Automated Method for Delineating Watershed, Drainage Pattern and Calculation of Flow Accumulation in Punjab Province using Digital Elevation Model

Umair bin Zamir* and Jamil Hassan Kazmi

Department of Geography, University of Karachi, Karachi-75270, Pakistan

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Abstract. Delineation of the watershed and drainage is among the prior requirement of any organised hydrological study. Delineating watershed is important for elucidating the geo-hydrological conditions of any geographical space. This study aims to explore the vitality of Digital Elevation Model (DEM) data in calculating the flow accumulation, flow length, drainage pattern and watershed basin delineation of Punjab as well as elevational profiling district wise and delineating the catchment density. The potential hydrological system developed is based on 1 arc second Aster GDEM data. Depression less DEM is developed by filling process. Furthermore flow accumulation, drainage pattern and watershed is demarcated on the basis of derived stream channels. This study presents the effectiveness of DEM data for hydrological studies and introduces a better method of water management in Punjab province of Pakistan.

Keywords: DEM, watershed, flow accumulation, drainage pattern

Introduction

The advent of satellite technology and access to a variety of remote sensing and GIS data types increases the prospects of understanding the terrain of geographical space with remarkable accuracy. GIS and remote sensing offers the combination of apparatus to speed up the decision and helps in enumerating more precise results.

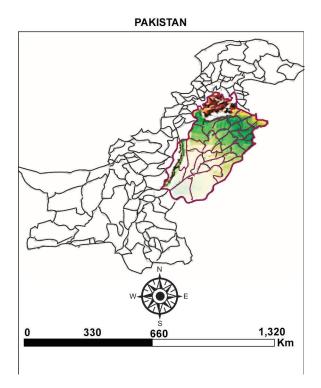


Fig. 1. Study area (Punjab province).





Hydrological risks and jeopardies can easily be cut and dried and tactics formulated to alleviate the loss and increases the decision making abilities. Geographic Infor-mation System (GIS) and Remote Sensing (RS) is an authoritative combination of technology, which is helpful in hydrological modeling, monitoring and mitigation. By using the Digital Elevation Model (DEM) automated and accurate watershed delineation and development of drainage network is possible, which is comparatively less time consuming, more accurate and provide easily calculable measurements than traditional manual techniques. GIS and RS have the aptitude to perform watershed management and help in developing high accuracy oriented hydrological mapping which promotes the Spatial Decision Support System (SDSS).

Materials and Methods

Study area. Various techniques are used for getting the desired objectives; methodological framework is classified into six stages (Fig. 2).

Data acquisition. The major data was obtained on request, from the United States Geological Survey (USGS). Most of the files were downloaded from there by assigning the Keyhole Markup Language (KML), file for the study area and by uploading it. Digital Elevation Model (DEM) raster scenes of the study area were selected and downloaded.

DEM reconditioning. DEM data obtained is not perfect for using until it is reconditioned. Sinks and Peaks (Fig. 3) are among the common resolution errors, therefore it is required to fill the sinks for proper delineation of watershed and streams. Filling of DEM helps in avoiding

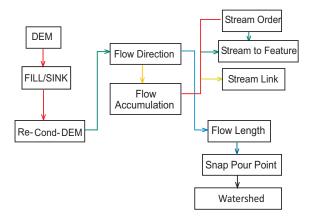


Fig. 2. Methodological framework (steps for delineating watershed).

discontinuity of the derived drainage network. The fill function in ArcGIS recapitulates until Z limits are filled (Tarboton *et al.*, 1991).

Calculating flow direction. Flow direction is calculated by directing steepest lineage obtained from each cell value (Fig. 4). The calculation is made as Change in z-value/distance* 100. All distances calculated are focusing cell centres. In case of cell extent is 1 then the distance between two orthogonal cells is 1, while if two cells flow towards each other are considered as sinks and have ill-defined flow direction (Jenson and Domingue, 1988).

Calculating flow accumulation. Flow accumulation is calculated by using flow accumulation tool in which cell values are designated as weightage flowing into each downslope cell in the output (Fig. 5). Cells of high

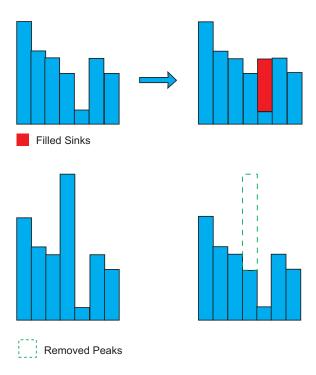


Fig. 3. Profile view of fill.

	/	\		32	64	128
<		<	>	16		1
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Fig. 4. Flow direction.

flow accumulation identifying areas of concentrated flow, cells with 0 accumulation values identified as ridges. Extracted flow accumulation used to create a stream network which requires to assign threshold, setnull (flowacc < 100, 1) (Tarboton *et al.*, 1991).

Identifying stream network. The output obtained from flow accumulation was further used for the identification of stream network, by applying the threshold using map

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	15	0	1
0	0	0	1	20	0
0	2	4	8	30	2

Fig. 5. Flow accumulation grid.

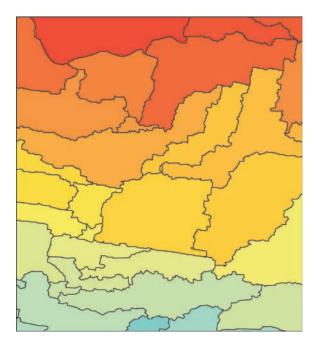


Fig. 6. Watershed.

algebra to the flow accumulation raster a stream network is outlined.

Delineating watershed. The final objective of this study is delineating watershed. Watershed is the upslope area which is playing its role in providing flow to given location, this type of zone is also referred as the catchment. For this to achieve flow direction raster is used in ArcGIS watershed function to determine the contributing areas (Fig. 6). In this study, flow accumulation threshold with specific pour point is used to delineate the watershed.

Results and Discussion

Advancement in Geographical Information System (GIS) and Remote Sensing (RS) in terms of availability of data and the advent of new tools increases the efficiency typically in hydrological studies which lead towards minimizing the expenses of acquisition of data as well as reduces the time and effort in performing the task with accuracy. Combo aid of GIS and RS helps in addressing the water resource issues and helps in investigating and modeling the solution of the issues. From the last two decades information acquisition paradigm rapidly shifted towards digital representations of topography (Martz and Garbrecht, 1992; Moore et al., 1991; Jenson and Domingue, 1988; Mark, 1984). The automated method was applied to the district of Punjab, Pakistan in order to demarcate the watershed, drainage pattern and flow accumulation (Fig. 7). In addition, elevation based characteristics are also extracted district wise (Table 1). By using 1 arc-second Aster GDEM Digital Elevation Model data statistical variational maps are developed representing the different district wise elevation characteristics (Fig. 8). This will be helpful in modeling the different hydrological studies. Furthermore, extracted elevation data is used in order to get the flow direction share district wise (Table 2) which helps in developing the flow accumulation probability plot district wise categorizes the Punjab in low, moderate and high accumulation probability zone (Fig. 9). Muzafargarh, Rajanpur are at high probability of accumulation, and Jhang, Multan, Rahimyarkhan and Bhawalpur are in the moderate accumulation category, while the remaining districts are in the low accumulation zone. Furthermore, the catchment area is delineated (Fig. 10) which is overlaid on the district boundaries of Punjab so that the catchment density district wise is calculated using polygon in polygon analysis (Fig. 11). It represents the east and the

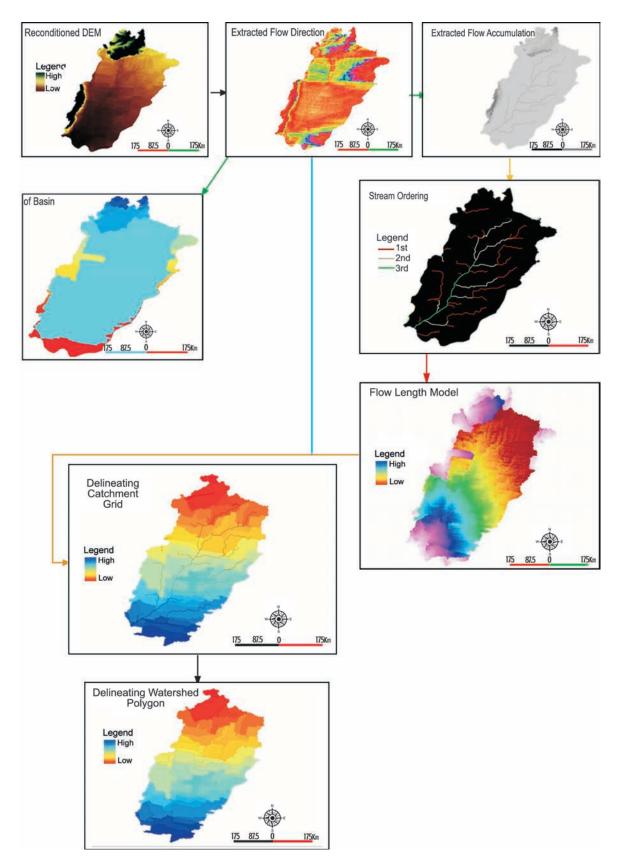


Fig. 7. Delineated results (steps from reconditioning to watershed delineation).

Table 1. Elevation based characteristics of Punjab districts

Among	=	District	Zone	Count	Area	Min	Max	Range	Mean	STD	MITS	Vari-	Maio-	Mino-	Median
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Mainwali 1 7814 0.54263900000 163 1390 1227 282.1360000000 150.93800000000 150.93800000000 150.93800000000 150.93800000000 150.93800000000 150.93800000000 150.93800000000 150.93800000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.9380000000 150.93800000000 150.9380000000 150.9380000000	32	Lodhran	32	3903	0.27104200000	101	126	25	111.83000000000	4.41416000000	436472.000000000000	26	109	101	112
Mandi Bahauddin 14 3696 0.25666700000 182 255 73 207.9180000000 9.07886000000 768466.0000000000 35 205 182 Multan 31 4944 0.3433300000 93 132 39 111.4370000000 8.9887600000 550946.000000000 38 101 95 Multan 31 4944 0.343330000 71 142 65 113.6230000000 11.4619000000 124860.000000000 38 101 95 Nankana Sahib 35 3756 0.26083300000 15 192 46 188.2480000000 7.1424500000 7.14245000000 7.14245000000 7.14245000000 7.14245000000 7.14245000000 7.14245000000 7.1414700000000 7.14141 7.14141 7.141410000000 7.144860000000 7.144860000000 7.14141 7.111 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141 7.14141	_	Mainwali	1	7814	0.54263900000	163	1390	1227	282.13600000000	150.93800000000	2204610.000000000000	675	185	163	212
Mutaeffargarh 31 4944 0.34333300000 93 132 39 111.43700000000 550946.0000000000 38 101 95 Muzaeffargarh 34 11132 0.7730560000 7 142 65 113.6230000000 11.4419000000 126486.0000000000 38 191 95 Nankana Sahib 35 3756 0.26083300000 163 29 46 182.2480000000 11.4451000000 100 14 193 208 Narowal 4 3096 0.2150000000 152 192 40 188.2410000000 1408457000000 190 47 193 208 Pakpattan 23 3667 0.2150000000 132 168 36 151.7700000000 451015000000 40 180 18 31 19 14 85 86.3867000000 451015000000 40 40 181 36 151.738000000 13.633700000000 13.6337000000000 13.633700000000 13.6337000000000 13.63373000000000 13.633730	14	Mandi Bahauddin	14	3696	0.25666700000	182	255	73	207.91800000000	9.07886000000	768466.000000000000	55	205	182	206
Muzaffargarh 34 III32 0.77305600000 7 142 65 II362300000000 II.4619000000 1264860.000000000 58 122 140 Nankana Sahib 35 3756 0.26083300000 163 209 46 189.2480000000 7.14245000000 710816.000000000 47 193 208 Narowal 4 3096 0.2150000000 215 319 104 251.4720000000 7.18557.000000000 40 181 9.24470000000 40 181 9.24470000000 40 181 9.24470000000 40 181 9.24470000000 40 40 18.5910000000 4.51015000000 40 40 18.5910000000 4.510150000000 40 40 18.5910000000 4.510150000000 40 40 18.598000000 4.510150000000 40 40 18.598000000 4.5101500000000 40 40 18.5980000000 4.510150000000 40 40 18.5988000000 4.510150000000 40 40 40 40 40 40<	31	Multan	31	4944	0.34333300000	93	132	39	111.43700000000	8.98876000000	550946.000000000000	38	101	95	109
Nankana Sahib 35 3756 0.26083300000 163 209 46 189.2480000000 7.1424500000 7.1816.0000000000 47 193 208 Narowal 4 3096 0.21500000000 215 319 104 251.4720000000 20.1498000000 778557.0000000000 100 241 311 31 Okara 15 5929 0.41173600000 152 192 40 168.5910000000 6.4509000000 99577.0000000000 40 167 189 Pakpattan 23 3667 0.2546530000 132 168 36 151.7970000000 4.5101500000 56638.00000000 40 167 189 Rahimi Yar Khan 20 16184 1.1238900000 61 146 85 86.9867000000 4.51015000000 4000000000 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41	34	Muzaffargarh	34	11132	0.77305600000	77	142	92	113.62300000000	11.46190000000	1264860.000000000000	58	122	140	116
Narowal 4 3996 0.2150000000 215 319 104 251.4720000000 20.1498000000 778557.0000000000 100 241 311 Okara 15 5929 0.4117360000 152 192 40 168.5910000000 6.4509900000 556638.000000000 40 167 189 Pakpattan 23 3667 0.2546530000 132 168 36 151.7970000000 4.5101500000 556638.00000000 33 151 189 Rahim Yar Khan 20 16184 1.1238900000 61 146 85 86.9867000000 1407790.00000000 33 151 136 Rawalpindi 3 6761 0.4695140000 12 47 124.200000000 3.6417790.000000000 1407790.000000000 189 48 146 Sahiwal 25 4331 0.4695140000 126 173 47 154.20000000 9.5358900000 1457820.000000000 12 48 159 Salikiwhura 7	35	Nankana Sahib	35	3756	0.26083300000	163	209	46	189.24800000000	7.14245000000	710816.000000000000	47	193	208	190
Okara 15 5929 0.41173600000 152 192 40 168.59100000000 6.45099000000 6.4509900000 6.45099000000 40 167 189 Pakpattan 23 3667 0.2465300000 13 168 36 151.7970000000 4.5101500000 556538.000000000 33 151 139 Rahim Yar Khan 28 367 1.46 85 86.9867000000 13.5317000000 1407790.00000000 34 78 146 39 Rayalpindi 3 6761 0.46951400000 11 245 204 106.138000000 13.53170000000 1407790.00000000 142 41 Rawalpindi 3 6761 0.46951400000 12 173 47 154.20700000000 9.5358900000 4048720.0000000000 48 159 18 Sahiwal 17 8048 0.55888900000 12 13 181.1410000000 17.42450000000 963450000000 1678720.0000000000 17.424500000000 17.4245000000000 17.4245000000000<	4	Narowal	4	3096	0.21500000000	215	319	104	251.47200000000	20.14980000000	778557.000000000000	100	241	311	247
tar Khan 23 3667 0.2546530000 132 168 36 151.7970000000 4.5101500000 556638.00000000 33 151 139 far Khan 28 9675 0.67187500000 41 245 204 166.138000000 13.5317000000 1407790.000000000 84 78 146 indi 28 9675 0.67187500000 41 245 204 166.138000000 29.2417000000 1407790.000000000 188 94 74 indi 3 6761 0.46951400000 318 1871 598.8340000000 9.53589000000 4048720.0000000000 48 150 126 a 7 4413 0.30045800000 126 173 47 154.20700000000 1.24745000000 48720.0000000000 72 184 143 ura 7 4413 0.30645800000 150 228 78 204.7570000000 1.24588000000 9.9353000000 9.9353000000 9.93532000000 9.93532000000 9.93532000000	15	Okara	15	5929	0.41173600000	152	192	40	168.591000000000	6.45099000000	999577.0000000000000	40	167	189	168
far. Khan 20 16184 1.1238900000 61 146 85 86.9867000000 13.6317000000 1407790.000000000 84 78 146 at 28 96.75 0.6718750000 41 245 204 166.138000000 29.2417000000 1026880.000000000 188 94 41 indi 3 6761 0.46951400000 318 218 1871 598.834000000 308.6210000000 4048720.000000000 1122 485 318 indi 3 6761 0.46951400000 318 218 1871 598.834000000 308.6210000000 4048720.000000000 48 159 126 ind 25 4331 0.300645800000 140 271 131 181.14100000000 1.2.078000000 448720.0000000000 72 184 143 ura 7 4413 0.30645800000 150 228 78 204.7570000000 7.2458000000 95593.00000000 73 230 216 x Singh </td <td>23</td> <td>Pakpattan</td> <td>23</td> <td>3667</td> <td>0.25465300000</td> <td>132</td> <td>168</td> <td>36</td> <td>151.79700000000</td> <td>4.51015000000</td> <td>556638.000000000000</td> <td>33</td> <td>151</td> <td>139</td> <td>151</td>	23	Pakpattan	23	3667	0.25465300000	132	168	36	151.79700000000	4.51015000000	556638.000000000000	33	151	139	151
und 28 9675 0.67187500000 41 245 204 106.1380000000 29.24170000000 1026889.000000000 188 94 41 indi 3 6761 0.46951400000 318 2189 1871 598.8340000000 308.62100000000 4048720.000000000 1122 485 318 ind 25 4331 0.30076400000 126 173 47 154.20700000000 9.5358900000 48 159 126 ina 17 8048 0.55888900000 140 271 131 181.14100000000 1.2.0078000000 667872.0000000000 72 184 143 ura 7 4413 0.30645800000 150 228 78 204.7570000000 7.7424500000 903593.000000000 72 184 143 ix Singh 24 240.92400000000 1.24588000000 55 208 150 216 153.5980000000 127 183 56 153.5980000000 7.90672000000 761402.0000000000	20	Rahim Yar Khan	20	16184	1.12389000000	61	146	85	86.98670000000	13.63170000000	1407790.00000000000	84	78	146	84
indi 3 6761 0.46951400000 318 2189 1871 598.83400000000 4048720.0000000000 1122 485 318 7 1 2 2 4331 0.30076400000 126 173 47 154.20700000000 667872.00000000000 48 159 126 126 128 431 0.30076400000 126 173 47 154.20700000000 12.0078000000 667872.00000000000 72 184 143 143 0.30645800000 150 228 78 204.7570000000 12.0458000000 95345.00000000000 73 2 30 216 12	솭	Rajanpur	- 38	9675	-0.67187500000	4	245	204	-106.13800000000	-29.24170000000	-1026889.0000000000000000	188	24	4	
25 4331 0.30076400000 126 173 47 154.20700000000 6.5388900000 6.712,000000000000 48 159 126 au 17 8048 0.55888900000 140 271 131 181.14100000000 12.0078000000 1457820.0000000000 72 184 143 aura 7 4413 0.30643800000 150 228 78 204.75700000000 12.4588000000 95593.00000000000 55 208 150 150 k Singh 24 4426 0.30736100000 127 183 56 153.5980000000 7.9067200000 761402.0000000000 77 150 127 30 5898 0.40958300000 111 156 45 129.09500000000 7.90672000000 761402.0000000000 46 131 153	3	Rawalpindi	3	6761	0.46951400000	318	2189	1871	598.83400000000	308.621000000000	4048720.000000000000	1122	485	318	464
a 17 8048 0.55888900000 140 271 131 181.14100000000 12.04780000000 1457820.0000000000 72 184 143 ura 7 4413 0.30645800000 150 228 78 204.75700000000 7.74245000000 93593.0000000000 55 208 150 k Singh 24 4426 0.27395800000 215 289 74 240.92400000000 12.4588000000 9594500000000 73 230 216 k Singh 24 4426 0.3073610000 127 183 56 153.5980000000 7.90672000000 679825.0000000000 57 150 127 30 5898 0.40958300000 111 156 45 129.09500000000 7.90672000000 761402.0000000000 46 131 153	25	Sahiwal	25	4331	0.30076400000	126	173	47	154.20700000000	9.53589000000	667872.000000000000	48	159	126	156
urra 7 4413 0.30645800000 150 228 78 204.7570000000 7.74245000000 903593.0000000000 55 208 150 k Singh 24 4426 0.30736100000 127 183 56 153.5980000000 9.95932000000 679825.0000000000 57 150 127 30 5898 0.40958300000 111 156 45 129.09500000000 7.90672000000 761402.0000000000 46 131 153	17	Sargodha	17	8048	0.55888900000	140	271	131	181.14100000000	12.00780000000	1457820.000000000000	72	184	143	183
5 3945 0.27395800000 215 289 74 240,92400000000 12.4588000000 950445,0000000000 73 230 216 k Singh 24 4426 0.30736100000 127 183 56 153.59800000000 9.95932000000 679825.0000000000 57 150 127 s	7	Sheikupura	7	4413	0.30645800000	150	228	78	204.75700000000	7.74245000000	903593.000000000000	55	208	150	205
ek Singh 24 4426 0.30736100000 127 183 56 153.59800000000 9.95932000000 679825.0000000000 57 150 127 183 58 0.40958300000 111 156 45 129.09500000000 7.90672000000 761402.0000000000 46 131 153	5	Sialkot	5	3945	0.27395800000	215	289	74	240.92400000000	12.45880000000	950445.000000000000	73	230	216	237
30 5898 0.40958300000 111 156 45 129.09500000000 7.90672000000 761402.0000000000 46 131 153	24	Toba Tek Singh	24	4426	0.30736100000	127	183	99	153.59800000000	9.95932000000	679825.000000000000	57	150	127	151
	30	Vehari	30	8685	0.40958300000	111	156	45	129.09500000000	7.90672000000	761402.000000000000	46	131	153	130

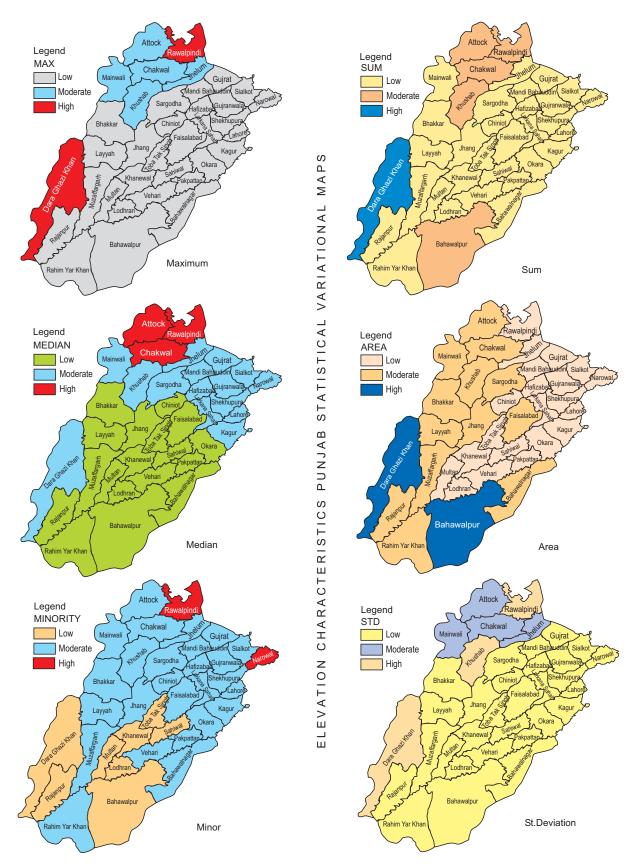


Fig. 8. Statistical variational map of Punjab district.

Table 2. Flow direction district-wise share of Punjab province

1 Mainwali 2 Attock 3 Rawalpindi 4 Narowal 5 Sialkot 6 Lahore 7 Sheikupura 8 Gujranwala 9 Gujrat 10 Chakwal 11 Hafizabad 12 Kasur 13 Jhelum 14 Mandi Bahauddin 15 Okara 16 Khushab 17 Sargodha 18 Bhakkar 19 Faisalabad 20 Rahim Yar Khan 21 Bahawalnagar 22 Jhang 23 Pakpattan 24 Toba Tek Singh 25 Sahiwal 26 Layyah 27 Bahawalpur 28 Rajanpur 29 Dera Ghazi Khan 30 Vehari 31 Multan 31 Lodhran	i 3 2 2 2 2 3 4 4 4 5 6 6 6 10 11 12 12 13 13 14 11 11 12 13 14 16 17 17 18 18 18 19 19 19 19 19 19 19 19 19 19 19 19 19	7814 9232 6761 3096 3945 2340 4413 4987 4987 4336 9079 3236 5347 4846 5929 9006	0.54263900000 0.64111100000 0.46951400000 0.21500000000 0.27395800000 0.1625000000 0.30645800000 0.30645800000 0.30648600000 0.63048600000		128 128 128	127	22 28640000000	32.25450000000	174224.00000000000000	~	4	128	×
		7814 9232 6761 3096 3945 2340 4413 4987 4987 4987 4987 8346 5347 8846 896 806	0.54263900000 0.64111100000 0.46951400000 0.21500000000 0.27395800000 0.1625000000 0.30645800000 0.34631900000 0.34631900000 0.63048600000 0.62472200000		128 128 128	127 127		32.25450000000	174224.000000000000	×	4	128	×
		9232 6761 3096 3945 2340 4413 4987 4336 9079 3236 5347 4846 5929 8048	0.64111100000 0.46951400000 0.21500000000 0.27395800000 0.1625000000 0.30645800000 0.34631900000 0.34831900000 0.348800000 0.3484800000		128	127	77.7304000000			٥		128	
		6761 3096 3945 2340 4413 4987 4336 9079 3236 5347 4846 5929 8006	0.46951400000 0.21500000000 0.27395800000 0.1625000000 0.30645800000 0.34631900000 0.34631900000 0.3448600000 0.52472200000		128		26.70220000000	31.25220000000	246515.000000000000	∞	4	140	16
		3096 3945 2340 4413 4987 4336 9079 3236 5347 4846 5929 9006	0.21500000000 0.27395800000 0.1625000000 0.30645800000 0.34631900000 0.63048600000 0.63048600000			127	23.191100000000	32.91480000000	156795.000000000000	8	4	128	~
		3945 2340 4413 4987 4336 9079 3236 5347 4846 5929 9006	0.27395800000 0.16250000000 0.30645800000 0.34631900000 0.30111100000 0.63048600000		128	127	11.91760000000	20.35740000000	36897.000000000000	∞	4	128	4
		2340 4413 4987 4336 9079 3236 5347 4846 3696 8006	0.16250000000 0.30645800000 0.34631900000 0.30111100000 0.63048600000		128	127	19.91360000000	25.28990000000	78559.000000000000	∞	16	128	16
		4413 4987 4336 9079 3236 5347 4846 3696 9006	0.30645800000 0.34631900000 0.30111100000 0.63048600000 0.22472200000		128	127	23.38590000000	29.65760000000	54723.000000000000	∞	4	128	∞
		4987 4336 9079 3236 5347 4846 3696 5929 8006	0.34631900000 0.30111100000 0.63048600000 0.22472200000		128	127	18.8824000000	26.05810000000	83328.000000000000	∞	4	128	~
		4336 9079 3236 5347 4846 3696 5929 8006	0.30111100000 0.63048600000 0.22472200000	1	128	127	18.72070000000	25.66160000000	93360.000000000000	~	4	128	8
		9079 3236 5347 4846 3696 5929 9006	0.63048600000		128	127	14.91470000000	22.08070000000	64670.00000000000	∞	4	128	~
		3236 5347 4846 3696 5929 9006 8048	0.22472200000	_	128	127	38.66110000000	38.92780000000	351004.000000000000	∞	64	2	32
		5347 4846 3696 5929 9006 8048	0000001011000	1	128	127	20.91500000000	25.55000000000	67681.00000000000	∞	16	128	16
		4846 3696 5929 9006 8048	0.37131900000	-	128	127	19.78380000000	26.70510000000	105784.000000000000	∞	4	128	∞
		3696 5929 9006 8048	0.33652800000	1	128	127	19.27450000000	33.62220000000	93404.000000000000	∞	4	32	4
		5929 9006 8048	0.25666700000	1	128	127	19.76730000000	27.98950000000	73060.000000000000	8	4	128	8
		9006	0.41173600000	1	128	127	19.19620000000	24.08820000000	113814.000000000000	~	16	128	16
		8048	0.62541700000	_	128	127	20.64830000000	33.50930000000	185959.000000000000	8	4	32	4
			0.55888900000	1	128	127	19.25390000000	26.43180000000	154955.000000000000	∞	4	128	~
		11158	0.77486100000	_	128	127	22.08860000000	31.08660000000	246465.000000000000	~	4	128	8
		9962	0.55319400000	_	128	127	19.03380000000	25.88000000000	151623.000000000000	~	4	128	8
Bahawalr Jhang Pakpattan Toba Tek Sahiwal Layyah Bahawaly Rajanpur Dera Gha Vehari Multan	Khan 20	16184	1.12389000000	1	128	127	26.25290000000	29.21340000000	424877.000000000000	∞	16	2	16
Jhang Pakpattan Toba Tek Sahiwal Layyah Bahawaly Rajanpur Dera Gha Vehari Multan Lodhran	ıgar 21	11553	0.80229200000	1	128	127	25.77060000000	27.91050000000	297728.000000000000	~	16	128	16
Pakpattan Toba Tek Sahiwal Layyah Bahawalt Rajanpur Pera Gha Vehari Multan Lodhran	22	8338	0.57902800000	1	128	127	22.50190000000	30.07520000000	187621.000000000000	8	16	128	8
Toba Tek Sahiwal Layyah Bahawalt Rajanpur Dera Gha Vehari Multan Lodhran	23	3667	0.25465300000	1	128	127	20.49880000000	25.02570000000	75169.000000000000	∞	16	128	16
	Singh 24	4426	0.30736100000	_	128	127	23.30770000000	26.06130000000	103160.000000000000	8	16	128	16
	25	4331	0.30076400000	_	128	127	20.98080000000	28.70750000000	90868.000000000000	8	4	128	8
	26	8518	0.59152800000	-	128	127	18.06180000000	28.09710000000	153850.000000000000	8	4	128	4
	ır 27	31825	2.21007000000	_	128	127	27.54080000000	29.27220000000	876487.000000000000	~	16	2	16
T '	28	9675	0.67187500000	_	128	127	18.29560000000	34.30310000000	177010.000000000000	8	4	32	4
	i Khan 29	22912	1.59111000000	+	128	127	23.49490000000	40.61880000000	538315.0000000000000	«	-	32	4
	30	8685	0.40958300000	1	128	127	21.65170000000	25.75390000000	127702.000000000000	~	16	128	16
_	31	4944	0.34333300000	1	128	127	20.47920000000	24.57400000000	101249.000000000000	∞	16	128	16
	32	3903	0.27104200000	1	128	127	22.78610000000	23.85220000000	88934.000000000000	∞	16	128	16
33 Khanewal	33	8615	0.40263900000	1	128	127	23.05420000000	27.99380000000	133668.000000000000	∞	16	128	16
34 Muzaffargarh		11132	0.77305600000	1	128	127	19.72010000000	30.87410000000	219524.000000000000	∞	4	32	4
35 Nankana Sahib	ahib 35	3756	0.26083300000	1	128	127	18.41450000000	23.37880000000	69165.000000000000	∞	16	128	∞
36 Chiniot	36	3698	0.25666700000	1	128	127	22.34060000000	27.15510000000	82571.000000000000	∞	16	128	16

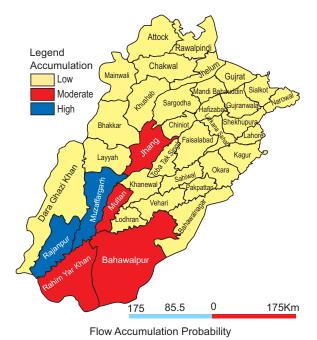


Fig. 9. Flow accumulation - district.

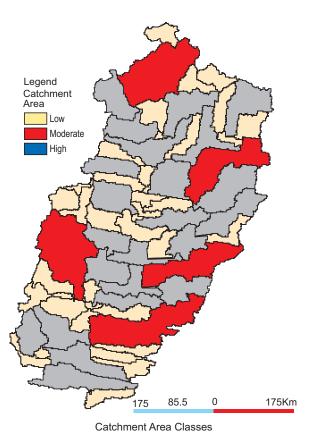


Fig. 10. Catchment zones.

westernmost districts of Punjab Bhawalpur and Dera Ghazi Khan is having a high catchment density encircling the 15 and 10 catchment polygon count respectively, (Table 3). While the Chakwal, Layyah, Kushab, Sargodha, Jhang, Bhakkar, Faisalabad districts are in moderate category and the remaining districts like Khanewal, Lodhran, Vehari, Pakpatan, Sahiwal, Okara, Toba tek Singh, Kasur, Nankana sahib, Hfizabad,

Legend
Catchment
Density
Low

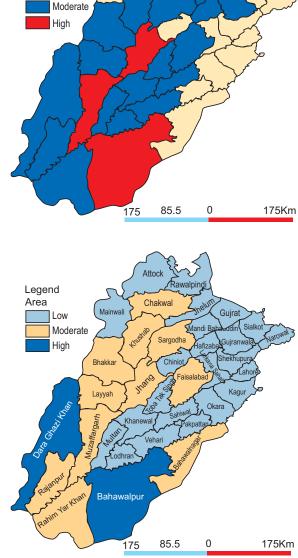


Fig. 11. Catchment density - district wise.

Catchment Density District-wise

Table 3. Catchment Density and Counts

Id	Name	Province	Cat_Dis_Ar	Cat_Dis_Co
1	Mainwali	Punjab	4778780687	3
2	Attock	Punjab	3901439487	2
3	Rawalpindi	Punjab	2089692611	4
4	Narowal	Punjab	0	0
5	Sialkot	Punjab	1589225322	2
6	Lahore	Punjab	823028890	2
7	Sheikupura	Punjab	2603449112	4
8	Gujranwala	Punjab	3305395712	6
9	Gujrat	Punjab	3006925737	4
10	Chakwal	Punjab	6547563755	6
11	Hafizabad	Punjab	2362742972	6
12	Kasur	Punjab	2717603804	3
13	Jhelum	Punjab	3270190343	3
14	Mandi Bahauddin	Punjab	2687784067	6
15	Okara	Punjab	4070488303	5
16	Khushab	Punjab	6557651414	9
17	Sargodha	Punjab	5865371647	8
18	Bhakkar	Punjab	6797850003	8
19	Faisalabad	Punjab	5858808069	6
20	Rahim Yar Khan	Punjab	9913077272	10
21	Bahawalnagar	Punjab	7829835559	4
22	Jhang	Punjab	6119635818	14
23	Pakpattan	Punjab	2721978337	4
24	Toba Tek Singh	Punjab	3270587698	6
25	Sahiwal	Punjab	3205987304	7
26	Layyah	Punjab	6129910485	8
27	Bahawalpur	Punjab	22758088164	15
28	Rajanpur	Punjab	7239180864	10
29	Dera Ghazi Khan	Punjab	15165159536	10
30	Vehari	Punjab	4382527642	7
31	Multan	Punjab	3671622565	8
32	Lodhran	Punjab	2915417722	6
33	Khanewal	Punjab	4295591785	8
34	Muzaffargarh	Punjab	8266040301	15
35	Nankana Sahib	Punjab	2767148666	3
36	Chiniot	Punjab	2703181366	5

Chiniot, Gujranwala, Mandi bhauddin, Jehlum districts etc are in the low catchment density zone.

Conclusion

It is concluded that, GIS and Remote Sensing play a vital function in calculating and delineating the

watershed, calculation of flow statistics, flow paths, stream network, drainage dynamics etc. It holds enough potential to address different hydrological associated issues. Development of watershed model using DEM and Hydrological tools provided in ArcGIS leading towards the accurate hydrological modeling as compared to the manual techniques or it is obvious that digital methods overcome the flaws of manual representation therefore, globally catchment geometric properties are preferably extracted by digital means. It is mandatory for the developing countries especially agro-based economic countries, like Pakistan to adopt such technological advancement for the better management of water and other resources. This study helps in understanding the usefulness of DEM data for hydrological studies and leads to derive a better technique of water management in Punjab province of Pakistan. Further calibration, adjustment and validation would give more precise results and enhance the possibilities for watershed and drainage pattern assessment. In the time to come, it will be indispensable to carry on this subject area to receive the optimal solutions for watershed management in the field region.

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