Pak. j. sci. ind. res. Ser. A: phys. sci. 2015 **58** (2) 90-98

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

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(receivd November 26, 2013; revised June 1, 2014; accepted June 25, 2014)

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.

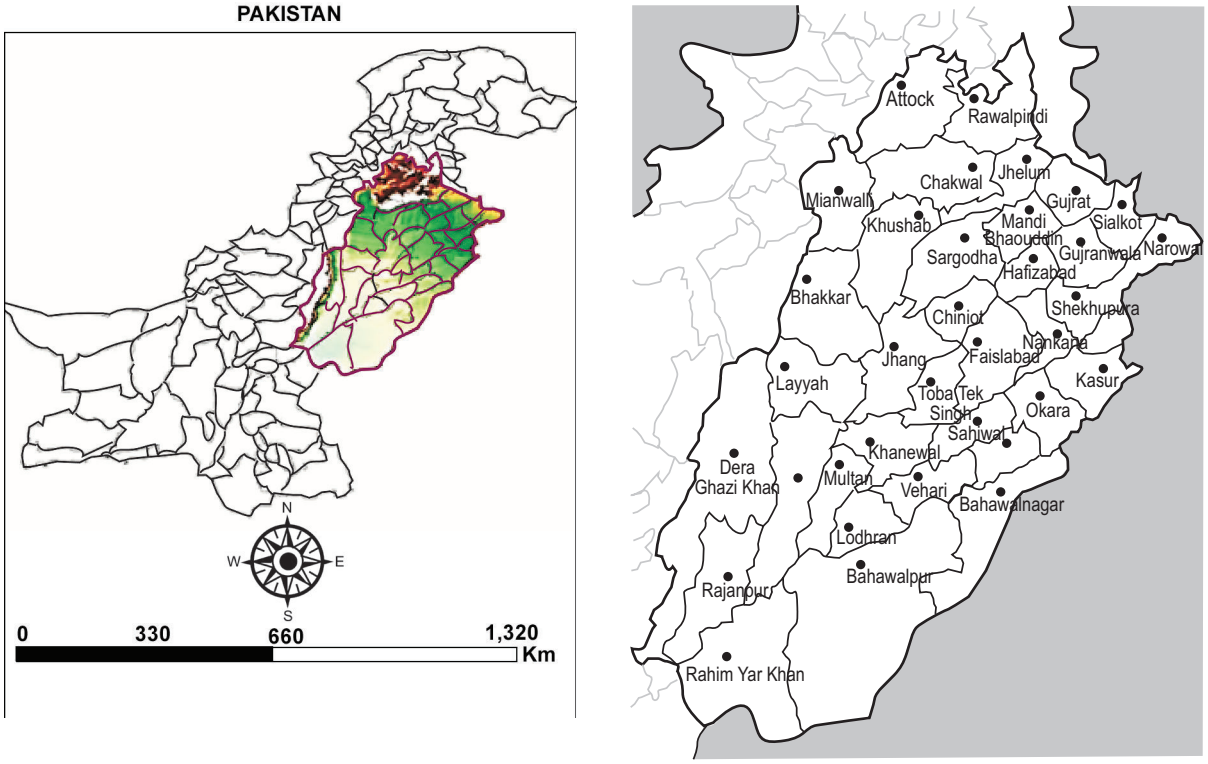

Fig. 1. Study area (Punjab province).

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

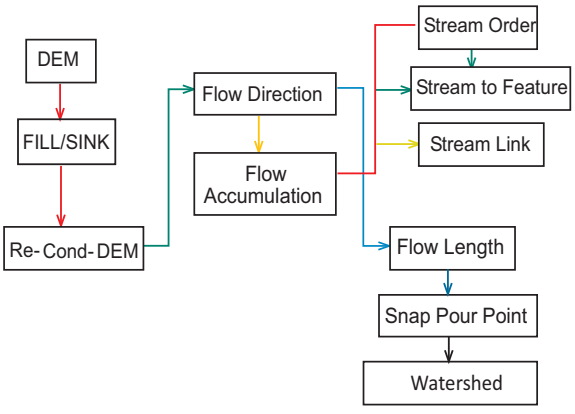


Fig. 2. Methodological framework (steps for delineating watershed).

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

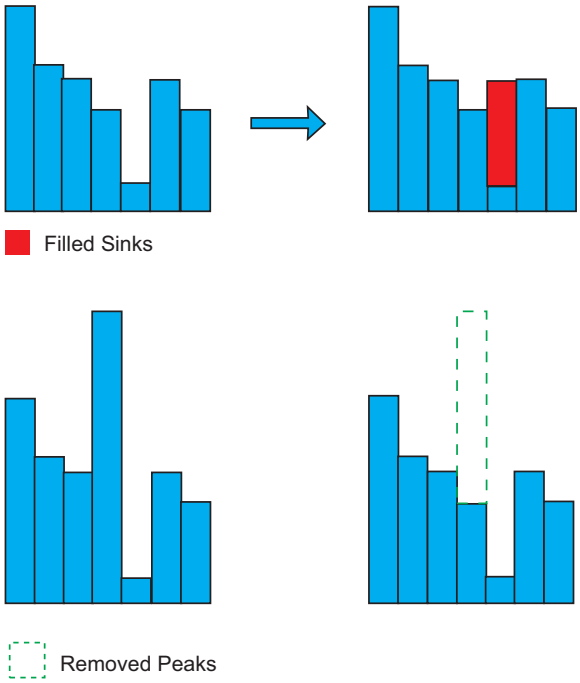


Fig. 3. Profile view of fill.

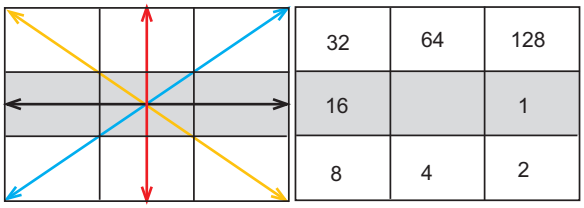


Fig. 4. Flow direction.

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

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.

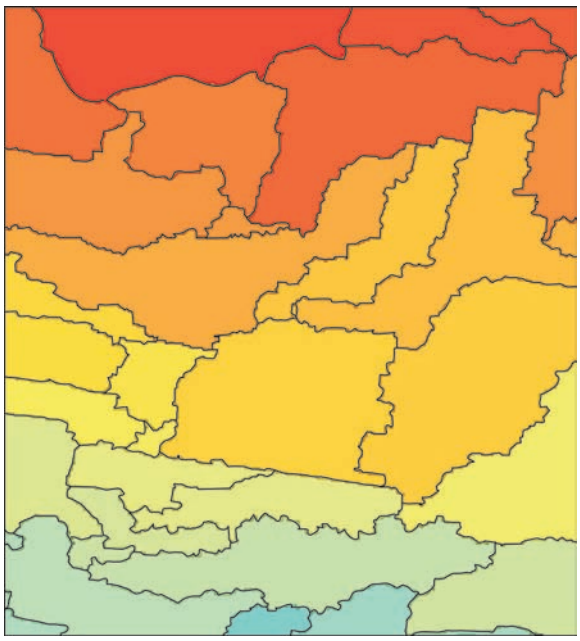


Fig. 6. Watershed.

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

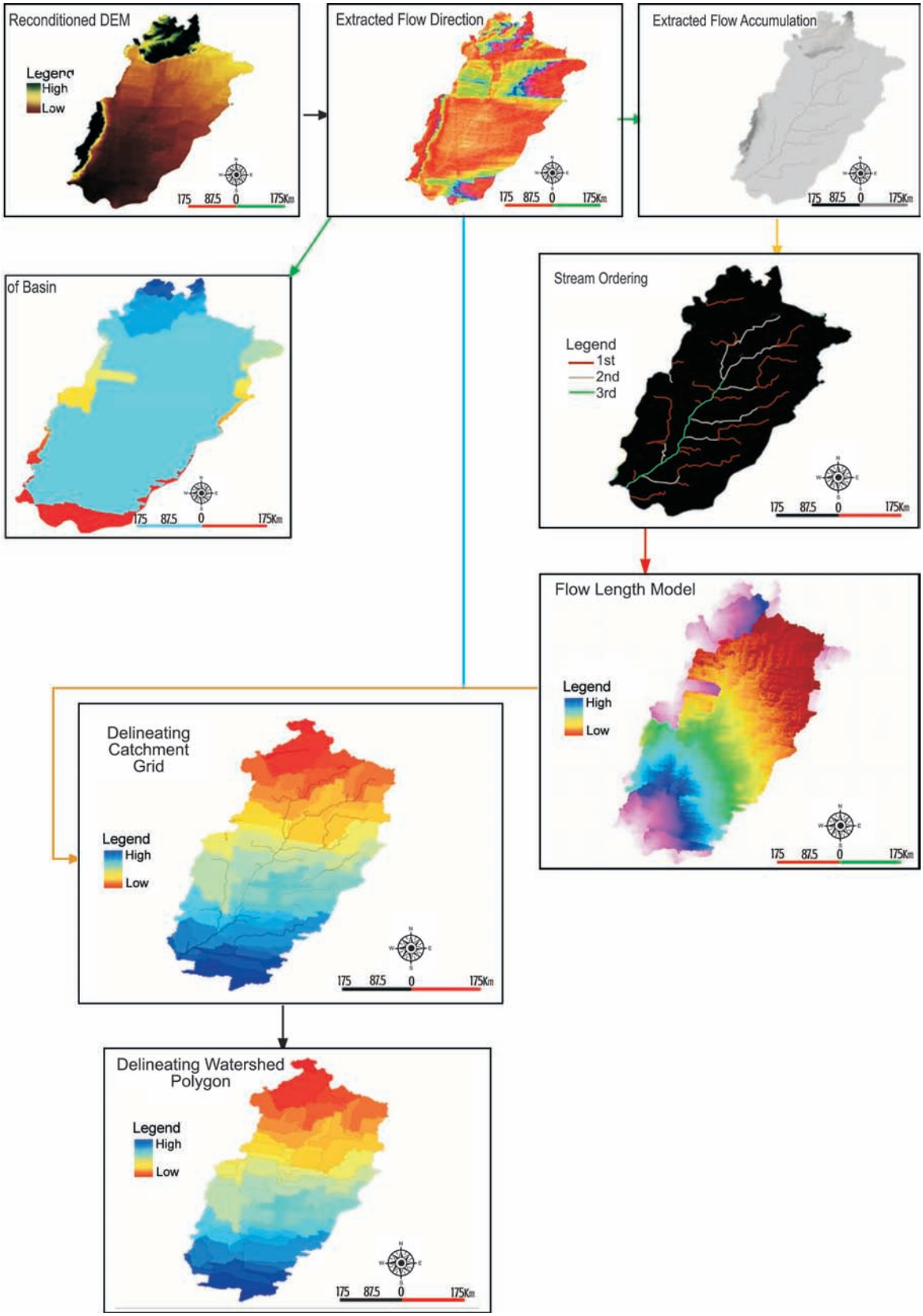


Fig. 7. Delineated results (steps from reconditioning to watershed delineation).

Table 1. Elevation based characteristics of Punjab districts

Id	District names	Zone_ code	Count	Area	Min	Max	Range	Mean	STD	SUM	Vari- ety	Majo- rity	Mino- rity	Median
2	Attock	2	9232	0.64111100000	214	961	747	395.38300000000	79.06030000000	3650180.00000000000	457	361	221	392
21	Bahawalnagar	21	11553	0.80229200000	120	179	59	146.81800000000	9.76701000000	1696190.00000000000	60	146	172	147
27	Bahawalpur	27	31825	2.21007000000	79	170	91	112.31200000000	14.46050000000	3574330.00000000000	90	112	79	112
18	Bhakkar	18	11158	0.77486100000	125	197	72	169.69400000000	11.53430000000	1893450.00000000000	62	163	195	168
10	Chakwal	10	9079	0.63048600000	236	1211	975	492.65500000000	136.21600000000	4472820.00000000000	675	481	237	472
36	Chiniot	36	3696	0.25666700000	136	199	63	167.88200000000	8.47456000000	620493.00000000000	55	161	145	168
29	Dera Ghazi Khan	29	22912	1.59111000000	66	2213	2147	462.14500000000	408.29200000000	10588700.00000000000	1793	109	69	283
19	Faisalabad	19	7966	0.55319400000	146	198	52	172.26500000000	9.75735000000	1372260.00000000000	53	176	146	174
8	Gujranwala	8	4987	0.34631900000	189	242	53	217.34400000000	9.60113000000	1083900.00000000000	52	224	189	221
9	Gujrat	9	4336	0.30111100000	203	376	173	250.73900000000	30.17700000000	1087200.00000000000	159	222	203	244
11	Hafizabad	11	3236	0.22472200000	177	219	42	197.18800000000	7.33245000000	638099.00000000000	42	199	177	198
22	Jhang	22	8338	0.57902800000	110	178	68	149.14000000000	14.48910000000	1243530.00000000000	68	161	177	153
13	Jhelum	13	4846	0.33652800000	179	818	639	307.19300000000	108.29700000000	1488660.00000000000	464	193	179	275
12	Kasur	12	5347	0.37131900000	157	211	54	185.96400000000	9.59967000000	994347.00000000000	55	179	211	186
33	Khanewal	33	5798	0.40263900000	105	158	53	130.37500000000	8.99953000000	755914.00000000000	52	128	105	129
16	Khushab	16	9006	0.62541700000	132	1408	1276	296.04900000000	236.95900000000	2666210.00000000000	759	177	143	180
6	Lahore	6	2340	0.16250000000	187	218	31	205.92600000000	4.80421000000	481867.00000000000	31	210	187	206
26	Layyah	26	8518	0.59152800000	118	170	52	138.98500000000	10.28370000000	1183880.00000000000	52	133	170	136
32	Lodhran	32	3903	0.27104200000	101	126	25	111.83000000000	4.41416000000	436472.00000000000	26	109	101	112
1	Mainwali	1	7814	0.54263900000	163	1390	1227	282.13600000000	150.93800000000	2204610.00000000000	675	185	163	212
14	Mandi Bahauddin	14	3696	0.25666700000	182	255	73	207.91800000000	9.07886000000	768466.00000000000	55	205	182	206
31	Multan	31	4944	0.34333300000	93	132	39	111.43700000000	8.98876000000	550946.00000000000	38	101	95	109
34	Muzaffargarh	34	11132	0.77305600000	77	142	65	113.62300000000	11.46190000000	1264860.00000000000	58	122	140	116
35	Nankana Sahib	35	3756	0.26083300000	163	209	46	189.24800000000	7.14245000000	710816.00000000000	47	193	208	190
4	Narowal	4	3096	0.21500000000	215	319	104	251.47200000000	20.14980000000	778557.00000000000	100	241	311	247
15	Okara	15	5929	0.41173600000	152	192	40	168.59100000000	6.45099000000	999577.00000000000	40	167	189	168
23	Pakpattan	23	3667	0.25465300000	132	168	36	151.79700000000	4.51015000000	556638.00000000000	33	151	139	151
20	Rahim Yar Khan	20	16184	1.12389000000	61	146	85	86.98670000000	13.63170000000	1407790.00000000000	84	78	146	84
28	Rajanpur	28	9675	0.67187500000	41	245	204	106.13800000000	29.24170000000	1026880.00000000000	188	94	41	100
3	Rawalpindi	3	6761	0.46951400000	318	2189	1871	598.83400000000	308.62100000000	4048720.00000000000	1122	485	318	494
25	Sahiwal	25	4331	0.30076400000	126	173	47	154.20700000000	9.53589000000	667872.00000000000	48	159	126	156
17	Sargodha	17	8048	0.55888900000	140	271	131	181.14100000000	12.00780000000	1457820.00000000000	72	184	143	183
7	Sheikupura	7	4413	0.30645800000	150	228	78	204.75700000000	7.74245000000	903593.00000000000	55	208	150	205
5	Sialkot	5	3945	0.27395800000	215	289	74	240.92400000000	12.45880000000	950445.00000000000	73	230	216	237
24	Toba Tek Singh	24	4426	0.30736100000	127	183	56	153.59800000000	9.95932000000	679825.00000000000	57	150	127	151
30	Vehari	30	5898	0.40958300000	111	156	45	129.09500000000	7.90672000000	761402.00000000000	46	131	153	130

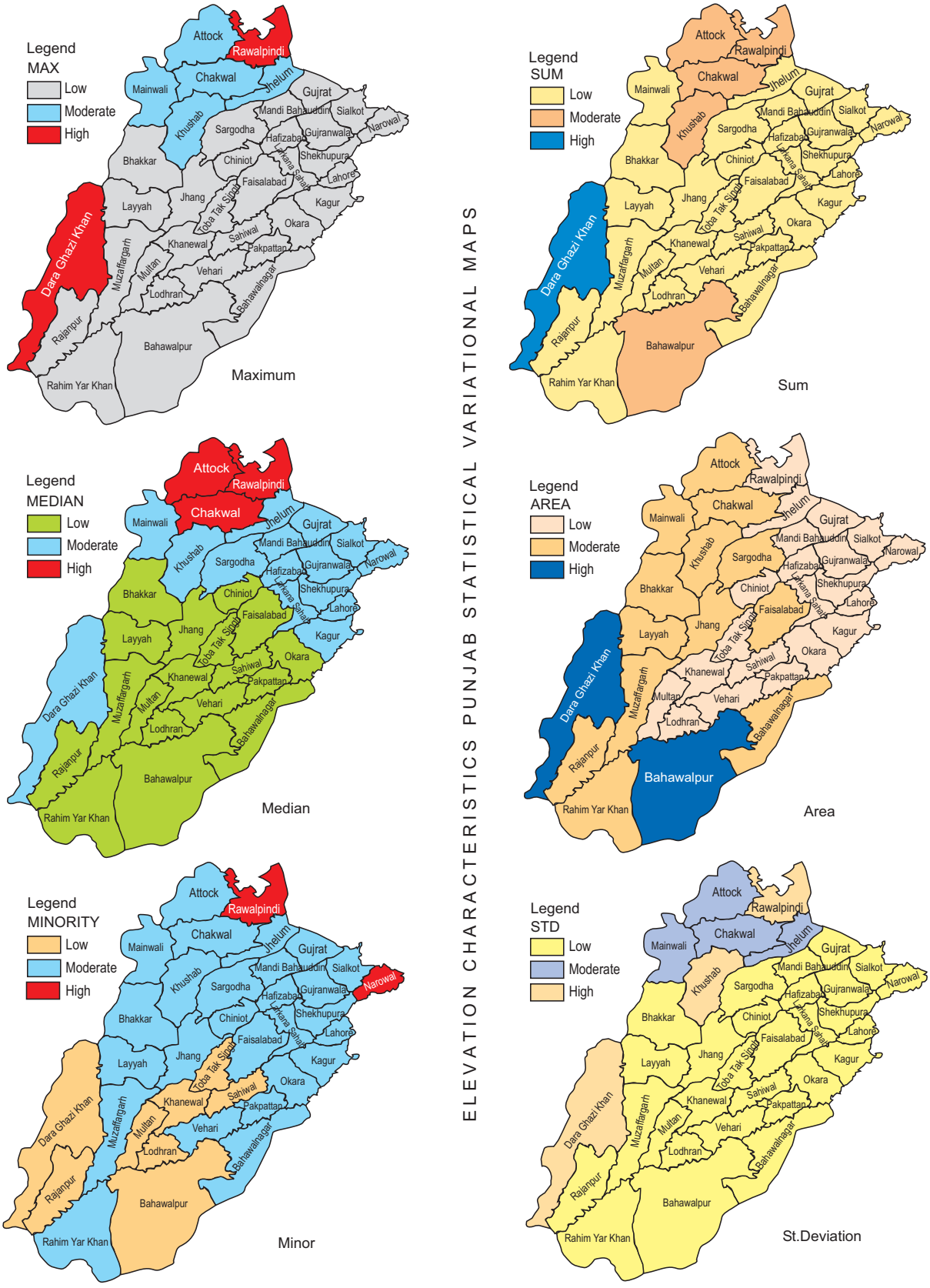


Fig. 8. Statistical variational map of Punjab district.

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

Id	District names	Zone_ code	Count	Area	Min	Max	Range	Mean	STD	SUM	Variety	Majority	Minority	Median
1	Mainwali	1	7814	0.54263900000	1	128	127	22.29640000000	32.25450000000	174224.00000000000	8	4	128	8
2	Attock	2	9232	0.64111100000	1	128	127	26.70220000000	31.25220000000	246515.00000000000	8	4	128	16
3	Rawalpindi	3	6761	0.46951400000	1	128	127	23.19110000000	32.91480000000	156795.00000000000	8	4	128	8
4	Narowal	4	3096	0.21500000000	1	128	127	11.91760000000	20.35740000000	36897.00000000000	8	4	128	4
5	Sialkot	5	3945	0.27395800000	1	128	127	19.91360000000	25.28990000000	78559.00000000000	8	16	128	16
6	Lahore	6	2340	0.16250000000	1	128	127	23.38590000000	29.65760000000	54723.00000000000	8	4	128	8
7	Sheikupura	7	4413	0.30645800000	1	128	127	18.88240000000	26.05810000000	83328.00000000000	8	4	128	8
8	Gujranwala	8	4987	0.34631900000	1	128	127	18.72070000000	25.66160000000	93360.00000000000	8	4	128	8
9	Gujrat	9	4336	0.30111100000	1	128	127	14.91470000000	22.08070000000	64670.00000000000	8	4	128	8
10	Chakwal	10	9079	0.63048600000	1	128	127	38.66110000000	38.92780000000	351004.00000000000	8	64	2	32
11	Hafizabad	11	3236	0.22472200000	1	128	127	20.91500000000	25.55000000000	67681.00000000000	8	16	128	16
12	Kasur	12	5347	0.37131900000	1	128	127	19.78380000000	26.70510000000	105784.00000000000	8	4	128	8
13	Jhelum	13	4846	0.33652800000	1	128	127	19.27450000000	33.62220000000	93404.00000000000	8	4	32	4
14	Mandi Bahauddin	14	3696	0.25666700000	1	128	127	19.76730000000	27.98950000000	73060.00000000000	8	4	128	8
15	Okara	15	5929	0.41173600000	1	128	127	19.19620000000	24.08820000000	113814.00000000000	8	16	128	16
16	Khushab	16	9006	0.62541700000	1	128	127	20.64830000000	33.50930000000	185959.00000000000	8	4	32	4
17	Sargodha	17	8048	0.55888900000	1	128	127	19.25390000000	26.43180000000	154955.00000000000	8	4	128	8
18	Bhakkar	18	11158	0.77486100000	1	128	127	22.08860000000	31.08660000000	246465.00000000000	8	4	128	8
19	Faisalabad	19	7966	0.55319400000	1	128	127	19.03380000000	25.88000000000	151623.00000000000	8	4	128	8
20	Rahim Yar Khan	20	16184	1.12389000000	1	128	127	26.25290000000	29.21340000000	424877.00000000000	8	16	2	16
21	Bahawalnagar	21	11553	0.80229200000	1	128	127	25.77060000000	27.91050000000	297728.00000000000	8	16	128	16
22	Jhang	22	8338	0.57902800000	1	128	127	22.50190000000	30.07520000000	187621.00000000000	8	16	128	8
23	Pakpattan	23	3667	0.25465300000	1	128	127	20.49880000000	25.02570000000	75169.00000000000	8	16	128	16
24	Toba Tek Singh	24	4426	0.30736100000	1	128	127	23.30770000000	26.06130000000	103160.00000000000	8	16	128	16
25	Sahiwal	25	4331	0.30076400000	1	128	127	20.98080000000	28.70750000000	90868.00000000000	8	4	128	8
26	Layyah	26	8518	0.59152800000	1	128	127	18.06180000000	28.09710000000	153850.00000000000	8	4	128	4
27	Bahawalpur	27	31825	2.21007000000	1	128	127	27.54080000000	29.27220000000	876487.00000000000	8	16	2	16
28	Rajanpur	28	9675	0.67187500000	1	128	127	18.29560000000	34.30310000000	177010.00000000000	8	4	32	4
29	Dera Ghazi Khan	29	22912	1.59111000000	1	128	127	23.49490000000	40.61880000000	538315.00000000000	8	1	32	4
30	Vehari	30	5898	0.40958300000	1	128	127	21.65170000000	25.75390000000	127702.00000000000	8	16	128	16
31	Multan	31	4944	0.34333300000	1	128	127	20.47920000000	24.57400000000	101249.00000000000	8	16	128	16
32	Lodhran	32	3903	0.27104200000	1	128	127	22.78610000000	23.85220000000	88934.00000000000	8	16	128	16
33	Khanewal	33	5798	0.40263900000	1	128	127	23.05420000000	27.99380000000	133668.00000000000	8	16	128	16
34	Muzaffargarh	34	11132	0.77305600000	1	128	127	19.72010000000	30.87410000000	219524.00000000000	8	4	32	4
35	Nankana Sahib	35	3756	0.26083300000	1	128	127	18.41450000000	23.37880000000	69165.00000000000	8	16	128	8
36	Chiniot	36	3696	0.25666700000	1	128	127	22.34060000000	27.15510000000	82571.00000000000	8	16	128	16

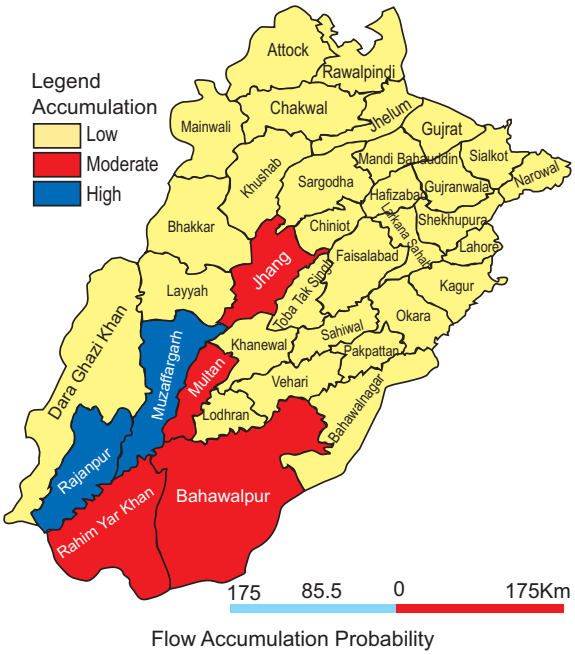


Fig. 9. Flow accumulation - district.

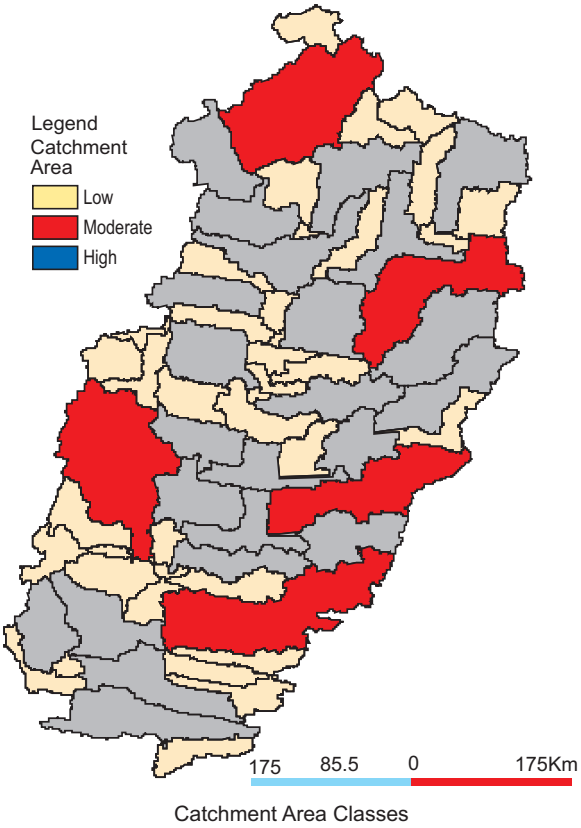
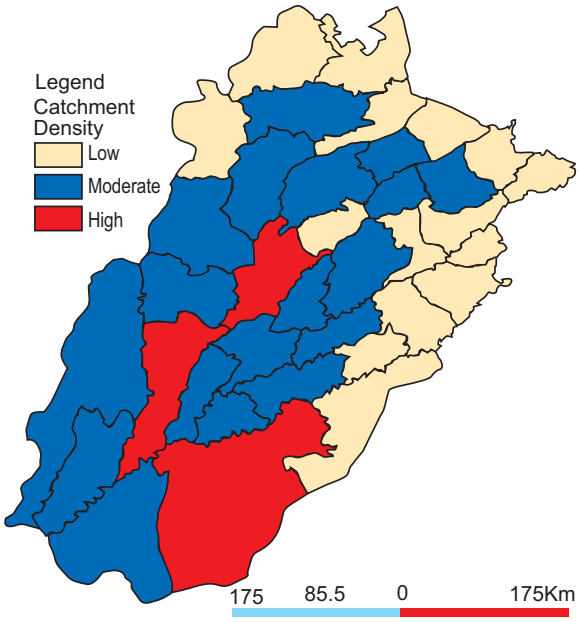


Fig. 10. Catchment zones.

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,



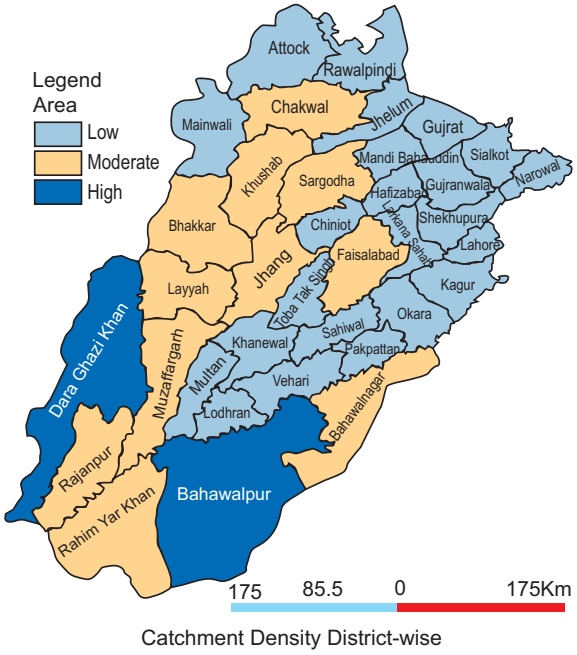


Fig. 11. Catchment density - district wise.

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.

References

Jenson, S.K., Domingue, J.O. 1988. Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing*, **54:** 1593-1600.

Mark, 1984. Link length distributions in drainage networks with lakes. *Water Resources Research*, **20:** 457-462.

Martz, L.W., Garbrecht, J. 1992. Numerical definition of drainage network and sub-catchment areas from digital elevation models. *Computers & Geosciences*, **18:** 747-761.

Moore, I.D., Grayson, R.B., Ladson, A.R. 1991. Digital terrain modelling: A review of hydrological, geomorphological and biological applications. *Hydrological Processes*, **5:** 3-30.

Tarboton, D.G., Bras, R.L., Rodriguez–Iturbe, I. 1991. On the extraction of channel networks from digital elevation data. *Hydrological Processes*, **5:** 81-100.