RIVER FLOW ESTIMATION FOR UNGAGED STATIONS USING GIS MODEL

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ABSTRACT

Geographic information system (GIS) has had a great progress in river engineering in recent years. Most of new developed softwares in this area have the GIS abilities or are able to interact with GIS software. The application of GIS in this area is mostly for pre and post processing of input and output data. In this research, water flow of river has been estimated in an ungaged point using ArcView. GIS has been used to calculate the physiographical characteristics of watershed, flow accumulation, flow directions, etc. Its high speed in estimating these characteristic which are lengthy in other methods, is its main advantage. For this research, Gharahsoo watershed in west of Iran has been selected. All calculated data was compared with the measured data in order to verify the method. The river water flow in the ungaged point was calculated using the information extracted from produced layers and water flow measurements in upstream and downstream stations. In order to control and verify the results, estimating the flow was made for a gaged station considering it as an ungaged station. Then, the results were compared with measured data in that station. Also, water flow in the same station was estimated using a time series analysis with ARMA model to compare the results of two forecasting methods.

KEYWORDS: Hydrology, Geographic Information System, River Flow Estimation

1. INTRODUCTION

In order to determine the amount of water which is available at individual sites, one needs to know or to be able to estimate water flows. In Iran, several places on rivers have been considered to use, store, or divert water resources. On the other hand, only in limited places, there are sites where gages are used to record hydrological data. At gaged locations, monitoring equipment records data for flow rate or stage along with the time of measurement. There are several available methods for distributing flows from gaged to ungaged sites, ranging from the very simple to the complex and laborious. On the simple side, the most widely used method is the distribution of flow in proportion to drainage area. In this case, the stream flow per unit area of watershed is assumed constant, and the naturalized flow at the ungaged site is calculated as the naturalized flow at the gaged site multiplied by the ratio of ungaged to gaged areas [3]. On the other extreme, there are generalized computer models of watershed hydrology that are able to compute sequences of daily or monthly stream flows for a given precipitation unit. Some of the most widely used methods are as follows:

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- Proportional relationships of discharge to change in hydrologic parameters.
- Modified curve number method developed by Natural Resource Conservation Service
- Regression equations fitted between gaged and ungaged locations
- Rainfall-runoff relationships
- Hydrologic simulation, e.g. HEC-HMS, SWAT

The first two methods are used frequently especially in the beginning stages of water resources studies. In the first method, the extending of flow rate to the ungaged location is based on drainage area and rainfall. In this method, the proportion of river flow to the unit area of watershed is considered constant. The advantage of hydrologic simulation is the accuracy of its predictions. Their major disadvantage is that they require considerable expertise, time and effort to be used effectively. In order to use each method, it is necessary to provide the required information and data. Therefore, GIS is playing an important role. At the present, most of hydrologic and river engineering softwares have directly the GIS capabilities or it can be linked to a GIS software. In later case, GIS is mostly used as pre and post processor tool. GIS is an assemblage of computer hardware and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis, and display or printing of spatial data [1]. All data in a GIS is geo referenced, i.e. located by means of geographical coordinates with respect to some reference system. This is how a GIS differs from computer-aided drafting or graphics program. GIS keeps data in digital format and it can combine different data and maps in different ways. Since GIS is using the fast and powerful computers, the speed of data processing in GIS environment is very high and it can do several analysis in a fraction of time which is not possible by other methods [1, 2]. In this paper, we are trying to show the ability of GIS in accelerating the data processing and calculating the stream flow in ungaged station in comparison of manual methods. It is obvious that because of large extend of data and information, we have to summarize the data in manual methods which causes increasing error or necessary time in calculations. Gharahsoo watershed has been selected for this research which is located in west of Iran.

2. METHODS AND MATERIALS

Stream flows can be calculated for different time periods in gaged stations. In order to extend the data for ungaged stations in upstream or downstream of those stations, proportional relationships of discharge to change in hydrologic parameters have been used in this paper. In addition, a time series analysis, ARMA model, has been used to compare the results. For the first method, the following equation has been used:

$$Q_{ungaged} = \left(\sum Q_{gaged}\right) * \left(\frac{Area_{ungaged} * PPT_{ungaged}}{\sum Area_{gaged} * PPT_{gaged}}\right) \tag{1}$$

where Q is the stream flow, Area is the upstream area of point of interest, and PPT is calculated as follow:

$$PPT = \frac{M_{ungaged}}{M_{gaged}} \tag{2}$$

where M is the mean annual precipitation in area.
In this method, it is assumed that gaged points and ungaged points are correlated and the river flow changes have linear relationships with hydrological parameters of the watershed.

2.1. Study area

Gharahsoo is a sub basin of Karkheh watershed in west of Iran. It is located between Zagross Mountains between 46^o 16' and 47^o 15' longitude and between 34^o 06' and 34^o 54' latitude. The main river in this basin is Gharahsoo. By merging two rivers, Merk and Gerdab, Gharahsoo is formed. There are 9 hydrometery stations along the river network in the basin. Mean annual river flow of Gharahsoo is 289 million cubic meters per year (MCM/y) and the maximum river flow has been 92.6 m^3/s. In this research, the precipitation and hydrometery data of 1976 to 1981 in Hojjat_Abad and Dooab_Merk stations have been used.

2.2. Preparing the basic information

The data required to determine the parameters for an area of interest are a digital elevation model (DEM), and a grid of the mean annual precipitation (PPT). Additionally, although not required, coverages of the main river basins and main streams are helpful to narrow down the extent of the data to use in the calculations. A Digital Elevation Model (DEM), consists of a sampled array of elevations for ground positions that are normally at regularly spaced intervals. Using a digital vector topographic map scale 1:250000, DEM theme was created for the region. The resolution of the DEM used in this project is 250 m (each cell has 500 m per side). Average elevation of the area was 1632 m above sea level. Using DEM, basin and sub basins borders have been identified directly by software and comparison with the manual created borders, a good agreement has been concluded. Figure 1 shows the DEM for area and the border of basin and sub basins.
A Digital Precipitation Model (DPM) also was created. Using this theme, one can find the precipitation of each point knowing its x and y coordinates. The relationship between elevation and precipitation has been calculated using available rain gage stations in the region. The calculated relationship is [10]:

$$P = 115.6 + 0.258h \quad (3)$$

where h is elevation above sea level (m) and P is the precipitation (mm).

2.3. Selecting only relevant data

The next step is to separate the data that is required for the analysis at hand from the rest of the data. This is necessary to make the computations shorter; if we use all the data to compute the parameters of one location we are evaluating thousands of cells that are not related to the location of interest.
One way to separate the relevant data from the rest is to first find out where are the points that need to be evaluated. Inserting a theme containing the location of the stations of interest could do this.

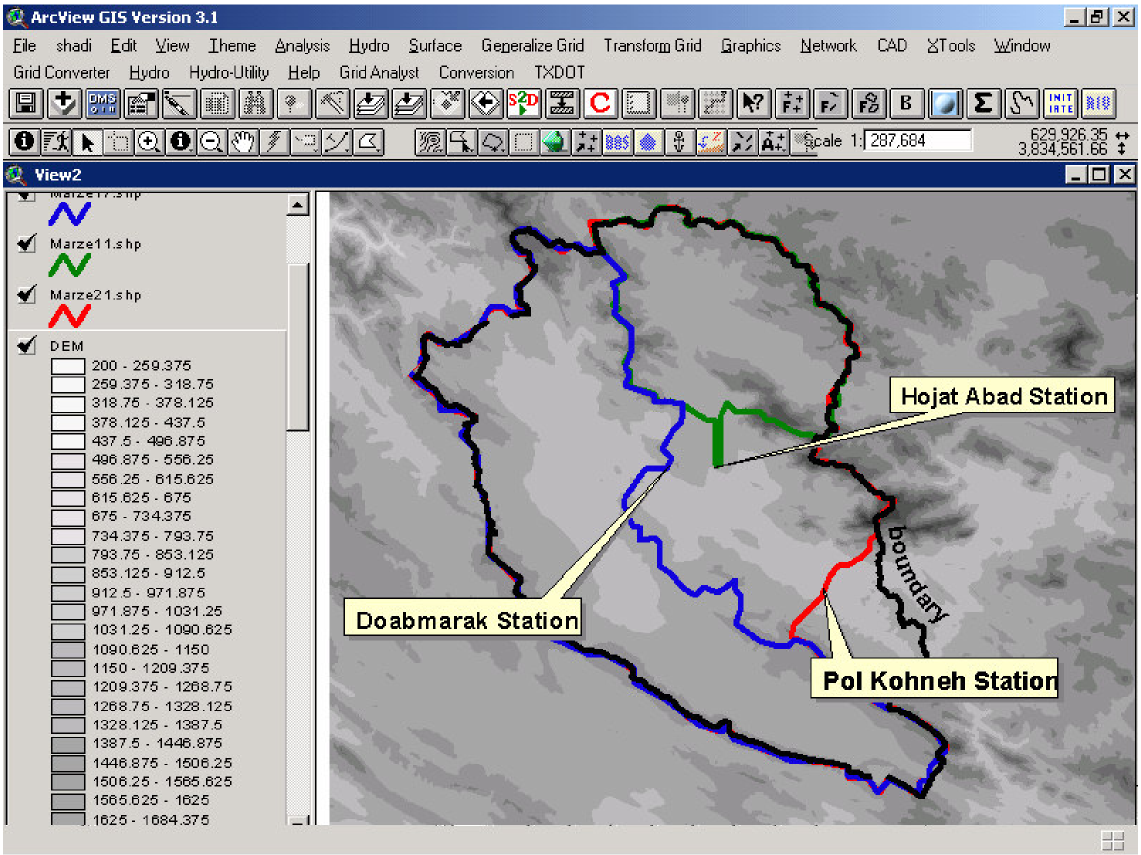

Figure 1. Digital Elevation Model and sub basins borders in ArcView

2.4. Develop flow direction and flow accumulation grids

To be able to delineate the draining areas of the watershed, we need to define the Flow Direction and Flow Accumulation grids for our data. To do this, we need to make a Filled DEM theme to fill the sinks that might exist in it. Then, each cell value is compared to eight neighborhood cells. The flow accumulation theme is calculated by finding the number of cells that drain their water into each cell. Using Flow Direction and Flow Accumulation command in ArcView, these two themes will be created [5, 6, 7].

2.5. Flow length upstream and downstream

The longest flow path is the maximum length of flow from the basin border to the outlet. The flow length downstream is the distance between the cell position to the outlet cell and the Flow length upstream is the distance between the cell position and the first cell in upstream of basin [10].

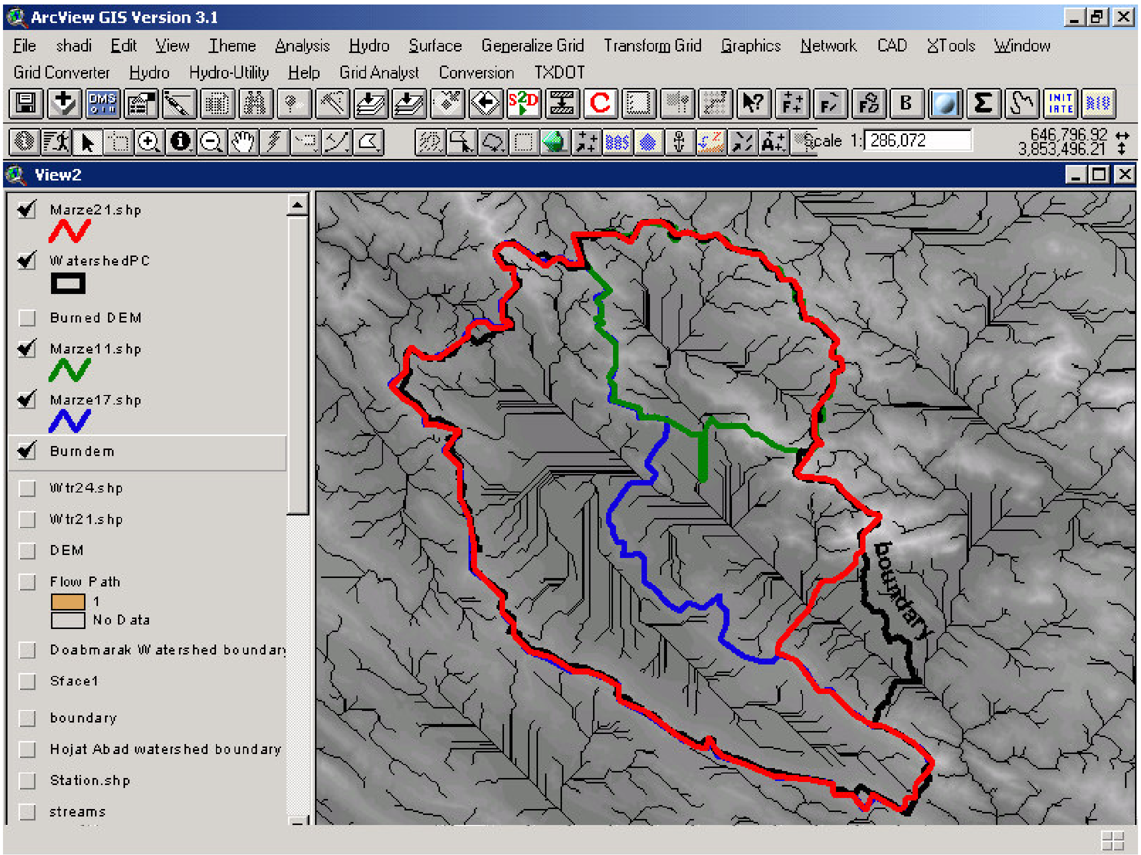

Figure 2. Burned DEM created from stream grids

2.6. Stream grids

Since creating the stream grid using DEM is not accurate, the river network map, prepared in AutoCAD, was imported into ArcView. Using the written script, the burned DEM theme was created. This is an accurate method to make the stream grids especially in flat areas. Figure 2 shows this layer in ArcView [10] .

3. RESULTS AND DISCUSSIONS

Arc View 3.2 was used in this study. Several scripts have been added to the original software to conduct the necessary calculations. Scripts were used to delineate the draining area of a point defined by the user with the mouse. Once the area is defined, the script then makes a weighed average of those grids to find the mean PPT. The area of each sub basin was extracted using DEM, sub basin border, and stream grids themes. Table 1 shows the calculated area by ArcView.

Using collected data from 1976 to 1981, average monthly flow in Pol_Kohneh point along Gharahsoo river was estimated using two gaged stations in upstream i.e. Hojjat_Abad and Dooab_Merk stations. There is a hydrometery station in Pol_Kohneh which is used to compare the calculated results and to evaluate the efficiency of the method. Figure 3 shows the regression between calculated and observed data in that station.

3.1. Prediction of ARMA model

In order to compare the results with another fast and easy method, ARMA model was used to predict the river flow in Pol_Kohneh Station. EVIEWS software was used for this part. Different Auto Regressive (AR) and Moving Average (MA) parameters were tested and finally an ARMA(2,2) had the best fit between the observed and calculated data. Figure 4, shows the comparison between ARMA, GIS and observed results. The percentage of error are shown in Table 2 for the two methods. As it is evident, the GIS based method has a better performance.

Table 1. Calculated drainage area using ArcView script

Station Name	**River Name**	**Drainage Area (km^2)**
Hojjat_Abad	Raz_Avar	1265
Dooab_Merk	Gharahsoo	2819
Pol-Kohneh	Gharahsoo	5135

4. CONCLUDING REMARKS

Performing calculations in GIS is faster and more accurate compared to manual calculations. In addition, creating, archiving, and transferring maps are easier in this environment. In this paper, the performance of GIS to determine in a semi-automatic way the parameters of each sub area of stations, was developed and is described in this document. Procedure is semi-automatic because it requires input from the user (point location and ID) for each site. The choice of data was made based mainly on its availability, but the procedures and scripts developed in this project can be applied directly over more accurate data. Nevertheless, the procedures developed in this project are readily usable and adaptable, and are mainly intended to serve as a starting point towards more sophisticated methods.

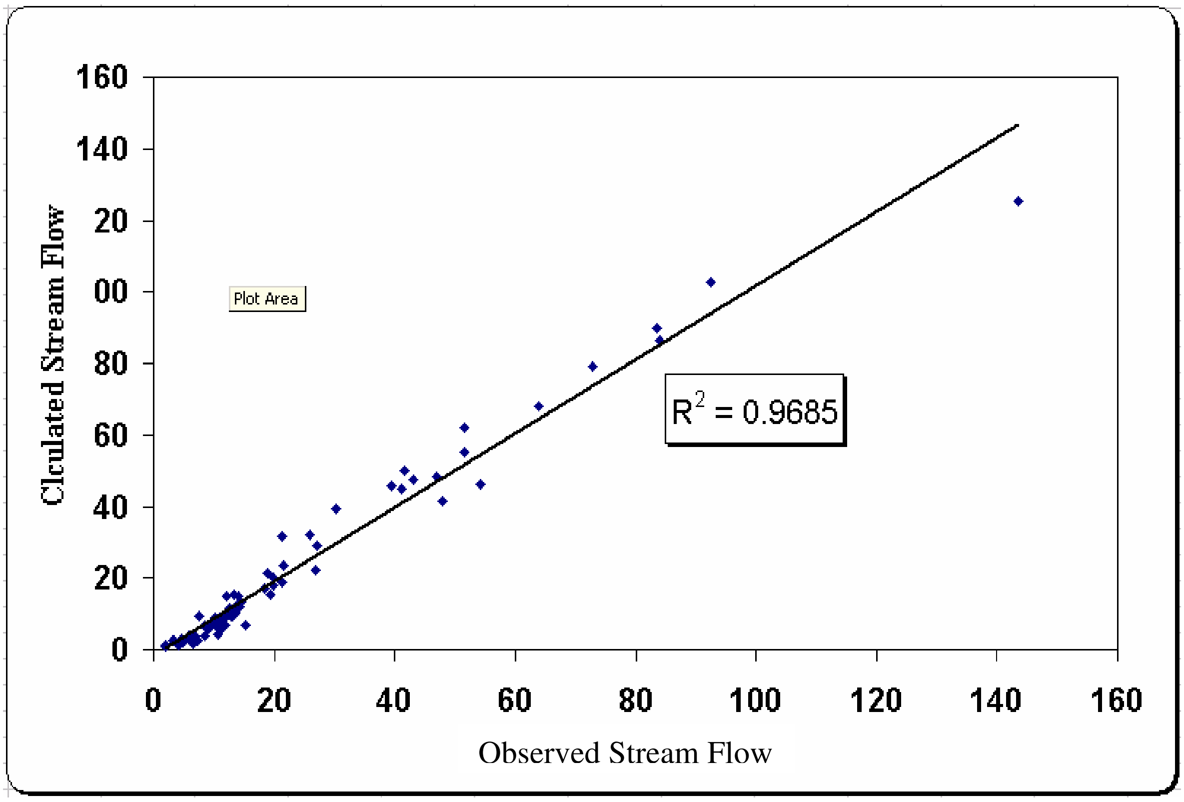

Figure 3. Correlation graph between observed and calculated stream flow

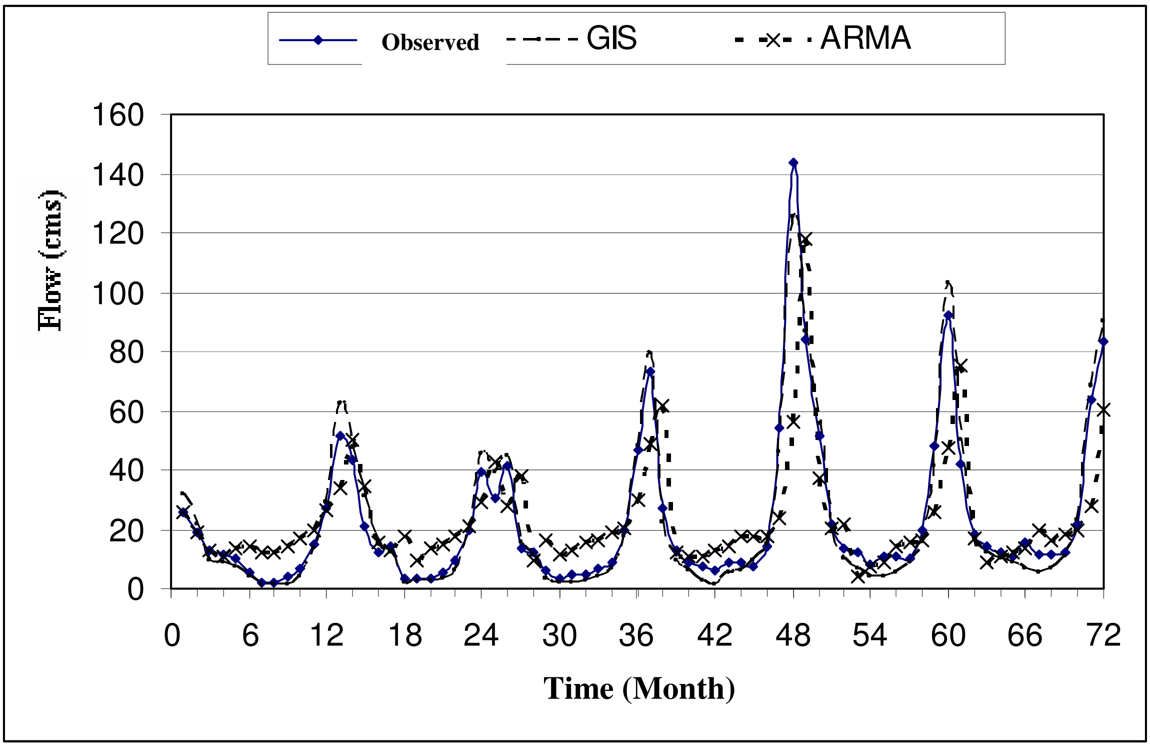

Figure 4. Comparison between different prediction methods and observed data

Table 2. Percentage error on estimating stream flow

Year	Average Error (%)					
	GIS			ARMA(2,2)		
	Max.	Ave.	Min.	Max.	Ave.	Min.
1355	66.98	29.68	7.53	36.12	13.58	0.00
1356	48.30	23.24	0.08	89.75	27.45	0.37
1357	52.98	26.77	2.71	63.39	20.30	1.33
1358	75.17	28.84	7.61	138.8	65.96	5.67
1359	59.07	25.73	3.09	68.57	35.32	8.57
1360	54.56	21.76	6.82	81.11	35.08	7.81
Total	75.17	26.00	0.08	138.81	32.95	0.00

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