AN INTEGRATED APPROACH FOR CATCHMENT PARAMETERIZATION THROUGH GEOSPATIAL ANALYSIS: A CASE STUDY OF KURANG RIVER BASIN, PAKISTAN

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ABSTRACT: *Catchment parameterization is mathematical analysis of configuration of earth's landforms through Geographical Information System techniques. The present work enunciates principal morphometric elements of Kurang River basin using geospatial techniques coupled with ArcHydro Tool. The catchment of Kurang River, covering an area of 617Km^2, is characterized by denudated hills and fluvial terraces carved by weathering and erosion of Mesozoic-Quaternary sedimentary deposits. ASTER data was utilized to prepare DEM with 30m spatial resolution for delineation of spatial and non-spatial aspects. Geographical Information System and ArcHydro Tool were utilized to work out flow direction, flow accumulation, stream density, drainage line and catchment area. In all, 91 streams with a total length of 129.72Km were identified. Average value of bifurcation ratio shows that development of the basin was independent of structural control. On the basis of coarse drainage density, the basin indicated low relief with highly permeable subsoil and thick vegetation. In all, the basin is 4th order in nature.*

Keywords: Kurang River, Catchment, Morphometery, Streams, GIS, ArcHydro, drainage Density

INTRODUCTION

Surface drainage systems are significant not only to hydrologists but to geologists, geographers, soil scientists and environmentalists [1&2]. Numerous features like lithology, structure, topography, climate and vegetal cover of an area control the evolution of a drainage system over space and time [3&4]. In the past many studies exist to accentuate the development of quantitative analysis of morphometric parameters to enunciate evolution of surface drainage system and basin characteristics [5,6,7,8,9,10,11,12&13]. As such morphometry describes evaluation of streams through mathematical calculations of outline of earth's landforms [13] and provides a quantitative description and comparison of all the fundamental units of surface drainage systems [8, 10,14&15]. Most of the previous morphometric analyses were carried out using conventional methods [e.g. 5&16] whereas now days automated quantitative analyses of basin morphometry are carried out using high spatial resolution remotely sensed data [17]. The present study focuses on evaluation of principal morphometric elements of drainage basin of Kurang River, Pakistan by using digital elevation model in geographical information system and characterizes linear and aerial aspects and relief features.

Geographical information system (GIS) methods are commonly used as convenient tools to analyze and integrate spatial and non-spatial data on geology, geomorphology, and hydrology and catchment parameterization [18&19]. GIS offers user friendly environment in storing, retrieving, manipulation and analyzing available and associated resources information [20].In GIS environment specially designed ArcHydro tool helps to calculate the morphometric parameters. In ArcHydro quantitative descriptors like elevation of a terrain, its gradient, area, shape and circularity ratios can be easily accessed through GIS applications. Moreover, GIS coupled with digital elevation model (DEM) and geomorphology provides interpretative techniques in delineation of morphometric parameters and landform characteristics for assessment and management of terrains and hydrological networks [21].

STUDY AREA

The Kurang River is dammed at Rawal Lake to supply water for the neighboring urban areas. The Kurang River joins the Soan River which is a major tributary of the River Indus. (Fig.1)

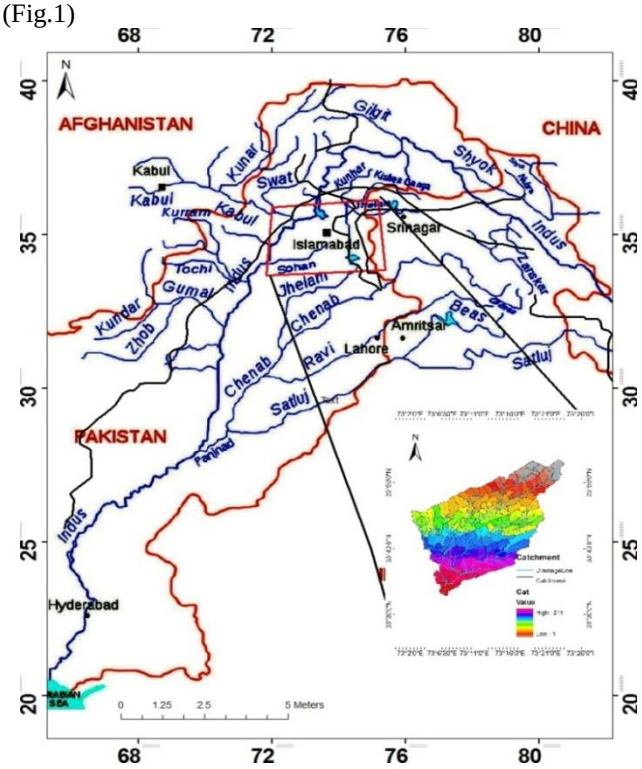

Fig.1 Location map of study area

The areas drained by Kurang River fall in humid tropical to arid zone that experience extreme climate with hot summers and cold winters. The temperature varies from freezing to 38ºC (mean = 28ºC) Easterly monsoon rain waters flow in

the river from June to September and rest of the year is dominated by inflow of westerly disturbances. Local thunder storms frequently flood the study area. Mean annual rain fall of the study area is 940mm. Head water regions of the Kurang River are characterized by cool summers and snowy winters. The hilly terrain of catchment is not well developed and sparsely populated whereas plain areas of Bahra Kahu and Kot Hathyal are heavily populated. The natural vegetation of the Kurang River catchment is related to the local climate and soil. Natural vegetation cover consists mostly of grasses, herbs, shrubs and trees.

Table 1: Stratigraphic Table, after Ahsan and Chaudhry [22]

Age	Formation	Lithology
Middle Pleistocene	Lei Conglomerate	Conglomerate
UNCONFORMITY		
Lower to Middle Miocene	Kamlial	Sandstone and shale
Middle Eocene to lower Miocene	Murree	Sandstone and shale
Early to Middle Eocene	Kuldana	Limestone, marls and claystone
Early Eocene	Chorgali	Limestone and shale
Early Eocene	Margala Hill	limestone
Late Paleocene	Patala	Shale and limestone
Middle Paleocene	Lockhart	limestone
Early Paleocene	Hangu	Laterite and clays
UNCONFORMITY		
Early Cretaceous to Late Cretaceous	Lumshiwal	Sandstone
Late Jurassic to Early Cretaceous	Chichali	Shale
Middle Jurassic	Samana Suk	Limestone
UNCONFORMITY		
BASE NOT EXPOSED		

MATERIAL AND METHODS

Demarcation of all streams and calculation of their length and area of watershed was carried out digitally in ArcGIS software version-10 (arc hydro tool) for morphometric analysis of the Kurang River. All the tributaries indicating various patterns and extents were digitized from the Survey of Pakistan topographical sheets No. 43G/1, 43G/2 and 43G/5 on a scale of 1:50,000. Moreover, ASTER-DEM with a spatial resolution of 30m along with band combination and filtering was utilized. Stream ordering techniques of Strahler [6&8] were adopted to give an order to each stream and further help was provided by ArcHydro Tool in ArcGIS software version-10. In addition to this, linear aspects of morphometry such as stream order (Nu), bifurcation ratio (Rb) and stream length (Lu) were calculated following the work of Horton [5], Strahler [6] and Chorley [23]. Moreover, areal morphometric aspects like drainage density (D), stream frequency (Fs), texture ratio (T), elongation ratio (Re), circularity ratio (Rc), form factor ratio (Rf) were worked out keeping in view the parameters outlined by Horton [5], and Pareta [24]. Wentworth's [25] method was adopted to carry out average slope analysis of the watershed area. The drainage density and frequency distribution analysis of the watershed area were completed using the Arc Hydro Tool in ArcGIS 10 software. The Arc Hydro tool is a geo spatial and temporal data model that assists to create, handle and display Arc Hydro data model such as the drainage parameters of the basin. The toolset operates in ArcGIS environment in sequential order.

RESULTS AND DISCUSSIONS

In DEM, certain cells with higher elevation values surround a cell with lower elevation value, a sink. The water will be trapped in a sink and reduces the discharge. In Arc Hydro environment left over sinks in the DEM of the Kurang River basin were filled at the first step and a flow direction was assigned. (Fig.2) In general, sink filling leads to accurate processing of morphometric evaluation and modification of elevation values in Arc Hydro tool and is carried out to standardize the raster. The normalized raster would indicate flow direction on the basis of hydrologic flow model via an eight direction pour point algorithm, D8 algorithm [26]. This algorithm, reflects that runoff from a given cell in a DEM will flow towards one of its eight neighbors [21]. This neighbor represents the steepest descent from that cell.

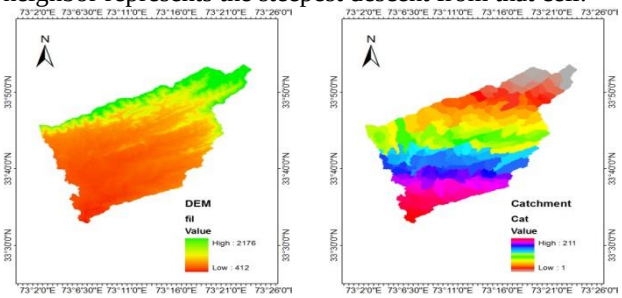

Fig. 2. DEM and Catchment Grid of the River Kurang

Flow accumulation is worked out on the basis of flow direction grid with the help of Arc Hydro Tool. The Arc Hydro Tool creates a flow accumulation grid that indicates number of accumulated cells in upstream direction of a cell. This process is carried out for every cell in input grid. Such cells are 690071 in number in flow accumulated map in the Kurang River basin. The area of flow accumulation grid for 30m×30m resolution DEM is about ($690071\times30\times30\times10^{-6}$) 621.12Km². The flow accumulation grid defines a stream. In the present study, the threshold value for the flow accumulated cell is calculated as 5.00Km². (Fig.3) It is known fact that smaller threshold value will produce a denser stream-network and results in a larger number of catchments. In stream segmentation, various defined streams are linked to generate a unique value for all the pixels belonging to a single stream segment. Stream segment may be a head segment or a segment between two segment junctions. In all, stream segmentation helps to generate catchments with respect to their segment. The Arc Hydro Tool then performs catchment grid delineation process that shows a raster region to represent catchments within the basin. The Tool defines one catchment for each stream segment in the basin. All the raster data created up to now is stored in a folder titled Layers.

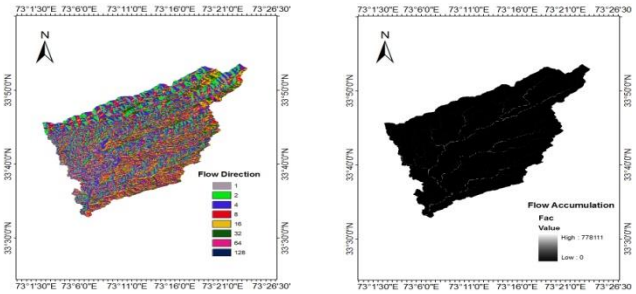

Fig. 3 Flow Direction and Flow Accumulation of the River Kurang

The ArcHydro Tool creates a shape file of the catchment in catchment polygon processing. The largest catchment in Kurang River basin is 62.36Km² and the smallest one has an area of 0.026 Km². The total area of Kurang River basin is 617Km². In next step the ArcHydro Tool converts stream link into drainage line for the whole drainage basin. In Kurang River basin, drainage line processing indicates 57 drainage lines. Minimum length of the stream is about 0.1Km whereas maximum length is 19Km. Total length of main stream is about 61 km. In all, the catchment polygon processing, drainage line processing and adjoining catchment processing in Arc Hydro Toolset transforms raster data to vector format.

Stream Order

Classification of stream networks in a drainage basin helps to discuss and understand their relationships. Several steam order systems exist but none have been accepted unanimously. Horton [5] was the pioneer to develop a quantitative method for the analysis of drainage systems. Strahler [6]) modified Horton's [5] provisional stream order scheme and presented a comprehensive approach to rank relative sizes of tributaries in a drainage basin.

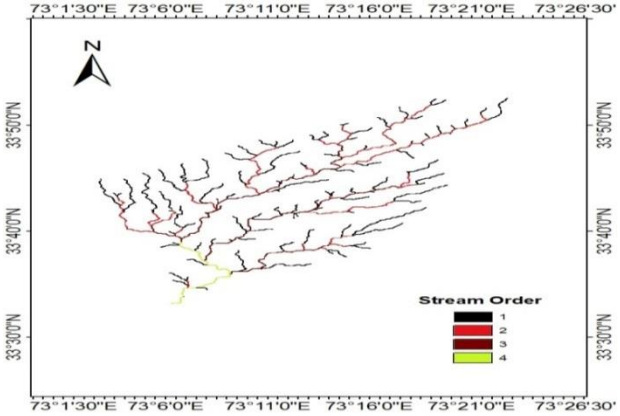

Fig. 4 Stream Order of Kurang River

This scheme is commonly used today [15]. In this scheme each headwater tributary is a first order stream and confluence of such two streams generate a second order stream Strahler [6]. Third order stream in this hierarchy of streams forms when two second order streams join together and so on. In the present work 72 first order streams are present and indicate maximum frequency in occurrence, in the Kurang River basin, followed by second, third and fourth order streams. (Fig.4)

Bifurcation Ratio

Bifurcation ratio expresses "the ratio of the number of stream segments of lower order to the number of stream segments of higher order" [26&27]. Bifurcation ratio (Rb) can be worked out through a mathematical expression: $Rb = N_i/N_{i+1}$. In this expression N_i represents a stream segment of lower order and N_{i+1} shows a stream segment of higher order. Many studies exist that relate the bifurcation ratios to the influence of geological structure on drainage pattern [28]. In a study Strahler [8] indicates a value of bifurcation ration between 3.0 and 5.0 where drainage patterns are not structurally controlled. Greater bifurcation ratios suggest structure controlled drainage patterns [29]. Development of drainage pattern in the Kurang River Basin is not under structural control as the average value of bifurcation ratio for is 4.21 (Fig.5) and such basin are considered well developed [5]. In addition to this, bifurcation ratio of 4.21 shows that higher order channels are 4.21 times less than that of lower order segments.

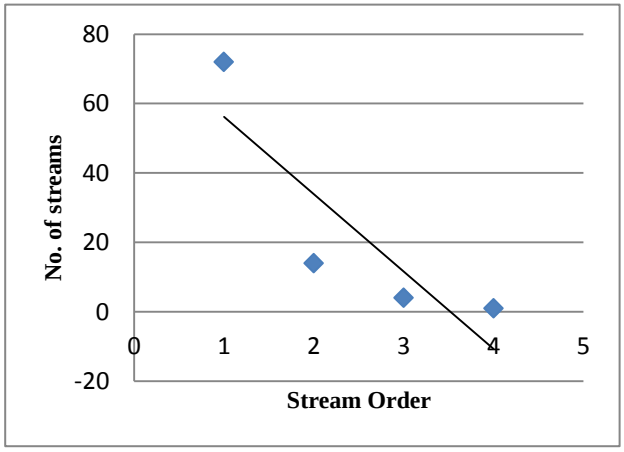

Fig.5 Bifurcation ratio of Kurang River (Rb)

Drainage Density

Stream length (L) per unit area (A) within a basin is drainage density, D= L/A, [5&7]. It indicates spacing between channels and is a function of climate, rock types, their structure and relief of the area [30]. Strahler [7] have discussed drainage density values in their work. They show that drainage density may be coarse (less than 5), medium (from 5 to 13.7), fine (from 13.7 to 155.3) and ultra-fine greater than 155. The drainage density of the Kurang River basin is coarse with a value of (328/617 Km/Km^2) $0.532Km/Km^2$. (Fig.6) Such values indicate that the Kurang River Basin has low relief with highly permeable subsoil and thick vegetation [30&27]. Higher values of drainage density in a drainage basin depict high relief, impermeable subsurface material and sparse vegetation [7].

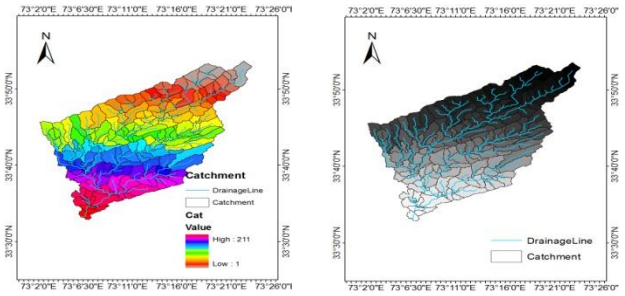

Fig. 6 Drainage Line along Catchment Grid

Stream Length Ratios

Horton [5] defines length ratio as a ratio between the mean lengths of lower order stream to the average length of higher order streams [7&31]. Stream length ratio describes the relative permeability of the bed rocks in a watershed [32]. In a study Singh & Singh [33] and Preta & Preta [28] show that changes in stream length ratios from one to next order indicate changes in development of geomorphic stages. The stream length ratio is 2.94 for Kurang River basin (Fig.7) that indicates slope variations at the late youth stage in the development of stream system.

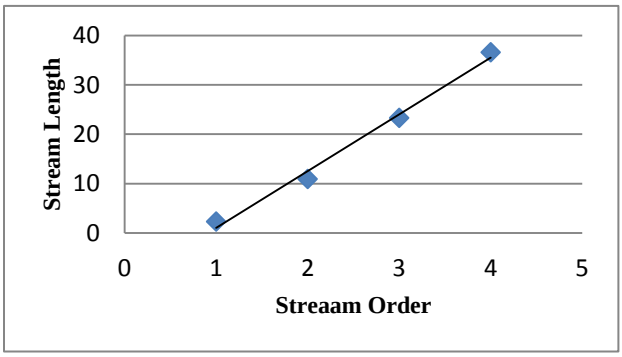

Fig. 7 Length ratio of Kurang River (Rl)

Stream Area Ratios

Ratio between the mean areas of lower order stream to mean area covered by the higher order stream is area ratio [5].The area ratio depends on the lithology of the bed rocks. Area ratio for Kurang River is 5.61 (Fig.8).

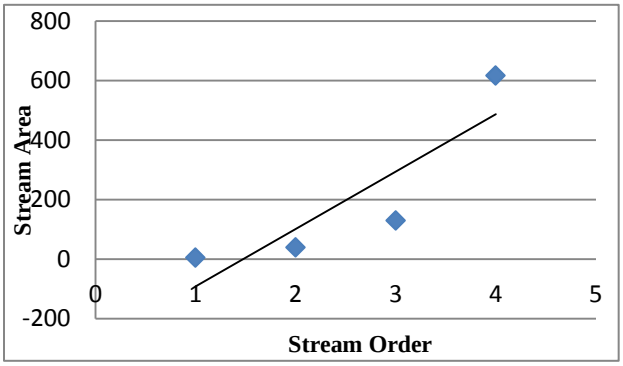

Fig.8 Area ratio of Kurang River (Ra)

CONCLUSIONS

Geographical Information System (GIS) is a good way to manage and analyze water recourse using Digital Elevation Model (DEM). Now a days, Arc GIS with ArcHydro extension provide a good way to delineate a watershed by calculating parameters such as watershed divides, sub watersheds divides, watershed area, drainage line, stream density, flow direction, flow accumulation, slope, elevation and drainage points. In addition to this, such calculations help to develop a hydrological model for drainage basin.

Based on morphometric analysis, Kurang River drains an area of about 617Km^2. Total length of streams is about 129.72Km and streams are mainly of 1st order. Moreover structural elements have no control on the development of the basin. Moreover, Kurang River basin is a low relief entity with highly permeable subsoil and thick vegetal cover of grasses, herbs, shrubs and trees.

Catchment parameters

The evaluated parameters for the river Kurang are shown in tables 1 and 2.

Table 1.Stream characteristics

Stream order	No of streams	average stream Length (km)	average stream area (sqkm)
1	72	2.33	4.50
2	14	10.92	39.48
3	4	23.30	129.72
4	1	6.85	617

Table 2. Catchment parameters

No.	Parameters	Value	Formulae
1.	area (sq km)	617	A
2.	Length of basin (km)	46.40	L
3.	Drainage Density	0.53	Dd = L/A
4.	Bifurcation ratio	4.21	Rb = Nu/ (Nu +1)
5.	length ratio	2.94	Rl = (Lu+1)/Lu
6.	Area ratio	6.19	Ra = (Au+1)/Au
7.	Stream frequency (Fu)	0.15	Fu = ∑N/A
8.	Form factor (Rf)	0.29	Rf = $A/(Lb)^2$
9.	Cumulative length	328.05	∑L
10.	Elongation ratio (Re)	1.89	Re = (2/Lb) × $A/\sqrt{A/\Pi}$
11.	Constant of channel Maintenance (C)	1.88	C = km^2/km

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