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DEVELOPMENT OF FLOOD DISCHARGE MODELS USING GIS

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ABSTRACT

Hydrological command of waterway system has been altering beneath the crash of mutually environment disparity and human actions in the overall milieu. With the advent of technology it is now possible to model the complete resource allocation of any hydrological network duly integrating both natural and artificial networks. Advance applications allow an excellent automated system to monitor, control and manage water allocations to better utilize water resources, minimize wastage and predict hazards. The first step to all of this is to have accurate information of the catchment areas, so that in coordination with concerned departments, modeling and predictions of futuristic results is possible which will yield better decision making leading to fructifying outcome. Physical hydrologic models for drainage areas are significant utensils to hold water assets management and foresee diverse hydrologic contacts and risks. Indus River is considered as salvation of Pakistan and it is also the largest river of the country. The approximate length of the river is 3180 kilometers and its drainage area exceeds 1165000 km^2. Having in view the worth of Indus River and its socio economic implication on Pakistan it was planned to carry out research work on upstream of Terbela from Kachura. The intended approaches of this work were to generate empirical equations based on hydrologic model on a particular reach of the river i.e. from Kachura to Tarbela reservoir and by utilizing Geographic Information Systems and Remote Sensing means. Also the watershed analysis of the upstream of Indus river basin was performed, thus fashioning an essential tool for running and setting up of water resources for state.

Key words: *River Indus, Peak flows, Arc GIS, Empirical approach, Multiple non-linear correlations.*

INTRODUCTION

The science and expertise of flood disaster mitigation speak to plan, preparation, aim, and operational aspects. High-quality guidelines and growth can lessen the exposure to flooding through systematization of land management and housing progress whilst well planned flood protection schemes will improve the crash of flooding. However, absolute defense from flooding is hardly ever a feasible purpose. Stipulation of flood forecasting and caution systems can transport major profits through giving premonition of coming up flooding, allowing opportune migration and managing of affected communications[1]. Flood defense and alertness have sustained to go up on the political program over the last decade accompanied by a force to improve flood forecasts[2,3,4,5]. Flood calculation is a vital device for dipping the harmful effects of flood actions. In reply to the blazing criticism it received for its treatment of the Easter 1998 floods in England and Wales, the Environment Agency, the administrator management body accountable, has totally overhauled its flood forecasting and counsel system, whilst at the European level, the European Commission has bigheartedly supported a figure of structure research programs to get better flood forecasting ability[6]. During the previous decade there has been marvelous progress in Hydrologic Modeling using GIS. The employ of digital topography models has exposed their budding to a number of analyses in hydrology. The coming out of individual computer programs on flood forecasting system really enhanced the forecasting intensity and has been useful all through the past decade[7]. Prepared flood forecasting systems shape a key element of vigilance strategies for unfortunate flood trial by providing premature warnings quite a few days in advance giving flood forecasting services, public fortification establishment and the community ample grounding time and thus dipping the impact of the flooding destitute[8,9,10,11].

Statistical hydrologic models have been used frequently, ever since the Darcy's Law (the funda-

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mental equation governing groundwater flow) revealed in 1856, the St. Venant equations unfolding unsteady open channel flow, developed in 1871, and a steady stream of analytical proceed in picture of the run of water has happened in the later decades. During 1950s Digital topography form were used for a range of geosciences submissions. The applications of computer models instigate to emerge by the middle of 1960s. Initially the idea was used in some cases of surface water flow and sediment transport. After that in the 1970s models worked in problems related to surface water class and groundwater flow. In 1980s groundwater transport was also incorporated. In 1990s era community grasp the efficacy of including GIS with hydrologic modeling. Petts endeavor to see the real meaning of the recent geographical loom to hydrology by recommending the root for the watershed and river systems to cooperate in such a way that could be lectured through GIS. Brown spotlighted on GIS in Hydrology excerpt the statement that hydrological GIS symbolize a modeling prospect. GIS perk up computations for watershed distinctiveness, flow figures, debris flow likelihood, and aids the watershed delineation by using Digital Elevation Models (DEMs). It supply a regular means for watershed investigation using DEMs and unvarying datasets such as land face, soil assets, gauging station site, and climate variables.

The stream flow conjecture accompanied by powerful precipitation–runoff models (with probabilistic climate forecasting stuffs) are becoming more normally used in prepared flood forecasting functions. The concert of banding flow forecasts at a range of places in a river sink can be considered by the way of probabilistic confirmation[12]. ArcGIS with Arc Hydro function provide the litheness to unite watershed datasets from one map source with brook and waterway systems. One can perform regression analysis between any two variables, to establish their dependency relationship on each other. Moreover empirical equations between different variables over a data spanning a time line can be established by, having known their multiple or exponential constants.

Empirical Equations for Peak Floods Presented by Some Researchers

A number of empirical formulae has been developed for the estimation of the flood peak and are fundamentally local formulae founded on statistical correlation of the experimental climax and significant catchment characteristics. To simplify the form of the equation, only a few of the many parameters affecting the flood peak are used. For example, almost all formulae used the catchment area as a parameter affecting the flood peak and most of them neglect the flood frequency as a parameter. In view of these, the pragmatic formulae are valid merely in the area for which they were devised and when applied to other areas, limitations of a certain equation must be kept in mind. However developing flood anticipations are to be conversed. Fresh learning by researchers have accepted importance of intellectual and institutional restrictions to water reserve executive building the finest exercise of pioneering decision-support technologies[13,14]. By far the simplest of the empirical relationships are those, which relate the flood peak to the drainage area.

The maximum flood discharge $Q_{p.}$ from a catchment area A is given by these formulae as

$$Q_p \quad f(A) \tag{1}$$

While there are a vast number of formulae of this kind proposed for various parts of the world, only a few popular formulae[15,16] are given in Table 1.

Objectives of the Study

A flood is abnormally high flow in water way. Floods are always been a threat for hydraulic structures. In this particular study River Indus is focused which is the main river in Pakistan. River Indus has many important hydraulic structures but the most important is Tarbela Dam. Therefore, in this study some empirical models have been developed which can be used to estimate floods by considering the statistical data of discharge and rainfall. Also the catchment area and the relative percent slopes were considered to make the model reliable estimation. The study will help to design other hydraulic structures and bridges within this specific reach.

Data Sources

The data was obtained from Surface Water Hydrology Pakistan (SWHP). The gauging stations of

Table 1: Empirical Formulas for the Peak Flows Developed by Other Researchers

No	Author	Year	Equation	Notations	Equation No
1	Dickens Formula	1865	$Q_p = C_D A^{3/4}$	Q_p is the maximum flood discharge (m^3/s) A is the catchment area (km^2) C_D is the Dickens constant value which ranges 6 to 30 depending upon the topography	(2)
2	Ryves Formula	1884	$Q_p = C_R A^{2/3}$	Q_p is maximum flood discharge (m^3/s) A is the catchment area (Km^2) C_R is the Ryves coefficient whose value ranges from 6.8 to 10.2 depending on the available topography.	(3)
3	Inglis Formula	1930	$Q_p = \frac{124A}{\sqrt{A+10.4}}$	A is the catchment area in km^2	(4)
4	Nawab Jang Bahadur Formula	—	$Q = CA^{((0.993-(1/14)(LogA))}$	A is the catchment area in km^2 Q is the peak discharge in cumecs C is a constant whose value ranges from 48 to 60	(5)
5	Dredge and Burge Formula	—	$Q = 19.5(A/L^{2/3})$	Q is the discharge in cumecs L is the length of the basin in km A is area of basin in km^2	(6)
6	Coutagne Formula	—	$Q = 150\ A^{1/2}$	Q is discharge in m^3/s, A is catchment area between 400 to 3000	(7)
7	W.P. Creager Formula	—	$Q = C\ [0.386A]^{0.894(0.386A\text{^}-0.048}$	Q is discharge in cumecs A is catchment area in km^2 C is a constant whose value is taken as 130	(8)
8	Rhind's Formula	—	$Q_p = 0.098\ CSR\ (0.386)^p$	Q_p is peak discharge in m^3/s, S is average slope above the point of interest taken for length of 5 km along the river, R is the highest rainfall recorded in the area in cm, C and P the coefficients.	(9)
9	Horton's Equation	—	$q_p = 71.2(T)^{1/4}(A)^{-1/2}$	q_p is discharge in m^3/s, A is drainage area in km2 and T the return period in years	(10)
10	US Geological Survey	1955	$Q_{2.33} = 0.0147CA^{0.7}$	C constant ranges from 1 to 100, Q2.33 is mean average annual flood with return period of 2.33 years	(11)
11	Pettis Formula	—	$Q_p = C.(P.B)^{5/4}$	Q_p is flood discharge of 100 years return period in m^3/s, P the one day rainfall of 100 years return period in cm, B the average width of the basin and C a coefficient (0.195 for desert and 1.51 for humid regions)	(12)
12	Fuller's Formula	1914	$Q_{Tp} = C_f A^{0.8} (1 + 0.8 \log T)$	Q_{Tp} is the maximum 24-h flood with a frequency of T years in m^3/s A is the catchment area in Km^2 C_f is the constant with values between 0.18 to 1.88	(13)

Kachura, Bunji, Shatial and Besham Qila were focused for water discharge data and precipitation data. The basic requirement for watershed analysis is the availability of Digital Elevation Model (DEM). The DEM is the central data aspect for assembling a model of a basin's hydrology. Investigation of the DEM permits for model illustration of the watercourse arrangement, as well as sub basins, inside the catchment. Digital Elevation Models are raster (or grid) depiction of spatially dispersed altitude of land situation that are spread by the USGS. This study used SRTM 3 DTED Level-1 90 m DEM of Sakardu–Terbela Area, covering a total of 185600 km^2. This DEM comprised a number of satellite images which were warped and edge matched. The ESRI Arc GIS version 9.2 and Arc Hydro Tools (special features of Arc GIS 9.2) were used for this research. Since Arc GIS 9.2 is the main software but in order to delineate watershed and sketching Thiesson polygon over the DEM, Arch Hydro Tools version 9.2 were used. Google Earth version 4.0 along with the provided maps of Indus River helped to exactly locate the original river line on river network that was being generated with help of DEM.

METHODOLOGY

Processing of DEM

A Hydro DEM is a DEM which is void of depressions or sinks. A depression is a cell or cells in an elevation model which are surrounded by higher elevation values. The basic requirement for watershed analysis is the availability of DEM (Digital Elevation Model).

With the help of SRTM3 DTED LEVEL-1 DEM 90m the hydro DEM i.e. Figure 1 was created thus removing sinks and depressions from the raw DEM. Figure 2 shows the flow diagram for processing of DEM. After this the grids were generated like Flow Direction, Flow Accumulation, Stream and Stream Link were produced. Now by using these grids, the vectors were generated and catchment areas, ad joint catchments, and Sub watersheds were formed. The Indus River – Main Stream was identified by comparing from available maps provided by SWHP and using Google Earth 4.0 in this regard. With the help of processed DEM mean slope of the individual catchment areas or sub-watersheds were calculated then the analysis of discharge and rainfall data was done.

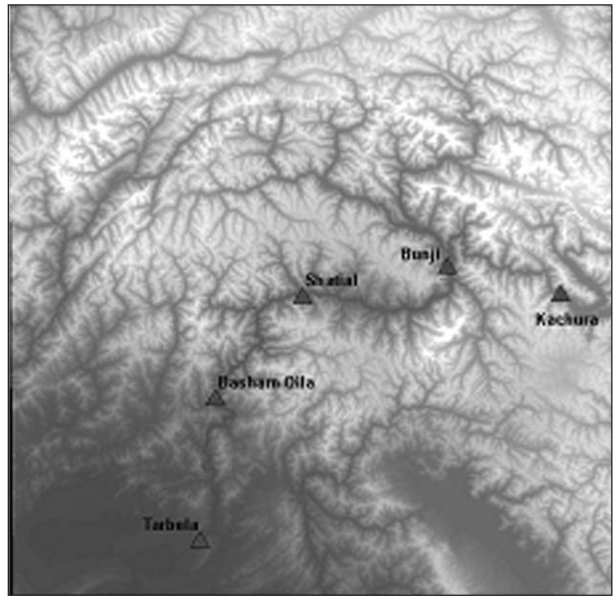

Figure 1: Hydro DEM of the study area

The hydrographs for each station were plotted as in Figure 9.

The longitudes and Latitudes of the under consideration gauging stations have been mentioned in Table 1.

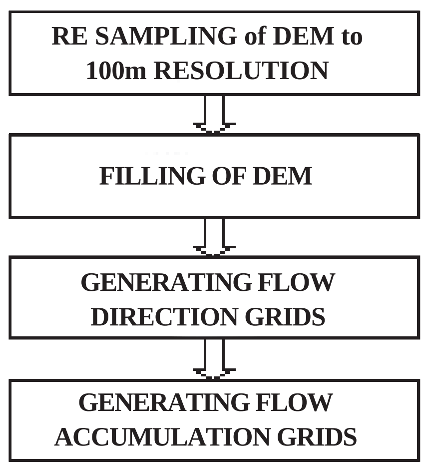

Figure 2: Flow diagram showing processing of DEM

Since almost all the equations discussed in Table 1 consider catchment areas as a prime factor to estimate peak flood. Therefore, the watershed values for the concerned gauging stations were gathered from SWHP. But in this research work DEM was also used to delineate the watersheds itself. By using the tools for watershed delineation it was found that the delineated areas have just a marginal difference with values gathered from SWHP. Hence, proves the accu-

Table 2: Locations of the Gauging Stations Present in the Reach

Sr. No	Gauging Stations	Longitudes	Latitudes
1	Kachura	75° 25’ 38"	35° 26’ 38"
2	Bunji	74° 36’ 35	35° 38’ 55"
3	Shatial	73° 32’ 10"	35° 34’ 48"
4	Basham Qila	72° 53’ 05"	34° 54’ 43"
5	Tarbela	72° 43’ 00"	34° 04’ 16"

racy to the utility of DEM. The catchment areas delineated by the software and by the SWHP are tabulated in Table 3.

It is important to note that with an exception of Kachura catchment (due to unavailability of DEM for this region), the calculated areas with Arc GIS 9.2 were found almost same to the values given by SWHP. Figure 4, 5, 6 and 7 show individual delineated watersheds for Kachura, Bunji, Shatial and Besham Qila respectively. Figure 3 shows the combined catchment area and location of gauging stations for the considered reach.

Table 3: Comparison of the catchment areas determined from DEM and reported by SWHP

Sr. No	Gauging Station	Catchment Area (km^2)	
		Calculated	SWHP Values
1	Bunji	142380	142286
2	Shatial	152706	156217
3	Besham Qila	161136	161356
4	Tarbela	171079	172325

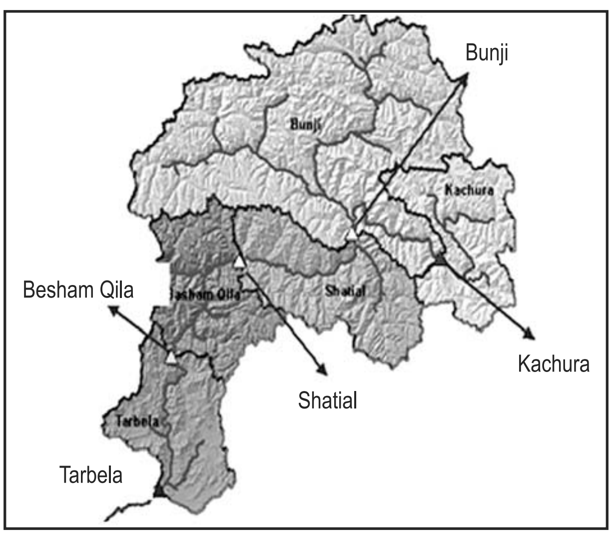

Figure 3: River Network and Delineated watershed Boundaries of Four Gauging Stations up to Tarbela

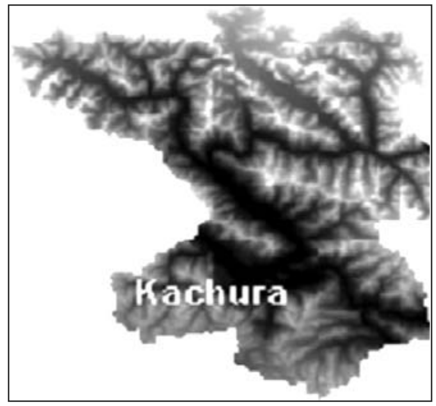

Figure 4: DEM and watershed boundary at Kachura

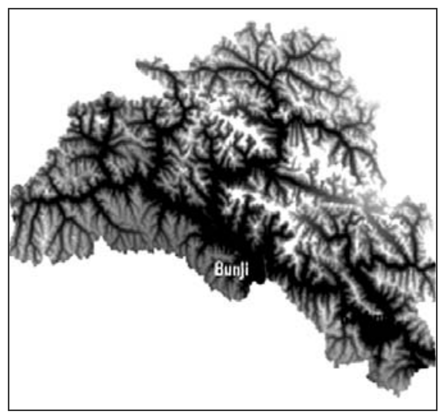

Figure 5: DEM and watershed boundary at Bunji

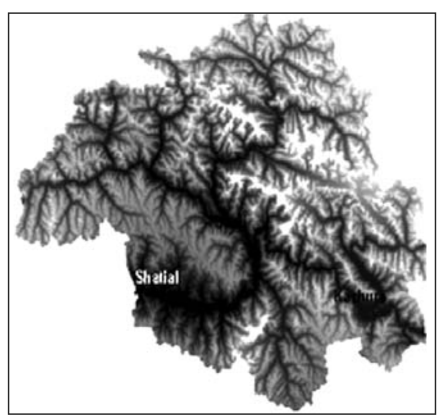

Figure 6: DEM and watershed boundary at Shatial

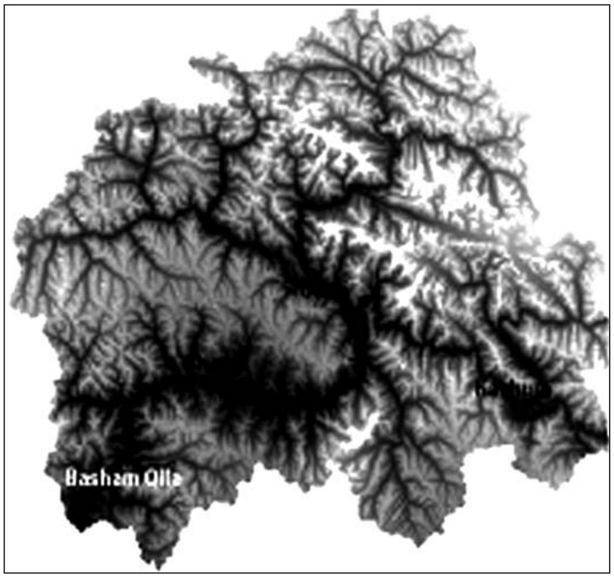

Figure 7: DEM and watershed boundary at Besham Qila

5.2 Catchment Areas and Development of Empirical Equations

Figure 8 highlights the methodology involved for developing the empirical equations for the said reach. After processing the DEM, the flow accumulation was given a certain threshold. A proper value of threshold will ensure such generation of river network that will match the SWHP maps. If the comparison gives satisfied results then the point coverages for the guging stations were plotted. And in case of No the threshold value has to be changed to get best results. Now with the help of plotted point coverages the catchment areas were delineated and these areas were used to calculate percent slopes of the respective delineated watersheds. After getting the required data from DEM the analysis of flood hydrographs at the four stations were carried out. Hydrographs for every station were sketched to observe the trend of the river at each gauging site like one shown in Figure 9.

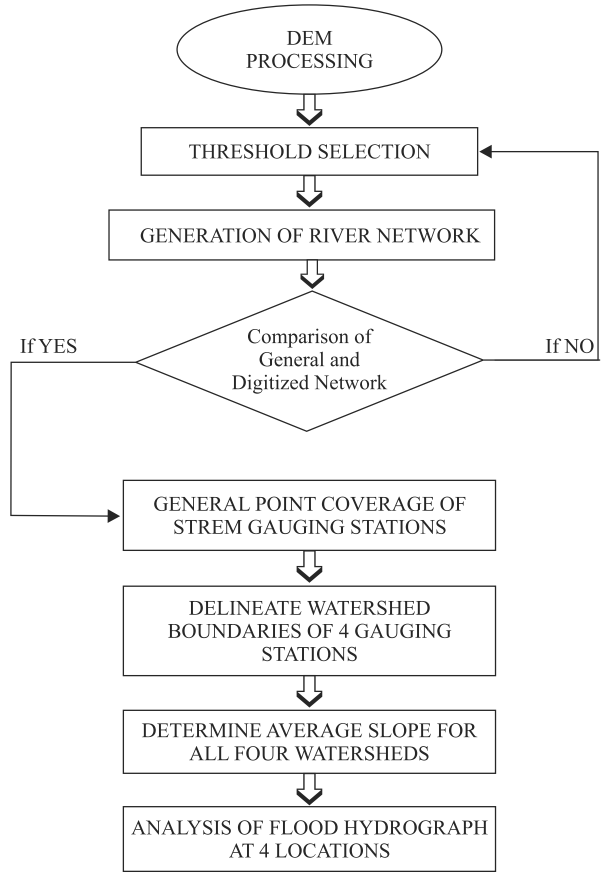

Figure 8: Flow diagram showing methodology adopted in the research

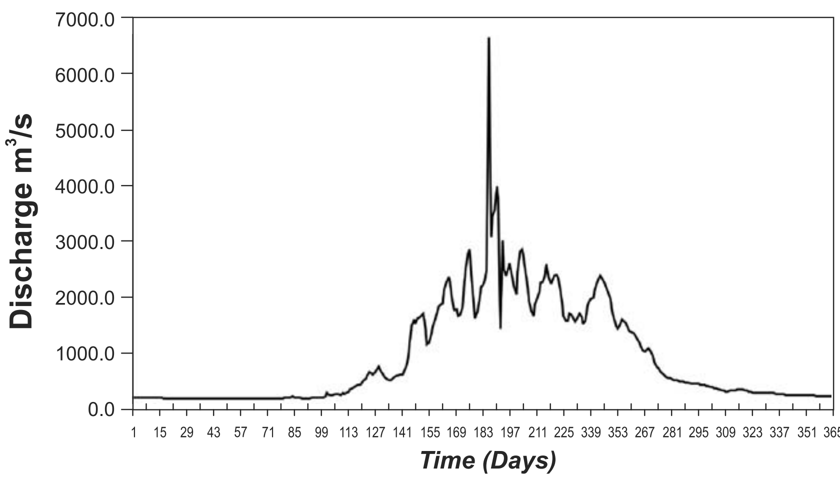

Figure 9: Hydrograph at Kachura gauging station for the year 1993

There are restrictions inside the models. In general, these models hold quite a few unidentified site-specific (e.g., runoff coefficient) and event-specific (e.g., rainfall intensity) factors, which are not easily started. Additionally, extended average guess have been used in resource investigation. In exacting, this is a matter for situation examination that is based upon the purpose of average climate circumstances to temporal replications of river runs[17].

More if precipitation is calculated on the land for overflow forecasting, the hydrologic reaction time is just a few hours, which are from time to time derisory[1].

The annual peak discharge and rainfall data were sorted out. The rain gages were plotted as point coverage and Thiesson polygons at these rain gages were sketched on DEM. Integration of data extracted from DEM as well as field data obtained from SWHP and establishment of relationships between different variables through regression analysis and formulation of simple equations between any two variables were performed.

RESULTS AND TESTS FOR DEVELOPED EQUATIONS

A number of empirical equations were developed in between average peaks, catchment areas, average slopes and peak rainfalls by using both linear regression and multiple non linear regression analysis. The results found in case of linear regression were very good with R^2 value not less than 0.8 almost for every case as one shown in Figure 10. But in case of rainfall the R^2 value was not very encouraging and goes down to 0.6. This fall of the regression model efficiency is because of the randomness of rainfall events as compared to the discharge flow at a gauging station and hence the value of R^2 is low.

The peak discharge, average slopes, catchment areas and rainfall data were used to carryout multiple non linear regression analysis. The data is tabulated in Table 4 to get the Area Slope Model of the form shown in equation 14.

$$Q = K\ A^m S^n \tag{14}$$

Table 4: Data Required For Non-Linear Regression Analysis

Station	Flood Peaks m^3/s	Areas km^2	Slopes percent
Kachura	5268	111360	66.1
Bunji	8065	142380	59.1
Shatial	9205	152706	58.0
Besham Qila	11194	161136	58.5

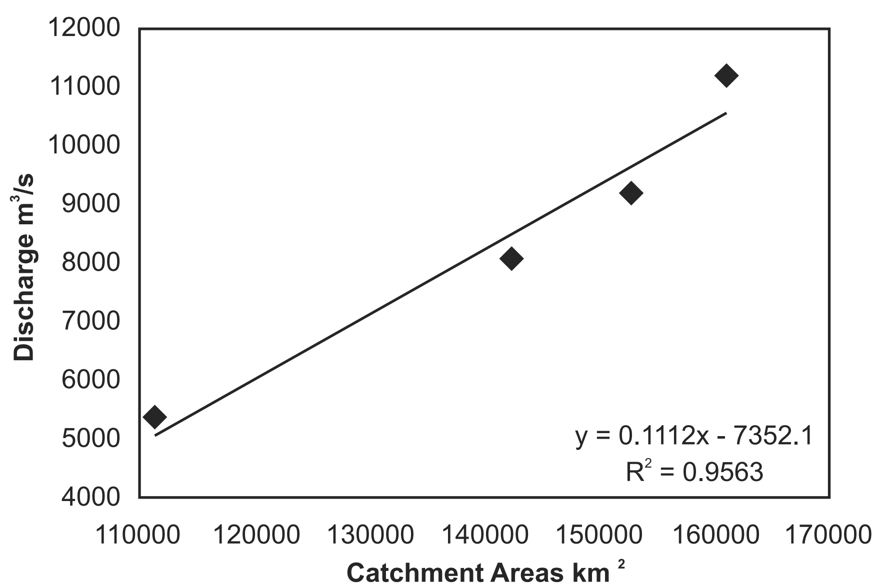

Figure 10: Graph between average peak discharge and catchment areas

Using MS-Excel Sheets for the solution of 3 × 3 matrix, we get the Equation 15 for upstream of Terbela reservoir first by considering Slope and catchment areas from which we develop Area Slope Model.

$$Q = 9.66 \times 10^{-12}.A^{2.4035} S^{1.446875} \quad (15)$$

Where

Q is the discharge in m^3/s, A is the catchment area in km^2 and S is the mean percent slope. The above equation was tested against the observed field values and was found as a very reliable model. This is shown in Figure 11.

This Area Slope Model has been compared with the other empirical equations developed by other reserchers. Considering the topography of Terbela the value of constants used in equations were carefully selected. Figure 12 compares Area Slope Model with some of the other equations as discussed before in table 1.

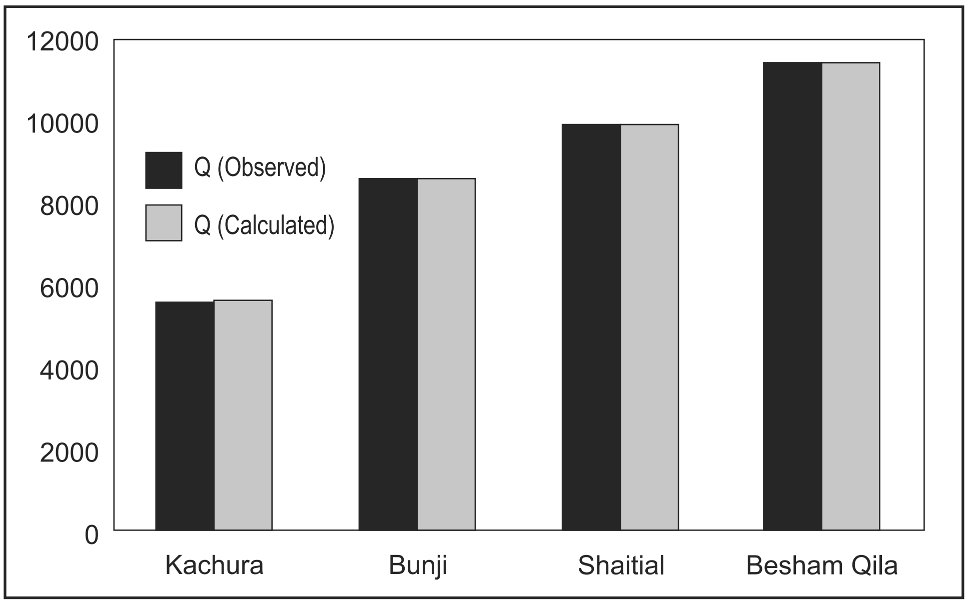

Figure 11: Comparison of estimated flood peaks and observed flood peaks by area slope model

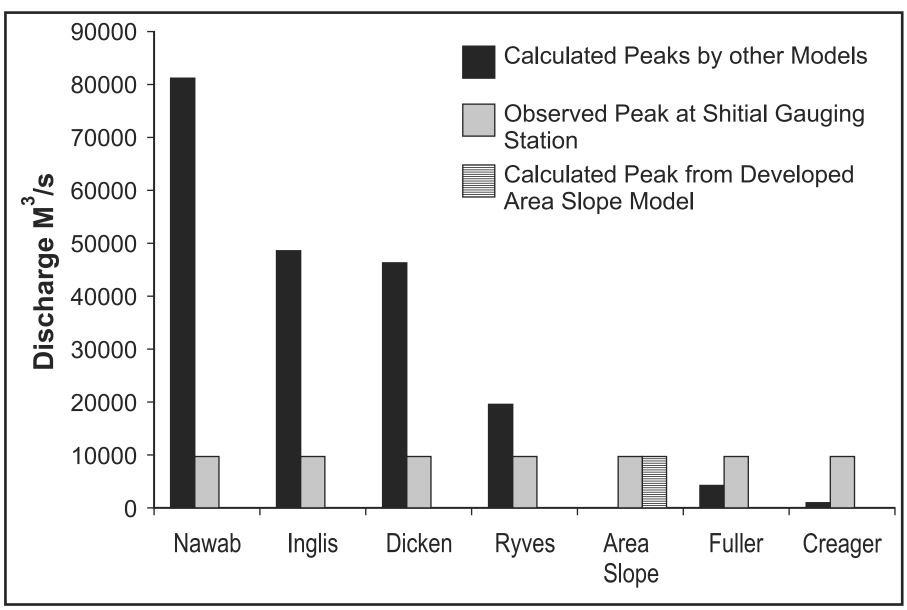

Figure 12: Comparison of developed area slope model with some other equations at Shatial gauging station

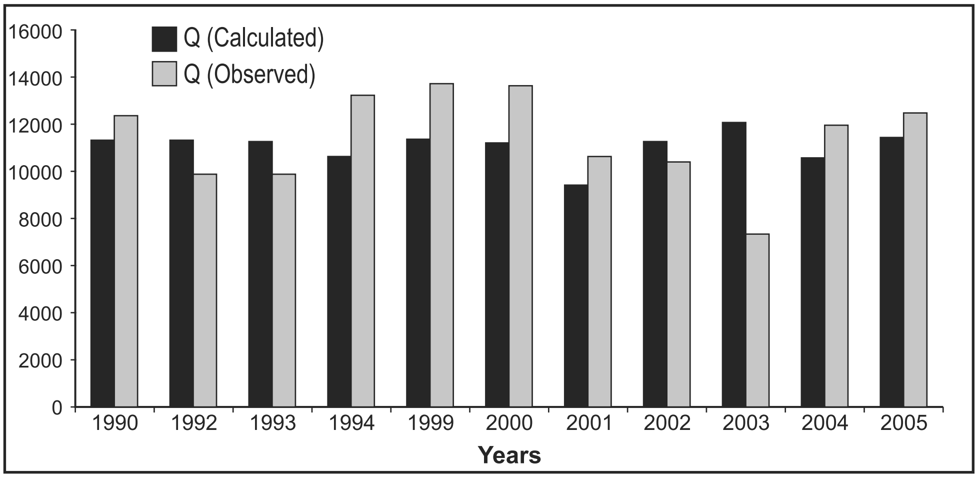

Figure 13: Comparison of estimated flood peaks and observed flood peaks by area rain model

On similar drift the equation 16, Area Rain Model was developed by considering rainfall data for each gauging station. Since the Thiesson polygons were sketched around the three existing rain gages therefore the empirical equations depend on the number of years that had been recorded.

One of the Area Rain Model developed is as shown for Besham Qila watershed.

$$Q_{Besham} = 93.78 A_{Besham}^{\ 0.38} R_{Besham}^{\ 0.23} \qquad (16)$$

Where

Q_{Besham} is the discharge produced for Besham Catchment., A_{Besham} is the area which rain gage covers as found from Thiesson polygon and R_{Besham} is the maximum depth of the rainfall measured at Besham rain gauge.

Figure 13 shows that the model was also tested against the observed field measurements. In this case the results for the calculated years were found satisfactory but for year 2003 the calculated peak was way high then the observed value. The flaw for this year can be of many reasons. The rain gauge may have some problem or the data observed for this period may be of some doubt.

CONCLUSIONS

Use of 90m DEM for hydrological analysis is sufficient enough to delineate stream, catchment areas and water sheds for achievement of dependable results, however 30 m DEM which is very costly but can produce exceptional results with respect to accuracy. Integration of GIS in hydrological analysis of river basin will yield reliable, accurate and precise results. The working on 11 years data resulted in slight differences achieved through regression models. However consistency of data for increased number of years may yield excellent results. Mean slope and the catchment areas calculated through DEM were found very accurate. Accordingly the regression models/equations produced very accurate results. The rainfall data for only Bunji is available for only three years being newly installed station. Therefore it is considered that after a sufficient period of time this station will help to make a better value of R^2 for the data being gathered from this station. Percent variation of all the empirical equations generated for 11 years data validate that further refinement of equations can be possible if a consistent data of fairly sufficient years is available

RECOMMENDATIONS

Rainfall impact over a catchment cannot be exactly elaborated momentarily over a particular gauging station; however its cumulative effect on storage reservoirs, Dams, weirs, barrages and sensitive bridges over the river x-sec can be devastating. It is recommended that the 11 years based models/empirical equations be tested over another span of 40 to 50 years at least in future, so that substantial refinement in the value of constants can be achieved. Integration of Information technology and GIS in departments like SWHP (Water and Power Development Authority, Pakistan) and MET will substantially improve their efficiency and data reliability. Use of state of the art and hi-tech equipment, which can be connected with management information system through data loggers and modems, will enable near to real time monitoring of Surface water hydrology projects. Data sharing and data interoperability environment should be promoted between different government departments like WAPDA, MET, Irrigation and WASA to cross check and enhance the reliability of their field data.

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