeed et al. 2007)	3	1	3.21	185	0.081	0.010					
8. Debarwa	1	23	2.26	5.6	0.032	0.135	4.9	3	6	0.6	1.2
	2	6	4.2	27.8	0.018	0.091					

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(Alemngus and Mathur 2014)	3	1	17.7	195	0.010	0.098					
9. Gherghera	1	58	2.45	5.9	0.027	0.136	2.9	1.4	3.3	0.9	1.4
	2	14	4.19	30.6	0.018	0.087					
(Alemngus and Mathur 2014)	3	5	10.2	101.0	0.010	0.064					
	4	2	4.47	259.9	0.016	0.025					
	5	1	4.19	525.7	0.011	0.117					
10. Long chi	1	46	1.13	2.5	0.210	0.444	3.7	2.4	4	0.6	1.1
	2	10	3.45	11.8	0.124	0.487					
(Shuyou et al. 2010)	3	4	3.19	32	0.073	0.514					
	4	1	9.94	141.8	0.054	0.364					
11. Long men	1	58	1.31	2.74	0.560	0.256	4	2.2	4.7	0.9	1.8
	2	13	2.48	12.3	0.560	0.123					
(Shuyou et al. 2010)	3	3	9.33	77.11	0.560	0.056					
	4	1	8.18	246.8	0.385	0.056					
12. Chaukhutia	1	134	1.41	2.27	0.191	0.910	5.3	2.5	5.7	0.5	2.4
	2	31	2.65	12.28	0.123	0.567					
(Kumar 2014)	3	7	7.21	60.18	0.041	0.174					
	4	1	20.7	452.3	0.019	0.074					

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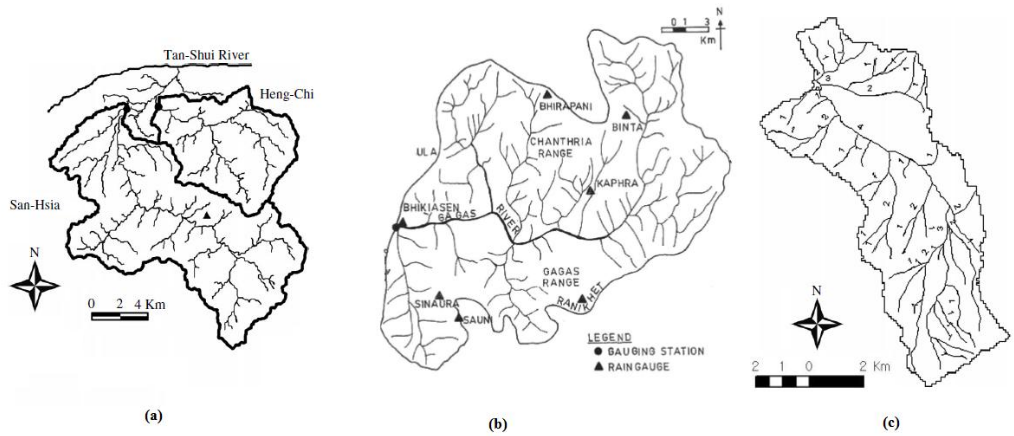

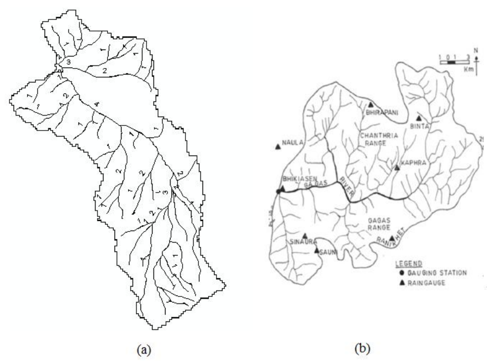

Fig. 1: Drainage network map

a)Heng-Chi catchment b) Gagas catchment ac) Kasilian catchment stream network b) Gagas catchr

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54. Relationships of geomorphologic parametersPrediction of Horton-Strahler order-law ratios

5.1. Estimation of bifurcation ratio (R_B)

To estimate the bifurcation ratio of a catchment, the information concerning 80 37 wa catchments with areas between 1 km^2 and 600 km^2 were used which had known values o area, with the presumption that R_B is a function of two variables, catchment area (A) main stream length (L). With the help of statistical package for the social sciences (S software (Norusis, 1999, Mohamoud and Parmar, 2006) and using the information c catchments an optimum relation was obtained as:

$$R_B = 0.0027A + 3.47 \quad (12)$$

Admittedly, the value of R_B was not dependent on L. The correlation coefficient of tl equation is 0.8 and the real mean bifurcation ratio of the catchments is 4. Fig.2 shows t linear regression.

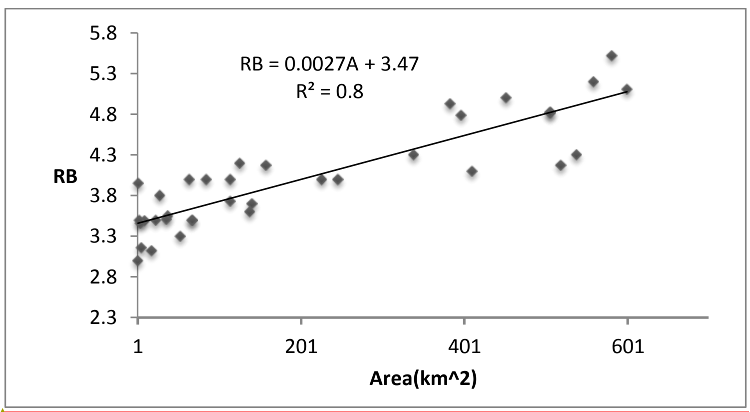

Fig.2: Linear regression between bifurcation ratio and the area of the catchment

Eq. (~~12~~12) indicates that in small catchments with area less than 600km^2, the value of between 3.47 and 4. It is suggested that Eq. (~~12~~12) be applied to catchments of areas 600km^2. It should be noted that, regarding ~~Eq. (7)~~Eq.(7) and R_B ~~and R_B~~, the values c N_i calculated for $i \leq \Omega$. Ω is the maximum order of the catchment. $N_{i=\Omega} = 1$ is conside

$N_{i-1} = R_B N_i$, $i \leq \Omega$ (Horton, 1945).

~~**5.2. Computation of stream length Ratio (R_L)**~~

To calculate the length ratio R_L, it was taken as a function of the main stream length whole catchment area. The fitted regression equation for the nine selected catchments ac to Table (1) is, as follows:

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$$R_L = 2.59 L^{0.41} \ A^{-0.2} \quad (13)$$

The correlation coefficient is equal to 0.91.

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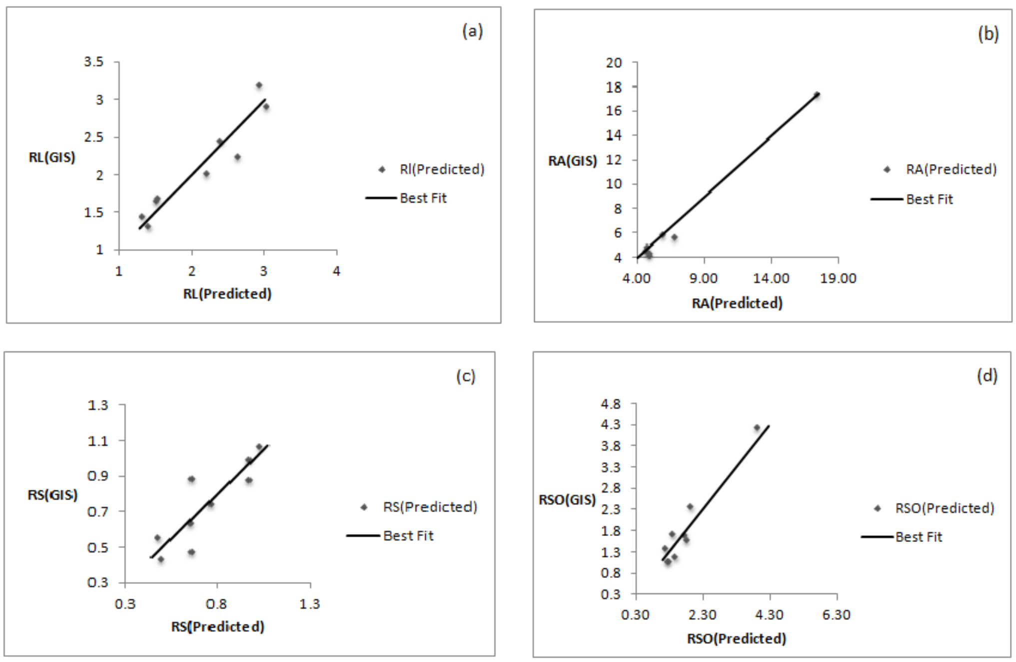

Fig3: GIS-based stream-order-law ratios versus predicted SOLR

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Fig.3a shows the calculated R_L values based on the Eq.13 in comparison with its real valu

Based on Eq. (8) and R_L, the values of $\overline{L_{c_i}}$ are calculated for $i \le \Omega$. $\overline{L_{c\Omega}} = L$ is conside

$\overline{L_{c_{i-1}}} = \overline{L_{c_i}} / R_L \ , i \le \Omega$ (Horton, 1945).

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~~**5.3. Computation of area ratio (R_A)**~~

The area ratio was assumed to be a function of the bifurcation ratio and the length ra fitted equation:

$$R_A = 0.597 R_B^{1.553} R_L^{-0.177} \quad (14)$$

The correlation coefficient is 0.99.

Fig.3b shows the calculated R_A values based on Eq.14 in comparison with its real value.

$\overline{A_\Omega} = A$ is considered and $\overline{A_{i-1}} = \overline{A_i} / R_A$, $i \leq \Omega$(Schumm, 1956).

~~**5.4. Computation of stream slope ratio (R_S)**~~

Stream slope ratio was assumed to be a function of R_B, R_L, and R_A. Equation (15), correlation coefficient 0.79, represents the fitted regression relation for the data.

$$R_S = 1.198 R_B^{1.26} R_L^{-0.97} R_A^{-1.04} \quad (15)$$

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~~**5.5. Computation of overland slope ratio (R_{SO})**~~

A nonlinear regression equation consisting of the parameters R_B, R_L, R_A, and R_S was calculate the slope ratio of the overland plane with the fitted relation:

$$R_{SO} = 0.366 R_B^{2} R_L^{-0.58} R_A^{-0.66} \quad (16)$$

The correlation coefficient of Eq. (16) is 0.93, and there is no strong correlation between R_S.

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Figs.3c and 3d show the fitness amounts of R_S and R_{SO} calculated by Eqs. 15 an comparison with the real values.

By the Eqs. (16) and (11) the slope of overland planes of the catchment could be obtainec be noted that the Eqs. (12) to (16) which are gained via the information about nine cat may be calibrated by adding more data. Given that the length of the main river and the ai catchments are known, the R_B, R_L, R_A, R_S, and R_{SO} ratios can be calculated by Eqs. (12) tc

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5. Prediction of catchment's geomorpological information

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The area of the catchment, the length and slope of the main river could be determined f ~~simple~~ topographic maps of the catchment (Scale:1:25000 to 1:50000). If a catchme maximum stream order Ω, it is inferred that the stream should be located at the en catchment with the mean slope $(\overline{S_{c_\Omega}})$ and the mean slope of the lateral overland plane $(\overline{S_{o_\Omega}})$ For instance, Fig. ~~2~~ 4 shows a small catchment with three sub-catchment (I, II, I maximum stream order is two $(\Omega = 2)$. The sub-catchment III is created with two lateral o planes and stream III is positioned at the end of the main catchment. Fig. ~~2~~ *4* shows tl slope of the stream III $(\overline{S_{c_2}})$ and mean slope of the two lateral overland planes $(\overline{S_{o_2}})$.

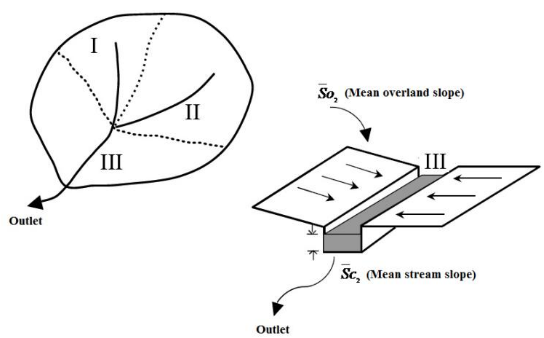

Fig. ~~2~~4. Catchment with maximum stream order ~~2~~two

If the values of the $\overline{S_{c_\Omega}}$, $\overline{S_{o_\Omega}}$, R_S and R_{SO} are known, with regard to Eqs. (10) and (value of the $\overline{S_{c_i}}$ and $\overline{S_{o_i}}$ are computable for lower orders $i < \Omega$ $(\overline{S_{c_{i-1}}} = \overline{S_{c_i}} / R_S$, $\overline{S_{O_{i-1}}} = \overline{S_{O_i}}\, R_{SO})$

To calculate the value of $P_{x_i x_j}$ in Eq. (1) the following equation is used:

$$P_{x_i x_j} = N_{i,j} / N_i$$ (

where $N_{i,j}$ is number of *i*th order stream contributing the flow to *j*th order stream; *i* number of *i*th order channel. The value of N_i is computable by the bifurcation ratio, but t the parameter $N_{i,j}$ the following equation is suggested:

$$N_{i,j} = 2N_i \exp(-0.64j)$$

which is obtained through nonlinear regression of the stream network data ba geomorphologic parameters of the Kasilian and the Gagas catchments. In the cat possessing DEM one needs to delineate stream network and order them by GIS s however, calculation of $N_{i,j}$ should be done manually and rendered by GIS operator wh time-consuming and difficult task.

66. Effect of ratios R_B, R_L, R_A, R_S and R_{SO} on DRH

In the previous section of this study, empirical equations were presented to geomorphologic ratios. Now, we apply the GIUH model to look into sensitivity analysis ratios and their effects on DRH and on peak flood. To this end, the information of the catchment was utilized.

Fig. (3a5a) illustrates the effect of bifurcation ratio upon DRH of the Kasilian catchme May, 1993.

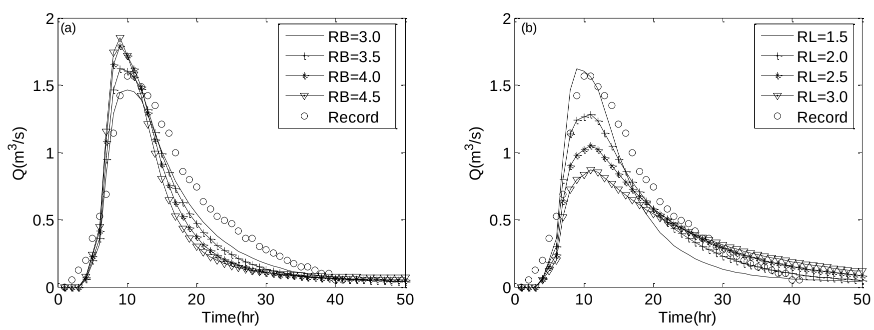

Fig. 35. Effect of R_B and R_L on direct runoff hydrograph DRH of the (Kasilian catchment)

The values of bifurcation coefficient 3, 3.5, 4, and 4.5 with 0.5 units increment were co for the Kasilian catchment, and the number of streams and the values of input parame GIUH model were computed and inserted to the model. The effect of R_B on shape of hyd and peak of the runoff is seen in Fig. (~~3a~~5a).The results of the model are compared with recorded runoff hydrographs.

To determine the effect of different values of R_B on the peak of runoff, the following equ relative sensitivity was used:

$$S_r = \frac{O_2 - O_1}{P_2 - P_1}(\overline{P}/\overline{O})$$

(~~17~~19)

where O and P represent particular model outputs and parameters, respectively. So, S_r g percentage change in O for a 1% change in P. $\overline{P}$ is given by $(P_1+P_2)/2$ and $\overline{O}$ is g $(O_1+O_2)/2$. Results confirmed that the least computational error in peak discharge relativ observed peak discharge was shown by R_B=3.5 with 3.5%. The actual R_B for the catchment is also 3.5. The mean relative sensitivity of R_B derived from Eq. (~~17~~19) is 0.56 Fig. (~~3b~~5b) shows the effect of R_L on DRH of the Kasilian catchment. The values of t were taken as 1, 1.5, 2, and 2.5 with a 0.5 increment. According to the results, R_L=1.5 h the least error in peak discharge with 3.6% value. The actual R_L of the catchment is 1.46, mean relative sensitivity of R_L amounts to 0.92. The larger the value of R_L, the higher pe The runoff is affected more by length ratio relative to bifurcation ratio, a fact seen also (~~3~~5). The next section of the paper was dedicated to the effects of area ratio on the runoff. The values of area ratio were regarded to be between 3 and 6 with 1 unit in values. Figure (~~4~~6) depicts the effect of area ratio on DRH.

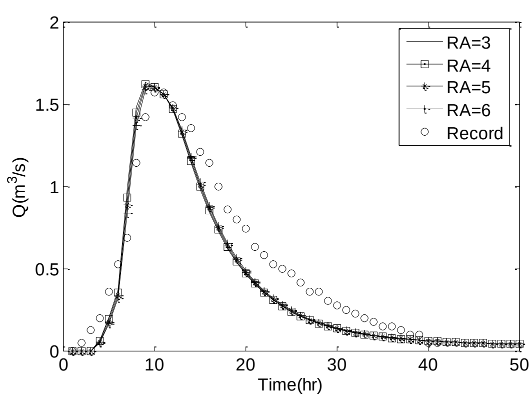

Fig.~~4~~6. Effect of area ratio on direct runoff hydrograph~~DRH~~ ~~of the~~ (Kasilian catchment)

As indicated by the results, the area ratio has had a slight effect on the runoff peak, alterations of this ratio do not noticeably influence the shape of hydrograph and flood pea

Fig. (~~5a~~7a) shows how R_S affects DRH for the values 0.1, 0.4, 0.7, and 1 with a 0.3 increr

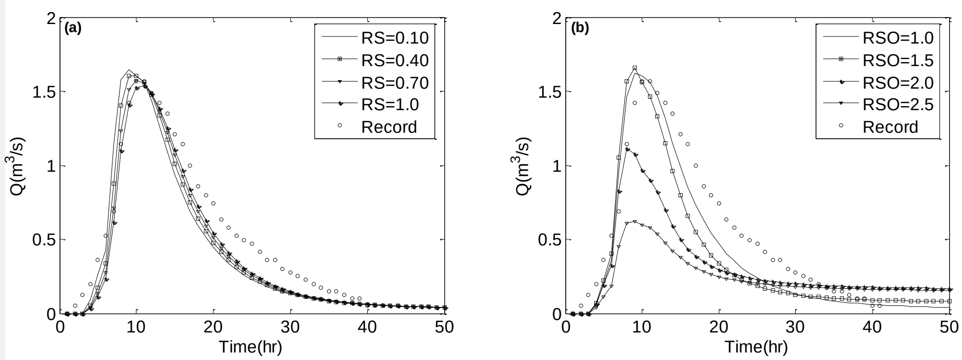

Fig. ~~5~~7. Effect of R_S and R_{SO} on ~~DRH~~ direct runoff hydrograph ~~of the~~(-Kasilian catchment)

The least error is 0.47 which corresponds to the ratio (0.7) while the actual slope rati Kasilian catchment is 0.38. Also, the mean relative sensitivity ratio is 0.042. The results that this parameter has little effect on runoff peak, too.

Figure (~~5b~~7b) shows the influence of R_{SO} on DRH for values of 1, 1.5, 2, and 2.5 with in as 0.5. The least error relates to the ratio 1 which is 3.54%, whilst that of Kasilian ca would be 1.1, and the mean relative sensitivity ratio 1.33. According to the results, the pa R_{SO} has remarkable effect on runoff peak.

According to the overall results, the relative sensitivity ratio of R_B, R_L, R_A, R_S, and R_{SO} 0.92, 0.01, 0.042, and 1.33 respectively. The most effect concerns, correspondingly overland slope ratio, length ratio, bifurcation ratio, slope ratio, and area ratio.

~~To calculate the value of~~ $P_{x_i x_j}$ ~~in Eq. (1) the following equation is used:~~

$$P_{x_i x_j} = N_{i,j} / N_i$$ ~~(~~

~~where $N_{i,j}$ is number of ith order stream contributing the flow to jth order stream; *~~
~~number of ith order channel. The value of N_i is computable by the bifurcation ratio, but t~~
~~the parameter $N_{i,j}$ the following equation is suggested:~~

$$N_{i,j} = 2N_i \exp(-0.64j)$$

~~which is obtained through nonlinear regression of the stream network data ba~~
~~geomorphologic parameters of the Kasilian and the Gagas catchments. In the cat~~
~~possessing DEM one needs to delineate stream network and order them by GIS s~~
~~however, calculation of $N_{i,j}$ should be done manually and rendered by GIS operator wh~~
~~time-consuming and difficult task.~~

~~7~~7. Verification

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7.1. Validation of stream-order-law ratios

In the previous sections, equations were proffered for computation of stream-order-la based on GP in nine different catchments in the world. For verification of the result regression equations the GP of three catchments Gagas, Heng-Chi, and Kasilian were app

Table (~~2~~3) lists the GP as well as stream-order-law ratios of the three selected catchmen Eqs. (12) to (16). The table (~~2~~3) also provides the ~~observed~~ values of stream order ra their computational errors.

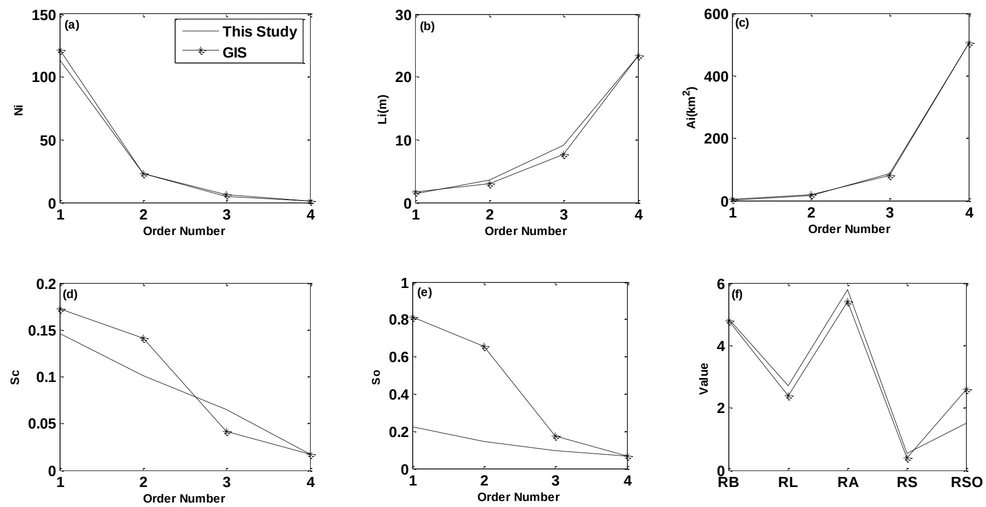

Fig. ~~6~~8. Verification of geomorphological parameters~~GP~~ in Gagas catchment

In order to calculate the error related to the stream- order-law ratios the Eq.20 below has used:

$$Error\% = 100*(R_P - R_{GIS})/R_{GIS} \qquad (20)$$

Where R_P is predicted stream-order ratio and R_{GIS} is GIS-based stream-order ratio.

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Table ~~2~~ 3 Calculated geomorphological parameters~~GP~~ of the Gagas, Heng-Chi, and Kasilian catchm

Catchment Name	Predicted Geomorphologic parameters										
	Order	N_i	$\overline{L_i}$	$\overline{A_i}$	$\overline{S_c}$	$\overline{S_o}$	R_B	R_L	R_A	R_S	R_{SO}
1. Gagas	1	113	1.38	2.6	0.146	0.222	4.84	2.72	5.78	0.53	1.5
	2	23	3.54	15.1	0.101	0.147					
	3	5	9.10	87.5	0.065	0.098					
	4	1	23.40	506.0	0.017	0.065					
GIS Results							4.80	2.40	5.40	0.40	2.60
%Error							0.40	13.7	7.6	21.0	41.4
2. Heng-Chi	1	47	0.32	1.0	0.104	0.654	3.61	2.26	3.80	0.68	1.2
	2	13	1.34	3.7	0.060	0.530					

	3	4	2.43	14.0	0.031	0.429					
	4	1	4.97	53.2	0.012	0.347					
GIS Results							3.30	2.60	4	0.60	1.10
%Error							9.4	13.7	5.0	13.3	9.1
3. Kasilian	1	49	0.49	1.1	0.109	0.563	3.65	2.09	3.92	0.72	1.3
	2	13	1.03	4.4	0.073	0.436					
	3	4	2.19	17.3	0.038	0.337					
	4	1	4.65	67.8	0.008	0.261					
GIS Results							3.5	1.5	4.3	0.4	1.1
%Error							4.3	43.2	8.8	89.5	18.2

Figs 68,– to 8 10 depict the GIS based and computational GP concerning the three ca catchments.

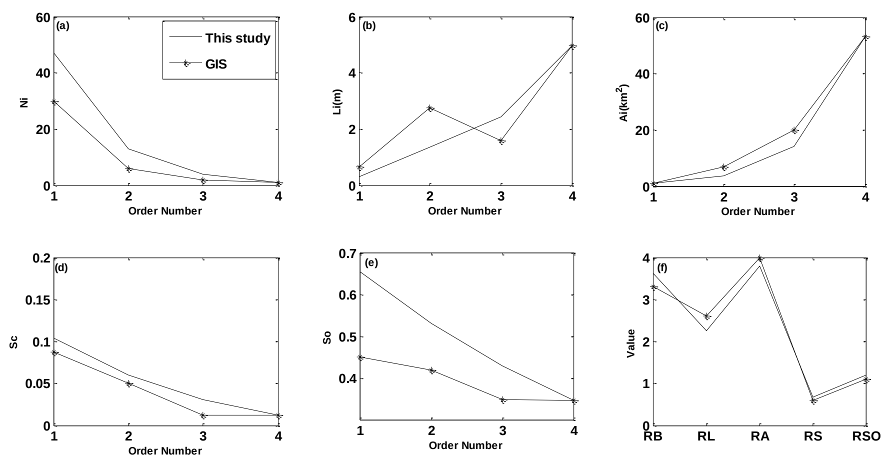

Fig.79. Verification of geomorphological parametersGP in Heng-Chi catchment

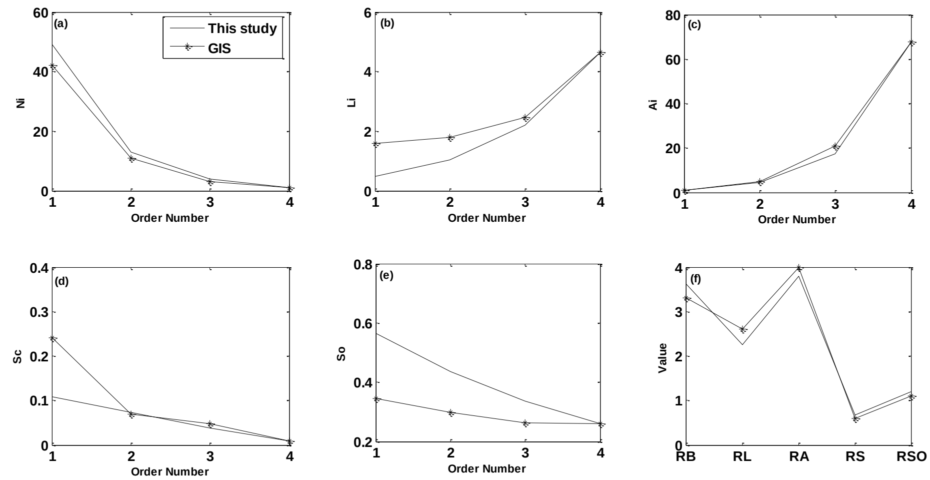

Fig.810. Verification of GP geomorphological inparameters in Kasilain catchment

The mean errors of regression equations in estimation of R_B, R_L, R_A, R_S, and R_{SO} in t selected catchments are, respectively, 4.7%, 23.5%, 7.1%, 41.3%, and 22.9%.

The greatest errors of the model emerged in estimation of, respectively, R_S, R_L, R_{SO}, R_A, As observed in Fig. (5a7a), the stream slope ratio has a slight affect on runoff, so its err be ignored. Regarding high sensitivity of the length and overland slope ratios their erro from 23 to 24 percent and it is recommended that the joint effects of all the ratios on DR selected catchments be considered.

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7.2. Validation of catchment's direct runoff

In the previous sections, the influences of GPSOLR on runoff were pondered separately, GP of the three catchments were estimated via the regression equations. To study accura estimations more deeply it is better to estimate the DRH using GIUH model. For this taking the information about excess rainfall hyetograph and recorded runoff of the Kasi the Heng-Chi catchments into consideration, we turn to verification of the predicted dire for the two catchments.

The model GIUH was employed in two cases, one in which geomorphologic paramete are GIS based and the other where empirical regression equations (GIS-unsupportedthi are concerned for the Kasilian and the Heng-Chi catchments. The results of the model case were compared with those of observed runoff recorded. Since the observed rur rainfall data of Gagas catchment were not available, this catchment was dispensed in ver phase. Figure 9 11 shows the results of GIUH model for DRH estimation in Kasilian ca for two events on 10th May 1992 and 4th May1993. Also, Fig. (1012) illustrates those i Chi catchment for two events July 1996 and October 2000.

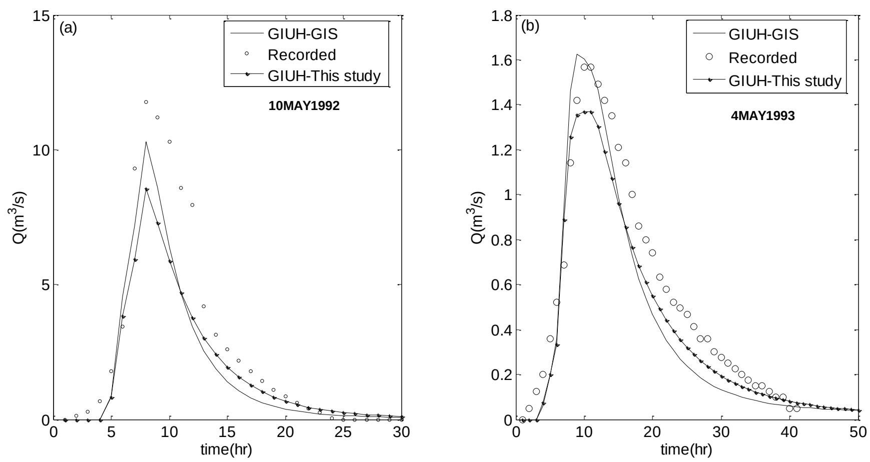

Fig.911. Estimation of Kasilian direct runoff hydrographDRH by GIUH model

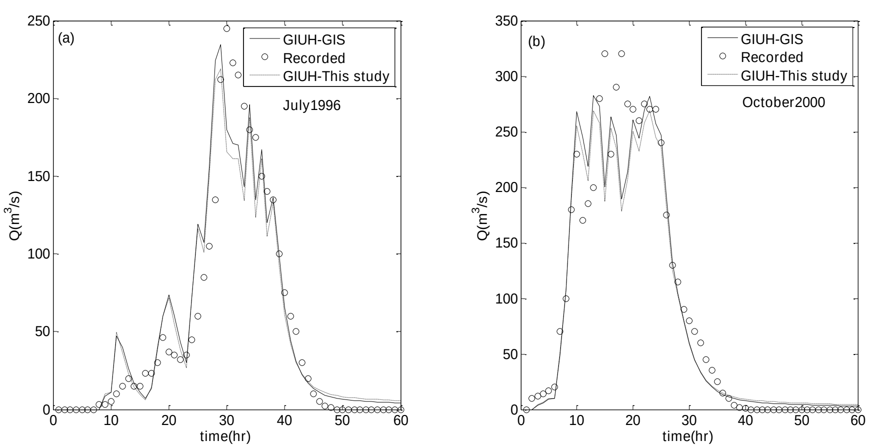

Fig.1012. Estimation of Heng-Chi DRH direct runoff hydrograph by GIUH model

To validate the fitness of the model for the Kasilian and Heng-Chi catchments, three ‹ statistical measures were ~~used,~~used the coefficient of efficiency (*CE*), ~~Root~~ root mea error (*RMSE*), and ~~Relative~~ relative error in peak (*REP*).

Estimation of these three parameters ~~is~~ are carried out by the following equations:

$$CE = 1 - \frac{\sum_{t=1}^{n}[Q_r - Q_s]^2}{\sum_{t=1}^{n}[Q_r - \overline{Q}_r]^2}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(Q_r - Q_s)^2\right]^{0.5}$$

$$REP = 100 \times [Qp_s - Qp_r] / Qp_r \quad ($$

where Q_r is the recorded discharge at time *t*; Q_s is the simulated discharge at time *t*; $\overline{Q}_r$ mean recorded discharge during the storm event; *n* is the number of discharge records dı storm event; Qp_s is the peak discharge of the simulated hydrograph and Qp_r is the ı peak discharge.

Table (~~3~~4) gives the values of *REP*, *CE*, and *RMSE* calculated for the two selected catchı GIS-supported and ~~GIS-unsupported~~ proposed method (this study) cases.

Table ~~3~~4. Validation result of the GIUH model

July1996	*REP*%	*CE*	*RMSE*
GIS	4.18	0.87	24.54
This study	10.62	0.86	25.44
October 2000			
GIS	11.81	0.93	31.22
This study	15.99	0.92	32.25
10 May 1992			
GIS	12.68	0.81	1.13
This study	27.33	0.76	1.26
4 May 1993			
GIS	3.5	0.87	0.10
This study	12.6	0.91	0.10

It is concluded that the computational error values of runoff peak (*REP*%) that could be (in this study) for the four rainfall-runoff events are, on average, 10% more than t resulting from actual information (GIS support). As seen in Figs (~~9~~11) and (~~10~~12), the r the GIUH model in the two cases concerning GIS and empirical equations are very close other. *CE* and *RMSE* are near-valued as well. The mean *CE* of the model was computed four events as 0.87 which is a satisfactory value.

8. Summary and conclusion

In this research, experimental equations were presented to work out geomorphologic and order-law ratios ~~parameters~~ of watersheds of less than 600 km^2 area. These equations are in accordance with the nonlinear regression method fitted to the stream-order-law ~~geomorphologic parameters~~ of nine different catchments of the world. The equations we under verification in three other selected catchments, and their results were compared wi calculated from GIS.

The geomorphologic ~~parameters~~and stream-order-law ratios of three catchments Gagas Chi, and Kasilian were determined based on the experimental equations given in this r and compared with their actual results. The average errors of the model in estimation of R_A, R_S, and R_{SO} in the three case study catchments were 4.7%, 23.5%, 7.1%. 41.3%, and respectively.

~~Finally, direct runoff hydrograph was estimated by GIUH with regard to the geomorp data computed for the three catchments, and then compared to the observed values.~~ Sensi bifurcation ratio (R_B), length ratio (R_L), area ratio (R_A), stream slope ratio (R_S), and o slope ratio (R_{SO}) to runoff of Kasilian catchment were investigated. It is shown that the sensitivity of R_B, R_L, R_A, R_S, and R_{SO} was 0.56, 0.01, 0.92, 0.042, and 1.33, respectiv greatest effect was related to, respectively, the overland slope ratio, length ratio, and bif ratio, and the least effect was related to area ratio, and streams slope ratio.

~~The geomorphologic parameters of three catchments Gagas, Heng-Chi, and Kasilia determined based on the experimental equations given in this research, and compared w~~

actual results. The average errors of the model in estimation of R_B, R_L, R_A, R_S, and R_s three case study catchments were 4.7%, 23.5%, 7.1%. 41.3%, and 22.9%, respectively.

Finally, direct runoff hydrograph was estimated by GIUH with regard to the geomor data computed for the three catchments, and then compared to the observed values.

Lastly, the estimated stream-order-law ratios geomorphologic parameters was were input GIUH model and the values of direct runoff hydrograph of two catchments Kasilian an Chi were calculated and compared with those of observed direct runoff. According to the the computational averaged error values of runoff peak (*REP*%) for the four rainfa events are, on average, 10% more than the error resulting from actual informatio Supported). The results of the GIUH model in the two cases concerning GIS and without very close to each other. *CE* and *RMSE* in the two cases are near-valued as well. Tl coefficient of efficiency of the model was computed for the four events as equal to 0.87.

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10-References

Alemngus, A, Mathur, B.S (2014) GEOMORPHOLOGIC INSTANTANEOUS HYDROGRAPHS FOR RIVERS IN ERITREA (EAST AFRICA), Journal of Indiai Resources Society, Vol. 34, No. 1.

Beer, T., and Borgas, M. (1993) Horton's laws and the fractal nature of streams, Water Res., 29(5), 1475–1487.

Choi, Y, Lee, G, Kim, J (2011). Estimation of the Nash model parameter based on co geomorphologicdispersion. J HydrolEng 16(10), 806–817.

Chang, C.-H and Lee, K. T (2008) Analysis of geomorphologic and hydrological charac in watershed saturated areas using topographic-index threshold and geomorphology-base model, Hydrol. Process., 22, 802–812.

Claps, P., Fiorentino, M., and Oliveto, G. (1996) Informational entropy of fractal river n J. Hydrol., 187, 145–156.

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Dodds, P. S., and Rothman, D. H. (1999) Unified view of scaling laws for river network Rev. E, 59(5), 4865–4877.

Dodds, P. S., and Rothman, D. H. (2001), Geometry of river networks: I. Scaling, fluct and deviations, Phys. Rev. E, 63, 016115.

Gupta, V.K, Waymire, E and Wang, C.T (1980) A representation of an instantane hydrograph from geomorphology. Water Resour. Res. 16 (5), 855–862.

Horton, R. E (1932) Drainage-basin characteristics, Eos Trans. AGU, 13,350– 361.

Horton, R. E (1945) Erosional development of streams and their drainage basins: Hydro approach to quantitative morphology, Geol. Soc.Am. Bull., 56, 275– 370.

Kumar, R, Chatterjee, C , Singh, RD, Lohani, AK and Kumar, S (2004) GIUH based C Nash models for runoffestimation for an ungauged basin and their uncertainty analys River Basin Manag, 2(4):281–190.

Kumar, R, Chatterjee, C, Singh, RD, Lohani, AK and Kumar, S (2007) Runoff estimatic ungauged catchmentusing geomorphologic instantaneous unit hydrograph (GIUH) Hydrol Process 21(14):1829–1840.

Kumar, A, Kumar, D (2008) Predicting direct runoff from hilly watershed using geomor and stream-order law ratios: case study. J Hydrol Eng, 13(7), 570–576.

Kumar, A (2015) Geomorphologic Instantaneous Unit Hydrograph Based Hydrologic R Models for Ungauged Hilly Watersheds in India, Water Resources Management, Febru 29, 3, 863-883.

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La Barbera, P., and Roth, G. (1994) Invariance and scaling properties in the distribu contributing area and energy in drainage basins, Hydrol. Process., 8, 125–135.

Lee, K.T., Yen, B.C., 1997. Geomorphology and kinematic-wave based hydrograph de J. Hydrol. Eng. ASCE, 123 (1), 73–80.

Lee, K.T (1998) Generating design hydrographs by DEM assisted geomorphic runoff sin a case study. J. Am. Water Resour. Assoc. 34 (2), 375–384.

Lee, K. T, and Chang, C. H (2005) Incorporating subsurface-flow mechanis geomorphology-based IUH modeling. Journal of Hydrology, 311:91–105.

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Mohamoud, Y. M., and Parmar, R. S. (2006): ESTIMATING STREAMFLOV ASSOCIATED HYDRAULIC GEOMETRY, THE MID-ATLANTIC REGION, USA1. of the American Water Resources Association, 42(3), 755.

Norusis, M.J. (1999): SPSS regression models 10.0.

Obi Reddy, GP., Maji, AK., Gajbhiye, KS. (2004) Drainage morphometry and its influ landform characteristics in a basaltic terrain, Central India—a remote sensing and GIS ap Int J Appl Earth Obs Geoinfo 6:1–16.

Ozdemir, H., Bird, D. (2009) Evaluation of morphometric parameters of drainage n derived from topographic maps and DEM inpoint of floods. Environ Geol 56:1405–1415

Peckham, S. D., and Gupta V. K. (1999) A reformulation of Horton's laws for lar networks in terms of statistical self-similarity, Water Resour. Res., 35(9), 2763–2777.

Raff, D. A., Smith, J. L. and Trlica, M. J. (2003) Statistical descriptions of channel n and their shapes on non-vegetated hillslopes in Kemmerer, Wyoming, Hydrol. Proce 1887–1897, doi:10.1002/hyp.1216.

Reis, A. H. (2006) Contractual view of scaling laws of river basins, Geomorphology, 7 206, doi:10.1016/j.geomorph.2006.01.015.

Rodriguez-Iturbe, I, Valdes, J.B (1979) The geomorphologic structure of hydrologic r Water Resour. Res. 15 (6),1409–1420.

Rodriguez-Iturbe, I, Gonzalez-Sanabria, M, Bras, R.L (1982). Ageomorphoclimatic theor instantaneous unit hydrograph. Water Resour. Res. 18 (4), 877–886.

Rodríguez-Iturbe, I., Marani, M., Rigon, R. , and Rinaldo, A. (1994) Self-organized riv landscapes: Fractal and multifractal characteristics, Water Resour. Res., 30(12), 3531–35

Rodríguez-Iturbe, I., and Rinaldo A. (1997) Fractal River Basins, Chance and Self-Orgai 547 pp., Cambridge Univ. Press, New York.

Sarangi A., Madramootoo, CA., Enright, P. (2003) Development of user Interface in Arc estimation of watershed geomorphology.CSAE/SCGR 2003 meeting, paper no. 03-120

Shreve, R. L. (1966). Statistical law of stream numbers. J. Geol. 74:17-37.

Smart, J. S (1972) Channel networks., Advances in hydroscience, Vol.8, V. T. Ch Academic Press, Inc., San Diego, Calif., 305-346.

Strahler, A. N (1952) Hypsometric (area-altitude) analysis of erosionaltopology, Bull. Ge Am., 63, 1117–1142.

Strahler, A. N (1957) Quantitative analysis of watershed geomorphology, Trans. AGU 913– 920.

Strahler, A. N (1964) Quantitative geomorphology of drainage basins and channel netw Handbook of Applied Hydrology, edited by Ven te Chow, pp. 4 –39, McGraw-Hill, New

Sabzevari, T, Fattahi, M.H, Mohammadpour, R and Noroozpour, S (2013) Prediction of and subsurface flow in catchments using the GIUH, under publication. Journal of Flo Management. , Vol 6. Issue 2, 135–145.

Sabzevari, T, Noroozpour, S (2014) Effects of hillslope geometry on surface and sul flows, Hydrogeology Journal,, Vol22,7, 1593-1604.

Schumm, S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth NJ. Bulletin of Geological Society of America 67, 597-646.

Shadeed, S, Shaheen, H and Jayyousi, A (2007) GIS-BASED KW–GIUH HYDROLC MODEL OF SEMIARID CATCHMENTS: THE CASE OF FARIA CATCH PALESTINE, The Arabian Journal for Science and Engineering, Volume 32, Number 1C

Shuyou, C, Lee, K.T, Juiyi H, Xingnian, L, Huang, E and Yang, K (2010) Analysis o in Ungauged Mountain Watersheds in Sichuan, China using Kinematic-wave-based Model, Journal of Mountain Science, Vol 7,2 , 157-166.

Valeriano MM, Kuplich TM, Storino M, Amaral BD, Mendes JN Jr, Lima DJ (2006) M small watershed in Brazilian Amazi-nia with shuttle radar topographic mission-90 Comput Geosci 32:1169–1181

Veitzer, S., and Gupta, V. (2000) Random self-similar river networks and deriva generalized Horton laws in terms of statistical simple scaling, Water Resour. Res., 36(4 1048.

Yen, B. C, and Lee, K. T (1997) Unit hydrograph derivation for ungauged watersheds by order laws, J. Hydrol. Eng., 2(1), 1–9.

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