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BASE FLOW SEPARATION BY CHOW METHOD

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ABSTRACT

The Godavari Basin ranks as the second-largest in India, encompassing approximately 9.5% of the nation's total land area. The Godavari River receives contributions from right-bank tributaries including the Darna, Pravara, and Manjra, and left-bank tributaries such as the Kadwa, Purna, Kaddam, Pranhita, Indravati, and Sabari. The study area comprises the Nagamthan sub-basin in the Upper Godavari Basin, Maharashtra, India, bounded by latitudes 19°40′ to 20° 30′ N and longitudes 73°30′ to 74°50′ E. It covers a basin area of 8,927.22 km² and has a perimeter of 613.24 km.

The Nagamthan sub-basin in the upper Godavari river basin, Maharashtra, India, underwent baseflow separation using the Chow graphical hydrograph method to derive direct runoff from 30 storm events spanning 1990–2019, utilizing daily runoff data from the Hydrology Data Users Group (HDUG), Nashik. Detailed calculations in 12-hour intervals across events (e.g., Event 1 peak direct runoff 15 m³/s; Event 8 peak 2150 m³/s; Event 18 peak 40.36 mm depth) reveal direct runoff ranging 0.22-40.36 mm, with means 8.5 mm and peaks clustering in 2005 monsoon events. These findings validate the Chow method's efficacy for semi-arid watersheds, isolating surface runoff for SCS-CN modeling, flood prediction, and prioritization, while underscoring needs for rainfall integration to compute runoff coefficients.
***Keywords* :** Curve Number, Base flow separation, direct runoff, Chow method.

Introduction

Baseflow in stream has long intrigued hydrologists (Nathan and McMohan, 1990; Tallaksen, 1995). Baseflow separations plays an important role to provide information about ground water status, seasonal flow and in stream ecology by considering broad sense and to subtract the base flow from total flow for small sense (Ducan, 2019; Miller *et al*., 2015). Generally streamflow is consisting of baseflow and direct runoff. Direct runoff is generally studied by unit hydrograph (Sherman 1932; Dooge 1973; Su, 1995). Many methods have been proposed for separating the base flow component from total stream flow. The most widely used methods of separating a stream hydrograph into two components, base flow and runoff, are analytical filtering methods or plotting graph on graph paper (Lott *et al*. 2016; Wahl and Wahl, 1988).

The base flow estimation can be grouped into two categories: Graphical Hydrograph Separation (GHS) methods, which need only daily stream flow data, and tracer Mass Balance (MB) methods, which rely on chemical constituents in the streams, stream flow discharges, and the stream flow end-member constituent concentrations (runoff and base flow) (Indarto *et al*., 2016; Gonzales and Nonner 2009).

The GHS methods include: (i) straight line method, recession curve method (Chow *et al* 1988), Chow method (Suresh, 2019) and Base flow index methods (Gerald, 2007; HEC-HMS, 2023). The Base flow index methods consist of local minimum method, fixed interval method, sliding interval method and Recursive Digital Filtering (RDF) method. RDF methods proposed by Chapman, Chapman and Maxwell, Lyne and Hollick and Eckhardt and the CMB method are used for base flow separation (Kouanda *et al*. 2018; Chapman and Maxwell, 1996; Lyne and Hollick, 1979; Eckhardt, 2005). The main objective of the present study is estimate direct runoff using Chow method for Nagamthan sub-basin in Upper Godavari river basin, Maharashtra State, India (GRMB, 2023).

Material and methods

Study Area

The Godavari Basin, the second-largest river basin in India, occupies approximately 9.5% of the country's total land area. It spans multiple states, with the largest shares in Maharashtra, Andhra Pradesh, and Chhattisgarh, followed by Odisha, Madhya Pradesh, Karnataka and the Union Territory of Puducherry. Hydrologically, the basin forms a cohesive unit defined by its dendritic drainage network, where all tributaries converge and discharge into the Bay of Bengal.

The Godavari River, the longest in the Indian Peninsula, originates at an elevation of 1,067 m near the Trimbak Hills in the Western Ghats, Nashik District, Maharashtra. Major right-bank tributaries include the Darna, Pravara, and Manjra, while left-bank contributors comprise the Kadwa, Purna, Kaddam, Pranhita, Indravati, and Sabari. Precipitation is predominantly received during the southwest monsoon season. The basin's delta, composed of fluvial sediments, exhibits gradual progradation into the Bay of Bengal (India-WRIS, NRSC).

The study area encompasses the Nagamthan sub-basin within the Upper Godavari Basin, Maharashtra, India, situated between latitudes 19º40′ to 20º30′ N, and longitudes 73º30′ to 74º50′ E (location map: Fig. 1). It spans an area of 8,927.22 km² with a perimeter of 613.24 km.

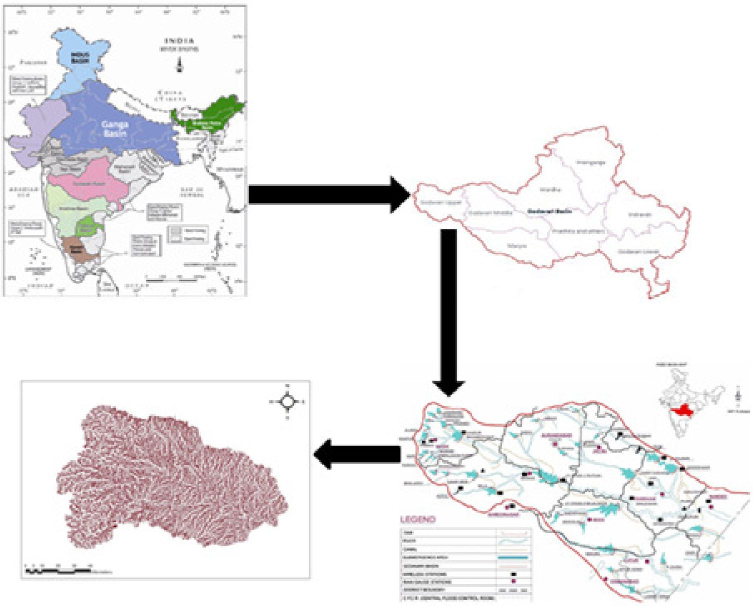


Fig. 1 : Location map of the Nagamthan sub-basin (Upper Godavari river basin)

Climate

From 1969 to 2004, the annual maximum temperature ranged between 31°C and 33.5°C. From west to east, the basin's maximum and minimum temperatures progressively rise. The mean daily minimum temperature rises from west to east in January, which may be considered a normal winter month; in the eastern portion of the Godavari basin, the mean daily maximum temperature is just marginally below 30 degrees Celsius, while in the western portion, it typically surpasses 30 degrees.

Annual rainfall in the Godavari basin varies considerably, ranging from 755 mm to 1531 mm, with an average of 1096.92 mm. However, the Western Ghats region within the basin experiences significantly higher rainfall, from 1000 to 3000 mm annually. Conversely, areas east of the Western Ghats receive less than 600 mm of rainfall per year (www.india-wris.nrsc.gov.in).

Methodology

There are various Graphical Hydrograph Separation (GHS) methods for base flow separation. GHS methods include: (i) straight line method, recession curve method (Chow *et al* 1988), Chow method (Suresh, 2019) and Base flow index methods (Gerald, 2007). In the present study Chow method (1964) was used for estimation of direct runoff for Nagamthan sub-basin in Upper Godavari river basin, Maharashtra State, India.

The baseflow separation using the Chow method involves the following sequential steps: First, extends the pre-storm base flow curve along the rising limb of the hydrograph to point M, positioned arbitrarily at a distance of one-tenth the base width from the peak (Fig. 2). Next, prolong the recession limb inward to intersect the vertical ordinate at the inflection point E. Then, identify point N at the midpoint between M and the peak G on the recession limb. Draw a smooth, upward-convex curve connecting M and N. The resulting segment BMNG delineates the baseflow hydrograph.

In the Nagamthan sub-basin of the upper Godavari river basin, baseflow separation was conducted using the Chow method on runoff data sourced from the Hydrology Data Users Group (HDUG), Nashik. This analysis targeted 30 specific storm events spanning from January 1990 to October 2019, with event periods ranging from short durations like 10/8/1990 to 13/8/1990 (Event 1) to others such as 23/10/2019 to 27/10/2019 (Event 30). The methodology involved event selection based on available hydrographs followed by base flow partitioning, enabling quantitative assessment of direct runoff for hydrological studies which is shown in table 1.

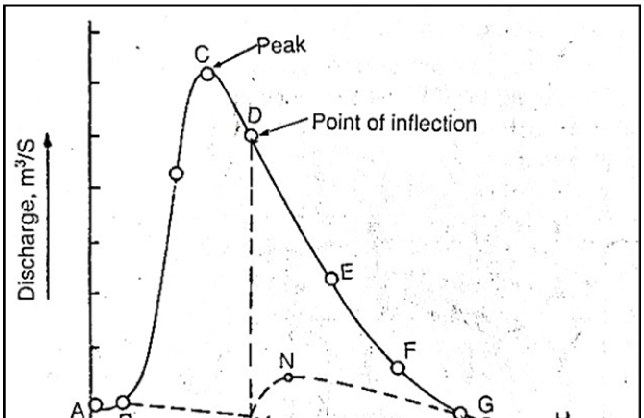


Fig. 2 : Chow method of base flow separation

Table 1 : Event selected for study

Event No.	Event period
1	10/8/1990 to 13/8/1990
2	17/8/1990 to 22/8/1990
3	12/7/1991 to 15/7/1991
4	3/8/1992 to 8/8/1992
5	28/7/1993 to 31/7/1993
6	2/8/1993 to 7/8/1993
7	27/9/1993 to 1/10/1993
8	27/8/1994 to 31/8/1994
9	2/9/1994 to 6/9/1994
10	1/8/1996 to 5/8/1996
11	5/9/1998 to 11/9/1998
12	26/9/1998 to 30/9/1998
13	2/10/1998 to 9/10/1998
14	25/08/2002 to31/08/2002
15	7/9/2004 to 12/9/2004
16	7/10/2004 to 13/10/2004
17	31/7/2005 to 7/8/2005
18	21/9/2005 to 28/9/2005
19	27/7/2006 to 1/08/2006
20	26/7/2007 to 31/7/2007
21	24/7/2009 to 29/7/2009
22	4/8/2014 to 8/8/2014
23	27/7/2015 to 1/8/2015
24	24/9/2016 to 28/9/2016
25	3/10/2016 to 9/10/2016
26	16/07/2018 to 20/07/2018
27	21/07/2018 to 27/07/2018
28	24/09/2019 to 02/10/2019
29	05/10/2019 to 12/10/2019
30	23/10/2019 to 27/10/2019

Conversion of ordinates of direct runoff hydrograph to direct runoff in mm

Direct runoff depth calculation from direct runoff hydrograph (DRH) ordinates provides essential volume quantification for unit hydrograph derivation and rainfall-runoff modeling in the Nagamthan sub-basin study. The process integrates successive discharge ordinates over time intervals to compute total direct runoff volume, subsequently converting to depth via catchment area normalization, supporting precise hydrological parameter estimation from separated base flow across 30 events.

The following are the Steps to compute direct runoff depth (in mm) from DRH ordinates

- **Sum DRH ordinates**:

Calculate total volume $V=\sum(Qi \times \Delta t)$

Where,

Qi represents each direct runoff ordinate (m³/s) and

Δt is the time interval (seconds).

- **Convert to cubic meters**:

  V=3600×(∑Qi for hourly data)

- **Normalize by area**:

  Compute depth d= V/ (A×1000) (mm),

Where,

A is catchment area in m^2

Results

In the Nagamthan sub-basin of the upper Godavari river basin, the Chow method effectively separated baseflow from total runoff hydrographs for 30 selected storm events, yielding direct runoff estimates critical for hydrological analysis. Calculations across time intervals (e.g., 12-hour steps) for events like Event 1 (peak total runoff 41 m³/s at 24 hours, direct runoff 15 m³/s) and Event 8 (peak 2754 m³/s total, 2150 m³/s direct at 24 hours) demonstrate progressive baseflow subtraction, with runoff rates declining to zero direct flow as baseflow stabilizes which is represented by table 2. This partitioning highlights the method's utility in isolating surface runoff contributions, facilitating advanced research in watershed modeling and flood prediction.

Table 2 : Calculation for ordinate of direct runoff from selected events

Selected events	Time elapsed	Ordinate of total Runoff rate (m^3/sec)	Base flow (m^3/sec)	Ordinate of Direct Runoff rate (m^3/sec)
Event - 1	0	26	26	0
	12	33	26	7
	24	41	26	15
	36	38	27	11
	48	35	27	8
	60	31	27	4
	72	27	27	0
Event - 2	0	170	170	0
	12	265	180	85
	24	366	185	181
	36	410	195	215
	48	441	200	241
	60	530	210	320
	72	610	220	390
	84	485	230	255
	96	361	255	106
	108	315	255	60
	120	262	262	0
Event - 3	0	115	115	0
	12	175	115	60
	24	225	116	109
	36	175	120	55
	48	145	119	26
	60	131	118	13
	72	118	118	0
Event - 4	0	2	2	0
	12	22	2	20
	24	47	2	45
	36	33	2	31
	48	20	3	17
	60	17	3	14
	72	15	3	12
	84	10	2	8

	96	4	2	2
	108	3	2	1
	120	2	2	0
Event - 5	0	11	11	0
	12	38	15	23
	24	64	19	45
	36	51	24	27
	48	37	27	10
	60	35	30	5
	72	34	34	0
Event - 6	0	36	36	0
	12	39	37	2
	24	44	38	6
	36	65	40	25
	48	99	41	58
	60	78	45	33
	72	62	46	16
	84	57	47	10
	96	53	47	6
	108	49	47	2
	120	47	47	0
Event - 7	0	421	421	0
	12	505	419	86
	24	621	415	206
	36	635	415	220
	48	645	415	230
	60	530	430	100
	72	454	425	29
	84	425	415	10
	96	406	406	0
Event - 8	0	604	604	0
	12	1050	604	446
	24	2754	604	2150
	36	1850	700	1150
	48	1471	680	791
	60	1300	660	640
	72	1138	650	488
	84	900	630	270
	96	637	637	0
Event - 9	0	637	637	0
	12	900	650	250
	24	1355	670	685
	36	1370	690	680
	48	1383	710	673
	60	1050	760	290
	72	864	770	94
	84	810	780	30
	96	781	781	0
Event - 10	0	170	170	0
	12	180	168	12
	24	192	166	26
	36	191	164	27

	48	190	167	23
	60	182	163	19
	72	177	159	18
	84	164	155	9
	96	152	152	0
Event - 11	0	26	26	0
	12	36	34	2
	24	51	40	11
	36	60	48	12
	48	70	55	15
	60	103	63	40
	72	151	71	80
	84	294	79	215
	96	429	86	343
	108	224	94	130
	120	137	112	25
	144	124	114	10
	156	117	117	0
Event - 12	0	49	49	0
	12	52	50	2
	24	56	53	3
	36	77	55	22
	48	200	57	143
	60	145	62	83
	72	106	65	41
	84	85	65	20
	96	65	65	0
Event - 13	0	59	59	0
	12	104	50	54
	24	182	50	132
	36	193	50	143
	48	203	50	153
	60	216	50	166
	72	231	50	181
	84	167	50	117
	96	136	55	81
	108	116	54	62
	120	102	53	49
	144	80	53	27
	156	57	51	6
	168	53	50	3
	180	49	49	0
Event - 14	0	38	38	0
	12	42	38	4
	24	50	38	12
	36	280	38	242
	48	466	39	427
	60	360	40	320
	72	270	60	210
	84	196	60	136
	96	119	57	62
	108	87	55	32

	120	63	51	12
	144	52	48	4
	156	48	48	0
Event - 15	0	40	40	0
	12	210	44	166
	24	414	48	366
	36	249	54	195
	48	178	66	112
	60	141	68	73
	72	117	72	45
	84	99	72	27
	96	89	75	14
	108	87	78	9
	120	81	81	0
Event - 16	0	430	430	0
	12	438	417	21
	24	457	405	52
	36	513	390	123
	48	598	378	220
	60	573	366	207
	72	554	367	187
	84	465	354	111
	96	392	339	53
	108	360	324	36
	120	335	308	27
	132	306	294	12
	144	282	282	0
Event - 17	0	645	645	0
	12	670	640	30
	24	712	635	77
	36	1000	630	370
	48	1569	630	939
	60	1920	620	1300
	72	2185	620	1565
	84	1870	620	1250
	96	1673	700	973
	108	1370	670	700
	120	1082	640	442
	132	835	620	215
	144	622	600	22
	156	600	600	0
	168	593	593	0
Event - 18	0	469	469	0
	12	1030	450	580
	24	1849	425	1424
	36	2040	395	1645
	48	2264	370	1894
	60	1600	350	1250
	72	1195	400	795
	84	800	370	430
	96	485	330	155
	108	390	300	90

	120	307	270	37
	132	270	250	20
	144	231	220	11
	156	200	190	10
	168	169	169	0
Event - 19	0	217	217	0
	12	265	250	15
	24	330	300	30
	36	630	340	290
	48	1115	380	735
	60	1260	410	850
	72	1395	450	945
	84	1330	500	830
	96	1253	610	643
	108	950	620	330
	120	624	624	0
Event - 20	0	18	18	0
	12	30	18	12
	24	44	18	26
	36	52	18	34
	48	59	18	41
	60	47	18	29
	72	38	20	18
	84	31	19	12
	96	25	19	6
	108	22	19	3
	120	19	19	0
Event - 21	0	362	362	0
	12	565	335	230
	24	823	310	513
	36	615	270	345
	48	512	285	227
	60	425	250	175
	72	347	220	127
	84	255	195	60
	96	172	165	7
	108	155	150	5
	120	136	136	0
Event - 22	0	450	450	0
	12	535	465	70
	24	648	480	168
	36	765	500	265
	48	852	515	337
	60	770	550	220
	72	702	575	127
	84	645	585	60
	96	595	595	0
Event - 23	0	229	229	0
	12	272	220	52
	24	317	215	102
	36	420	210	210
	48	580	205	375

	60	612	200	412
	72	640	195	445
	84	660	190	470
	96	670	185	485
	108	395	180	215
	120	170	170	0
Event - 24	0	55	55	0
	12	165	51	114
	24	280	45	235
	36	246	45	201
	48	218	44	174
	60	126	48	78
	72	57	42	15
	84	42	36	6
	96	26	26	0
Event - 25	0	56	56	0
	12	112	50	62
	24	186	48	138
	36	152	46	106
	48	125	60	65
	60	114	54	60
	72	108	49	59
	84	95	44	51
	96	82	38	44
	108	60	34	26
	120	40	28	12
	132	30	22	8
	144	21	21	0
Event - 26	0	5	5	0
	12	95	27	68
	24	214	50	164
	36	445	70	375
	48	799	100	699
	60	570	125	445
	72	385	153	232
	84	270	160	110
	96	174	174	0
Event - 27	0	174	174	0
	12	227	157	70
	24	290	149	141
	36	360	140	220
	48	448	124	324
	60	360	120	240
	72	300	135	165
	84	230	120	110
	96	178	105	73
	108	130	95	35
	120	98	85	13
	132	85	80	5
	144	76	76	0
Event - 28	0	44	44	0
	12	55	40	15

	24	76	35	41
	36	350	35	315
	48	830	30	800
	60	895	27	868
	72	946	25	921
	84	700	25	675
	96	508	60	448
	108	370	73	297
	120	269	65	204
	144	205	50	155
	156	155	40	115
	168	100	30	70
	180	32	25	7
	192	28	25	3
	204	28	28	0
Event - 29	0	31	31	0
	12	50	30	20
	24	74	30	44
	36	170	30	140
	48	243	30	213
	60	215	30	185
	72	186	38	148
	84	157	38	119
	96	129	36	93
	108	93	34	59
	120	45	33	12
	144	37	31	6
	156	32	29	3
	168	30	28	2
	180	28	28	0
Event - 30	0	4	4	0
	12	63	8	55
	24	107	12	95
	36	147	17	130
	48	180	21	159
	60	135	30	105
	72	80	33	47
	84	57	36	21
	96	39	39	0

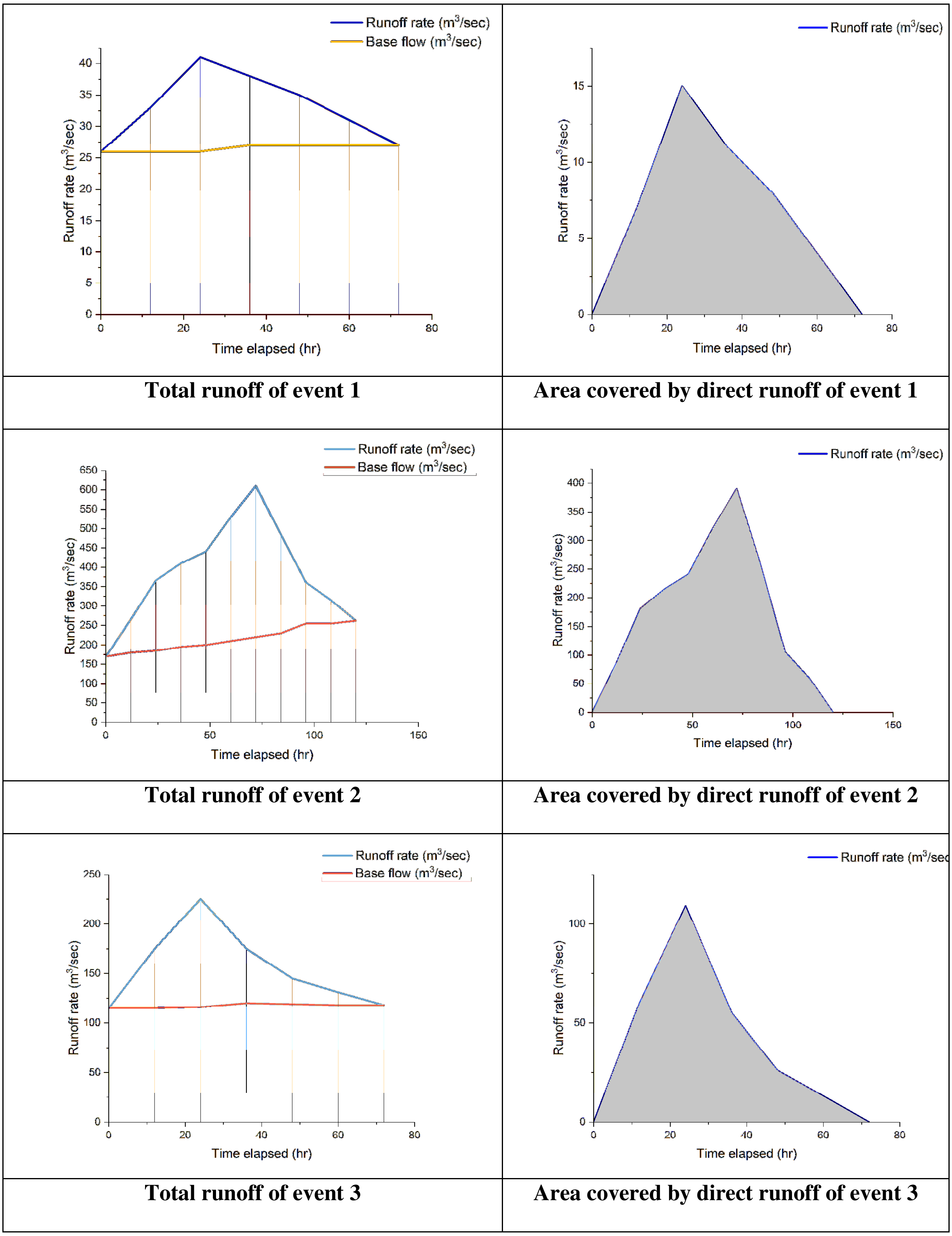


Fig. 3 : Total runoff and area covered by direct runoff of event 1 to event 3

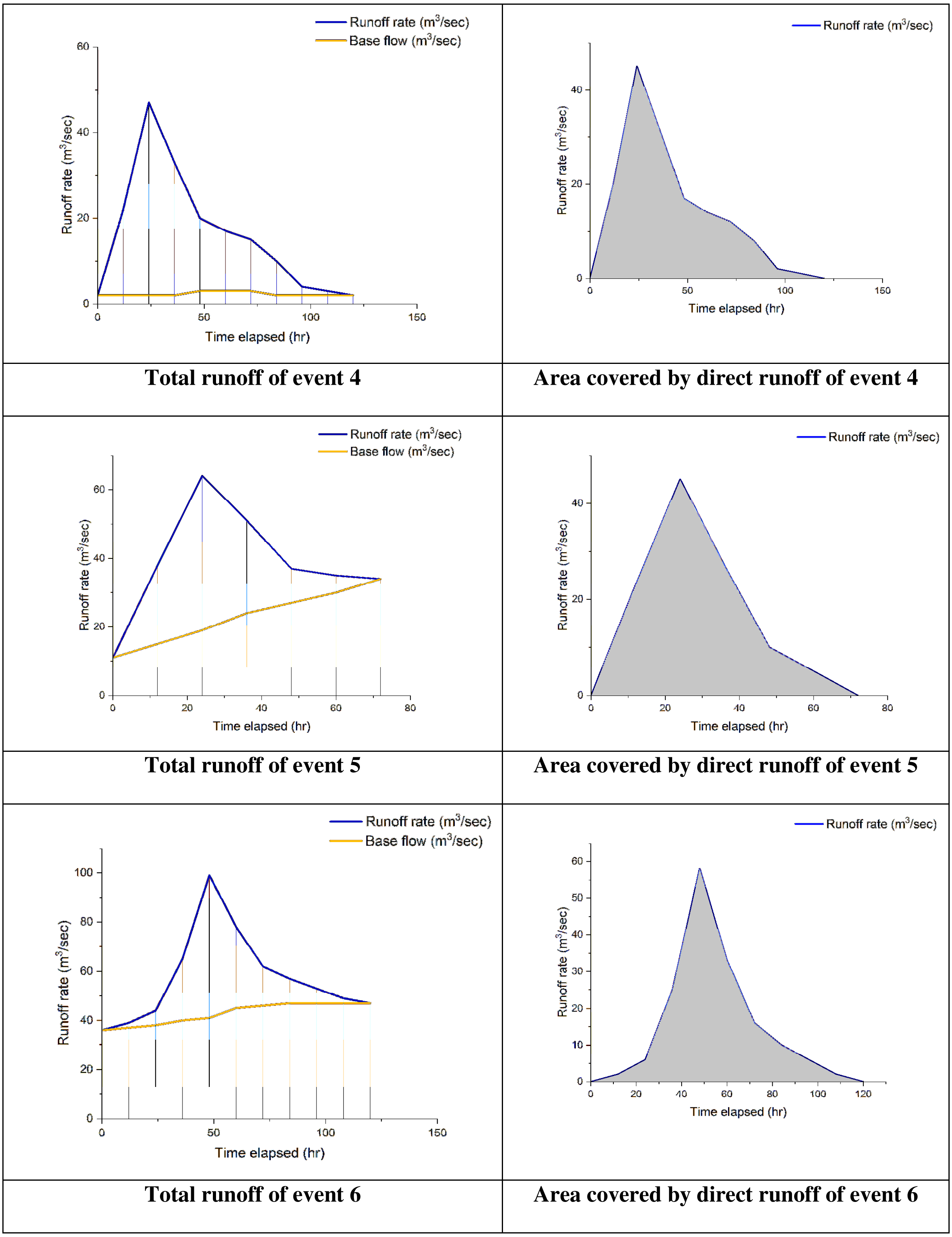


Fig. 4 : Total runoff and area covered by direct runoff of event 4 to event 6

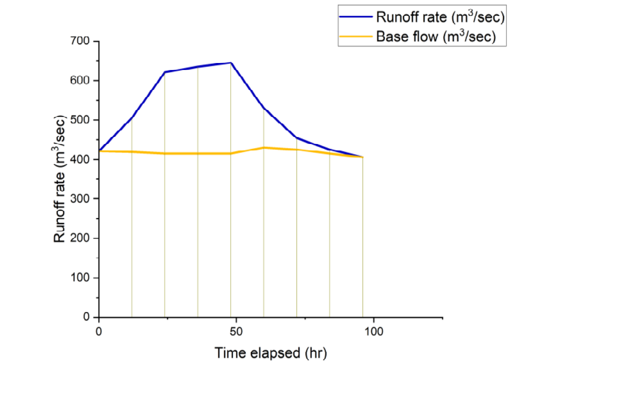
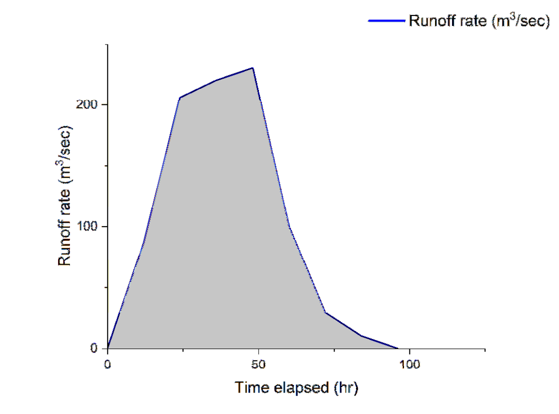
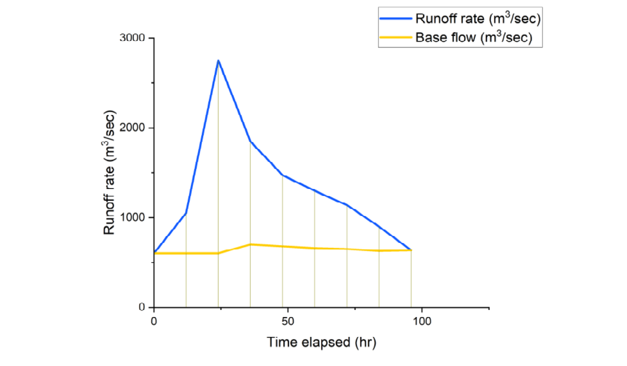
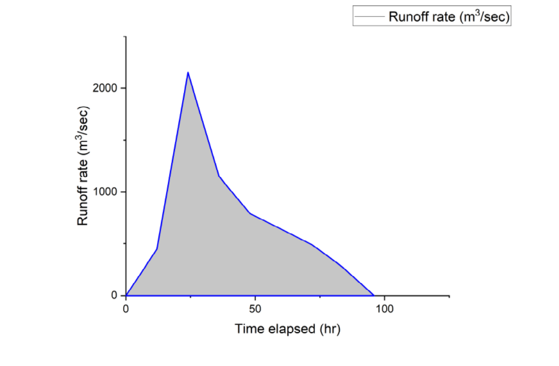
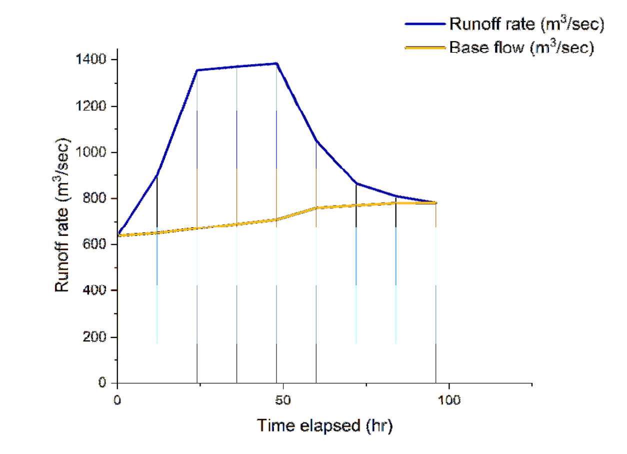
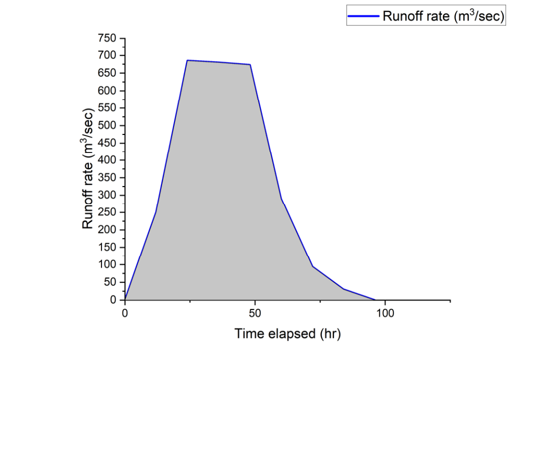
	
Total runoff of event 7	**Area covered by direct runoff of event 7**
	
Total runoff of event 8	**Area covered by direct runoff of event 8**
	
Total runoff of event 9	**Area covered by direct runoff of event 9**

Fig. 5 : Total runoff and area covered by direct runoff of event 7 to event 9

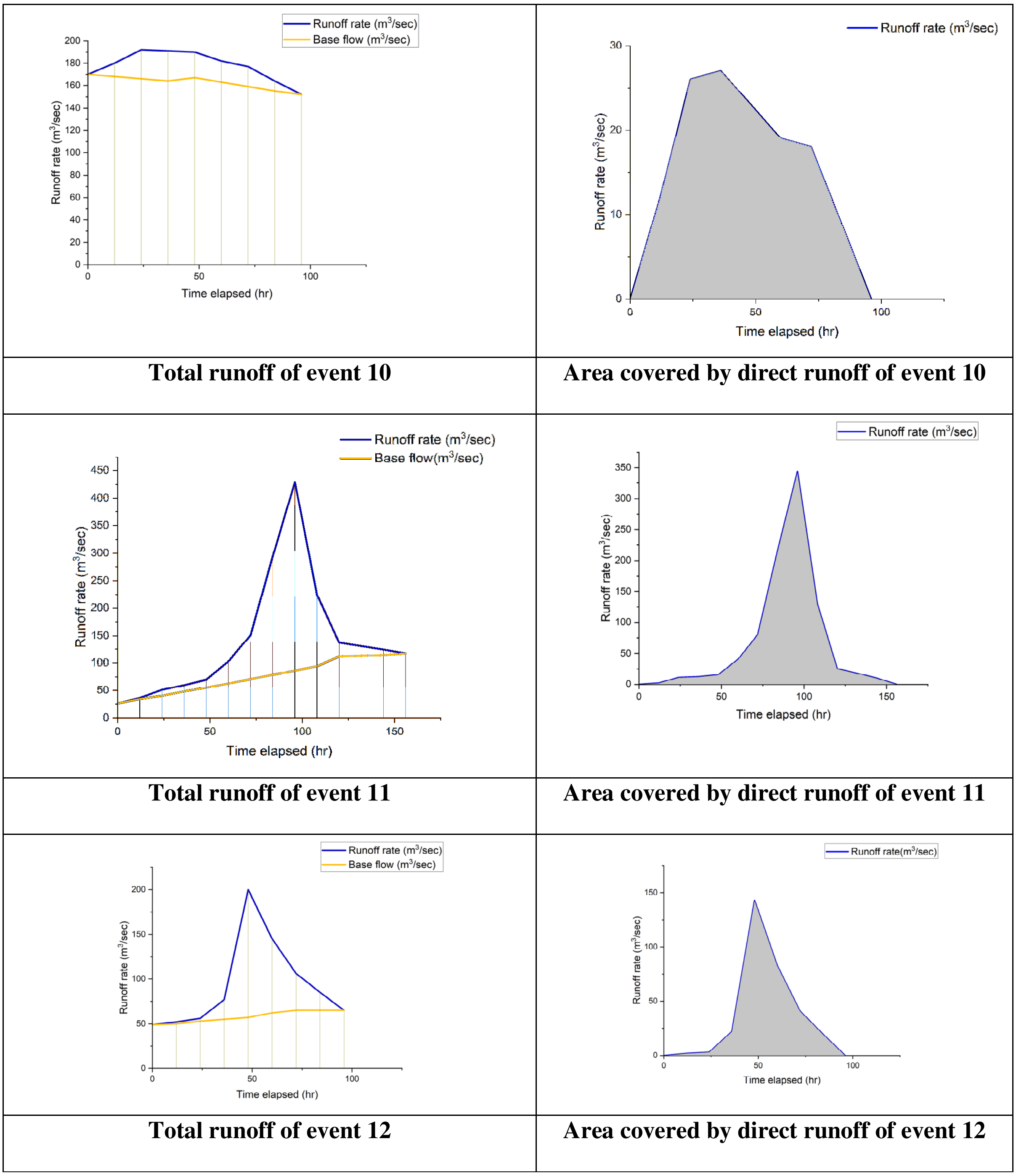
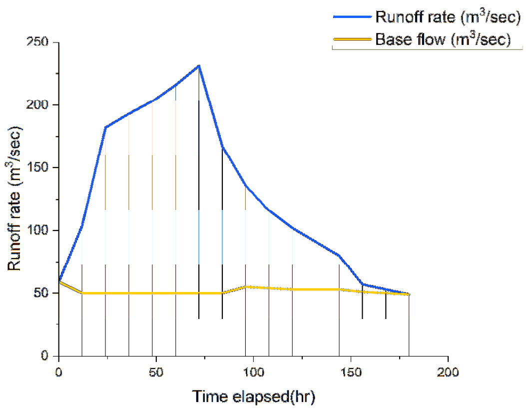
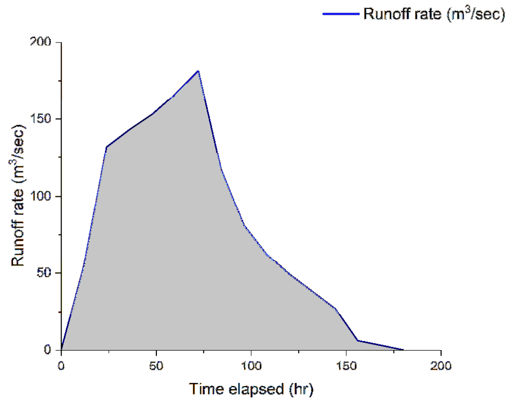


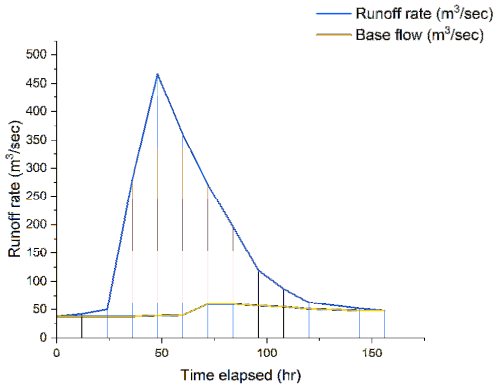
Fig. 6 : Total runoff and area covered by direct runoff of event 10 to event 12



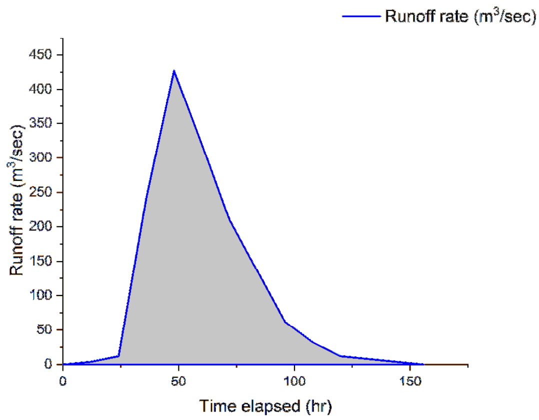
Total runoff of event 13



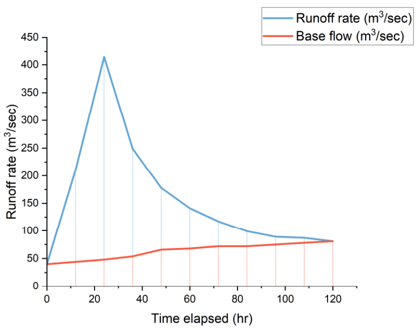
Area covered by direct runoff of event 13



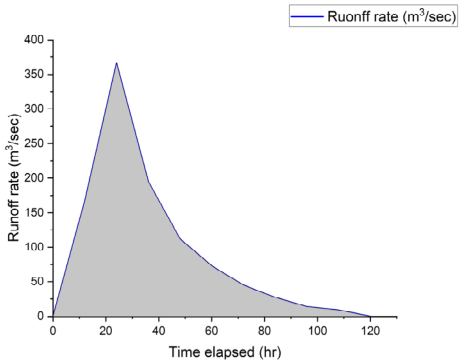
Total runoff of event 14



Area covered by direct runoff of event 14

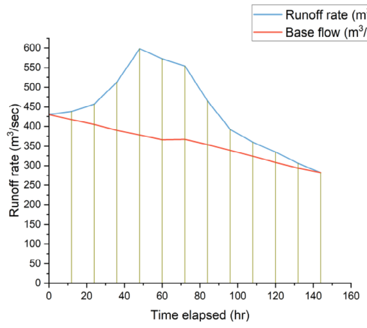


Total runoff of event 15

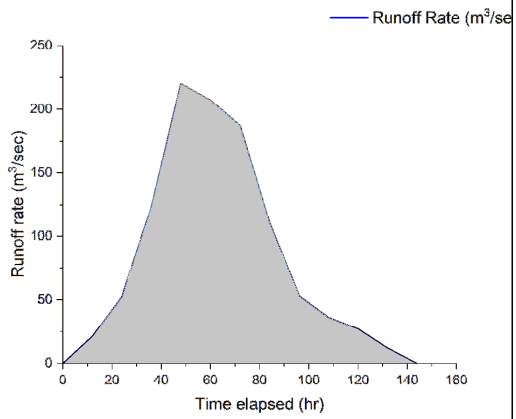


Area covered by direct runoff of event 15

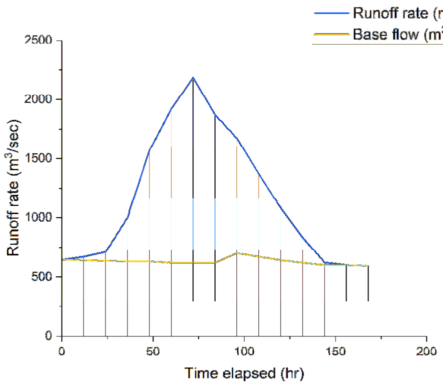
Fig. 7 : Total runoff and area covered by direct runoff of event 13 to event 15



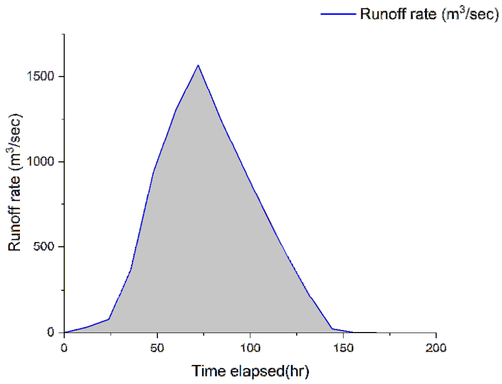
Total runoff of event 16



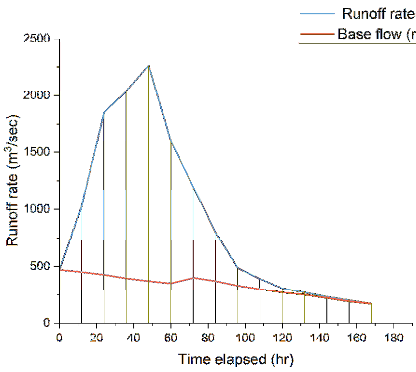
Area covered by direct runoff of event 16



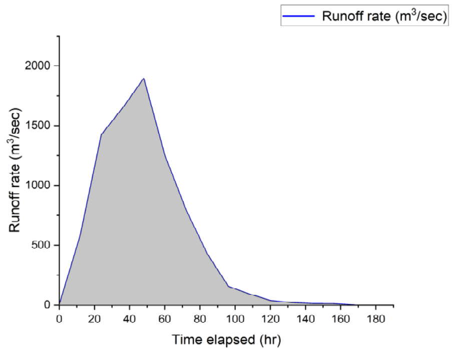
Total runoff of event 17



Area covered by direct runoff of event 17

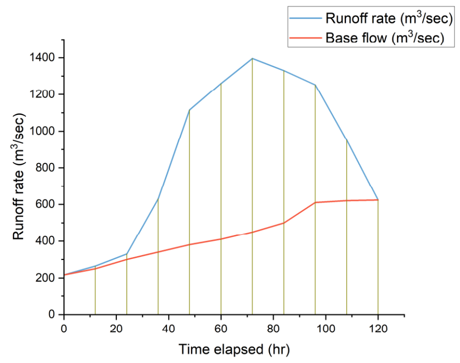


Total runoff of event 18

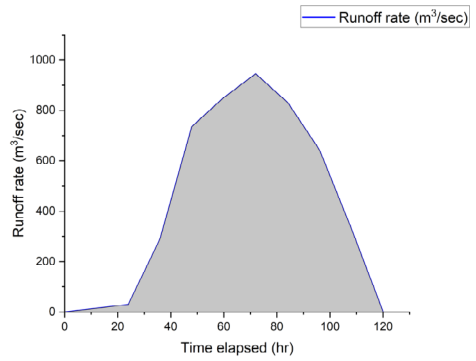


Area covered by direct runoff of event 18

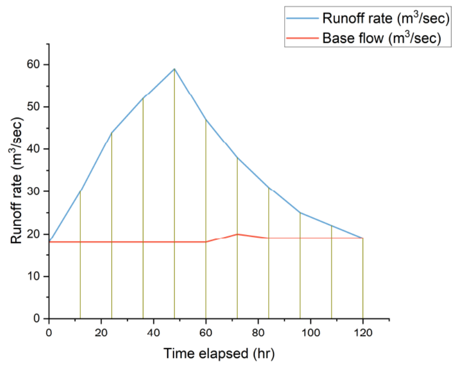
Fig. 8 : Total runoff and area covered by direct runoff of event 16 to event 18



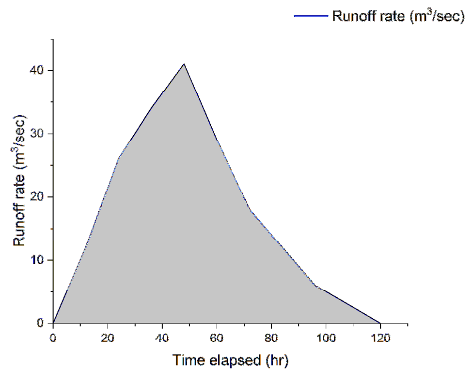
Total runoff of event 19



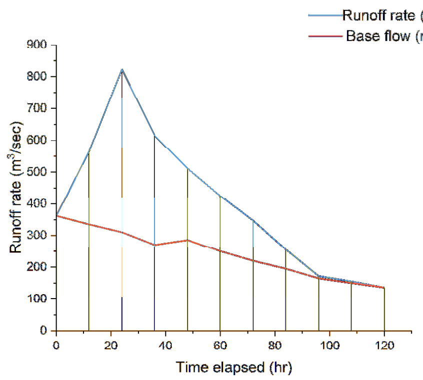
Area covered by direct runoff of event 19



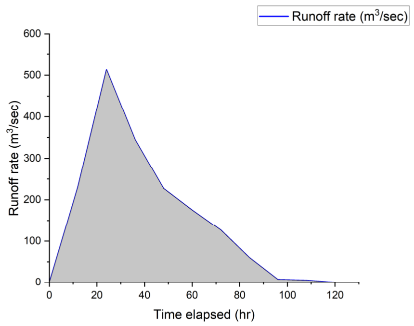
Total runoff of event 20



Area covered by direct runoff of event 20

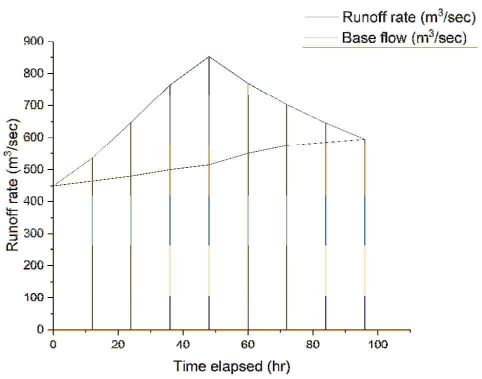


Total runoff of event 21

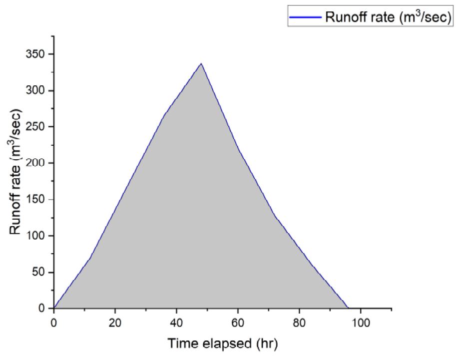


Area covered by direct runoff of event 21

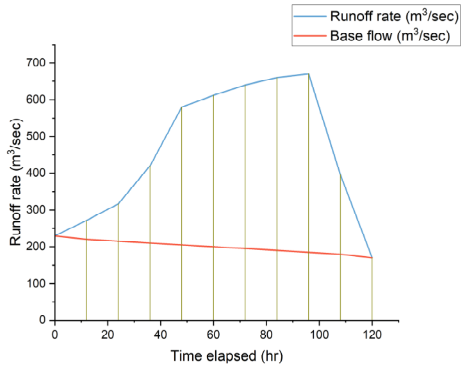
Fig. 9 : Total runoff and area covered by direct runoff of event 19 to event 21



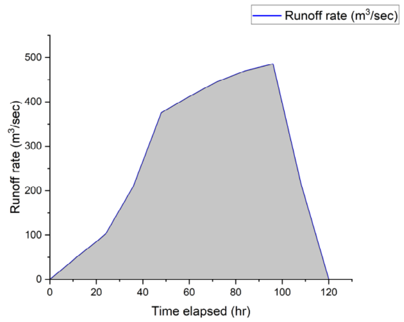
Total runoff of event 22



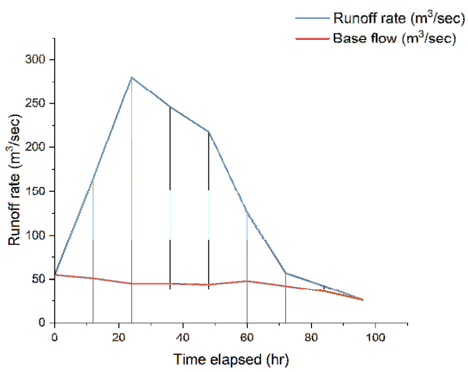
Area covered by direct runoff of event 22



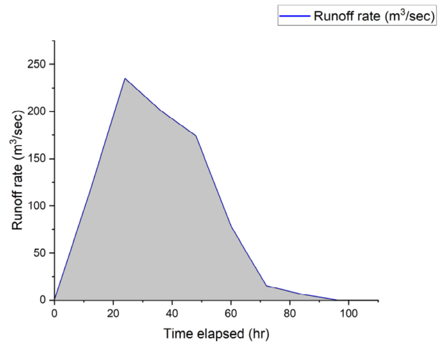
Total runoff of event 23



Area covered by direct runoff of event 23

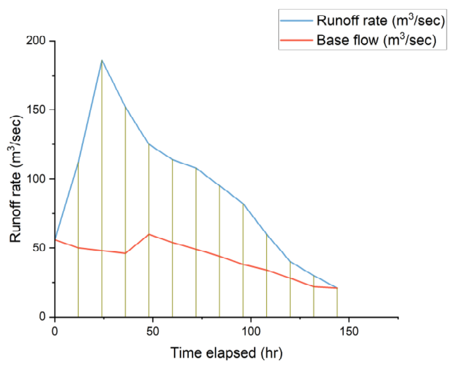


Total runoff of event 24

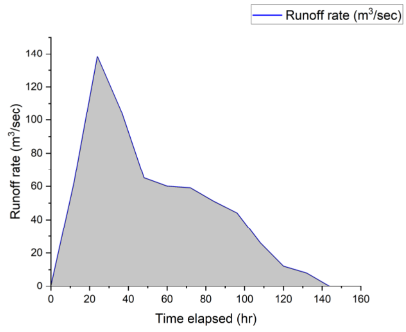


Area covered by direct runoff of event 24

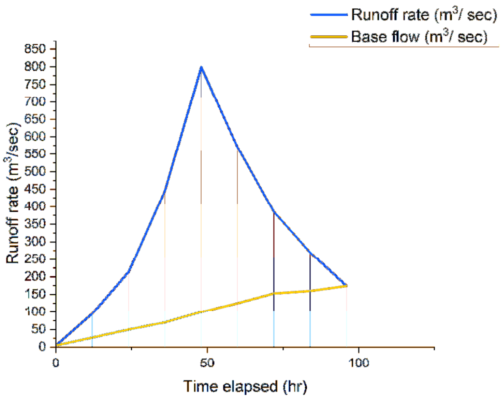
Fig. 10 : Total runoff and area covered by direct runoff of event 22 to event 24



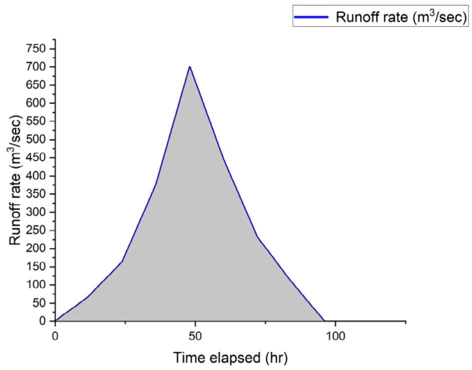
Total runoff of event 25



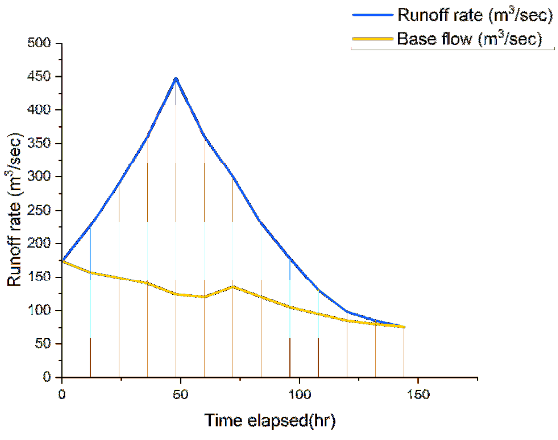
Area covered by direct runoff of event 25



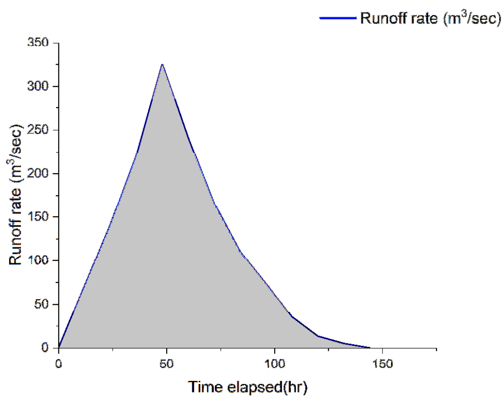
Total runoff of event 26



Area covered by direct runoff of event 26

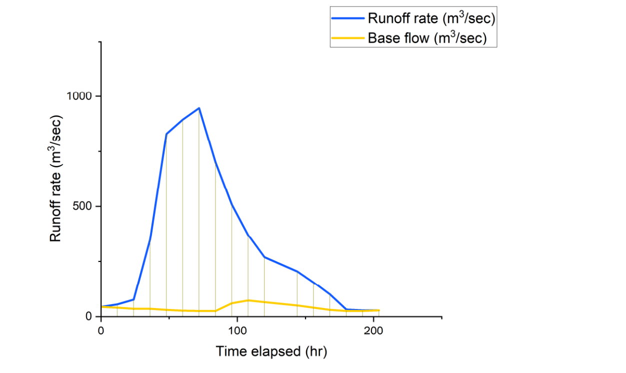


Total runoff of event 27

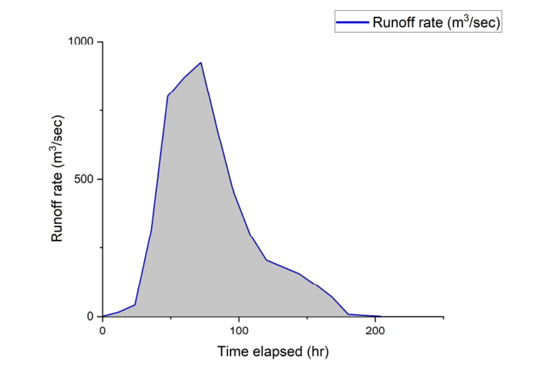


Area covered by direct runoff of event 27

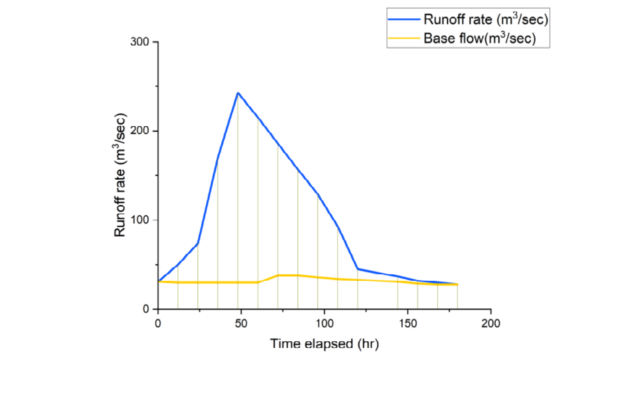
Fig. 11 : Total runoff and area covered by direct runoff of event 25 to event 27



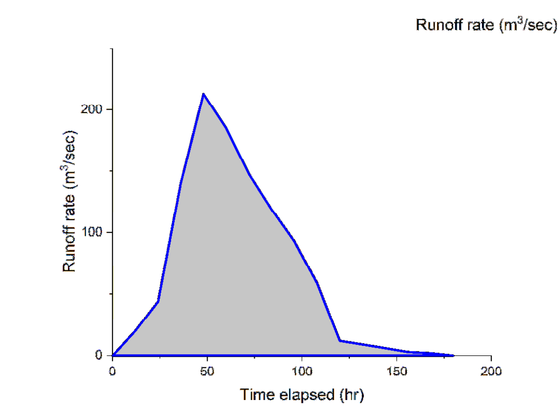
Total runoff of event 28



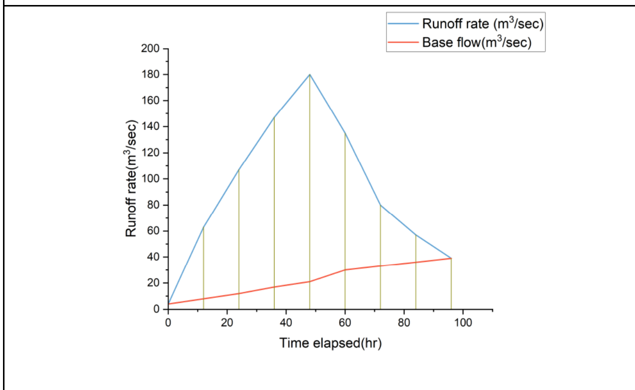
Area covered by direct runoff of event 28



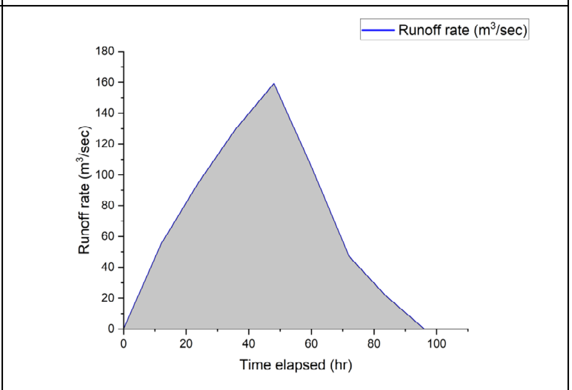
Total runoff of event 29



Area covered by direct runoff of event 29



Total runoff of event 30



Area covered by direct runoff of event 30

Fig. 12 : Total runoff and area covered by direct runoff of event 28 to event 30

These graphical representations, embedded alongside tabular data, quantify event-specific hydrograph areas and facilitate interpretation of groundwater versus overland flow contributions, underpinning robust hydrological modeling and validation which is represented from Fig. 3 to Fig.12.

Table 3 : Direct runoff in mm from selected events

Event No.	Event period	Direct Runoff (mm)
1	10/8/1990 to 13/8/1990	0.22
2	17/8/1990 to 22/8/1990	8.97
3	12/7/1991 to 15/7/1991	1.27
4	3/8/1992 to 8/8/1992	0.73
5	28/7/1993 to 31/7/1993	0.53
6	2/8/1993 to 7/8/1993	0.76
7	27/9/1993 to 1/10/1993	4.26
8	27/8/1994 to 31/8/1994	28.72
9	2/9/1994 to 6/9/1994	13.08
10	1/8/1996 to 5/8/1996	0.65
11	5/9/1998 to 11/9/1998	4.27
12	26/9/1998 to 30/9/1998	1.52
13	2/10/1998 to 9/10/1998	5.68
14	25/08/2002 to31/08/2002	7.07
15	7/9/2004 to 12/9/2004	4.87
16	7/10/2004 to 13/10/2004	5.08
17	31/7/2005 to 7/8/2005	38.15
18	21/9/2005 to 28/9/2005	40.36
19	27/7/2006 to 1/08/2006	22.58
20	26/7/2007 to 31/7/2007	0.88
21	24/7/2009 to 29/7/2009	8.17
22	4/8/2014 to 8/8/2014	6.03
23	27/7/2015 to 1/8/2015	13.38
24	24/9/2016 to 28/9/2016	3.98
25	3/10/2016 to 9/10/2016	3.05
26	16/07/2018 to 20/07/2018	10.13
27	21/07/2018 to 27/07/2018	6.76
28	24/09/2019 to 02/10/2019	23.88
29	05/10/2019 to 12/10/2019	5.05
30	23/10/2019 to 27/10/2019	2.96

Table 3 presents direct runoff depths (in mm) estimated using the Chow method (1964) for 30 storm events in the Nagamthan sub-basin, Upper Godavari river basin, Maharashtra, India, from 1990 to 2019. Direct runoff values range from 0.22 mm (Event 1) to 40.36 mm (Event 18), with notable peaks during intense events like 38.15 mm (Event 17) and 28.72 mm (Event 8). These results highlight variable surface runoff contributions, supporting hydrological modeling and watershed management applications.

Conclusion

Application of the Chow method successfully quantified direct runoff for Nagamthan sub-basin storms, revealing dominant baseflow in low-yield events and substantial quickflow in peaks exceeding 30 mm. Findings validate the technique for semi-arid watersheds, aiding SCS-CN parameter calibration and flood risk assessment. Future studies should integrate rainfall data for runoff coefficient to enhance predictive accuracy.

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