

IRRIGATION DEPARTMENT

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2016/17**

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Irrigation Department
Colombo 07
Sri Lanka**

***Hydrological Annual 2016/17 – Hydrology Division, Irrigation Department.
58th year of publication***

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Foreword

The annual publication by the Hydrology Division of the Irrigation Department contains hydrological data collected during the water year 2016/17 (from October 2016 to September 2017). The first publication of this series was made for the water year 1959/60.

During the recent years hydro meteorological network of the country has been upgraded and modernized under the Dam Safety and Water Resources Planning Project, funded by the World Bank. Most of the manual stations were automated while introducing new stations at important locations. Total of 167 stations will be implemented at the completion of this project covering the entire country.

Part I and II of this journal provide the general information of the river basins and the salient hydrological features pertaining to the current water year.

Part III of the journal is allocated for the technical papers and research work carried out by the engineers of the Irrigation Department. Two technical papers have been included in the part III of this journal.

Out of these two technical papers “Experience during the flood in May 2017 in the wet zone of Sri Lanka” presents the necessity of preparing for these types of disasters with regard to all river basins vulnerable for flooding. Also this paper discusses about the use of automated hydro-meteorological data in flood forecasting and early warning.

“Mapping surface water with remote sensing” presents the applications of remote sensing techniques in water resources management. Satellite remote sensing and GIS techniques facilitate the investigation of surface water changes and how to overcome the lack of insitu data. This research was done for the catchments in Milingimbi Island, Australia and will help to extend this experience in Sri Lankan catchments too.

Eng. (Mrs.) R.M.M.R. Alawathugoda,
Director of Irrigation (Hydrology)

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PART I

- **Terminology and Abbreviations**
- **Conversion Factors**
- **River Basin Map and Drainage Area**
- **Hydrometric Stations**

TERMINOLOGY AND ABBREVIATIONS USED IN PUBLICATION

Flood Hydrograph	-	A plot of discharge against time.
Annual Flood Peak	-	Highest value of discharge for the year indicated by the hydrograph
Maximum Flood Peak	-	Maximum observed flood peak during the period of observation.
Average Annual Rainfall	-	Arithmetic mean of annual rainfall values for the period of observation.
Rainfall Intensity	-	Cumulative depth of rainfall during a particular duration.
Annual Runoff	-	The total volume of water measured at a particular point for the year.
Average Annual Runoff	-	Arithmetic mean of annual run-off for the period of observation.
Annual Yield	-	Annual yield is the volume of water available to the tank from its own catchment (without diversions) during the year.
Specific Yield	-	$\frac{\text{Yield (MCM)}}{\text{Catchment Area (Sq.Kms)}}$
Duty	-	Duty is the irrigation requirement (issued from the sluice) during a cultivation season for one hectare
		$\text{Duty (meters)} = \frac{\text{Sluice Issue (ha.m)}}{\text{Area Cultivated (ha)}}$
Evaporation	-	The transfer of water into the atmosphere from a free water surface.
Potential Evapotranspiration	-	The evapotranspiration from vegetal cover and from soil surface when the root zone is saturated.

CONVERSION FACTORS

Length

Imperial		Metric / SI
1 inch	= 1/12 foot	0.0254 m
1 foot	= 1/3 yard	0.3048 m
1 yard	= 3 feet	0.9144 m
1 Engineering chain	= 100 feet	30.48 m
1 mile	= 52.8 chains = 5280 feet	1609 m

Area

Imperial		Metric / SI
1 square foot	= 144 square inches	0.0929 m ²
1 acre	= 43,560 ft ²	4,047 m ² = 0.4047 ha
2.47 acres		1 ha
1 square mile	= 640 acres	259 ha = 2.59 km ²

Volume & Discharge

Imperial		Metric / SI
1 cubic foot per second (cusec)		28.317 l/s
1 cusec during 1 day	= 1.983 acre.ft	2,446.57 m ³
1 acre.foot		1,234 m ³
1 acre.foot/day		14.28 l/s = 1234 m ³ /d
1 acre.inch	= 3.630 ft ³	102.8 m ³

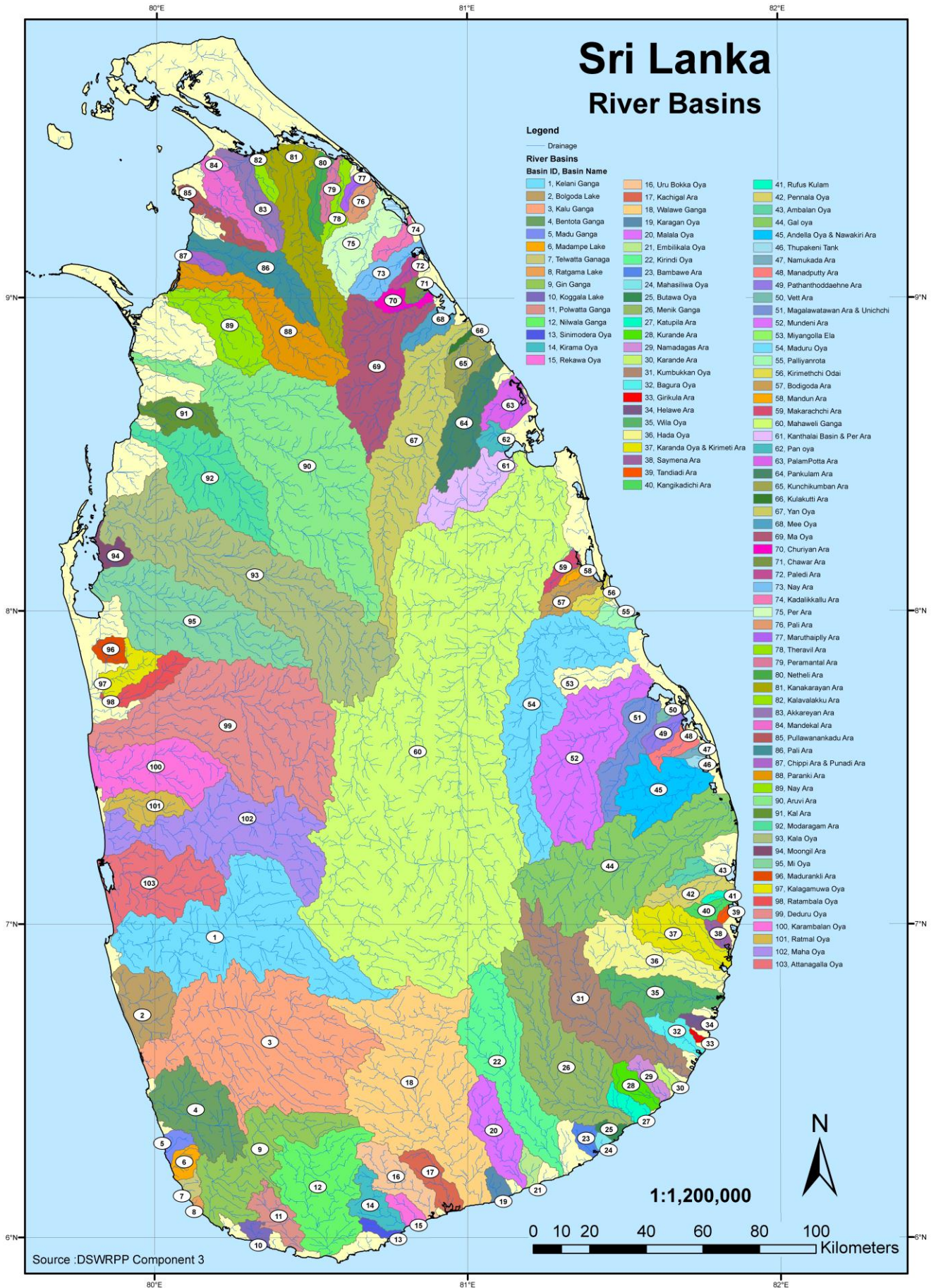
Map scales

Imperial		Metric / SI
1 inch : 10 feet		1 : 120
1 inch : 20 feet		1 : 240
1 inch : 66 feet		1 : 792
1 inch : 132 feet		1 : 1,584
1 inch : 264 feet		1 : 3,168
1 inch : 528 feet		1 : 6,336
1 inch : 1 mile		1 : 63,360

Weight

Imperial		Metric / SI
1 pound		0.4536 kg
2.24 pound		1 kg
1 ton		1,016 kg
2,240 pounds		1 Metric Ton = 1000 kg
1 bushel (paddy)		22.88 kg
1 bushel/acre		56.5 kg/ha

Sri Lanka River Basins



RIVER BASINS OF SRI LANKA

	River Name	Drainage Area (Sq.km)	River Name	Drainage Area (Sq.km)
1	Kelani Ganga	2340	41 Rufus Kulam	27
2	Bolgoda Ganga	396	42 Pannel Oya	195
3	Kalu Ganga	2839	43 Ambalan Oya	112
4	Bentara Ganga	667	44 Gal Oya	1911
5	Madu Ganga	69	45 Andella Oya	534
6	Madampe Ganga	90	46 Tumpam Keni	18
7	Telwatta Ganga	41	47 Namakada Aru	12
8	Ratgama Lake	13	48 Mandipattu Aru	90
9	Gin Ganga	915	49 Pathantoppu Aru	101
10	Koggala Ganga	55	50 Vett Aru	22
11	Polwatta Ganga	232	51 Magalavatavan Aru	304
12	Nilwala Ganga	1043	52 Mundeni Aru	1373
13	Sinimodara Oya	35	53 Miyangolla Ela	228
14	Kirama Oya	183	54 Maduru Oya	1439
15	Rekawa Oya	70	55 Pulliyanpota Aru	87
16	Urubokka Oya	373	56 Kirimechchi Odai	89
17	Kachigal Ara	208	57 Bodigolla Aru	132
18	Walawe Ganga	2424	58 Mandan Aru	26
19	Karagan Oya	60	59 Makarachchi Aru	59
20	Malala Oya	409	60 Mahaweli Ganga	10266
21	Embilikala Oya	69	61 Kantalai Aru	437
22	Kirindi Oya	1156	62 Palampotta Aru	97
23	Bambawe Ara	66	63 Panna Oya	164
24	Mahaseelawa Oya	13	64 Pankulam Aru	377
25	Buthawa Oya	37	65 Kunchikumban Aru	245
26	Menik Ganga	1301	66 Palakutta Aru	8
27	Katupila Ara	111	67 Yan Oya	1518
28	Kurunda Ara	99	68 Mi Oya	89
29	Nabadagas Ara	110	69 Ma Oya	1042
30	Karambe Ara	54	70 Churiya Aru	105
31	Kumbukkan Oya	1227	71 Chavar Aru	35
32	Bagura Oya	93	72 Palladi Aru	66
33	Girikula Oya	14	73 Manal Aru	194
34	Helawa Ara	38	74 Kodalikallu Aru	92
35	Wila Oya	472	75 Per Aru	392
36	Heda Oya	615	76 Pali Aru	70
37	Karanda Oya	425	77 Maruthapillay Ary	36
38	Seman Aru	72	78 Thervil Aru	104
39	Tandiadi Aru	20	79 Piramanthal Aru	91
40	Kangikadichi Aru	78	80 Methali Aru	114

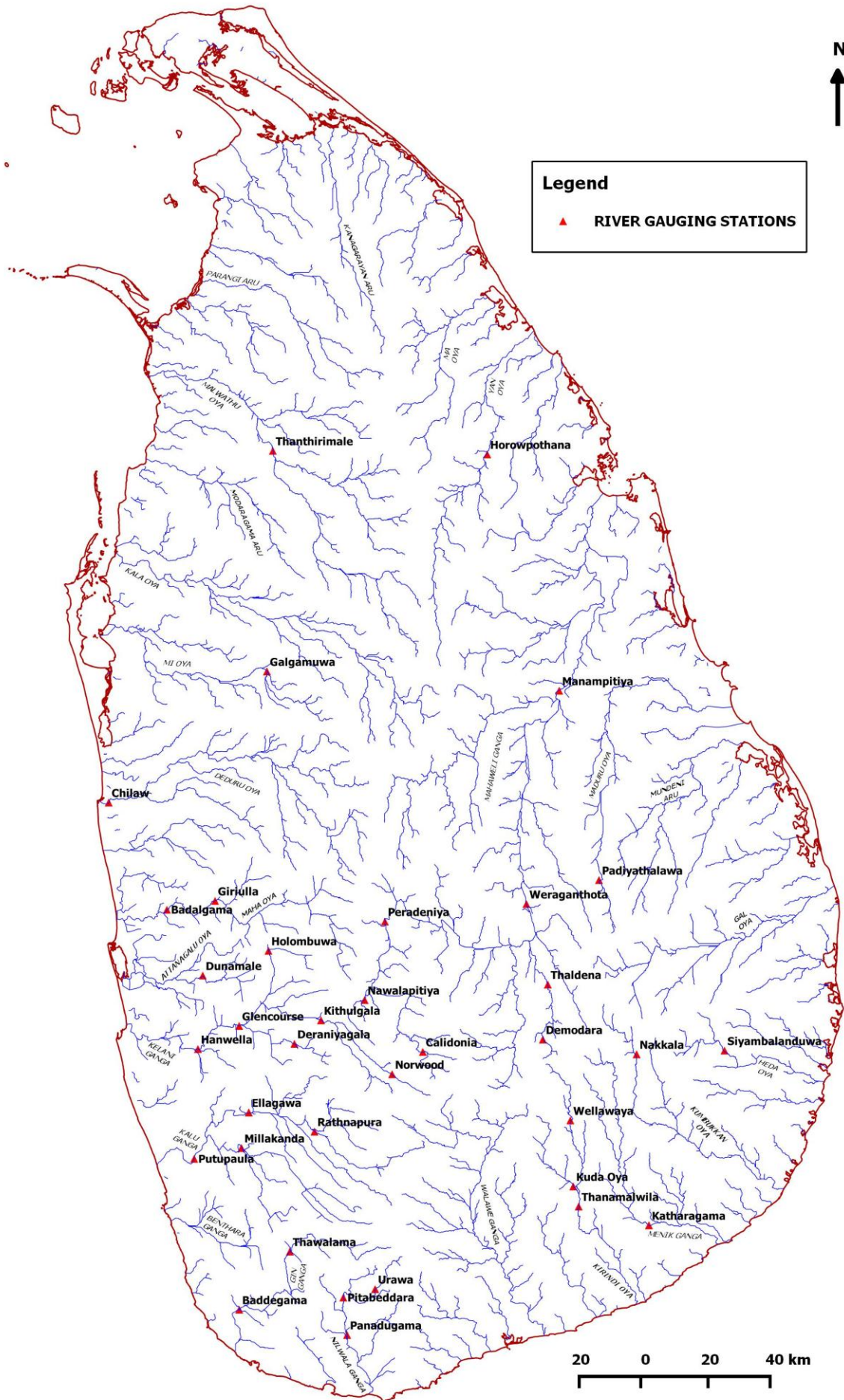
81	Kanakarayan Aru	604
82	Kalwalappu Aru	68
83	Akkarayan Aru	244
84	Mandekal Aru	208
85	Pallavarayan Kaddu Aru	311
86	Pali Aru	451
87	Chappi Aru	79
88	Parangi Aru	770
89	Nay Aru	717
90	Aruvi Aru	3291
91	Kal Aru	210
92	Moderagama Aru	1001
93	Kala Oya	2526
94	Moongil Aru	78
95	Mee Oya	1555
96	Madurankuli Aru	128
97	Kalagamune Oya	169
98	Rathambala Oya	244
99	Deduru Oya	2622
100	Karambala Oya	693
101	Ratmal Oya	341
102	Maha Oya	1470
103	Attanagalu Oya	811
	Area of Jaffna Peninsula including Vadamarachchi Lagoon, but excluding islands of Kayts , Kartivu	1018
	Residual area comprising largely, coastal zones intervening between adjacent river basins of Sri Lanka	5049
	Total	65591

Source: Water Resources Planning Project under component 03 of DSWRPP- 2013

HYDROMETRIC STATIONS - 2016/17
(According to River Basin)

Name of Station	River Basin	Coordinates	Catchment Area (Sq.Km)
1. Norwood	Kelani Ganga	(6°50'22"N, 80°36'42"E)	97
2. Kithulgala	Kelani Ganga	(6°59'26"N, 80°24'44"E)	383
3. Deraniyagala	Kalani Ganga	(6°55'28"N, 80°20'16"E)	183
4. Holombuwa	Kelani Ganga	(7°11'07"N, 80°15'53"E)	155
5. Glencourse	Kelani Ganga	(6°58'28"N, 80°10'58"E)	1463
6. Hanwella	Kelani Ganga	(6°54'34"N, 80°04'46"E)	1782
7. Rathnapura	Kalu Ganga	(6°40'42"N, 80°23'39"E)	603
8. Ellagawa	Kalu Ganga	(6°43'55"N, 80°12'36"E)	1393
9. Millakanda	Kalu Ganga	(6°37'56"N, 80°11'23"E)	780
10. Putupaula	Kalu Ganga	(6°36'06"N, 80°03'26"E)	2598
11. Baddegama	Gin Ganga	(6°10'33"N, 80°10'27"E)	749
12. Thawalama	Gin Ganga	(6°20'31"N, 80°19'49"E)	377
13. Urawa	Nilwala Ganga	(6°14'12"N, 80°34'18"E)	59
14. Pitabeddara	Nilwala Ganga	(6°12'47"N, 80°28'31"E)	310
15. Panadugama	Nilwala Ganga	(6°06'30"N, 80°28'40"E)	445
16. Wellawaya	Kirindi Oya	(6°42'35"N, 81°06'40"E)	172
17. Thanamalwila	Kirindi Oya	(6°28'06"N, 81°08'03"E)	749
18. Kuda Oya	Kirindi Oya	(6°31'29"N, 81°07'24"E)	291
19. Katharagama	Menik Ganga	(6°24'56"N, 81°19'51"E)	787
20. Nakkala	Kumbukkan Oya	(6°53'42"N, 81°17'49"E)	216
21. Siyambalanduwa	Heda Oya	(6°54'18"N, 81°32'36"E)	295
22. Padiyathalawa	Maduru Oya	(7°23'01"N, 81°11'31"E)	159
23. Demodara	Mahaweli Ganga	(6°56'12"N, 81°02'03"E)	78
24. Thaldena	Mahaweli Ganga	(7°05'27"N, 81°02'53"E)	276
25. Calidonia	Mahaweli Ganga	(6°54'07"N, 80°41'52"E)	148
26. Nawalapitiya	Mahaweli Ganga	(7°02'51"N, 80°32'04"E)	176
27. Peradeniya	Mahaweli Ganga	(7°16'03"N, 80°36'30"E)	1168
28. Weraganthota	Mahaweli Ganga	(7°19'00"N, 80°59'18"E)	4092
29. Manampitiya	Mahaweli Ganga	(7°54'53"N, 81°05'10"E)	7418
30. Horowpothana	Yan Oya	(8°34'39"N, 80°52'43"E)	720
31. Thanthirimale	Malwathu Oya	(8°35'14"N, 80°16'31"E)	2116
32. Galgamuwa	Mee Oya	(7°58'07"N, 80°15'34"E)	299
33. Chilaw	Deduru Oya	(7°36'01"N, 79°48'57"E)	2610
34. Giriulla	Maha Oya	(7°19'30"N, 80°06'53"E)	1192
35. Badalgama	Maha Oya	(7°18'00"N, 79°58'47"E)	1360
36. Dunamale	Aththanagalu Oya	(7°06'56"N, 80°04'50"E)	153

LOCATIONS OF HYDROMETRIC STATIONS



PART II

- **Rainfall**
- **Variation of Rainfall**
- **Rainfall Intensities**
- **Evaporation and Evapotranspiration**
- **Stream Flow Data**
- **Runoff / Rainfall Ratio**
- **Flood Hydrographs**

RAINFALL

MONTHLY RAINFALL AT THE PRINCIPAL STATIONS OF METEOROLOGY DEPARTMENT

(In mm)

Upper line : Current year 2016/17

Lower line: Long term average from 1970/71 to 2015/16

Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	NEM Total	SWM Total	Annual Total
Anuradhapura (8°21'00"N, 80°22'48"E)	135 248	166 250	66 208	109 81	40 55	142 67	116 167	224 89	9 14	11 27	148 34	113 73	656 910	621 404	1277 1314
Badulla (6°58'48"N, 81°03'00"E)	68 243	137 272	105 277	177 176	122 91	283 99	60 191	95 109	64 36	28 66	89 68	133 123	892 1157	469 592	1361 1750
Bandarawela (6°48'36"N, 80°57'36"E)	51 248	166 244	41 192	132 111	72 67	205 99	57 177	185 108	132 52	50 59	59 57	106 136	666 961	588 589	1255 1550
Batticaloa (7°42'36"N, 81°42'00"E)	61 178	315 362	130 432	338 238	22 128	132 73	5 53	8 47	33 31	78 33	197 39	87 70	998 1411	407 273	1406 1684
Colombo (6°54'00"N, 79°51'36"E)	374 333	405 336	165 158	83 69	92 69	134 117	81 245	343 320	142 202	47 118	70 105	355 227	1253 1083	1039 1217	2292 2300
Galle (6°01'48"N, 80°13'12"E)	371 316	333 305	63 175	225 85	37 68	82 94	179 220	351 287	94 199	137 155	179 156	239 249	1111 1042	1179 1265	2289 2308
Hambantota (6°07'12"N, 81°07'48"E)	26 129	178 212	103 124	158 63	67 41	89 57	81 92	142 83	22 49	20 35	28 52	52 75	621 626	344 386	965 1012
Jaffna (9°40'47"N, 80°01'48"E)	48 240	432 375	121 261	87 72	26 35	120 33	0 61	30 62	11 19	13 27	70 50	91 61	833 1015	214 281	1047 1297
Katugastota (7°19'48"N, 80°37'48"E)	83 280	174 293	61 199	105 97	62 70	294 88	41 190	148 142	78 133	40 125	104 100	101 138	779 1027	512 828	1291 1855
Katunayaka (7°10'12"N, 79°52'48"E)	127 355	268 313	35 131	27 49	3 66	137 119	16 211	234 289	182 162	35 86	50 96	383 190	596 1035	900 1033	1495 2068
Kurunegala (7°27'36"N, 80°22'12"E)	123 355	306 315	27 151	76 66	55 70	288 137	128 276	151 194	171 141	26 100	83 86	176 148	876 1095	736 944	1612 2039

MONTHLY RAINFALL AT THE PRINCIPAL STATIONS OF METEOROLOGY DEPARTMENT

(in mm)

Upper line : Current year 2016/17

Lower line : Long term average from 1970/71 to 2015/16

Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	NEM Total	SWM Total	Annual Total
Mahailuppallama (8°07'12"N, 80°27'36"E)	167 253	170 265	43 200	154 83	0 71	189 67	70 178	229 99	18 15	20 29	97 36	126 93	723 940	560 450	1283 1390
Mannar (8°58'48"N, 79°54'36"E)	10 160	194 269	60 203	126 49	3 43	42 44	0 92	20 57	8 8	0 13	49 10	79 48	435 768	156 228	591 996
Monaragala * (6°51'36"N, 81°21'00"E)	111 234	91 237	99 234	169 142	91 114	221 124	117 210	188 126	8 36	99 43	90 90	22 79	782 1085	523 584	1305 1669
Nuwara Eliya (6°57'36"N, 80°45'36"E)	70 238	111 227	53 189	144 113	82 67	204 67	72 134	168 172	56 185	39 173	128 140	162 168	663 901	624 973	1288 1873
Polonnaruwa * (7°54'36"N, 81°01'48"E)	87 341	384 343	145 513	302 242	60 164	152 81	17 112	70 119	1 5	15 36	42 55	131 85	1129 1684	275 413	1405 2097
Potuvil * (6°52'48"N, 81°49'48"E)	13 134	342 269	39 318	378 286	194 134	95 78	0 73	30 54	1 12	24 16	22 22	25 56	1062 1220	101 234	1163 1454
Puttalam (8°01'48"N, 79°49'48"E)	15 228	262 257	12 139	125 51	20 41	61 64	24 166	25 103	7 33	2 21	6 18	113 66	494 780	176 406	671 1186
Rathmalana (6°48'36"N, 79°52'48"E)	375 361	478 354	76 168	120 71	48 67	78 118	98 269	323 324	192 201	25 123	50 118	375 245	1175 1139	1063 1280	2239 2419
Rathnapura (6°40'48"N, 80°24'00"E)	156 454	235 373	164 225	39 123	33 140	364 208	201 365	983 445	376 415	184 294	353 284	612 379	991 1524	2709 2183	3700 3706
Trincomalee (8°34'48"N, 81°15'60"E)	88 210	175 363	81 337	180 137	19 91	235 45	0 52	40 66	1 28	172 58	107 79	95 118	777 1185	415 401	1192 1586
Vauniya (8°46'00"N, 80°30'00"E)	113 227	232 276	89 252	262 92	24 71	146 56	91 133	172 85	13 18	24 44	147 50	212 98	866 974	659 427	1525 1401

Note :- ‘*’ Denotes Long term average less than specified above. ‘NEM’ denotes North-East Monsoon. ‘SWM’ denotes South-West Monsoon.

MONTHLY RAINFALL AT THE GAUGING STATIONS OF IRRIGATION DEPARTMENT

(In mm)

Upper line : Current year 2016/17

Lower line: Long term average from 1989/90 to 2015/16

Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	NEM Total	SWM Total	Annual Total
Badalgama (7°18'00"N, 79°58'47"E)	117 345	191 257	26 131	21 51	11 59	201 82	15 204	248 223	176 148	18 79	73 102	358 165	566 924	889 921	1454 1845
Calidonia (6°54'07"N, 80°41'52"E)	67 309	132 286	5 139	58 82	14 78	306 116	111 246	241 213	129 257	80 233	244 192	155 160	583 1010	959 1302	1542 2312
Deraniyagala (6°55'28"N, 80°20'16"E)	325 570	440 398	12 180	27 108	11 119	570 221	302 443	1052 549	504 455	264 343	477 302	791 421	1384 1595	3390 2514	4774 4109
Dunamale * (7°06'56"N, 80°04'50"E)	170 484	234 327	37 195	58 57	39 70	307 165	55 332	485 391	197 238	58 132	99 146	644 252	845 1298	1538 1491	2383 2789
Ellagawa * (6°43'55"N, 80°12'36"E)	180 427	371 374	76 176	80 115	28 146	213 219	84 396	652 415	265 324	147 222	264 276	835 352	949 1458	2246 1985	3196 3442
Galgamuwa (7°58'07"N, 80°15'34"E)	35 237	206 255	90 199	129 72	21 52	116 83	48 234	133 99	21 21	25 23	42 44	196 68	597 898	464 490	1061 1388
Glencourse * (6°58'28"N, 80°10'58"E)	206 531	354 479	42 227	191 98	3 128	340 282	279 404	702 436	267 337	177 218	196 244	722 299	1135 1744	2344 1937	3479 3681
Hanwella * (6°54'34"N, 80°04'46"E)	250 442	519 361	47 214	112 121	42 103	304 164	149 345	759 375	203 268	100 182	151 187	745 296	1274 1405	2107 1652	3381 3057
Holombuwa (7°11'07"N, 80°15'53"E)	173 462	17 378	45 194	72 88	9 90	318 187	122 355	312 304	195 258	100 180	141 165	438 244	634 1398	1309 1505	1943 2903
Horowpothana (8°34'39"N, 80°52'43"E)	99 197	210 297	80 341	211 153	33 93	112 43	28 91	56 67	2 16	107 29	261 81	148 86	744 1124	602 370	1346 1494
Kithulgala (6°59'26"N, 80°24'44"E)	233 616	318 362	44 173	43 94	9 118	314 194	157 432	825 586	450 536	264 452	493 389	633 450	961 1557	2823 2845	3784 4402

MONTHLY RAINFALL AT THE GAUGING STATIONS OF IRRIGATION DEPARTMENT

(in mm)

Upper line : Current year 2016/17

Lower line : Long term average from 1989/90 to 2015/16

Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	NEM Total	SWM Total	Annual Total
Kuda Oya (6°31'29"N, 81°07'24"E)	57 207	198 262	47 156	102 85	84 55	168 95	91 169	180 66	19 11	12 13	24 16	67 46	656 861	391 322	1047 1183
Nakkala (6°53'42"N, 81°17'49"E)	134 270	184 365	108 267	183 163	69 124	239 88	76 179	122 109	20 40	84 52	278 85	89 107	916 1277	668 571	1584 1848
Norwood (6°50'22"N, 80°36'42"E)	79 393	194 299	17 157	31 120	18 87	367 177	127 349	389 294	138 340	100 306	266 231	294 215	705 1232	1314 1735	2018 2966
Padiyathalawa (7°23'01"N, 81°11'31"E)	55 238	384 369	192 457	423 266	134 158	119 70	8 130	74 90	46 36	79 59	152 97	254 128	1306 1557	611 541	1917 2098
Peradeniya (7°16'03"N, 80°36'30"E)	70 310	209 262	33 174	106 80	48 62	310 90	61 207	291 177	119 161	132 120	141 98	228 124	776 977	970 888	1747 1866
Siyambalanduwa (6°54'18"N, 81°32'36"E)	77 236	161 374	213 305	309 214	137 124	118 70	117 145	64 91	35 47	109 65	67 64	33 93	1016 1323	424 506	1440 1829
Thanamalwila (6°28'06"N, 81°08'03"E)	71 203	344 270	33 145	127 78	29 52	187 89	90 174	236 65	16 8	8 10	30 19	75 36	791 837	454 312	1245 1150
Thawalama * (6°20'31"N, 80°19'49"E)	291 560	630 439	353 302	196 216	71 196	306 252	514 387	993 504	201 375	237 291	405 276	580 407	1847 1965	2930 2239	4776 4204
Urawa * (6°14'12"N, 80°34'18"E)	263 404	496 410	258 299	163 124	30 182	65 207	186 332	579 362	191 205	81 167	188 162	297 299	1274 1627	1522 1526	2796 3154
Wellawaya (6°42'35"N, 81°06'40"E)	96 261	196 373	117 194	136 115	73 100	418 167	188 251	112 116	4 20	34 29	61 32	41 96	1036 1209	439 543	1476 1752

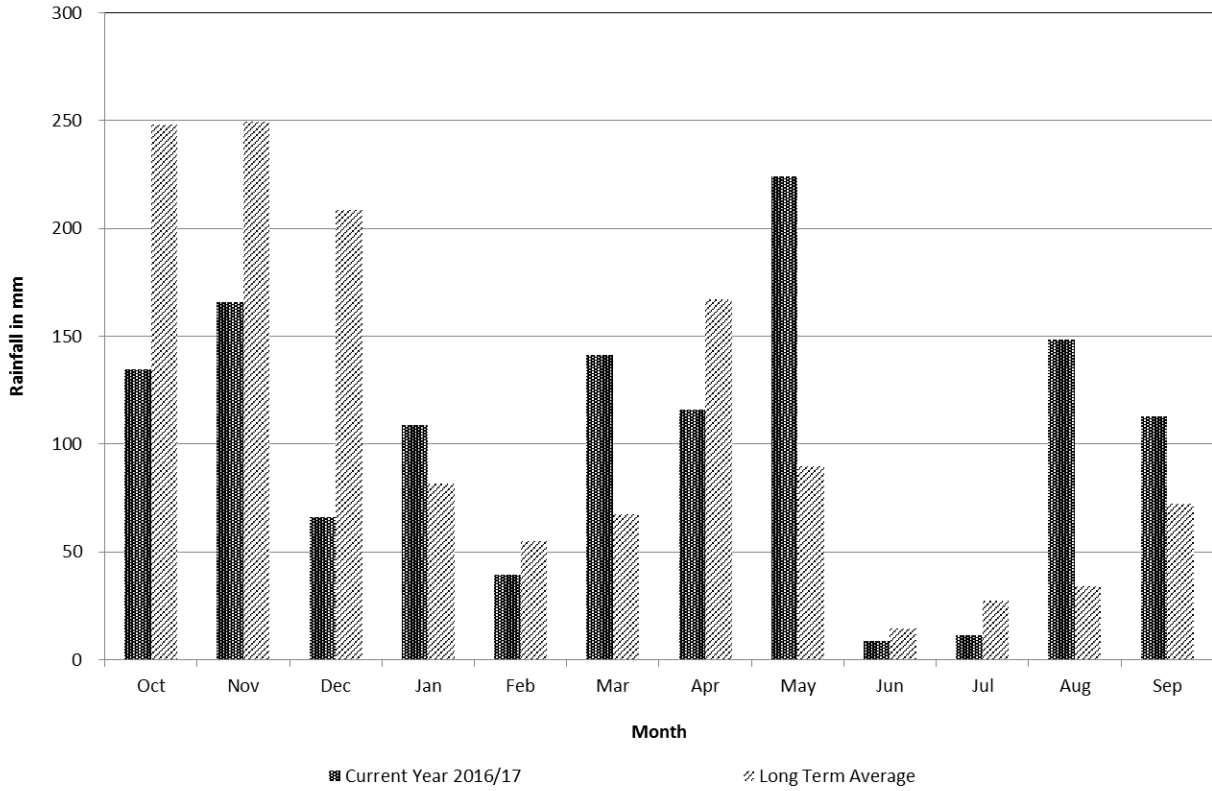
Note :- ‘*’ Denotes Long term average less than specified above. ‘NEM’ denotes North-East Monsoon. ‘SWM’ denotes South-West Monsoon.

VARIATION OF RAINFALL

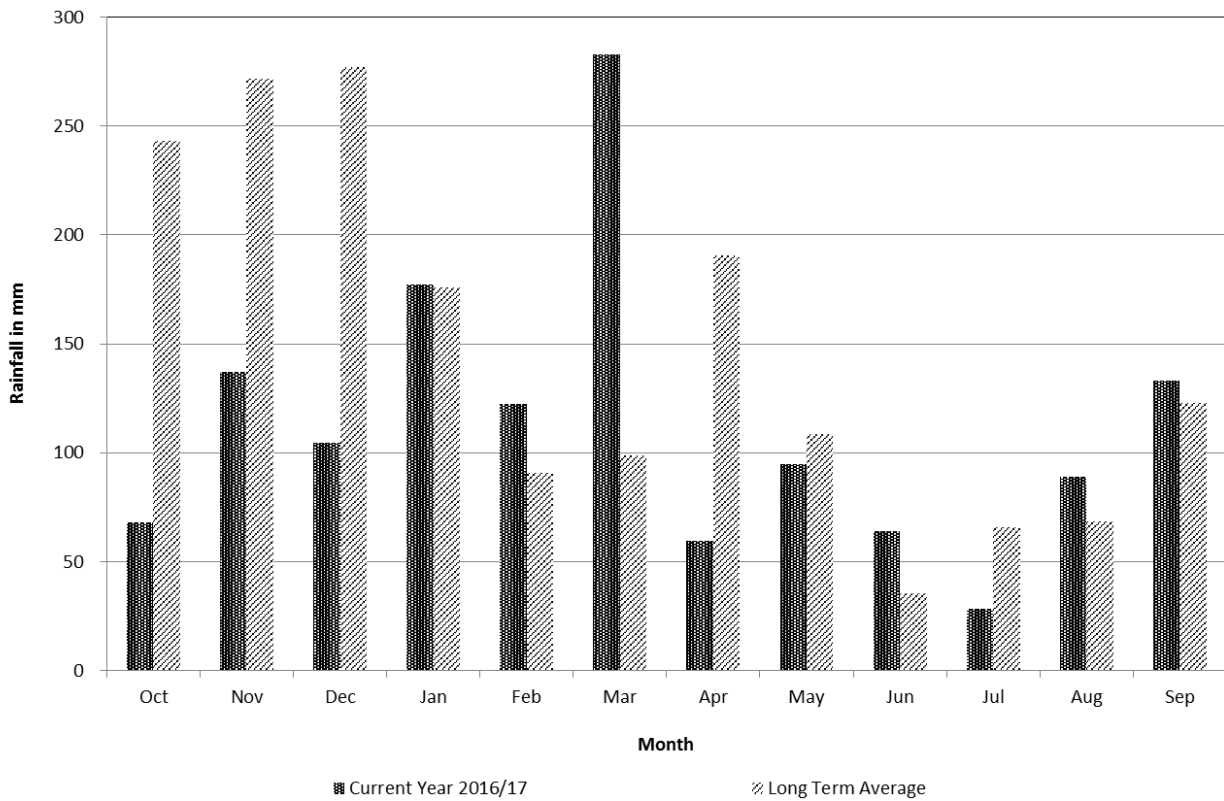
- **Temporal variation of Rainfalls at each station
(Current year versus Long-Term average)**
- **Spatial variation of Rainfalls
(Current year versus Long-Term average)**

**TEMPORAL VARIATION OF RAINFALLS
AT EACH STATION**

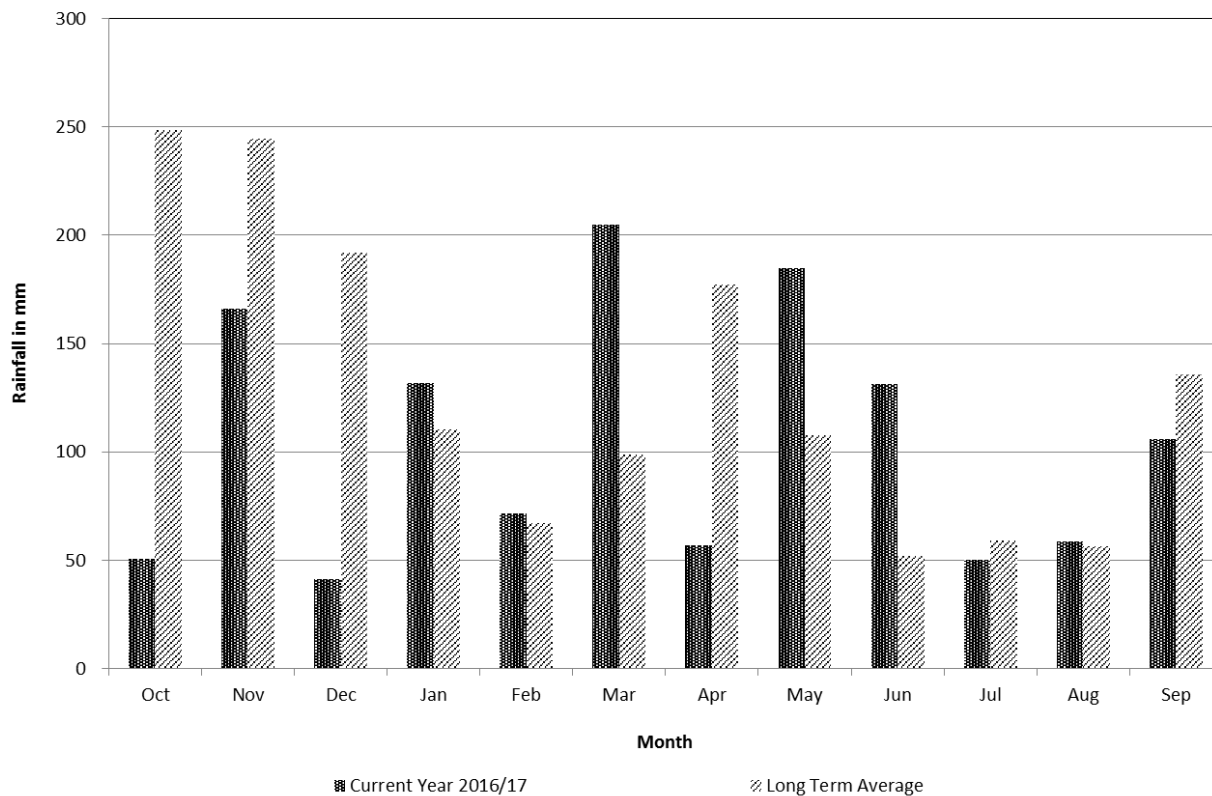
Variation of Rainfall at Anuradhapura



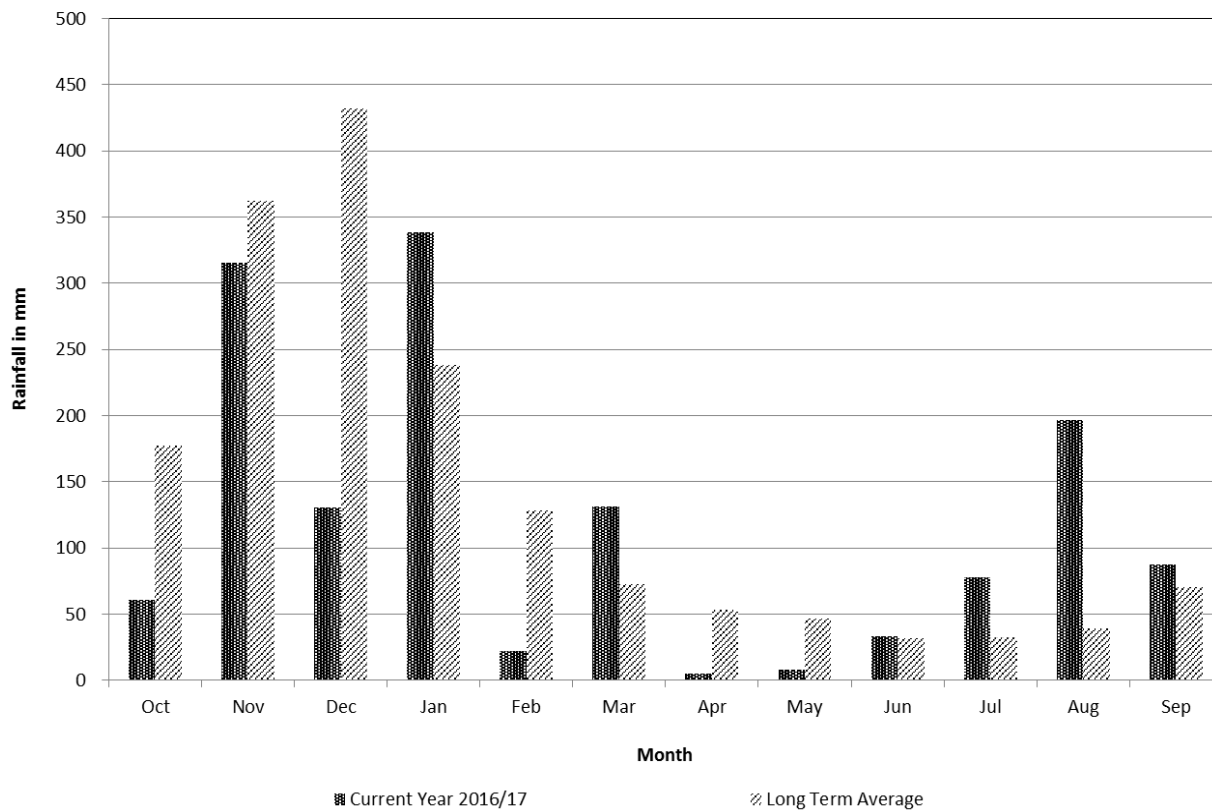
Variation of Rainfall at Badulla



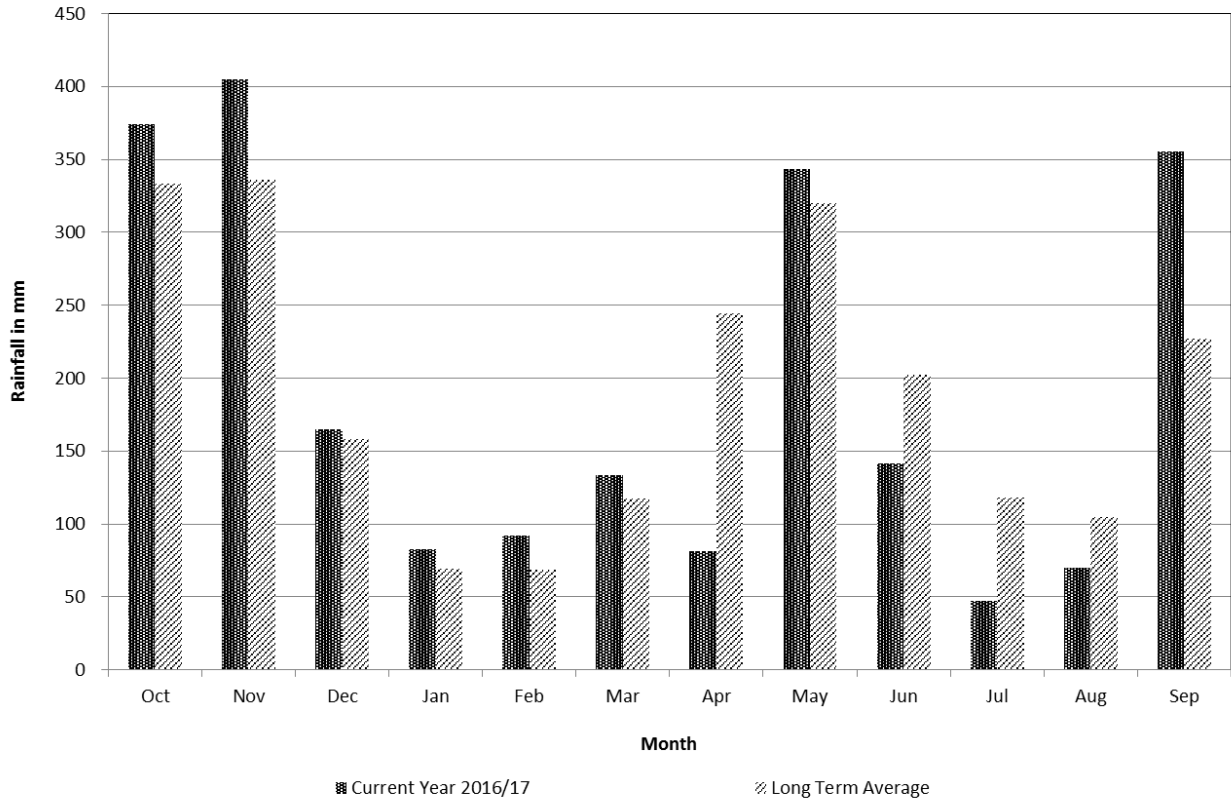
Variation of Rainfall at Bandarawela



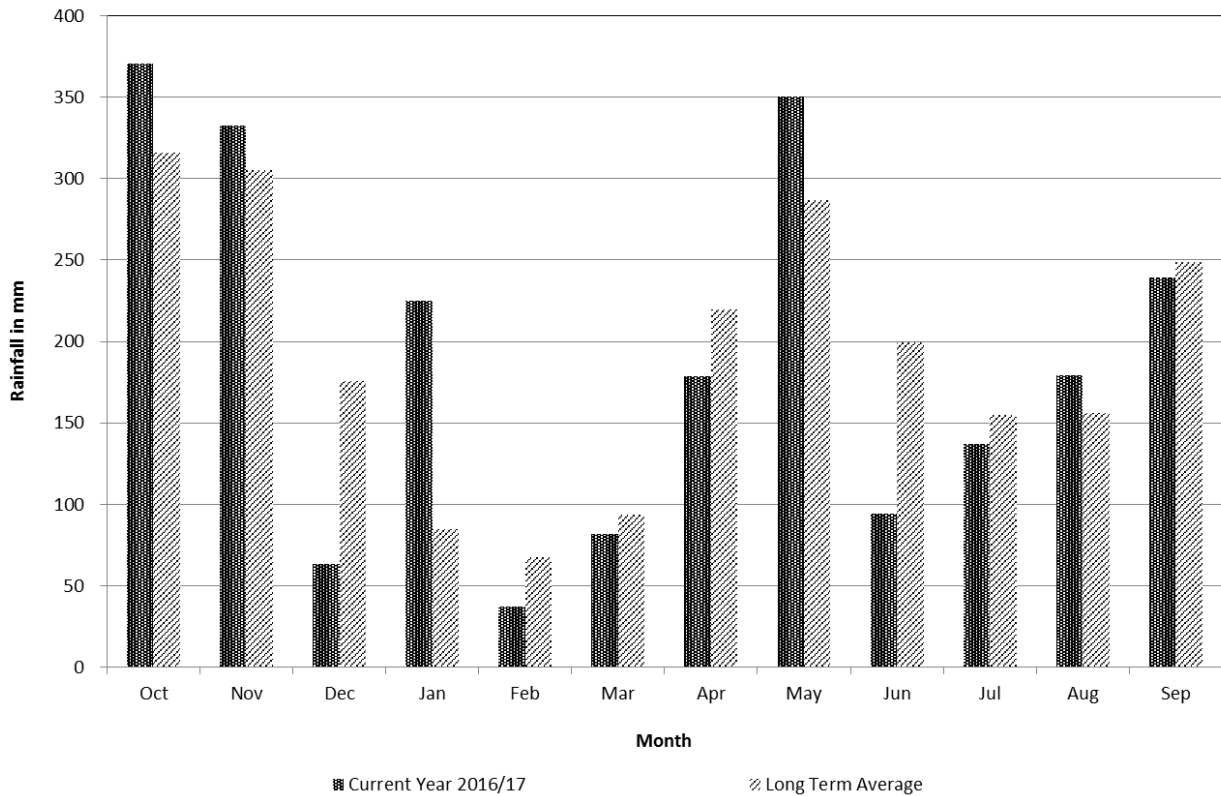
Variation of Rainfall at Batticaloa



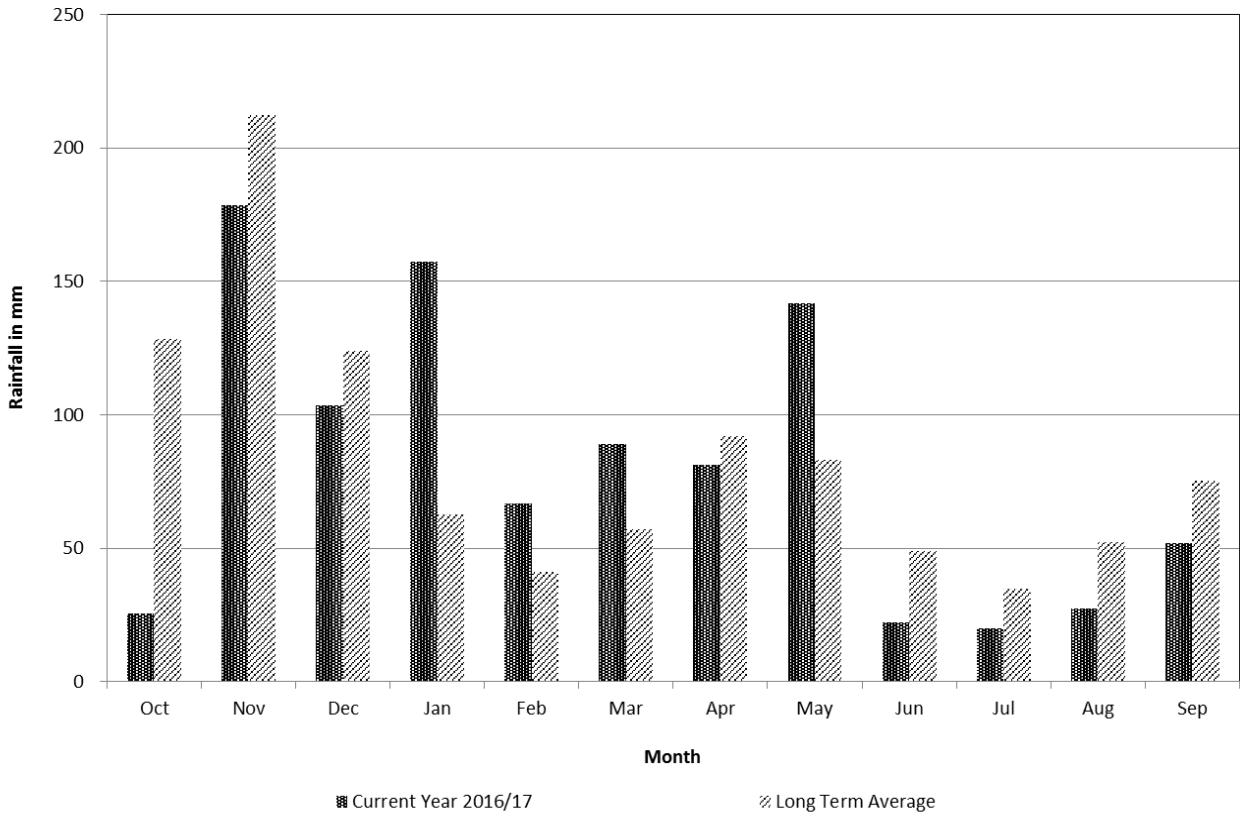
Variation of Rainfall at Colombo



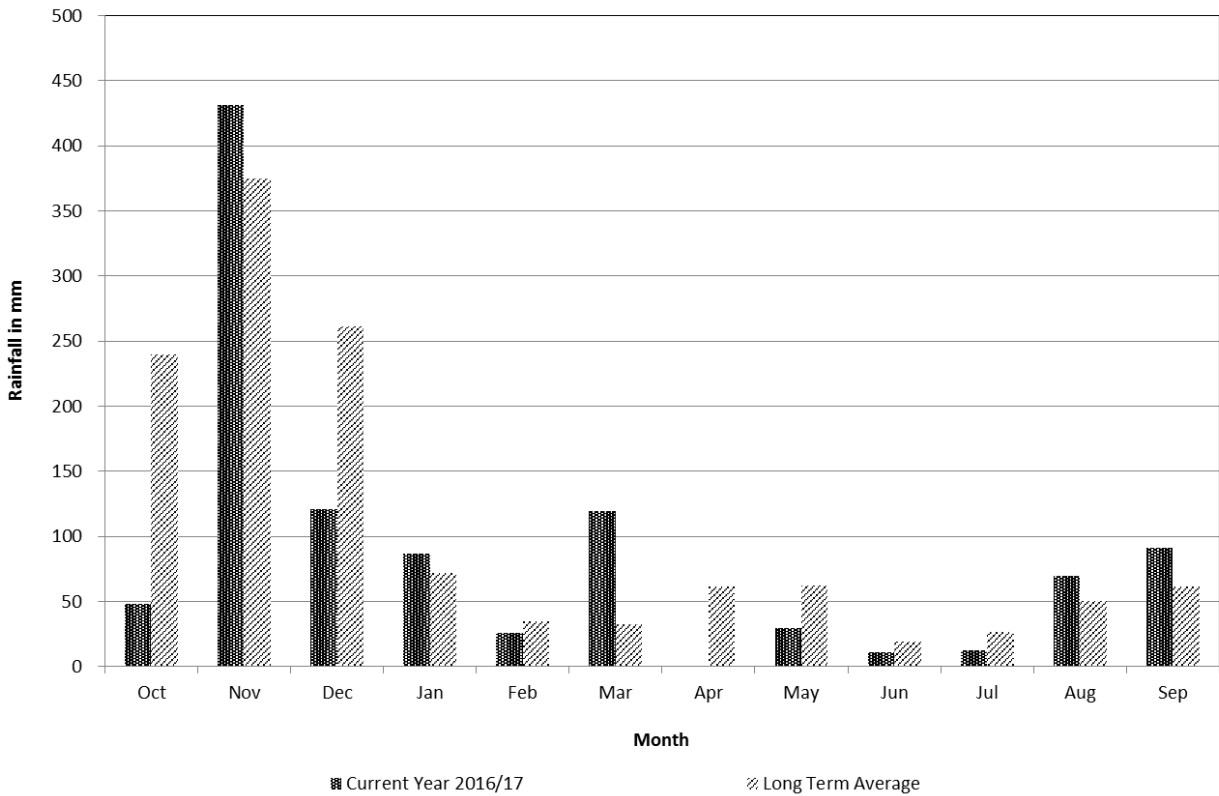
Variation of Rainfall at Galle



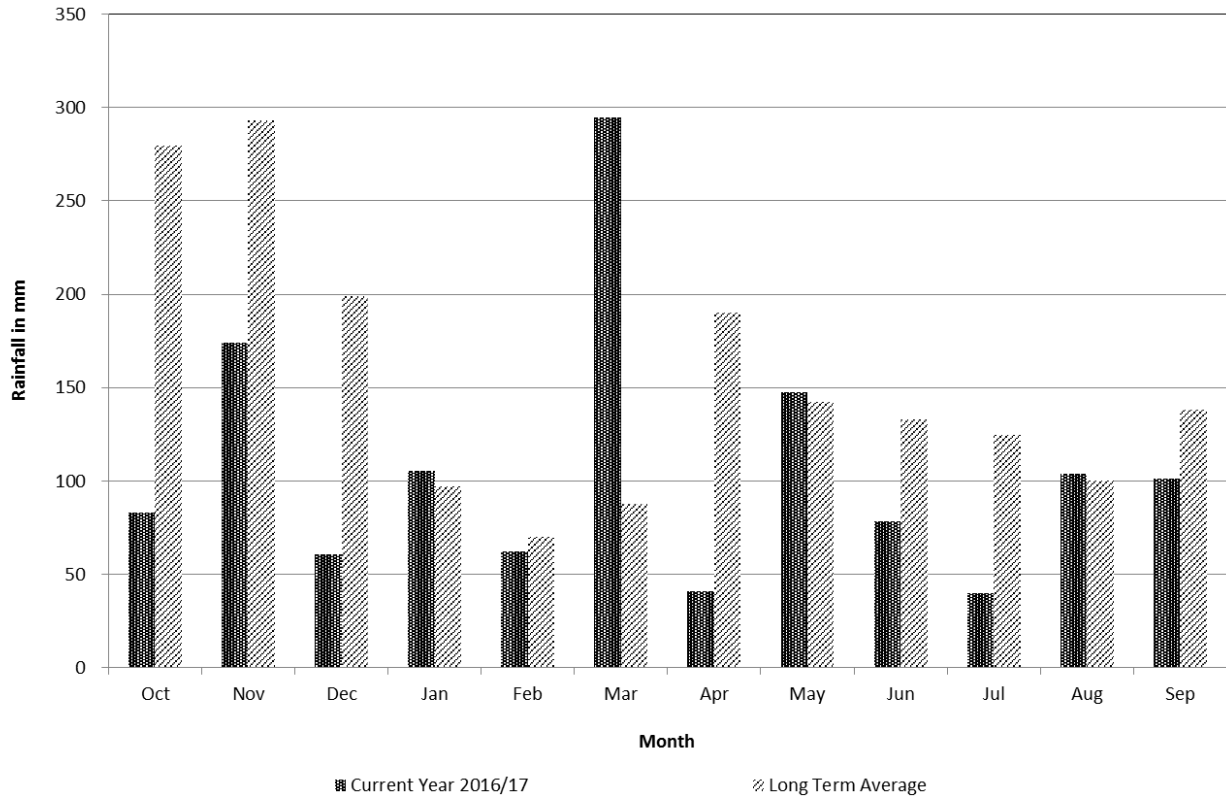
Variation of Rainfall at Hambanthota



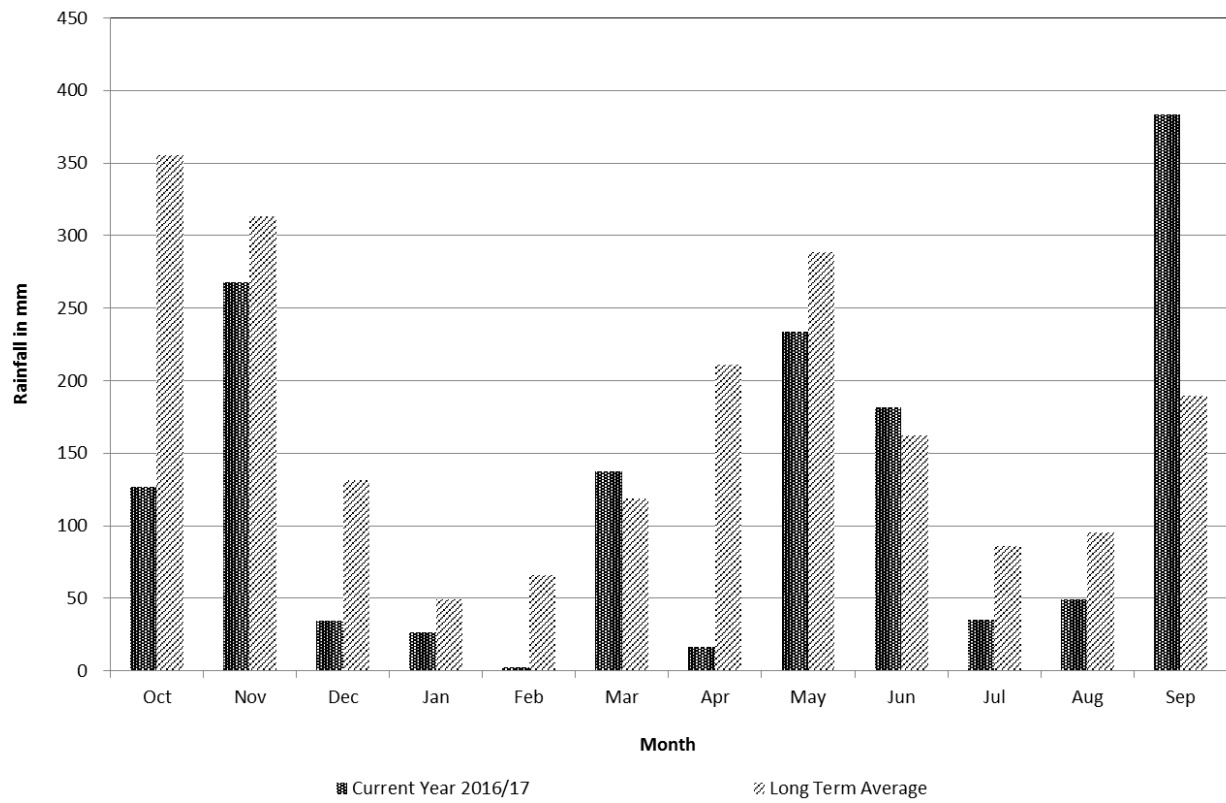
Variation of Rainfall at Jaffna



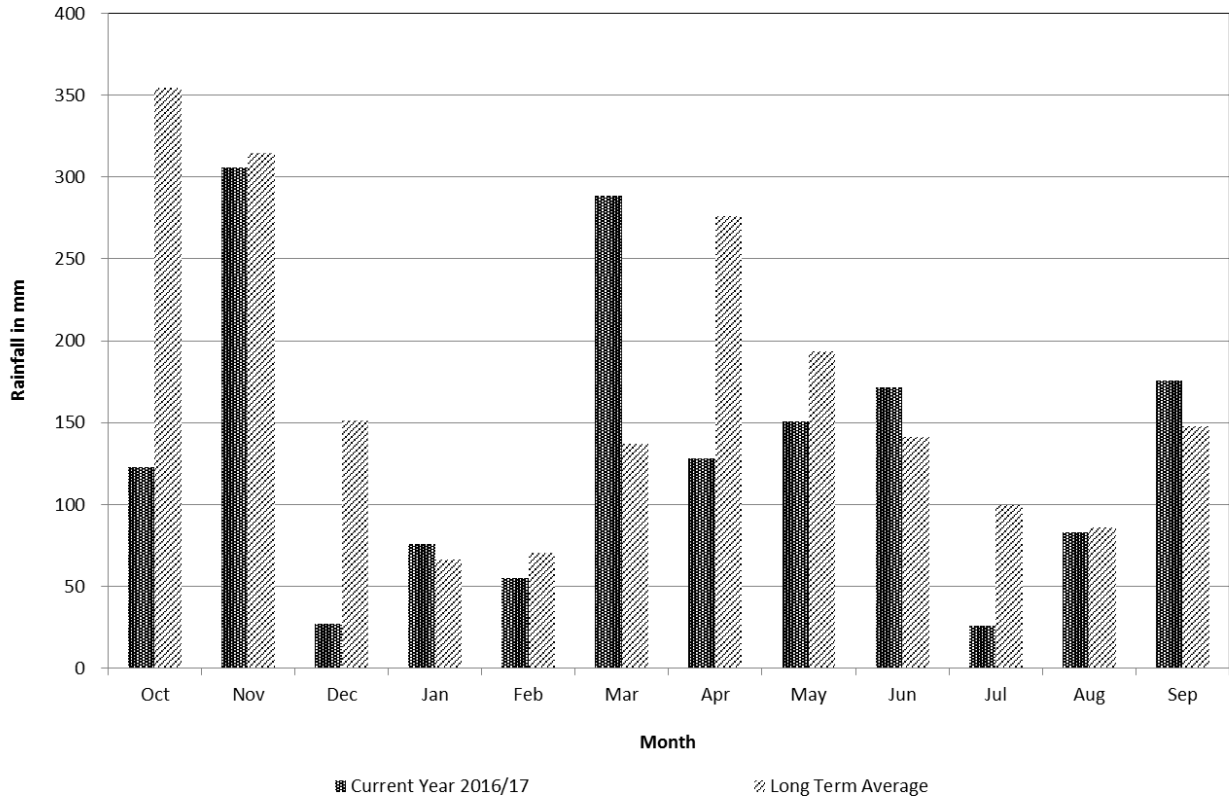
Variation of Rainfall at Katugasthota



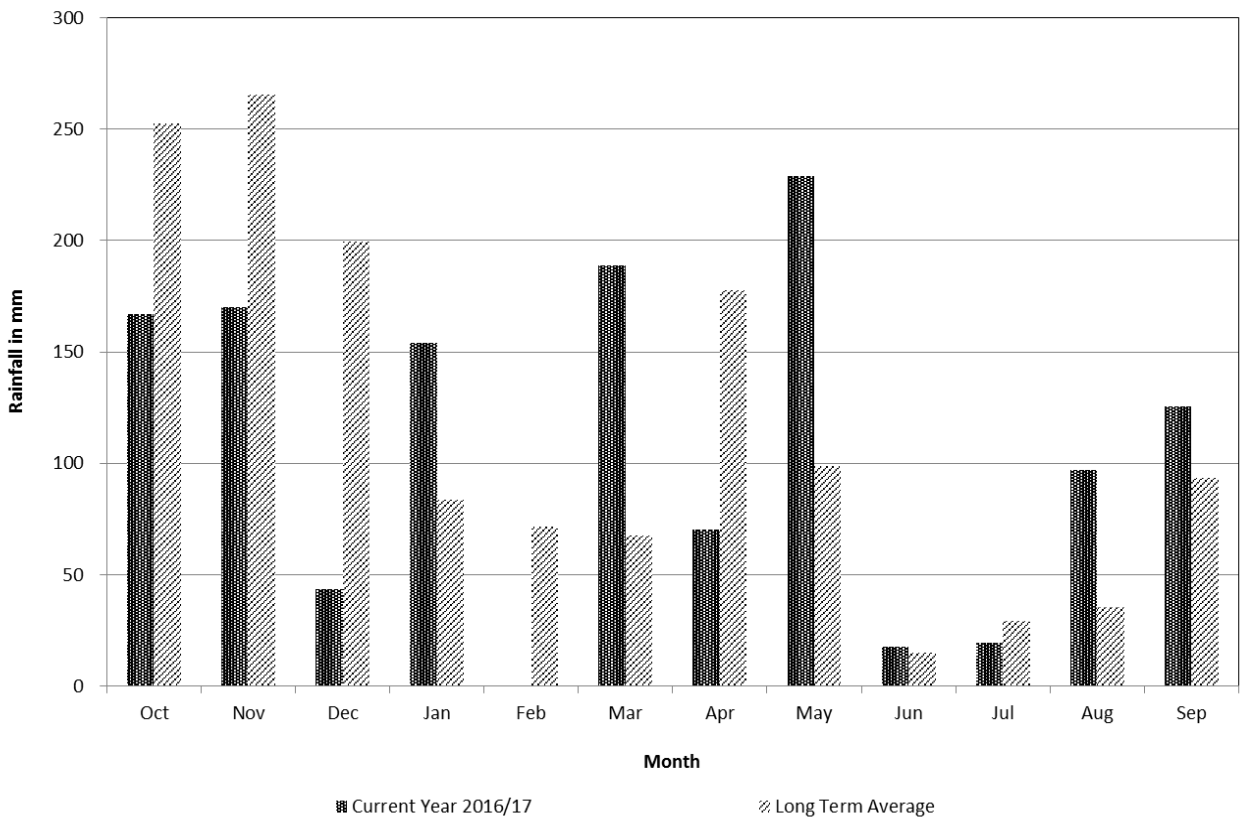
Variation of Rainfall at Katunayaka



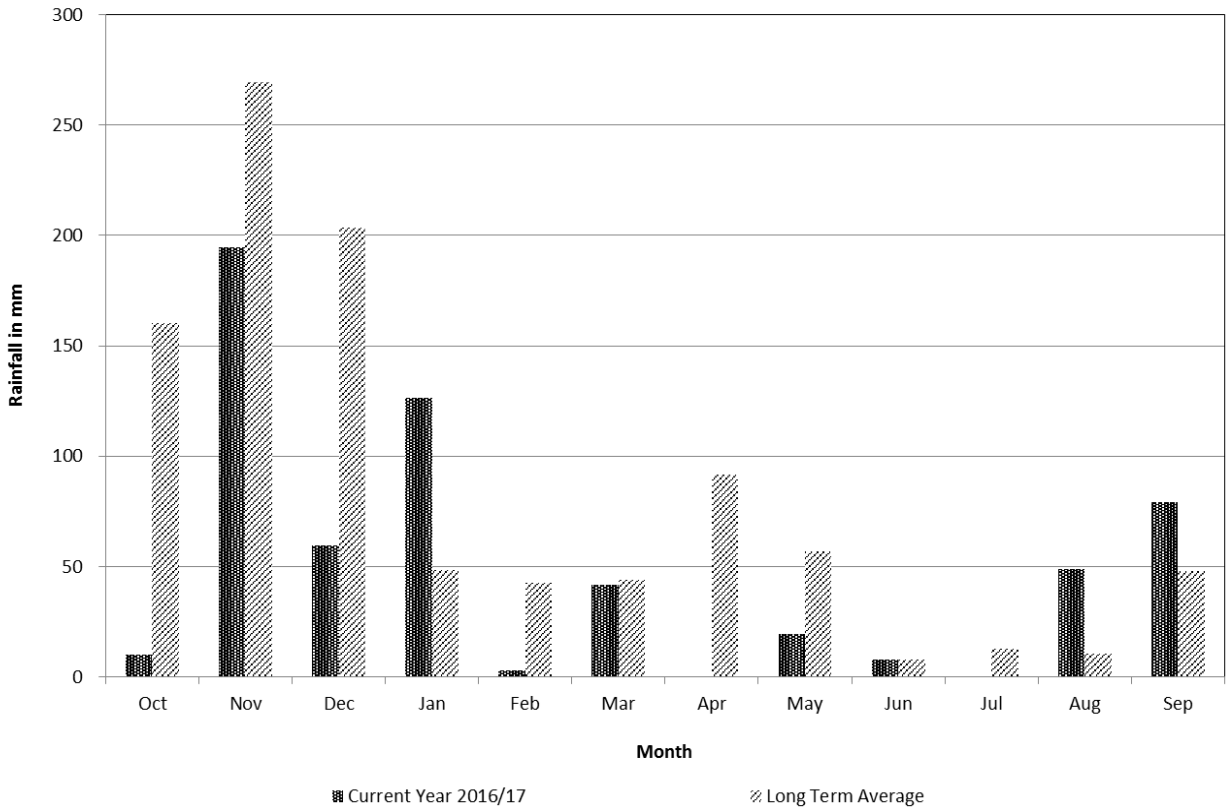
Variation of Rainfall at Kurunegala



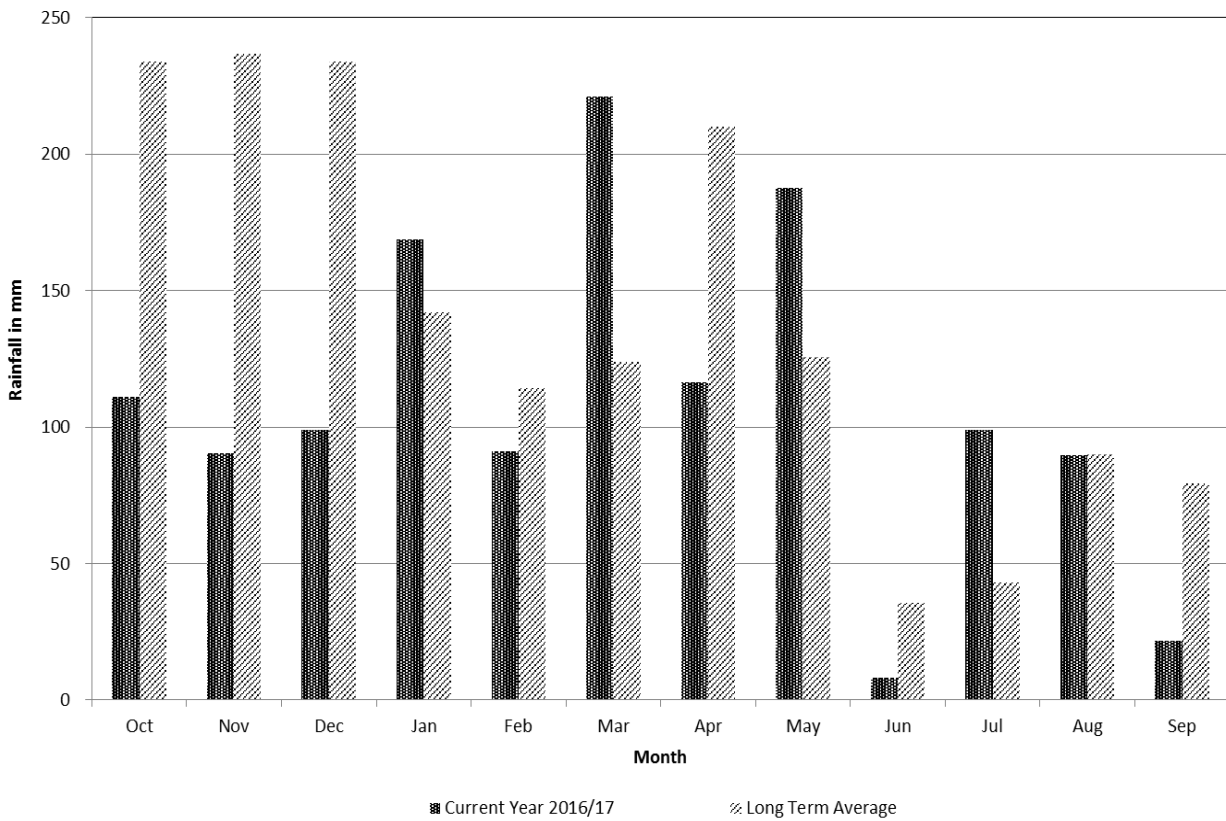
Variation of Rainfall at Mahailuppallama



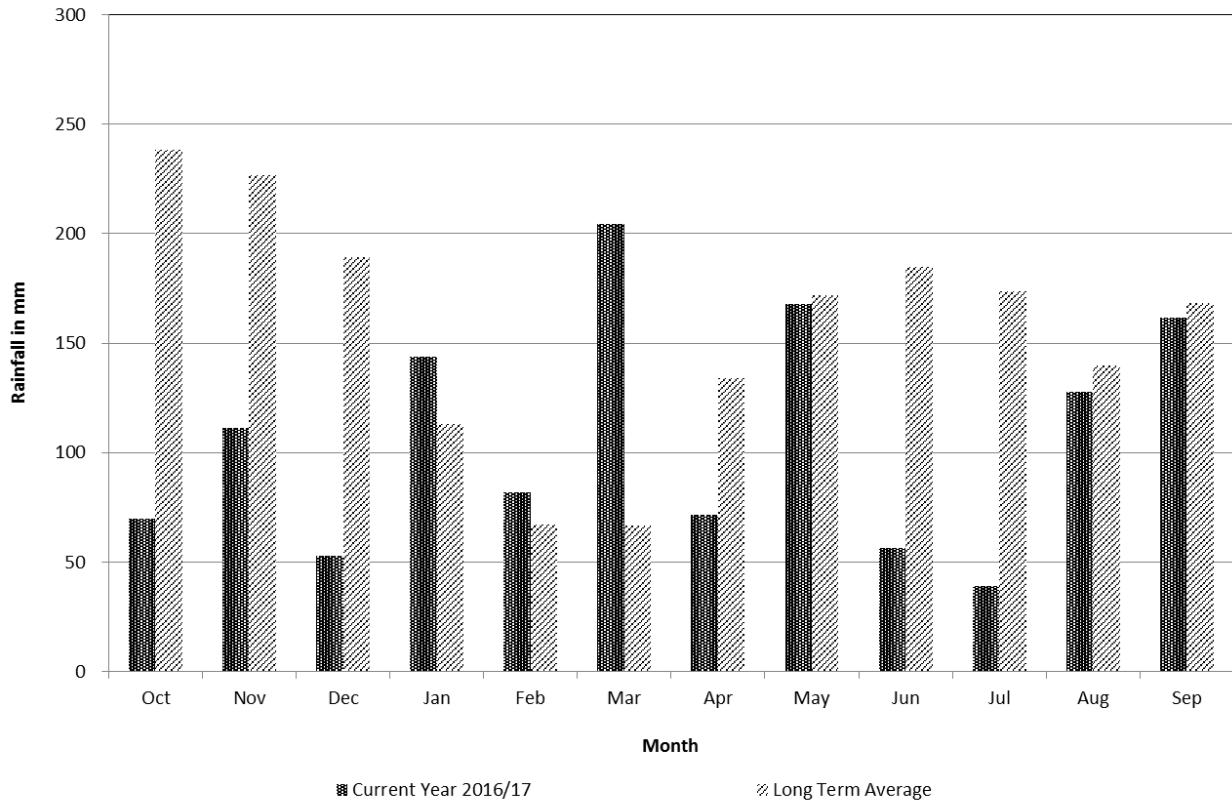
Variation of Rainfall at Mannar



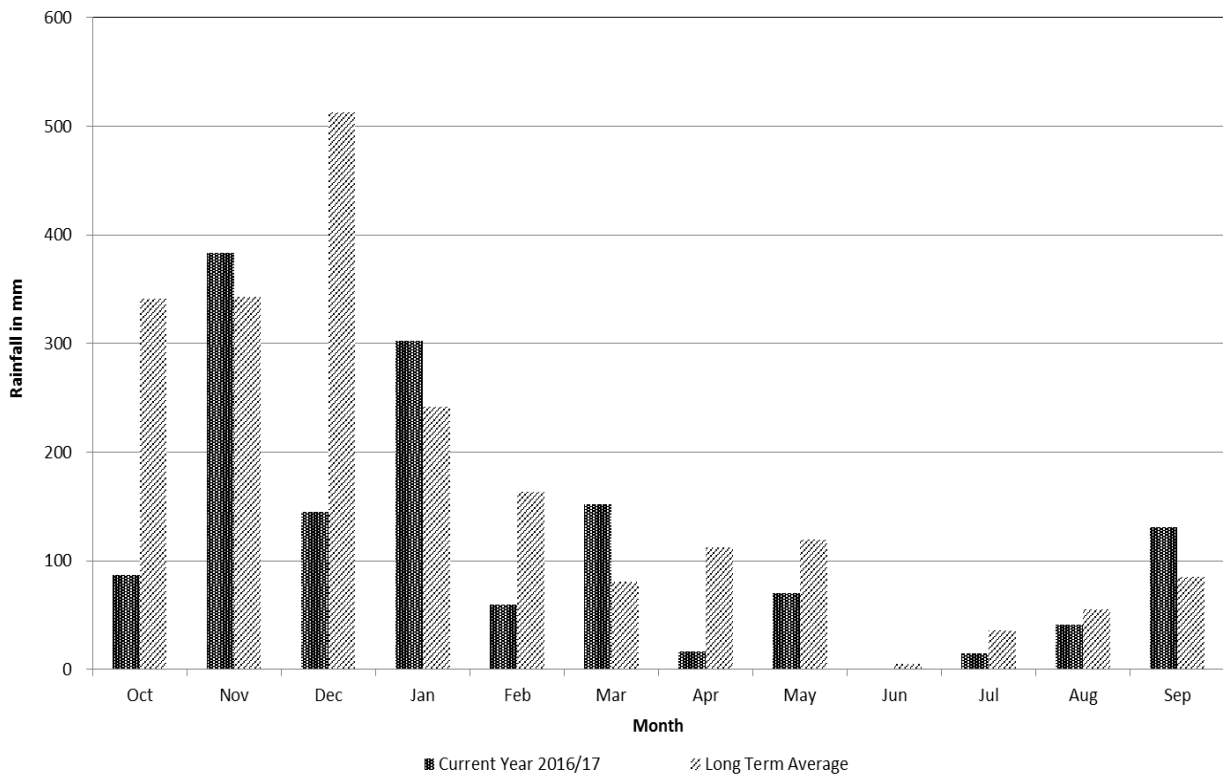
Variation of Rainfall at Monaragala



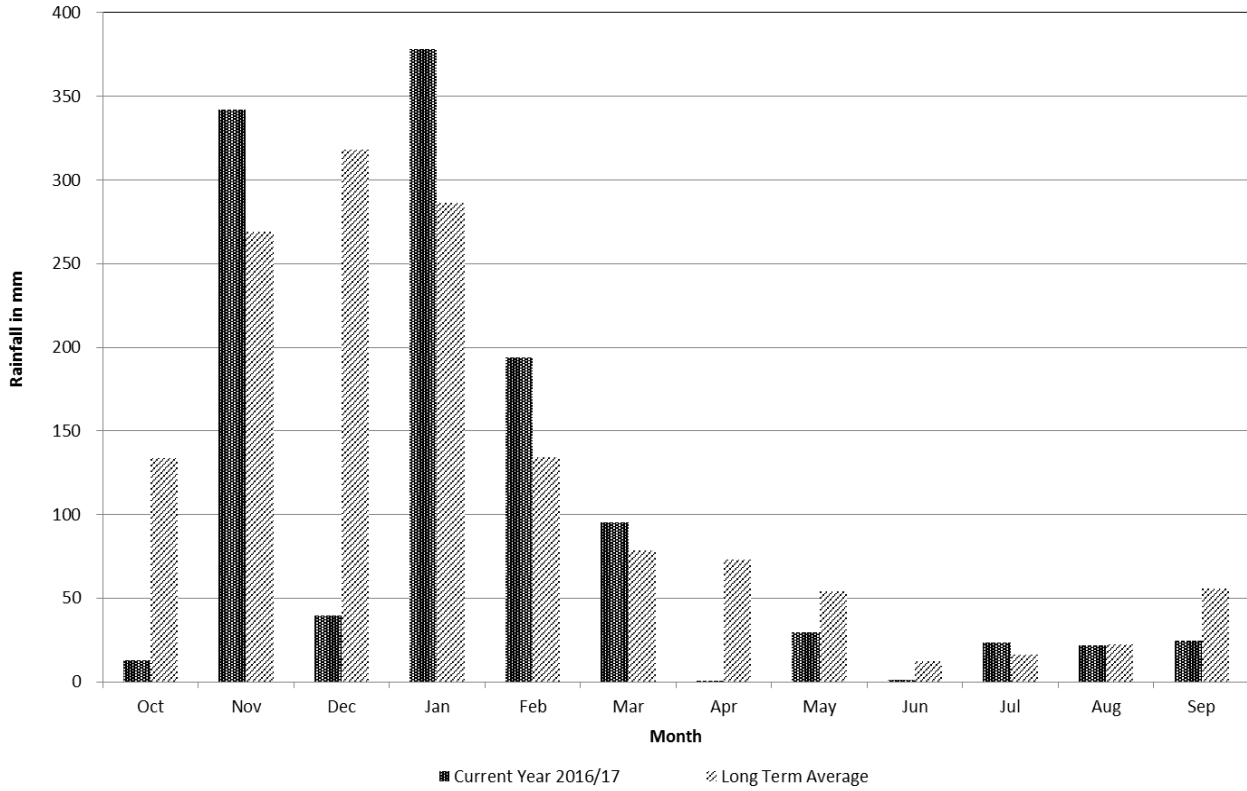
Variation of Rainfall at Nuwara Eliya



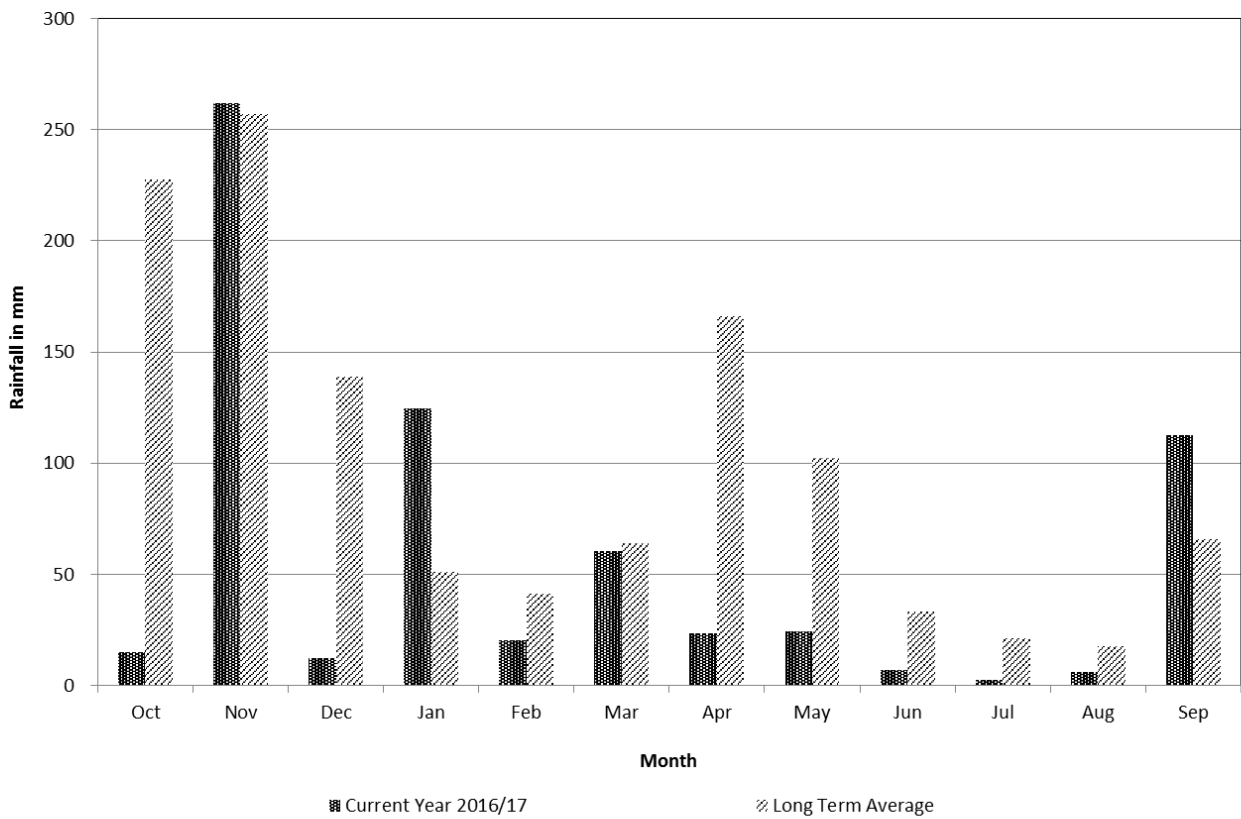
Variation of Rainfall at Polonnaruwa



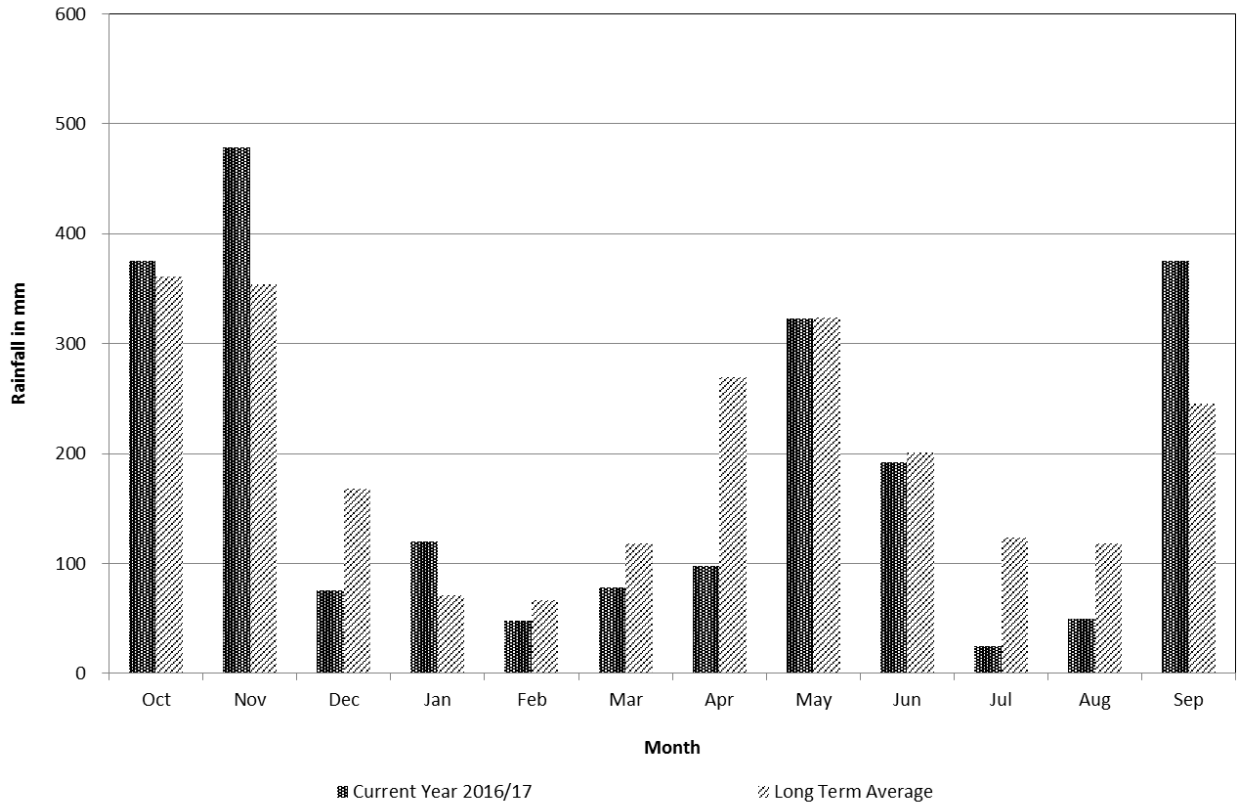
Variation of Rainfall at Potuvil



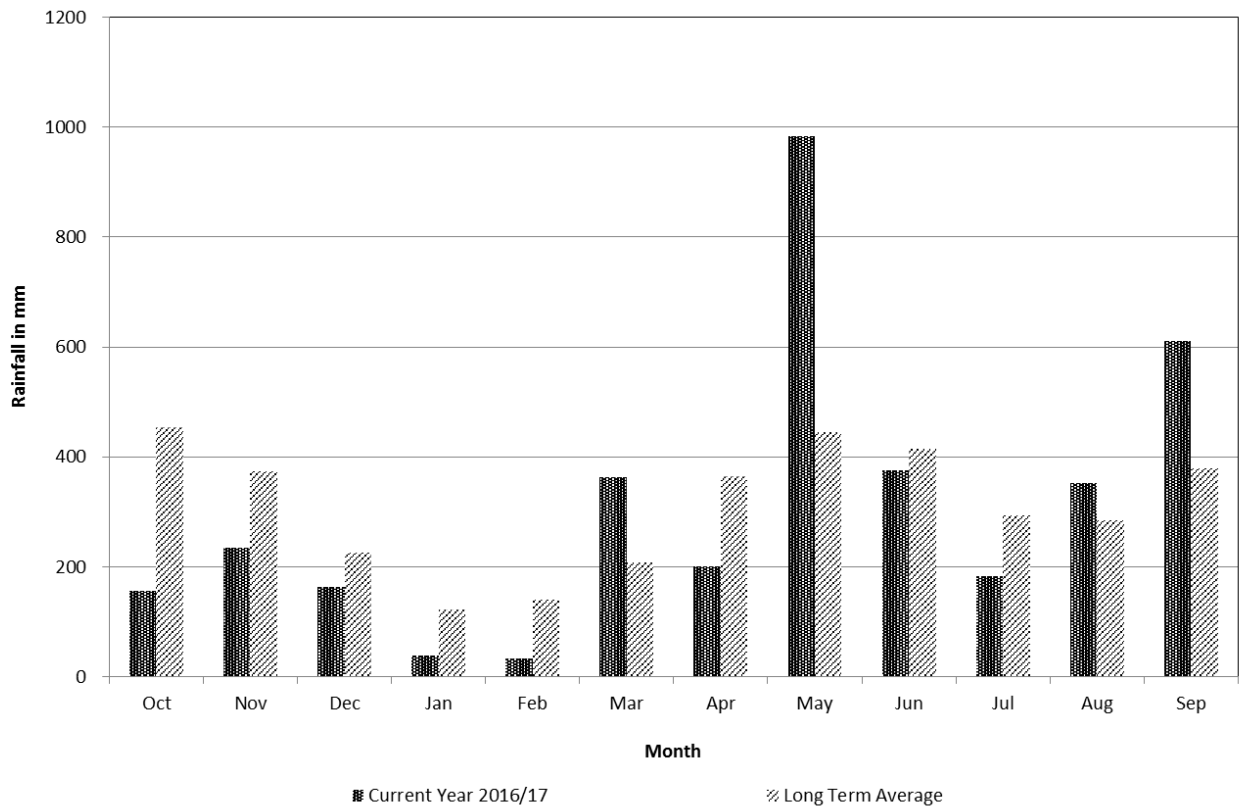
Variation of Rainfall at Puttalam



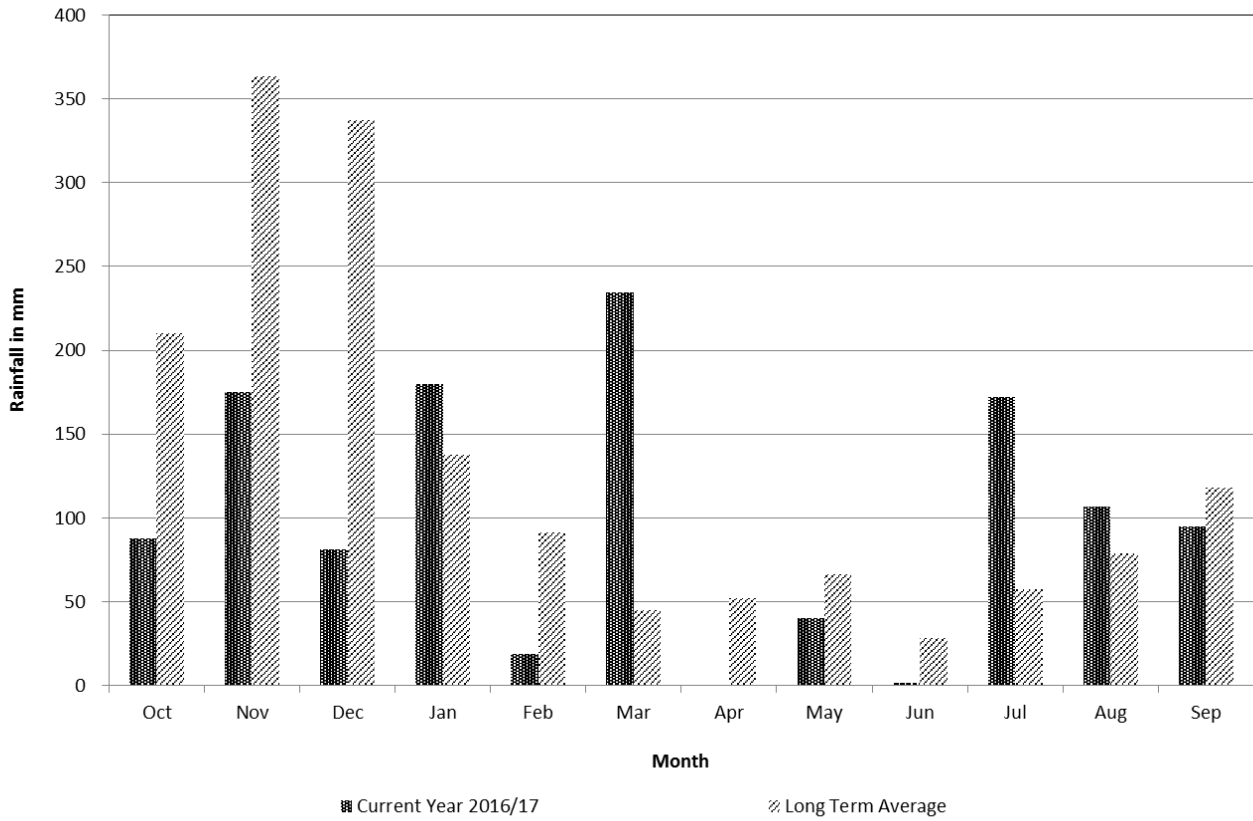
Variation of Rainfall at Rathmalana



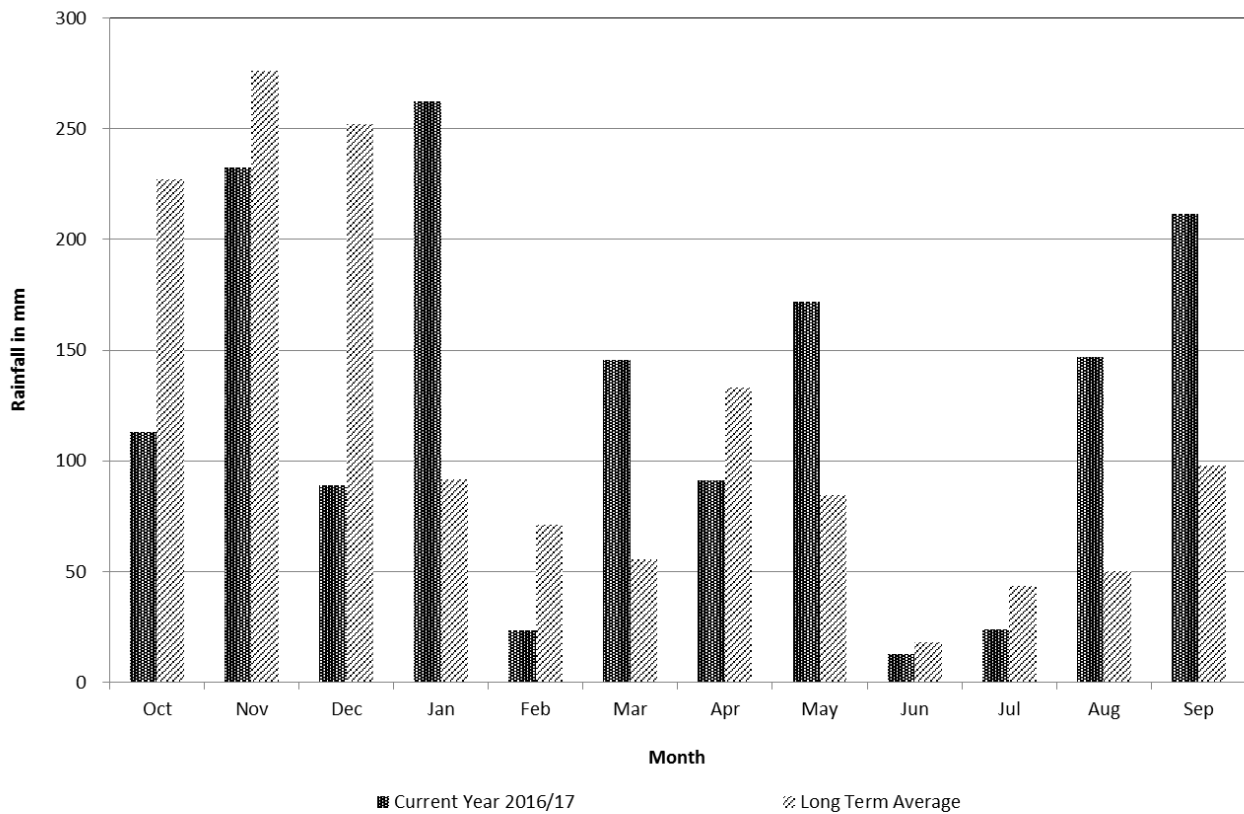
Variation of Rainfall at Rathnapura



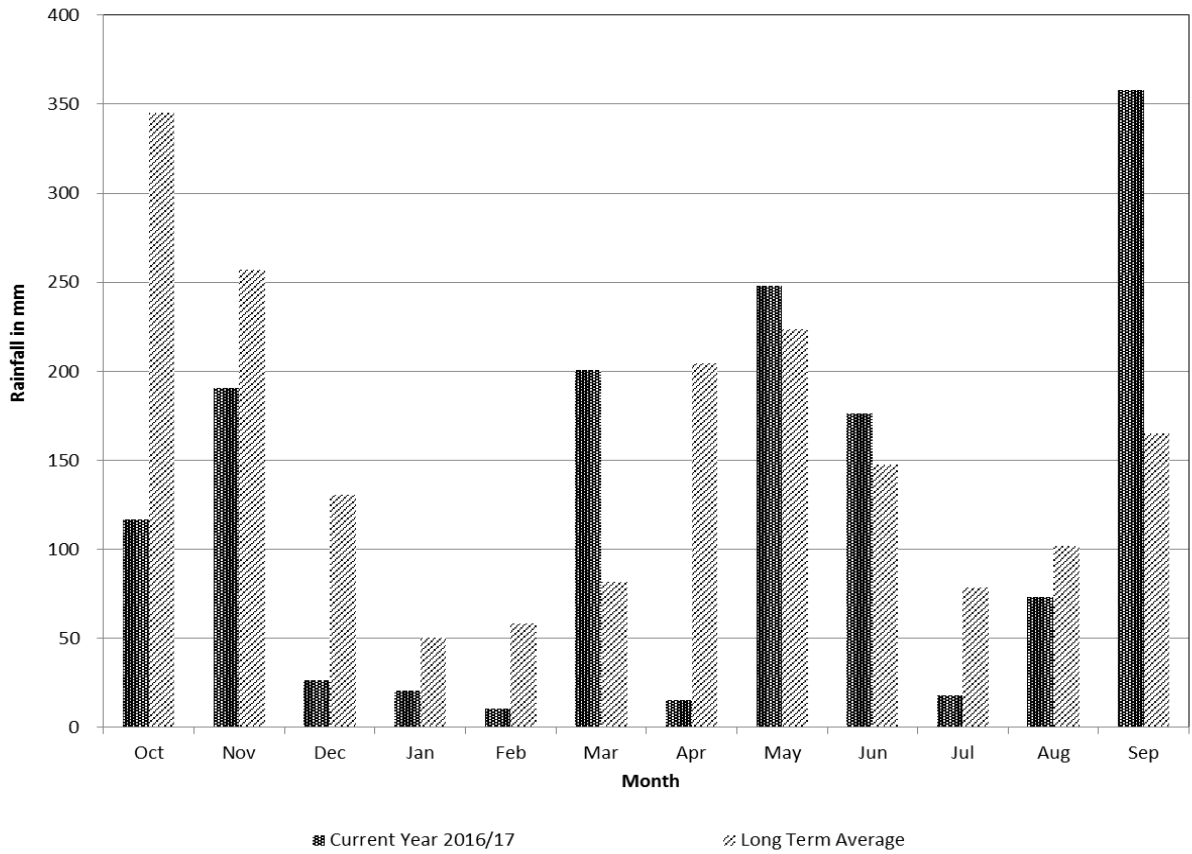
Variation of Rainfall at Trincomalee



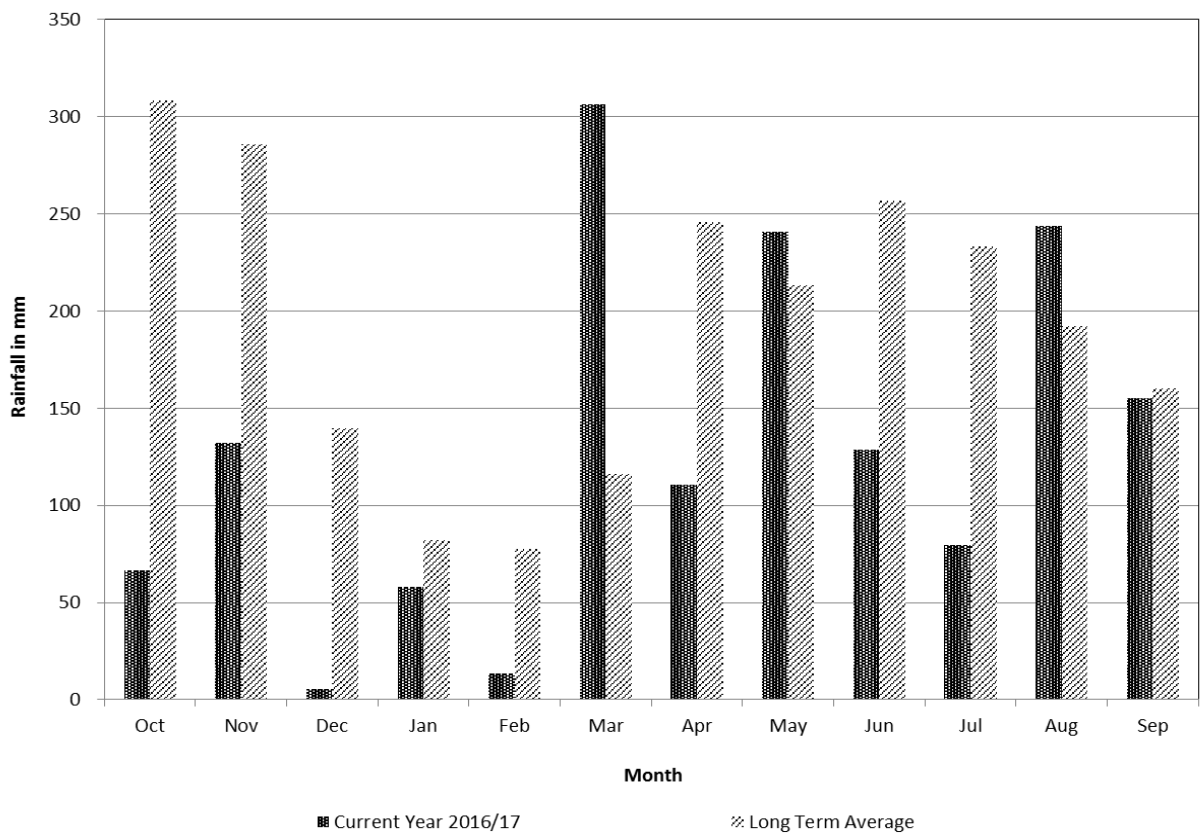
Variation of Rainfall at Vauniya



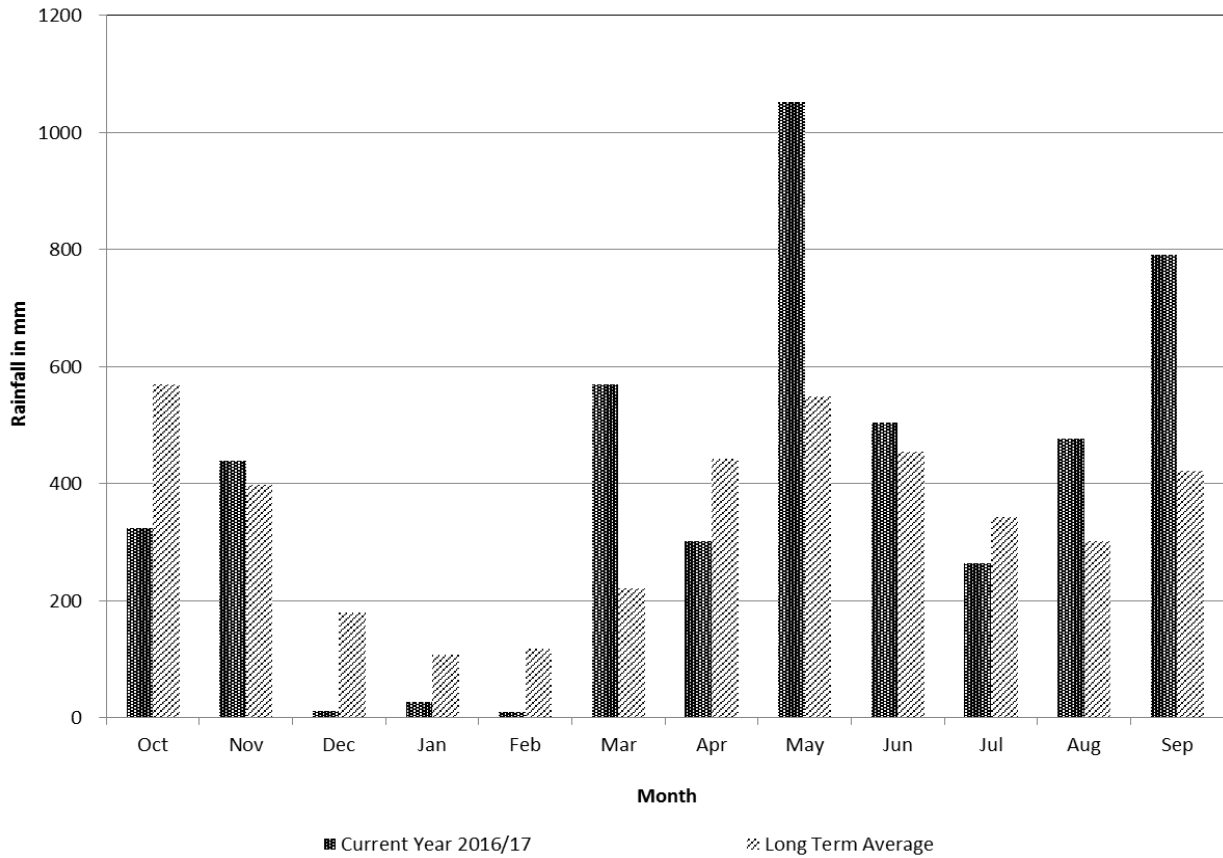
Variation of Rainfall at Badalgama



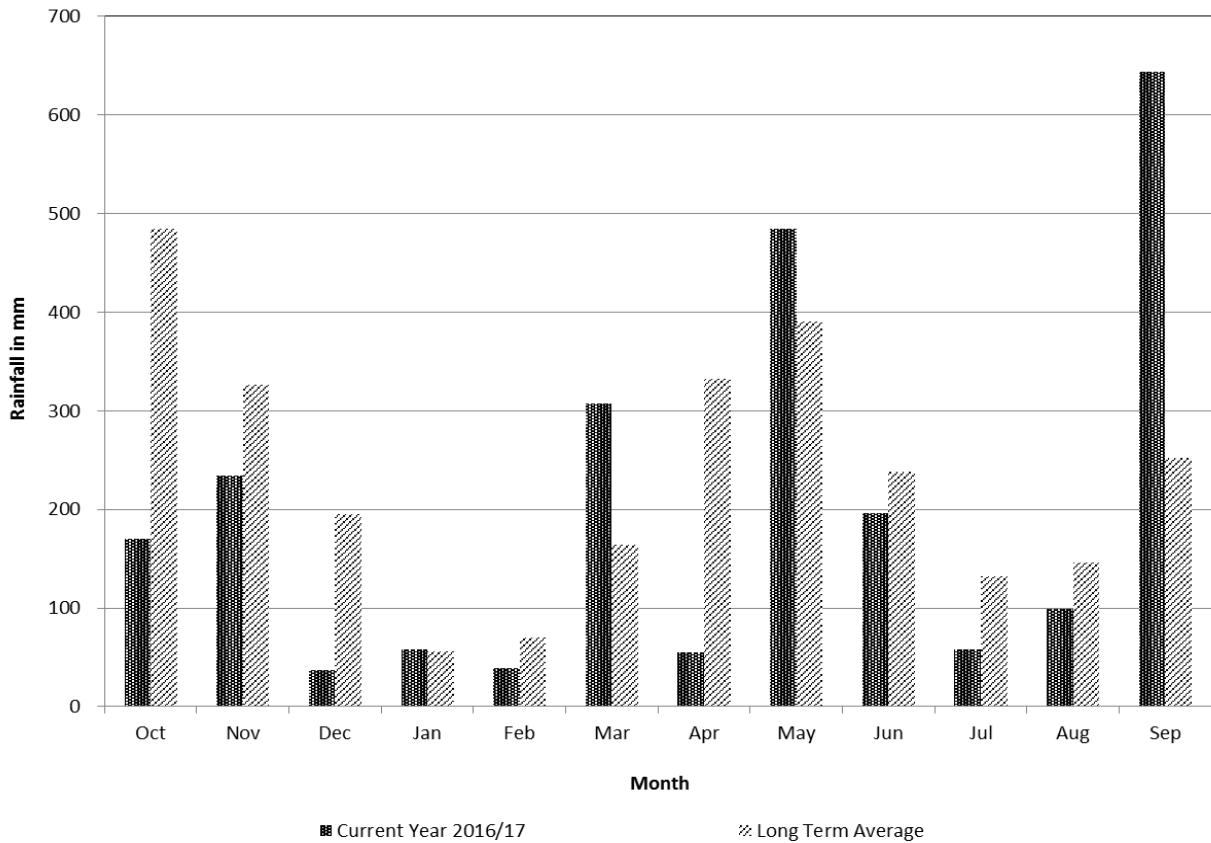
Variation of Rainfall at Calidonia



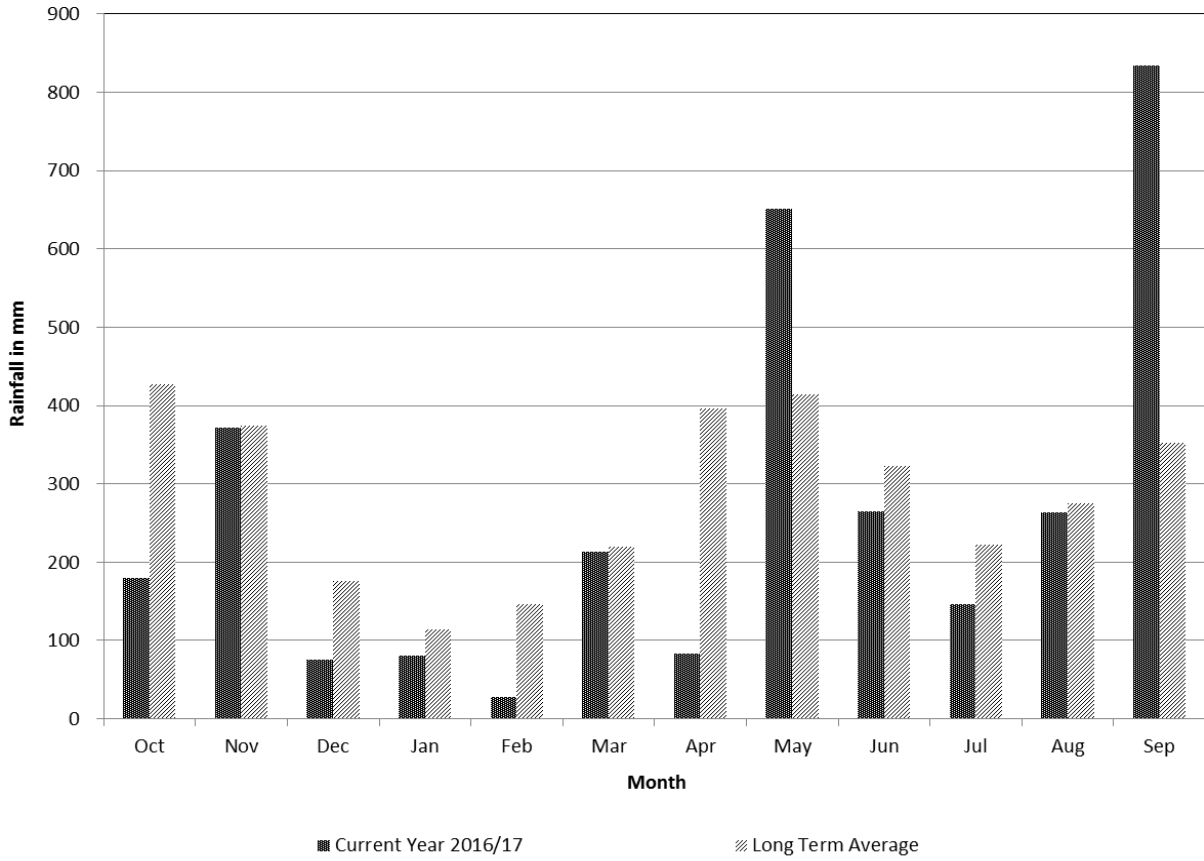
Variation of Rainfall at Deraniyagala



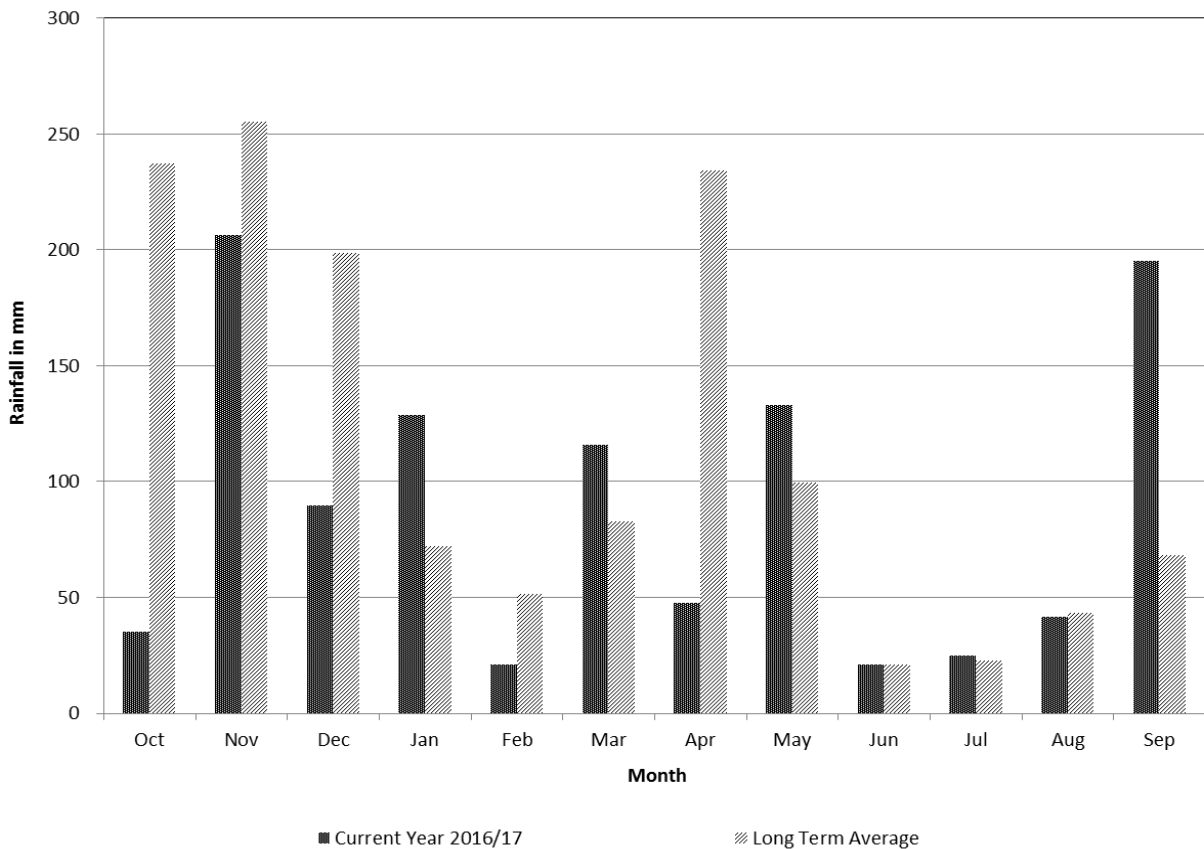
Variation of Rainfall at Dunamale



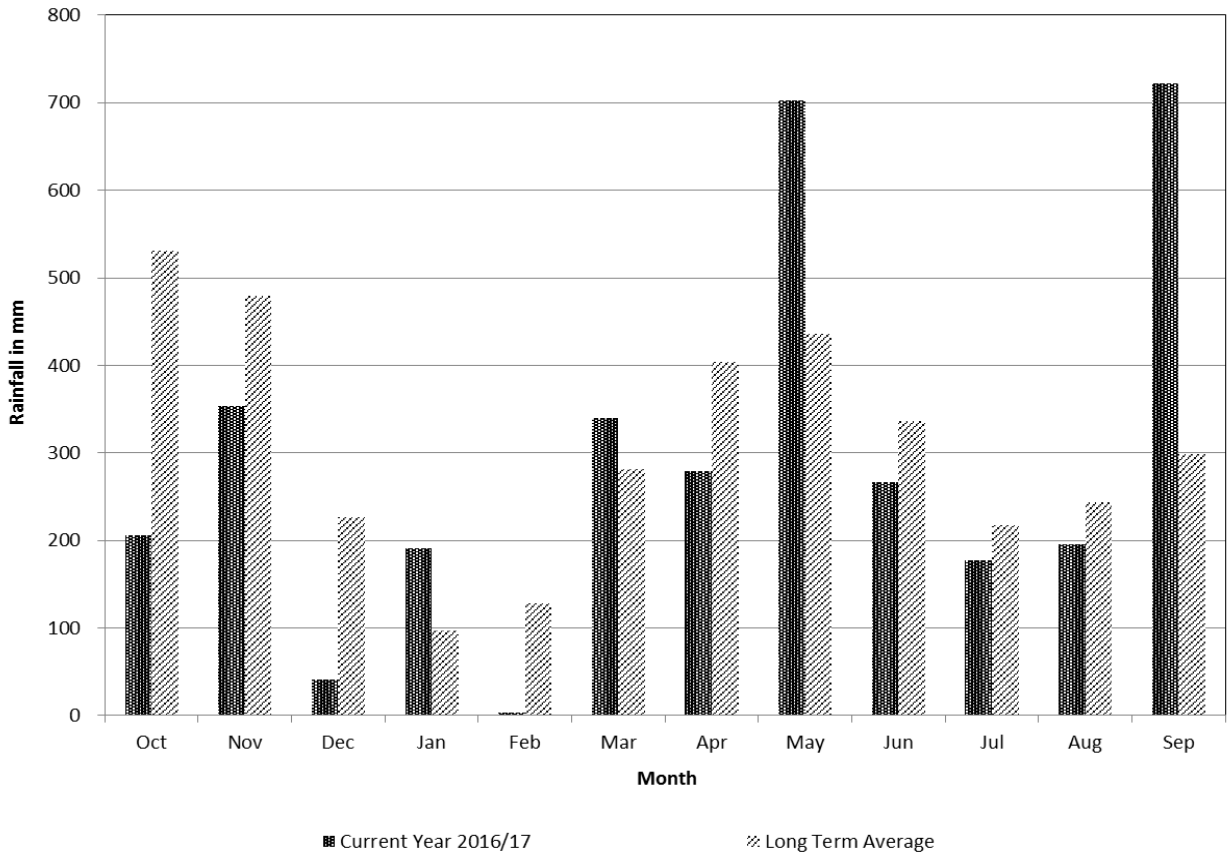
Variation of Rainfall at Ellagawa



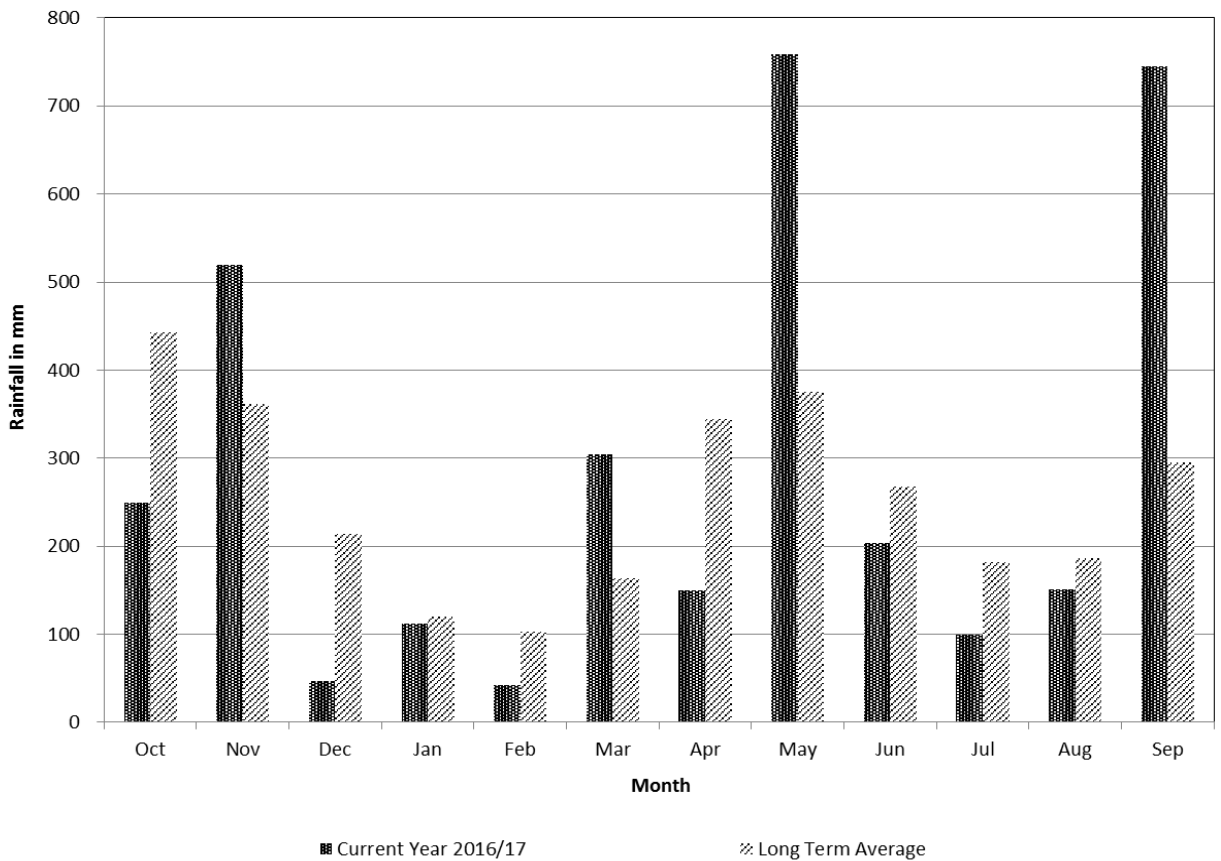
Variation of Rainfall at Galgamuwa



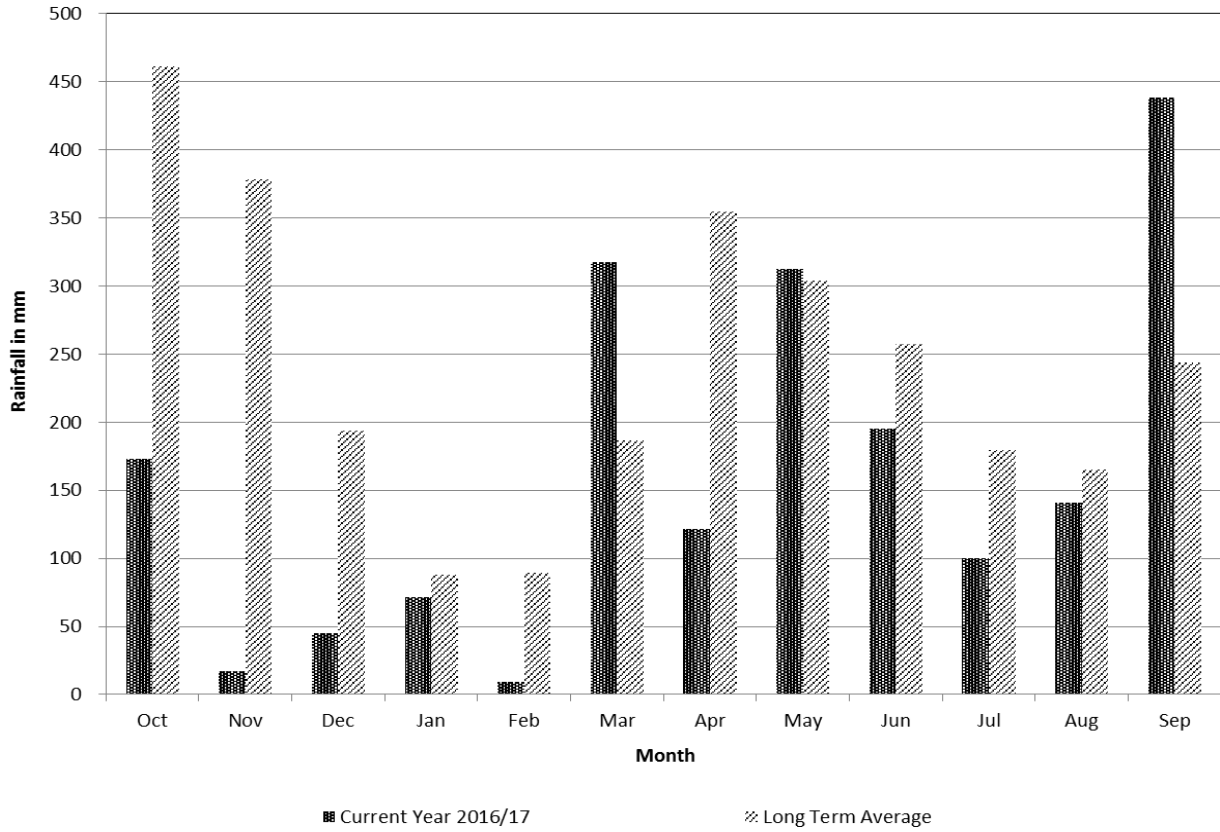
Variation of Rainfall at Glencourse



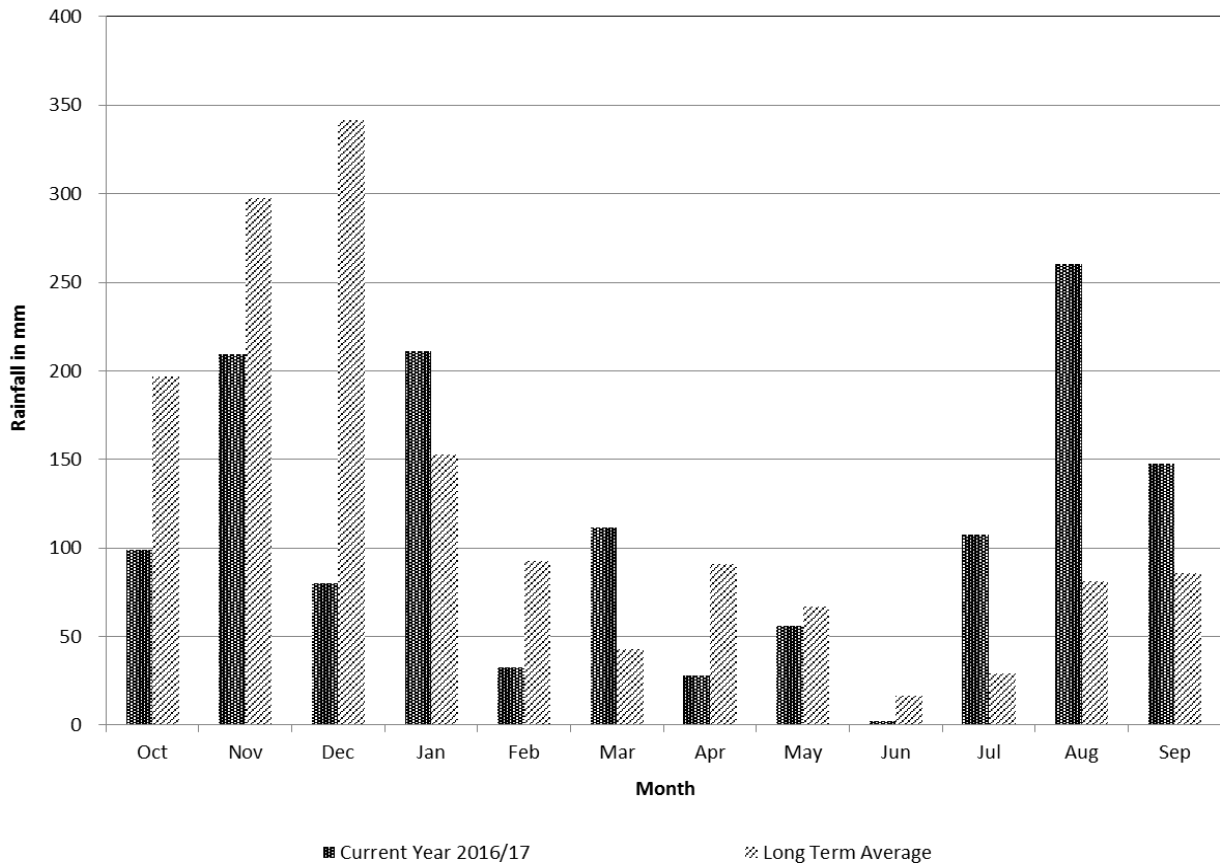
Variation of Rainfall at Hanwella



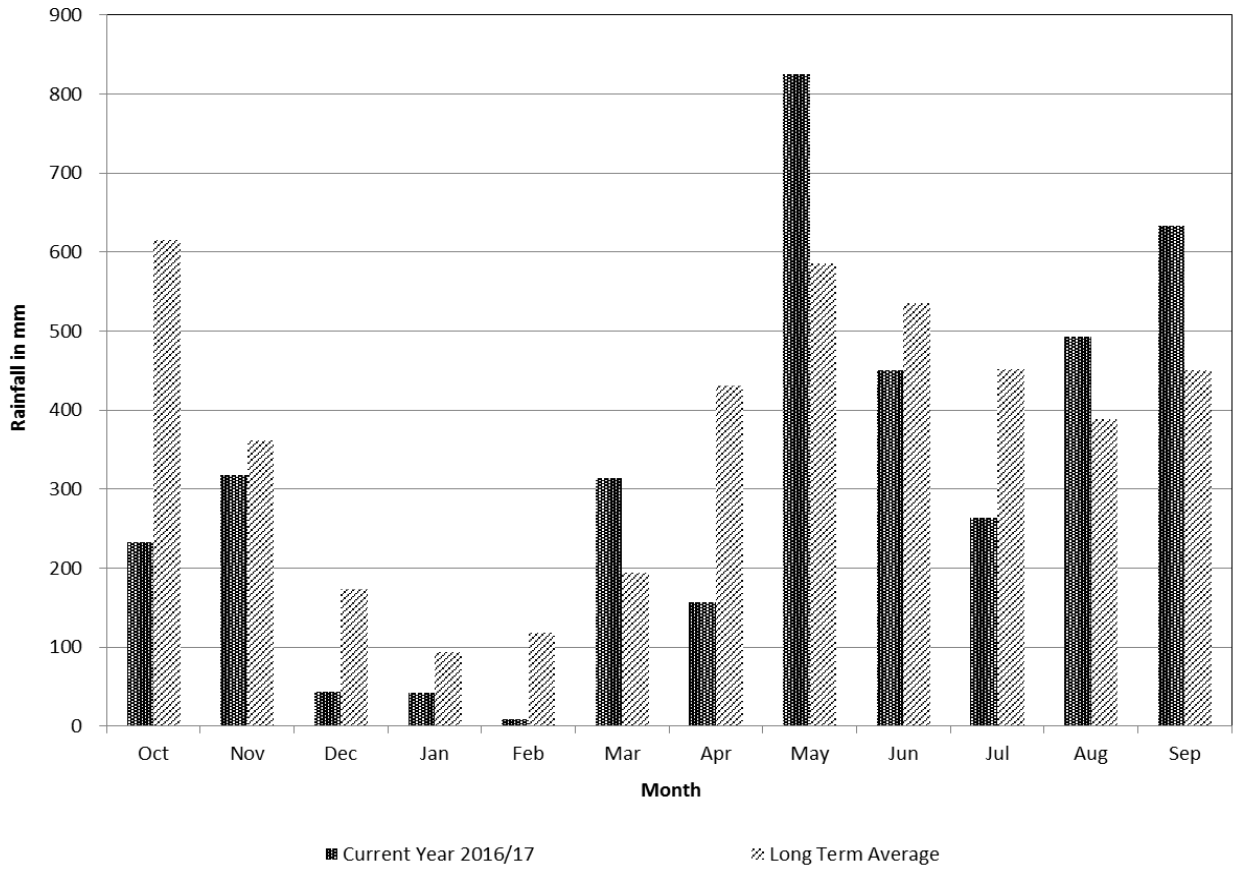
Variation of Rainfall at Holombuwa



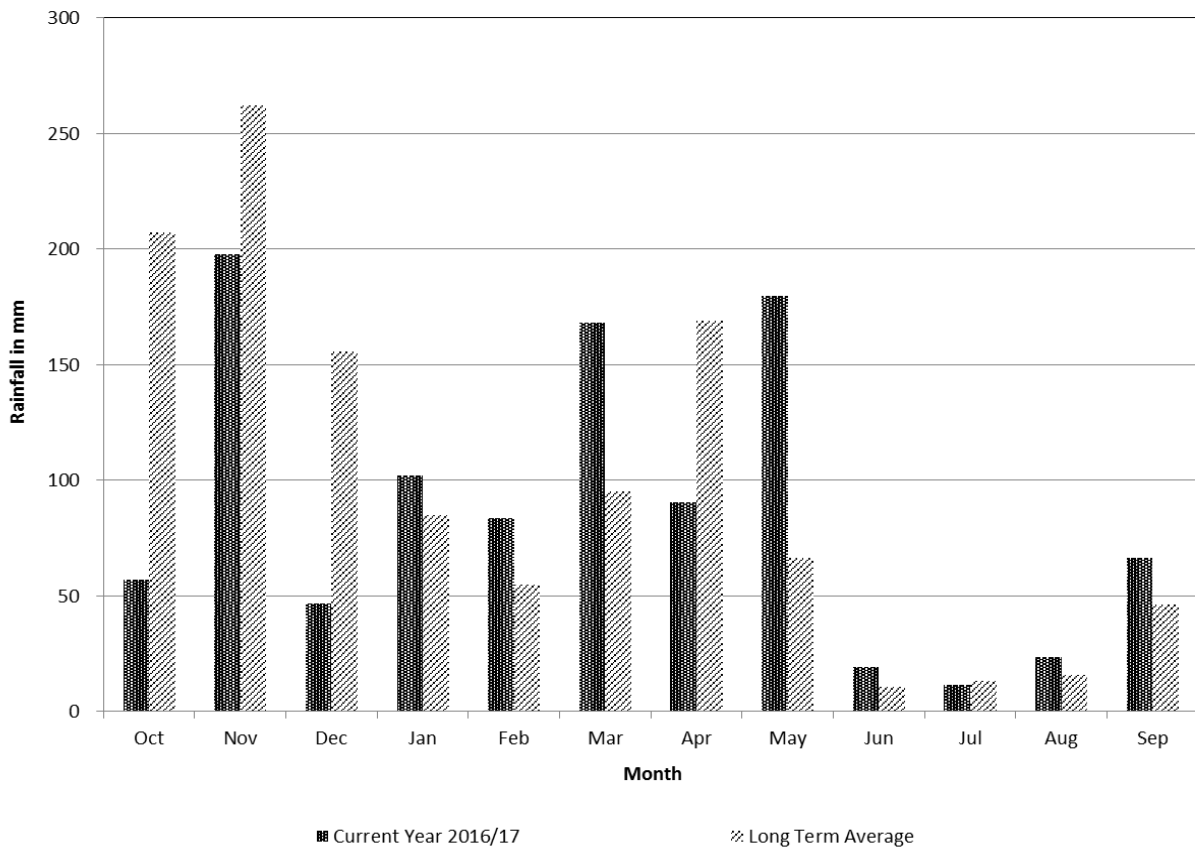
Variation of Rainfall at Horowpothana



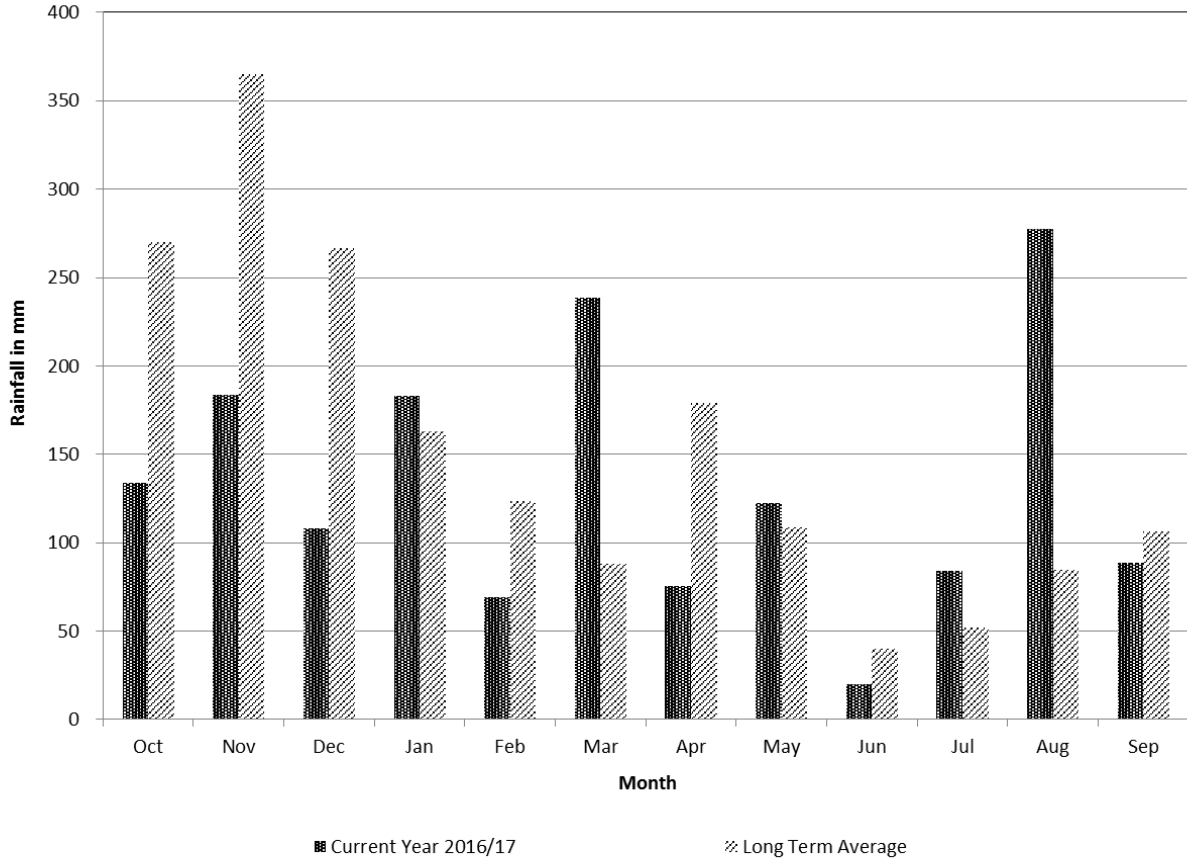
Variation of Rainfall at Kithulgala



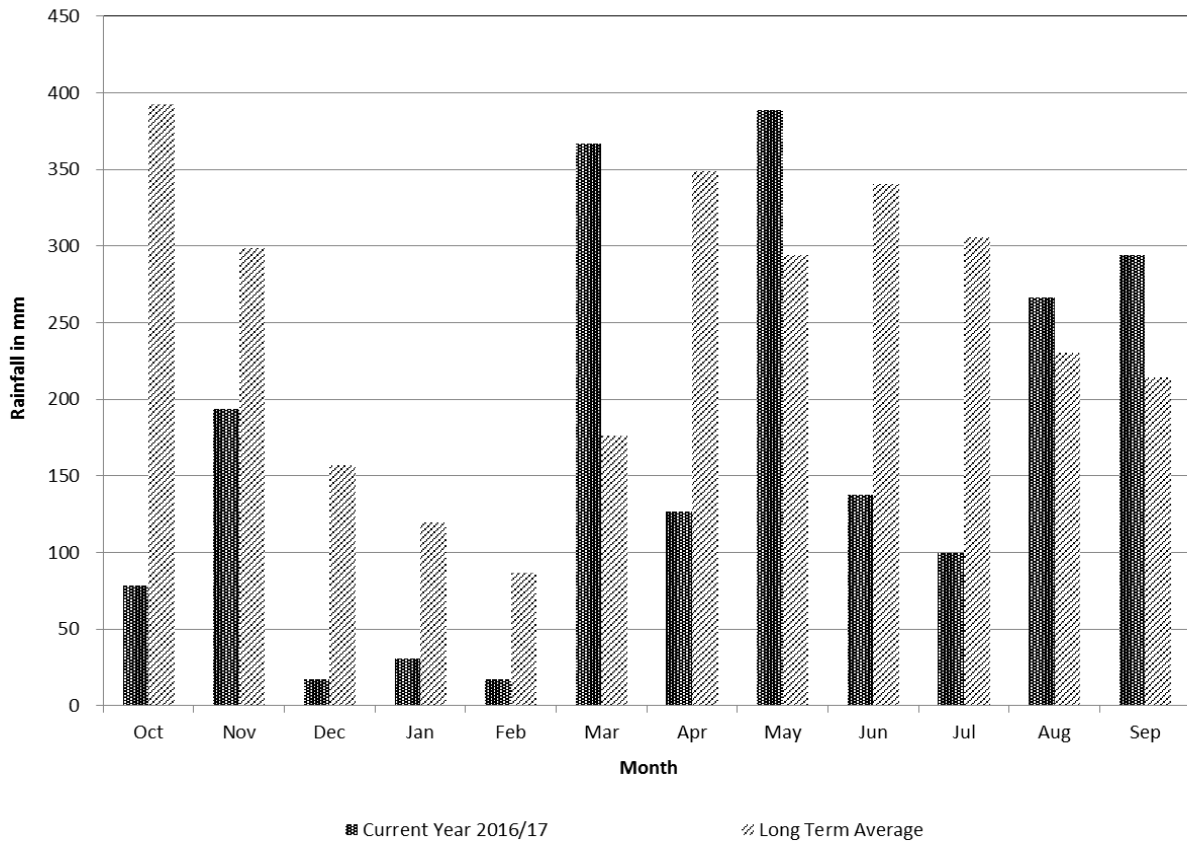
Variation of Rainfall at Kuda Oya



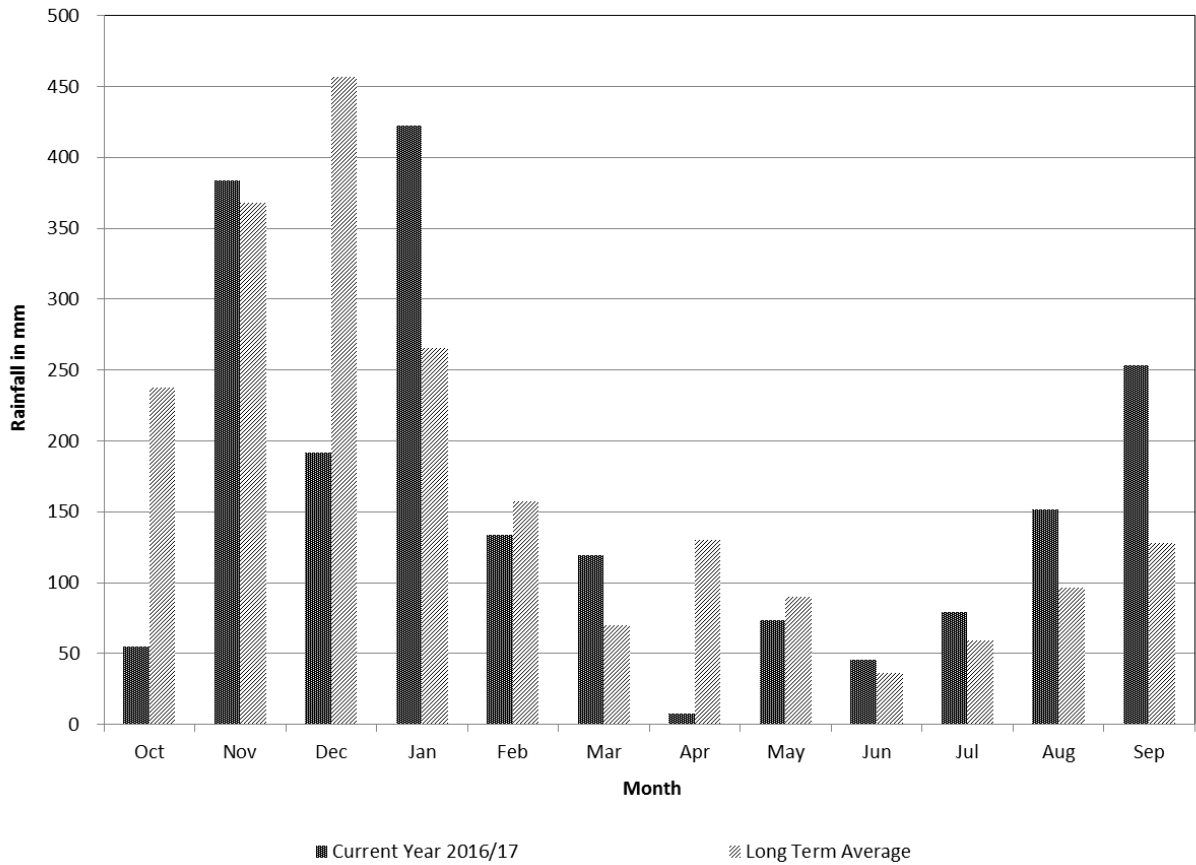
Variation of Rainfall at Nakkala



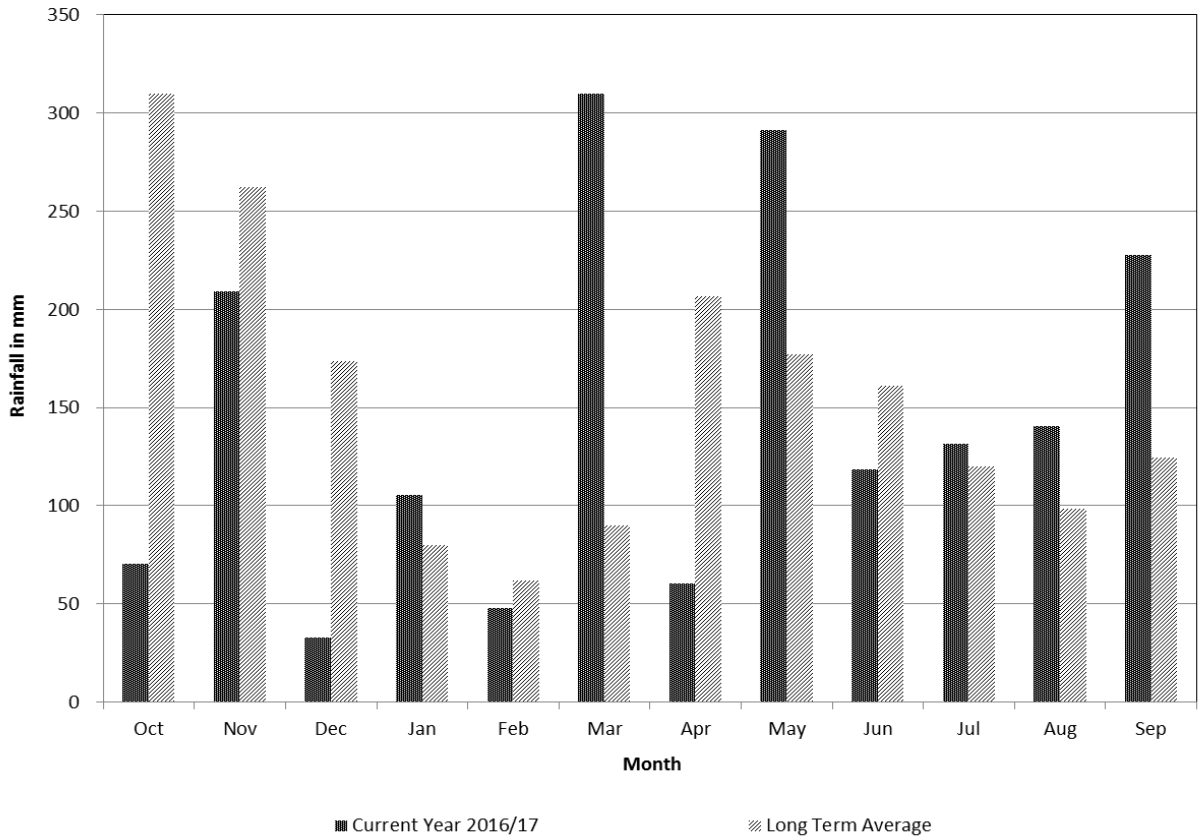
Variation of Rainfall at Norwood



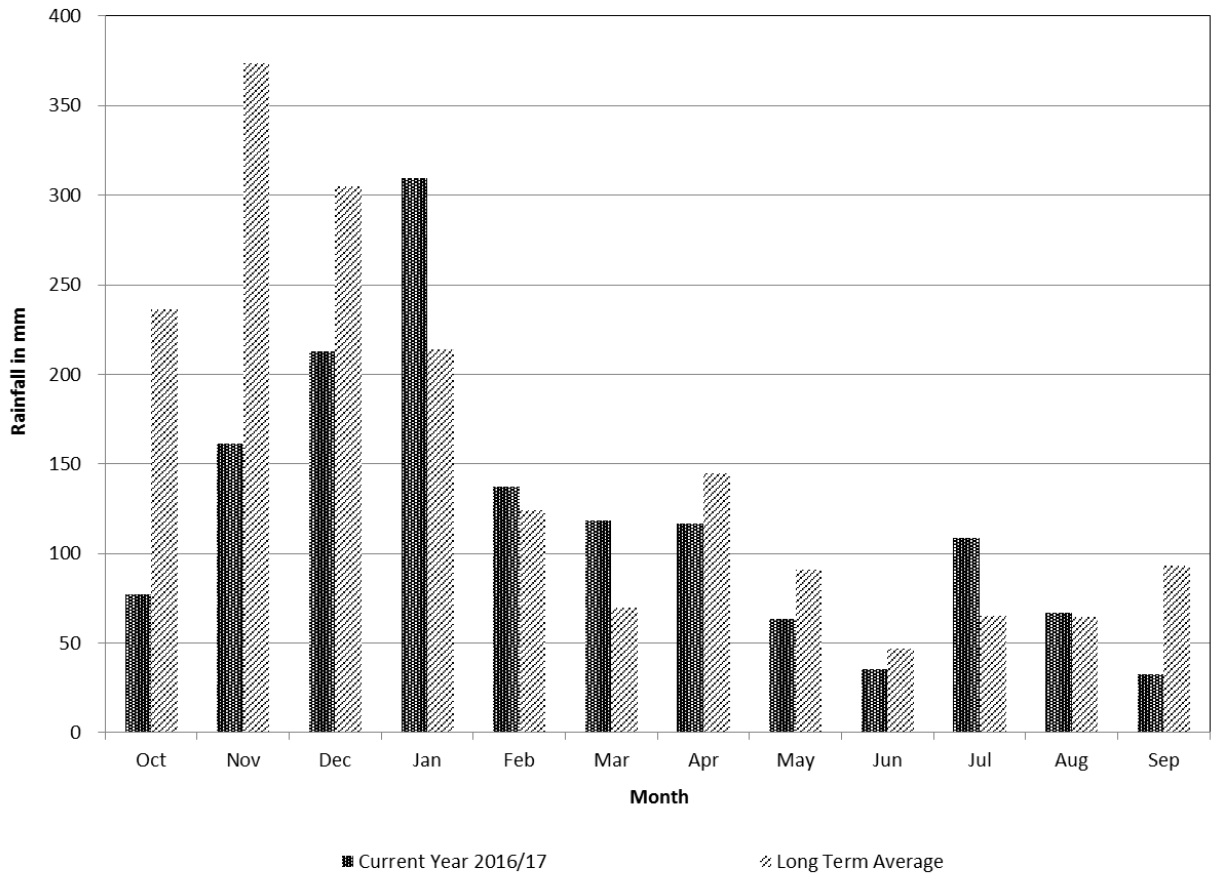
Variation of Rainfall at Padiyathalawa



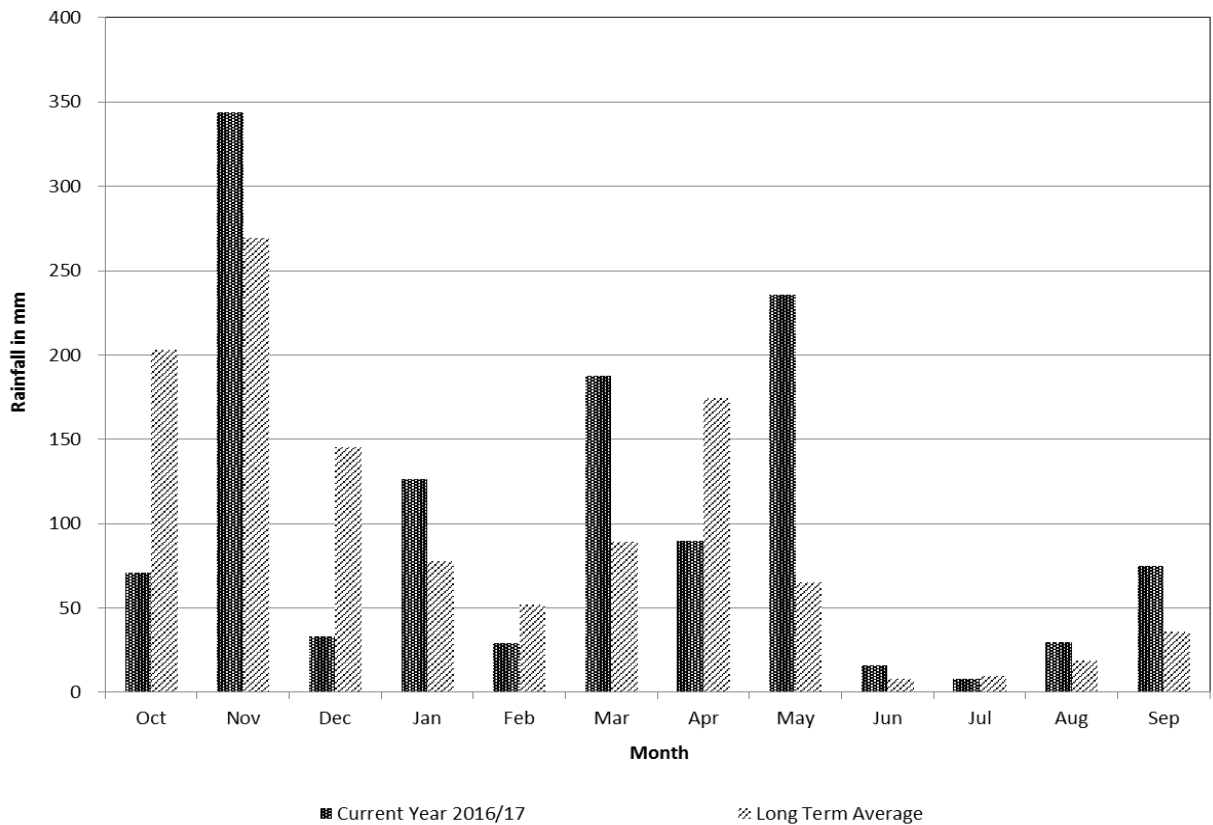
Variation of Rainfall at Peradeniya



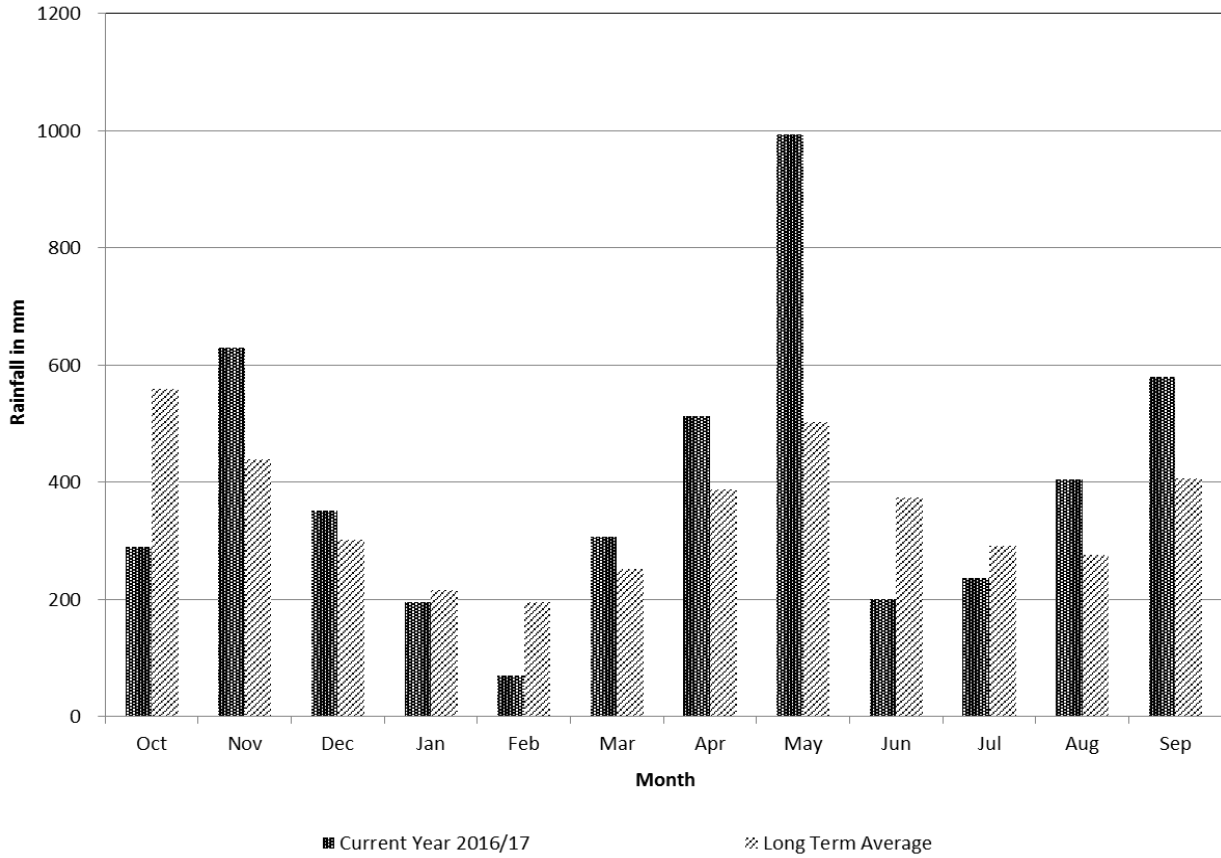
Variation of Rainfall at Siyambalanduwa



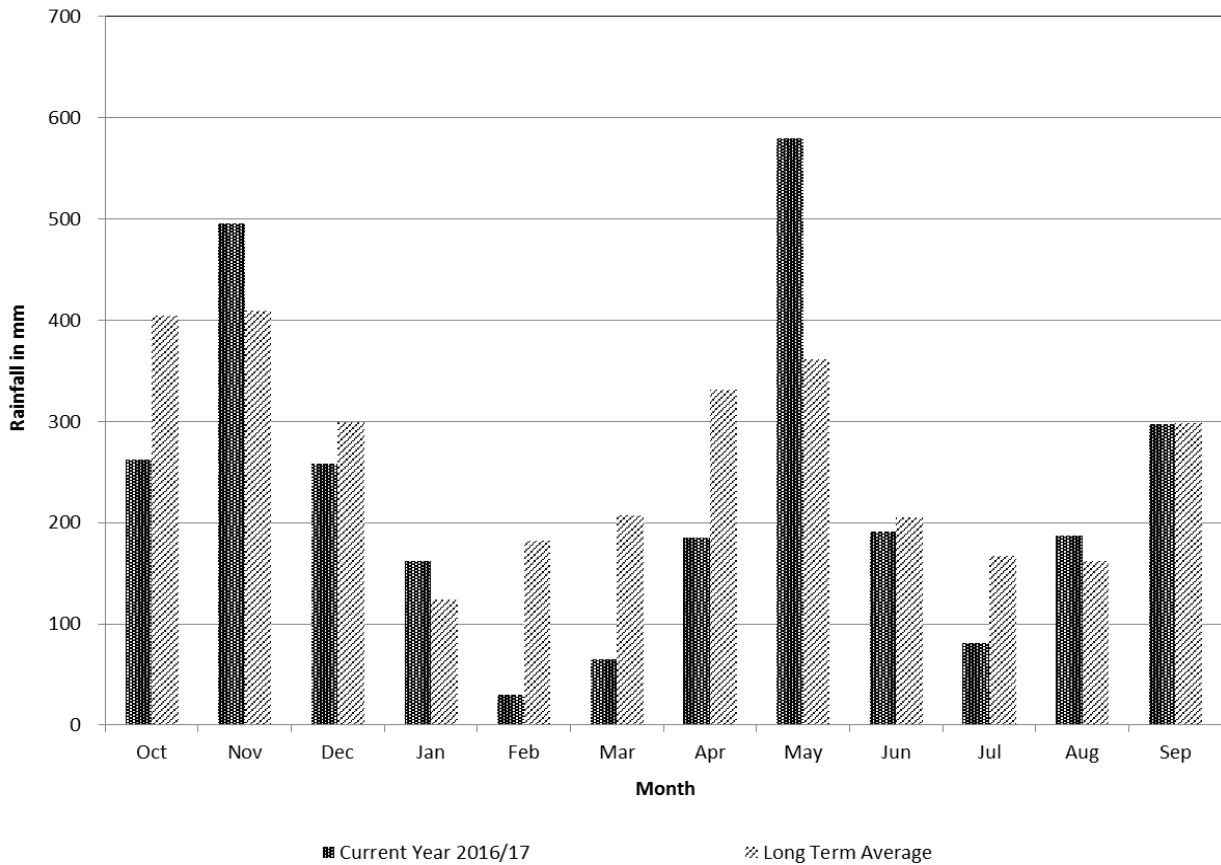
Variation of Rainfall at Thanamalwila



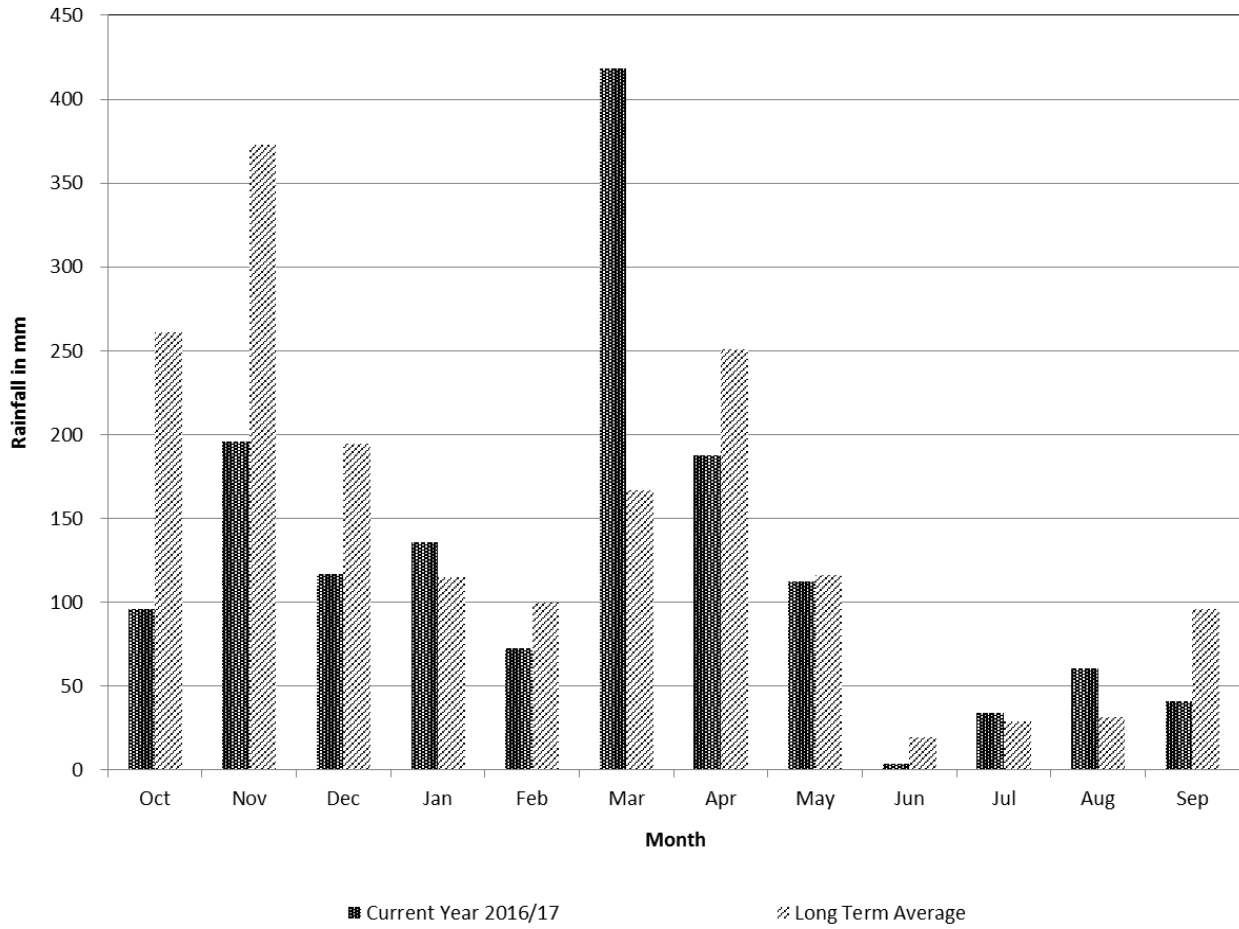
Variation of Rainfall at Thawalama



Variation of Rainfall at Urawa



Variation of Rainfall at Wellwaya



SPATIAL VARIATION OF RAINFALLS OVER THE ISLAND

➤ **NEM (North-East Monsoon) Rainfall Distribution**

The entire country has received less rainfalls during the North-East monsoon comparing to the long term average. North-Western coastal area has experienced a severe drought while the entire dry zone receiving remarkably less rainfalls affecting the food production of the country.

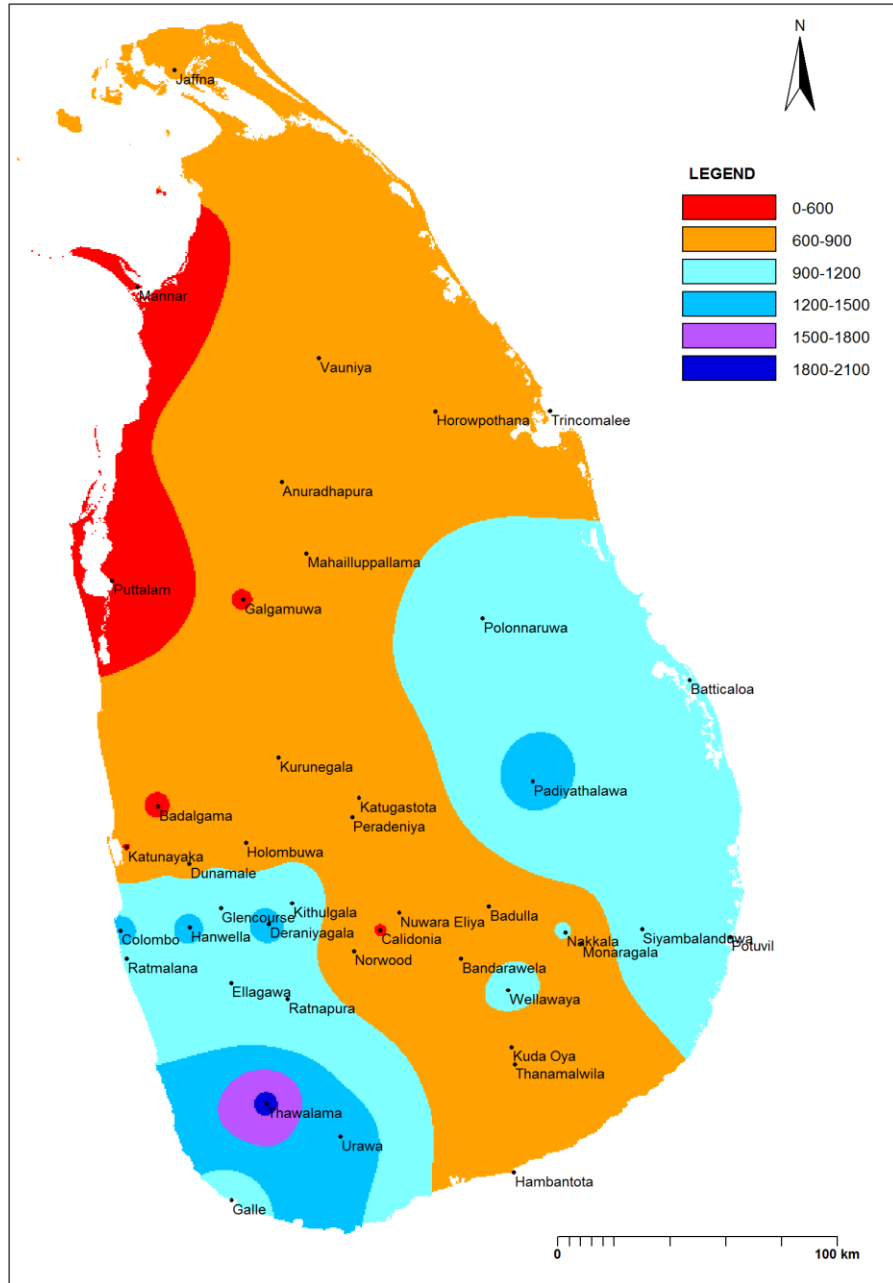
➤ **SWM (South-West Monsoon) Rainfall Distribution**

The country has received higher rainfalls during the season when compare to the long term average. However the South- West monsoon rains are mainly concentrated on the South-Western quadrant of the country as depicted in the figure. Further, North-Central and North-Eastern plains have received above normal rainfalls.

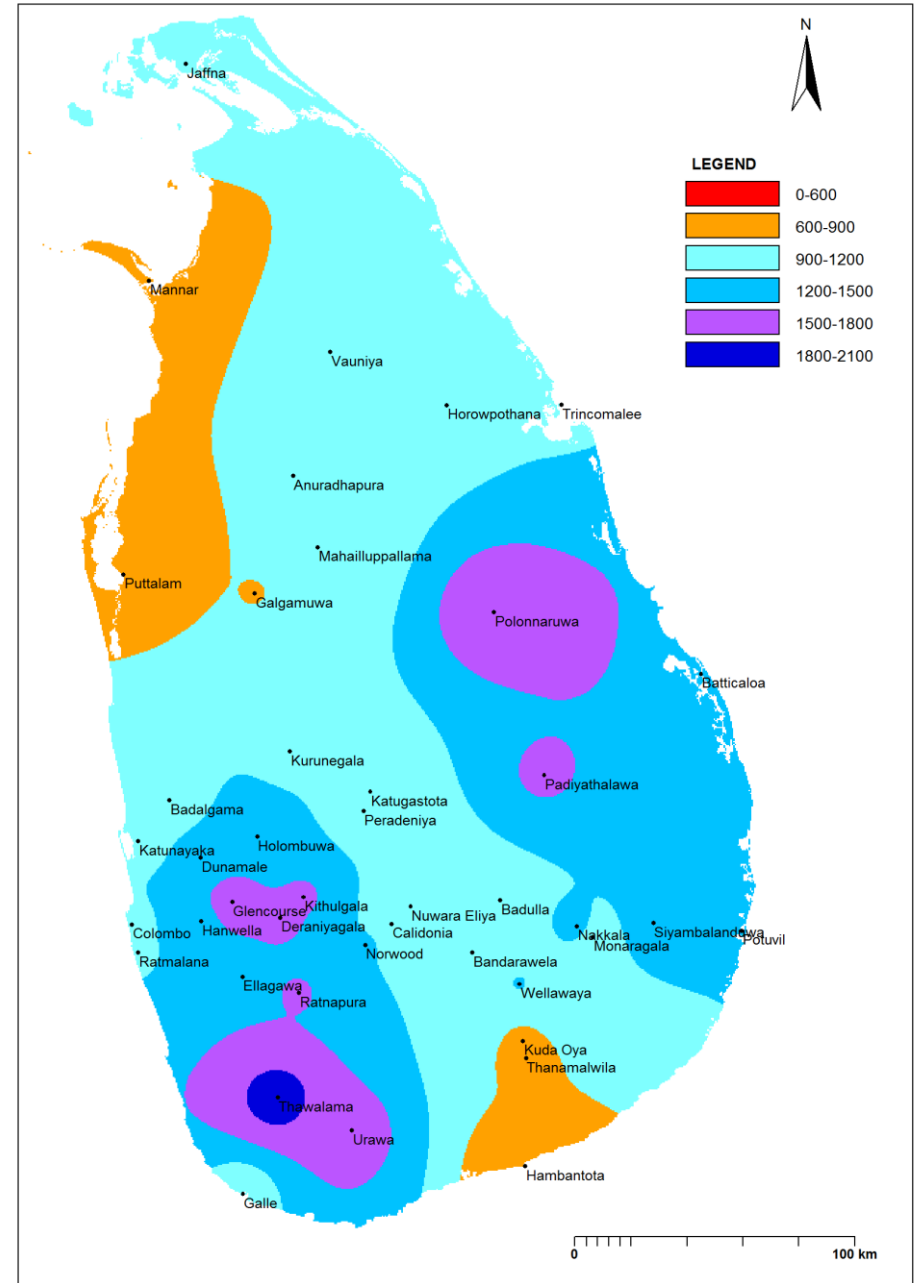
➤ **Annual Rainfall Distribution**

The annual rainfall of the current year is very low and the year 2016/17 can be designated as dry year; in which the paddy cultivation of the country was seriously affected. This effect is most significant in the dry zone where extensive food production is practiced.

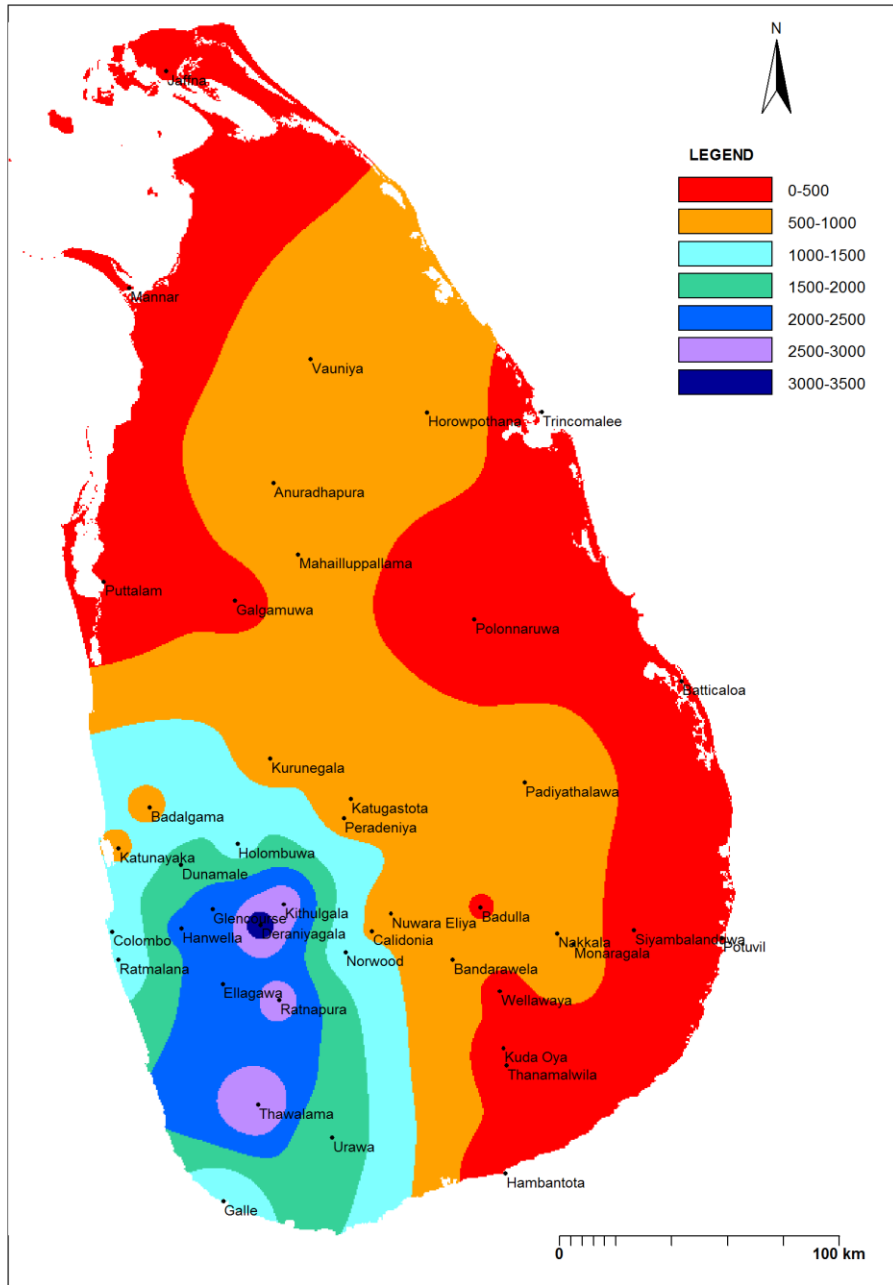
NEM Rainfall Distribution – Current year 2016/17



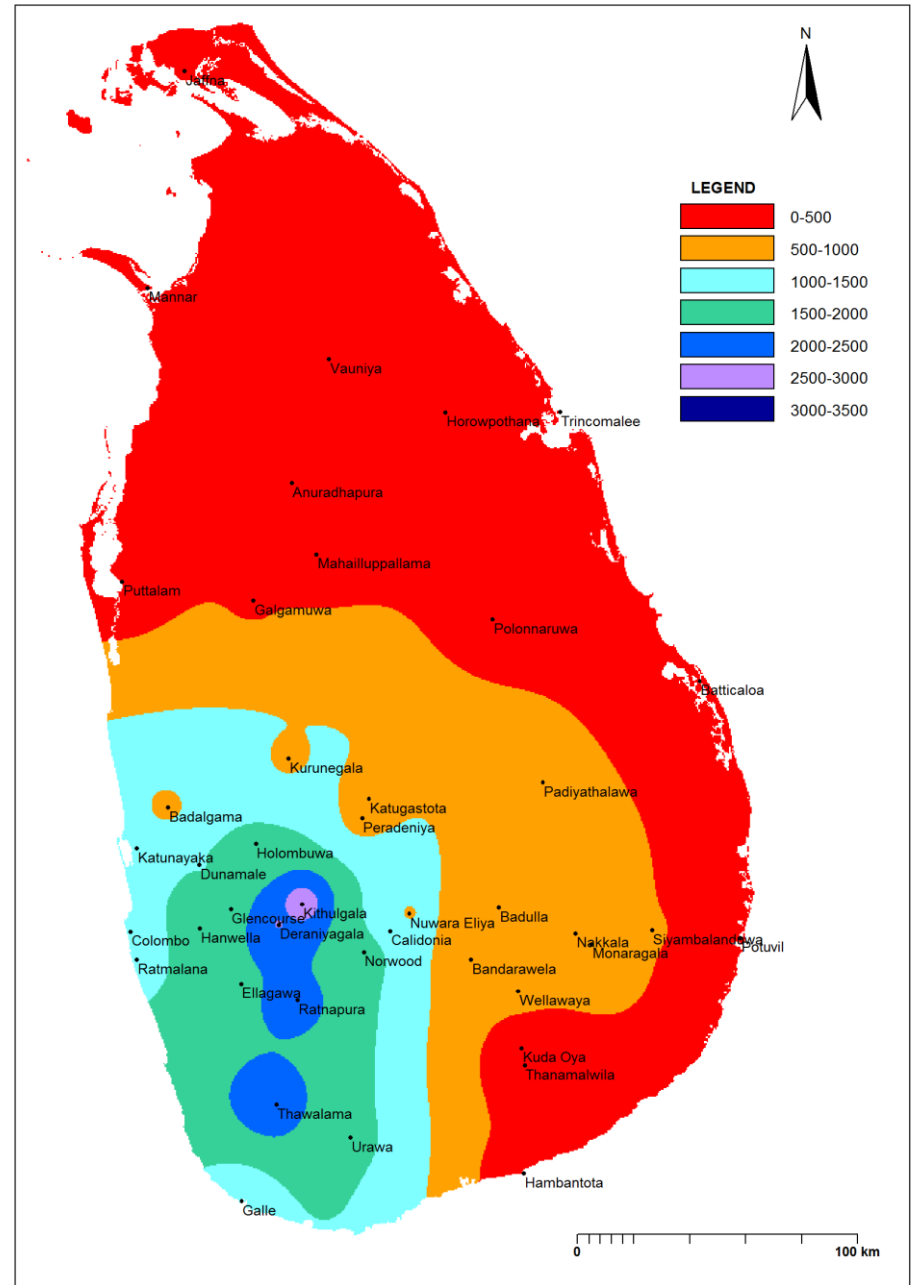
NEM Rainfall Distribution – Long Term Average



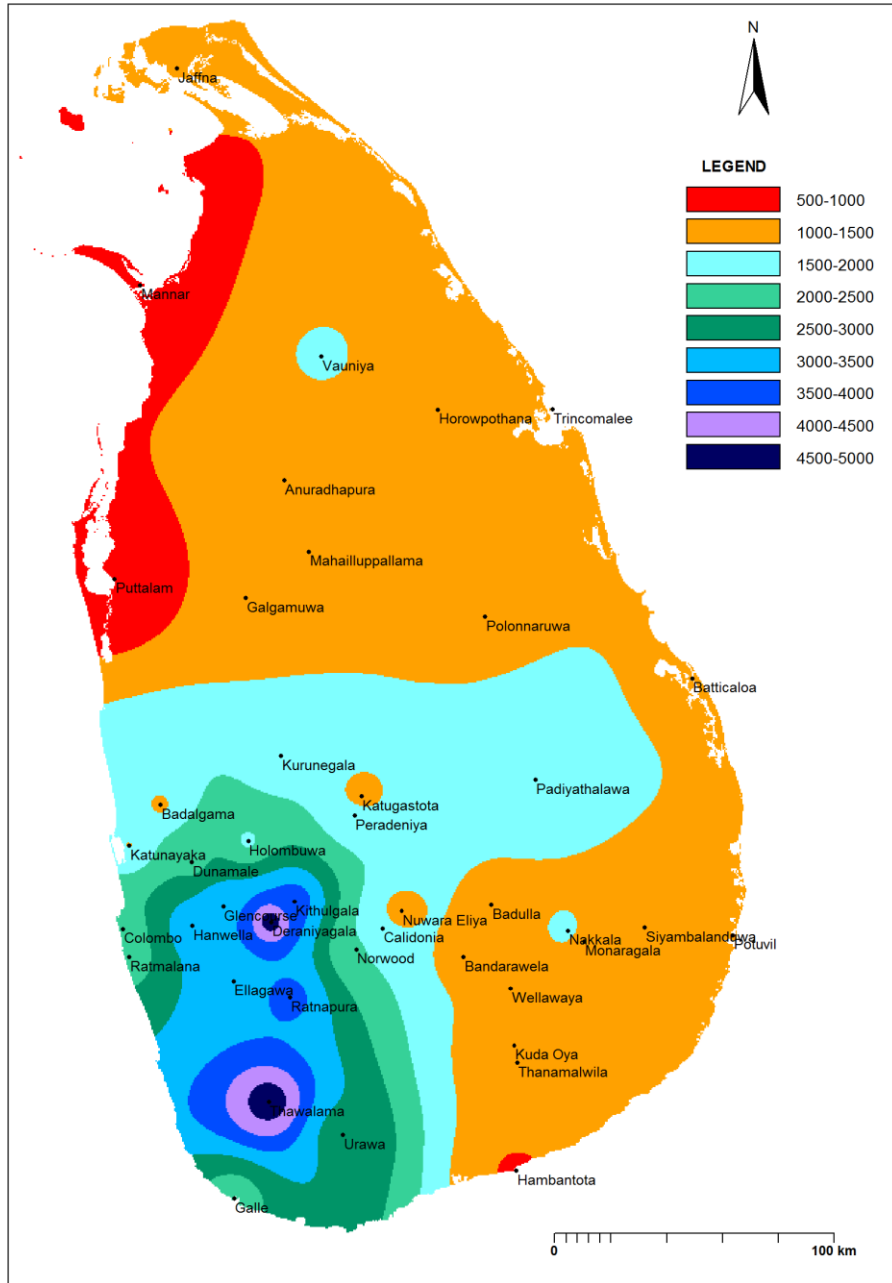
SWM Rainfall Distribution – Current year 2016/17



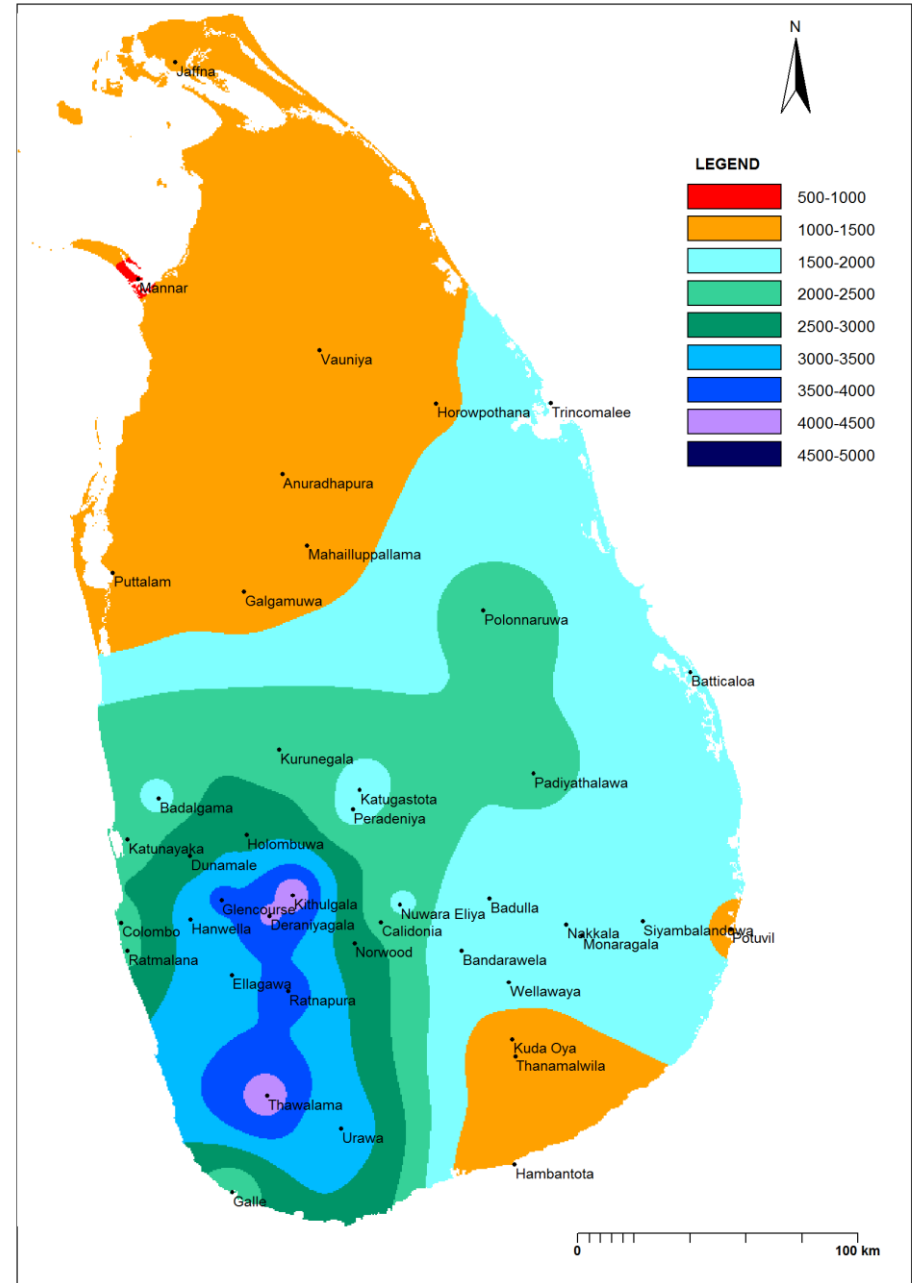
SWM Rainfall Distribution – Long Term Average



Annual Rainfall Distribution – Current year 2016/17



Annual Rainfall Distribution – Long Term Average



RAINFALL INTENSITIES

RAINFALL INTENSITY ANALYSIS
WATER YEAR 2016/17
(Maximum Depth of Rainfall in mm)

Station	Duration in Hours								
	1	3	6	12	24	48	72	96	120
Badalgama	54	56	71	86	102	121	124	124	131
Baddegama	59	100	117	194	212	291	310	313	313
Deraniyagala	140	178	227	266	304	438	451	459	496
Dunamale	67	119	145	201	244	260	264	294	327
Ellagawa	52	87	109	136	137	255	354	372	379
Galgamuwa	45	46	49	49	52	93	104	110	116
Giriulla	68	104	105	105	105	155	155	155	187
Glencourse	59	101	161	204	246	302	325	382	396
Hanwella	96	181	220	306	350	413	429	430	449
Holombuwa	49	59	65	84	87	144	151	164	203
Horowpathana	70	71	72	75	75	86	109	139	171
Kitulgala	52	89	121	139	158	195	205	242	280
Kuda Oya	70	77	77	79	79	83	95	95	104
Millakanda	142	339	428	545	615	776	784	790	823
Nakkala	72	131	131	131	131	133	136	141	172
Padiyathalawa	54	107	108	108	108	176	210	279	298
Panadugama	76	119	183	240	354	450	469	472	472
Peradeniya	62	69	69	69	69	92	92	114	136
Pitabeddara	80	127	216	316	334	378	424	424	431
Putupaula	115	182	248	258	292	371	404	406	422
Siyambalanduwa	78	91	91	93	93	124	134	179	205
Thanamalwila	42	78	130	143	143	187	187	197	240
Thawalama	105	141	152	244	360	410	556	606	612
Urawa	48	98	166	254	259	334	359	369	369
Wellawaya	43	73	93	93	93	120	129	133	146

**EVAPORATION
AND
EVAPOTRANSPIRATION**

MONTHLY PAN EVAPORATION (In mm)

Upper line : Current year 2016/17

Lower line : Long term average up to 2015/16

Name of Station	Period of Records	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total		
														NEM	SWM	Annual
Agalawaththa (6°32'00"N, 80°09'00"E)	6	92.2 74.8	77.5 66.4	87.0 66.3	97.9 77.4	88.3 84.2	102.1 103.4	85.1 82.1	83.3 84.0	84.7 72.1	81.6 77.8	75.9 74.9	68.6 73.5	545.0 472.6	479.2 464.4	1024.2 937.0
Badalgama (7°18'03"N, 79°58'50"E)	10	115.2 84.6	81.9 70.1	105.3 70.0	117.0 91.5	128.8 104.8	115.5 107.4	130.6 91.9	105.7 81.9	86.6 76.1	107.0 88.7	93.0 96.1	78.6 85.1	663.7 528.5	601.6 519.9	1265.3 1048.4
Bandarawela * (6°49'48"N, 80°58'48"E)	23	86.8 72.5	39.9 57.5	67.2 54.1	79.5 64.3	80.4 77.7	73.1 100.5	80.5 81.9	85.5 96.8	75.3 99.1	96.4 104.0	75.1 108.1	67.6 86.9	426.9 426.5	480.4 576.8	907.3 1003.3
Batewela (6°37'14"N, 80°35'27"E)		132.8 -1	126.7 -1	110.3 -1	110.8 -1	94.9 -1	94.1 -1	113.3 -1	139.9 -1	122.4 -1	116.5 -1	141.1 -1	135.7 -1	669.5 -1	768.8 -1	1438.4 -1
Bombuwela * (6°33'36"N, 80°01'12"E)	24	102.3 88.8	78.0 82.1	86.8 78.8	91.4 88.0	78.5 91.7	101.4 110.7	98.6 97.8	85.8 92.7	76.8 90.7	79.6 91.7	84.8 102.0	77.9 91.0	538.4 540.2	503.6 565.9	1041.9 1106.1
Colombo * (6°54'00"N, 79°51'36"E)	23	124.0 92.7	99.3 85.6	106.2 88.4	115.7 109.2	123.2 108.2	105.4 128.3	132.1 111.9	118.9 105.7	95.8 97.2	118.1 101.0	121.4 115.8	104.8 101.4	673.7 612.3	691.2 633.0	1364.8 1245.3
Dunamale (7°07'00"N, 80°04'55"E)		109.3 -1	79.7 -1	86.3 -1	97.0 -1	126.7 -1	116.3 -1	105.6 -1	94.6 -1	81.9 -1	91.3 -1	85.2 -1	87.0 -1	615.3 -1	545.4 -1	1160.8 -1
Galgamuwa (7°58'13"N, 80°15'18"E)	16	112.8 94.5	71.5 75.5	84.6 68.2	86.0 82.3	94.1 94.0	123.6 127.2	130.7 104.8	129.3 113.0	124.6 111.4	153.4 125.1	138.7 130.6	103.7 112.7	572.6 541.9	780.3 697.7	1352.8 1239.5
Giradurukotte * (7°24'00"N, 81°04'48"E)	23	108.8 108.1	67.8 79.7	-1 69.0	-1 73.3	79.8 84.6	103.6 117.7	119.8 114.1	125.8 137.9	132.3 147.6	141.4 160.1	111.7 169.6	109.2 143.9	-1 532.4	740.2 873.2	-1 1405.6
Horowpathana (8°34'39"N, 80°52'43"E)	3	133.1 120.6	62.9 74.4	76.1 73.3	79.1 75.7	84.8 84.0	101.9 111.6	137.0 119.4	141.5 121.8	152.8 151.2	175.4 171.4	157.6 160.7	106.2 159.4	538.0 539.5	870.5 883.8	1408.4 1423.3
Huruluwewa (8°13'28"N, 80°43'04"E)		180.5 -1	90.0 -1	100.0 -1	121.0 -1	96.7 -1	138.5 -1	164.8 -1	134.2 -1	160.3 -1	194.1 -1	172.8 -1	156.5 -1	726.7 -1	982.7 -1	1709.3 -1
Kantale (8°21'50"N, 80°58'58"E)	16	163.2 107.2	103.5 66.2	91.5 64.5	93.9 70.1	101.3 90.0	117.5 122.0	169.6 116.1	146.3 132.1	167.0 159.4	161.0 156.5	125.3 159.3	121.8 149.2	671.0 520.1	891.0 872.6	1562.0 1392.7
Kurunegala * (7°28'12"N, 80°20'60"E)	23	111.6 84.4	73.1 71.1	94.0 77.3	100.9 96.8	112.3 107.4	110.0 128.4	118.0 93.0	95.9 97.1	91.2 86.4	110.9 92.8	99.1 101.5	80.2 94.1	601.9 565.5	595.2 565.0	1197.0 1130.5
Mahailuppallama * (8°07'12"N, 80°27'36"E)	23	124.0 97.8	68.6 70.3	78.6 65.7	73.9 75.5	83.8 89.1	109.1 130.0	124.5 111.1	118.6 130.7	130.8 130.8	154.0 142.6	133.2 154.4	101.4 133.5	538.1 528.3	762.6 803.1	1300.6 1331.4

MONTHLY PAN EVAPORATION (In mm)

Upper line : Current year 2016/17

Lower line : Long term average up to 2015/16

Name of Station	Period of Records	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total		
														NEM	SWM	Annual
Padaviya (8°49'29"N, 80°45'56"E)		163.7 -1	84.5 -1	87.2 -1	122.1 -1	98.0 -1	120.5 -1	166.9 -1	169.4 -1	173.6 -1	195.3 -1	161.5 -1	149.5 -1	676.0 -1	1016.2 -1	1692.2 -1
Padiyathalawa (7°23'00"N, 81°11'30"E)	10	161.8 113.4	74.3 75.9	98.1 58.5	93.8 70.1	98.4 87.8	125.8 117.8	153.4 114.8	156.1 124.2	163.8 142.5	181.8 154.4	163.1 159.0	120.1 130.4	652.3 523.5	938.2 825.3	1590.5 1348.8
Palugasdamana (7°57'01"N, 81°01'12"E)	26	159.7 121.9	67.0 70.6	82.7 65.4	66.1 78.5	82.7 95.9	103.1 133.0	135.6 130.6	141.8 156.6	153.9 173.8	195.2 185.3	151.5 182.3	110.0 166.0	561.3 565.3	888.0 994.6	1449.3 1559.9
Panadugama (6°08'00"N, 80°29'00"E)		97.4 -1	68.4 -1	88.3 -1	83.2 -1	89.3 -1	92.7 -1	93.1 -1	60.1 -1	66.1 -1	99.4 -1	86.9 -1	90.2 -1	519.3 -1	495.9 -1	1015.2 -1
Parakrama Samudraya (7°56'21"N, 80°59'11"E)		175.6 -1	68.3 -1	84.8 -1	95.1 -1	87.8 -1	115.0 -1	139.0 -1	148.8 -1	185.9 -1	206.6 -1	187.4 -1	134.9 -1	626.6 -1	1002.7 -1	1629.4 -1
Pelwatta (6°24'36"N, 81°07'12"E)	2	133.0 92.8	79.7 91.4	105.9 86.1	116.0 121.6	114.3 109.0	148.7 132.6	114.7 115.2	116.2 110.9	131.1 136.3	133.2 154.9	139.4 160.1	131.8 141.3	697.6 633.5	766.4 818.7	1464.1 1452.1
Puttalam * (8°01'48"N, 79°49'48"E)	24	148.2 117.2	80.7 82.4	96.4 78.7	106.4 95.3	111.9 112.2	138.3 148.5	155.7 130.9	152.4 147.2	158.8 145.7	174.7 153.1	-1 162.3	-1 147.7	681.9 634.4	-1 886.9	-1 1521.2
Rathnapura * (6°40'48"N, 80°24'00"E)	23	74.4 74.0	58.7 74.9	72.9 70.9	81.4 85.4	85.6 93.2	88.0 113.5	92.0 90.4	72.2 83.9	67.5 79.8	73.7 81.6	67.7 87.4	65.0 78.5	461.1 511.8	438.1 501.6	899.2 1013.4
Seetha Eliya * (6°55'48"N, 80°47'60"E)		71.3 -1	46.6 -1	68.6 -1	78.0 -1	182.7 -1	100.8 -1	108.5 -1	91.2 -1	59.1 -1	-1 -1	-1 -1	-1 -1	548.0 -1	-1 -1	-1 -1
Senanayaka Samudraya (7°13'05"N, 81°32'49"E)		153.7 -1	90.9 -1	102.2 -1	101.9 -1	123.4 -1	136.7 -1	135.9 -1	138.1 -1	144.3 -1	165.5 -1	117.8 -1	108.8 -1	708.8 -1	810.4 -1	1519.2 -1
Sewanagala (6°22'58"N, 80°54'19"E)	23	153.5 121.7	78.1 101.2	103.7 92.5	116.4 112.7	119.2 119.0	137.2 146.9	133.1 121.3	129.3 133.7	129.9 139.1	187.3 165.9	163.0 167.4	125.5 139.4	708.2 694.0	868.1 866.8	1576.3 1560.8
Siyambalanduwa (6°54'17"N, 81°32'44"E)	1	120.3 83.5	71.5 79.3	104.6 144.1	96.8 84.2	83.7 87.7	90.3 113.4	100.3 95.9	102.1 94.7	111.3 103.4	122.0 107.7	113.0 106.0	100.8 113.7	567.2 592.2	649.5 621.4	1216.7 1213.6
Thanamalwila (6°28'06"N, 81°08'03"E)	2	151.6 99.1	55.3 85.3	88.3 84.9	104.7 106.1	93.5 105.7	87.2 121.0	103.8 104.2	104.4 91.1	108.1 130.4	160.2 152.9	156.8 156.4	120.8 148.7	580.6 602.0	754.1 783.6	1334.7 1385.6

Note :- Missing data is denoted by -1, '**' Denotes data obtained from Meteorology Department
'NEM' denotes North-East Monsoon, 'SWM' denotes South-West Monsoon

OPEN WATER EVAPORATION (E_o) & POTENTIAL EVAPOTRANSPIRATION FOR REFERENCE CROP (E_{To}) – 2016/17

Weather Station : **Pelwaththa**
Co-ordinate : **6° 41' N, 81° 12' E**
Altitude : **152 m**

Month	Temp. Avg. °C	Humidity Avg. %	Sunshine hrs	Wind Speed km/day	E _o mm	E _{To} mm
Oct	29.1	56.82	6.87	70.15	170.3	132.4
Nov	27.2	73.90	4.10	56.01	118.1	89.9
Dec	27.2	65.72	7.96	64.09	152.3	114.8
Jan	26.1	64.10	6.72	104.90	146.5	113.6
Feb	26.7	64.54	7.31	95.07	149.4	115.0
Mar	27.7	67.04	7.84	41.76	176.0	131.8
Apr	29.0	64.38	7.55	41.85	173.9	130.1
May	29.2	63.23	6.98	80.55	178.2	138.3
Jun	29.3	59.61	8.06	94.84	187.0	147.9
Jul	30.0	57.32	7.80	109.19	187.9	145.5
Aug	29.7	60.12	7.09	136.33	186.5	147.3
Sep	29.2	60.79	6.32	106.37	170.8	136.0
Annual	28.4	63.13	7.05	83.43	1996.9	1542.6

Weather Station : **Padiyathalawa**
Co-ordinate : **7° 23' N, 81° 11' E**
Altitude : **100 m**

Month	Temp. Avg. °C	Humidity Avg. %	Sunshine hrs	Wind Speed km/day	E _o mm	E _{To} mm
Oct	25.8	79.00	6.98	63.82	139.1	104.4
Nov	22.1	93.67	2.56	39.95	74.0	55.7
Dec	21.8	94.26	5.00	29.50	83.9	62.3
Jan	21.0	90.19	5.08	25.30	87.1	64.3
Feb	22.0	88.89	6.74	29.61	106.0	78.9
Mar	23.7	89.03	6.98	30.99	141.0	106.3
Apr	26.2	83.37	8.18	36.24	168.9	128.0
May	26.6	82.48	6.28	55.02	161.4	123.0
Jun	26.6	76.07	6.63	70.97	162.7	124.0
Jul	27.4	82.58	7.05	75.79	174.0	131.8
Aug	25.7	77.32	7.39	62.60	169.8	128.4
Sep	24.8	87.57	6.27	42.95	137.8	104.2
Annual	24.5	85.37	6.26	46.90	1605.6	1211.2

OPEN WATER EVAPORATION (E_o) & POTENTIAL EVAPOTRANSPIRATION FOR REFERENCE CROP (E_{To}) – 2016/17

Weather Station : Palugasdamana
Co-ordinate : 8° 00' N, 81° 00' E
Altitude : 52 m

Month	Temp. Avg. °C	Humidity Avg. %	Sunshine hrs	Wind Speed km/day	E _o mm	E _{To} mm
Oct	26.9	69.71	6.13	41.71	155.3	118.4
Nov	26.9	88.57	2.69	14.52	97.8	75.1
Dec	26.7	89.68	3.79	21.34	105.5	80.7
Jan	25.7	92.39	5.24	20.20	116.6	85.7
Feb	23.7	91.75	5.96	23.33	125.9	91.0
Mar	27.7	89.39	6.59	20.62	159.5	123.1
Apr	27.9	79.00	8.08	20.74	180.0	127.1
May	30.3	74.26	5.42	40.83	157.8	112.3
Jun	29.3	67.93	6.49	55.57	165.1	121.6
Jul	30.9	66.26	7.13	52.14	179.6	137.7
Aug	30.1	74.48	6.54	43.81	170.4	130.4
Sep	28.5	75.97	5.39	21.87	149.1	111.5
Annual	27.9	79.95	5.79	31.39	1762.6	1314.7

Weather Station : Agalawaththa
Co-ordinate : 6° 32' N, 80° 09' E
Altitude : 65.5 m

Month	Temp. Avg. °C	Humidity Avg. %	Sunshine hrs	Wind Speed km/day	E _o mm	E _{To} mm
Oct	27.26	81.73	5.65	44.36	129.5	98.0
Nov	26.19	85.40	3.11	29.94	90.0	67.0
Dec	27.30	82.08	4.72	40.77	97.7	67.9
Jan	26.96	79.68	5.27	40.11	105.4	78.7
Feb	26.87	80.20	6.04	39.04	119.6	86.3
Mar	27.87	76.44	6.43	43.15	151.8	115.0
Apr	27.51	76.25	6.03	45.42	154.8	116.5
May	27.93	83.50	4.22	46.98	141.6	108.6
Jun	26.55	82.55	4.55	42.90	141.4	107.1
Jul	27.77	79.11	5.43	53.16	156.8	119.9
Aug	27.37	82.39	5.05	54.13	147.7	112.8
Sep	26.12	82.67	4.27	45.12	127.1	95.6
Annual	27.14	81.00	5.06	43.76	1563.6	1173.5

OPEN WATER EVAPORATION (E_o) & POTENTIAL EVAPOTRANSPIRATION FOR REFERENCE CROP (E_{To}) – 2016/17

Weather Station : **Dunamale**
Co-ordinate : **7° 00' N, 80° 00' E**
Altitude : **20 m**

Month	Temp. Avg. °C	Humidity Avg. %	Sunshine hrs	Wind Speed km/day	E _o mm	E _{To} mm
Oct	30.6	87.71	6.64	33.82	149.9	116.8
Nov	26.0	91.27	4.11	13.44	96.3	71.1
Dec	26.8	87.48	5.38	17.79	99.0	74.2
Jan	25.8	83.50	5.61	18.17	122.2	91.0
Feb	24.7	82.07	6.87	22.11	141.4	103.2
Mar	28.1	88.65	7.06	21.88	165.8	127.7
Apr	27.4	86.57	5.43	27.44	148.5	112.8
May	28.0	90.03	3.59	26.57	125.8	97.3
Jun	26.5	89.63	3.93	27.50	123.8	94.1
Jul	27.8	87.10	4.71	31.63	137.4	105.5
Aug	26.7	91.23	2.74	32.47	113.8	87.8
Sep	26.8	89.43	4.42	21.83	150.1	119.6
Annual	27.1	87.89	5.04	24.55	1574.0	1201.3

STREAM FLOW DATA

STREAM FLOW DATA - WATER YEAR 2016/17

Upper line : Runoff in MCM

Lower line : Basin Rainfall in mm

Name of station & River Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annul Runoff & Annual Basin Rainfall 2016/17	Long-term Average of Annual Runoff & Basin Rainfall up to 2015/16		Peak Flood for 2016/17 & Observed Maximum Flood Peak up to 2015/16		
														value	yrs	cumecs	Time	Date
1 Badalgama R.B. 102	10.22	76.79	10.33	4.49	2.99	19.38	27.47	22.94	47.00	17.07	16.43	72.89	328.00	1273.64	51	184.21	8:00am	02.11.2016
	164.8	262.4	25.6	106.1	35.3	240.0	92.1	256.7	264.5	102.3	195.8	406.4	2151.8	2372.6		1982.16	12:00mn	24.09.1971
2 Baddegama R.B. 9	111.24	236.68	112.78	109.81	84.37	128.52	138.16	389.61	181.29	99.88	119.91	213.65	1925.91	2125.98	10	691.92	11:00am	28.05.2017
	263.4	500.8	248.3	229.7	47.8	331.9	250.5	821.8	194.5	212.9	311.0	436.2	3848.7	3743.8		573.43	4:00pm	03.06.2008
3 Calidonia R.B. 60	6.75	8.21	5.99	6.21	4.46	11.76	7.06	12.19	12.73	6.67	12.17	16.38	110.58	212.97	32	53.12	2:00pm	26.05.2017
	88.0	156.2	56.2	88.6	39.5	294.3	110.8	259.5	103.5	72.3	187.3	152.6	1608.8	2047.3		178.48	3:00pm	12.06.2014
4 Deraniyagala R.B. 1	31.00	45.00	13.09	6.23	2.94	10.51	13.34	94.79	70.69	33.42	66.65	89.68	477.34	603.10	60	571.96	7:00am	26.05.2017
	630.3	552.5	17.8	12.7	9.0	314.0	175.5	934.5	433.3	276.1	511.6	584.1	4451.4	5087.8		2313.00	9:00am	31.05.1985
5 Dunamale R.B. 103	2.92	19.01	5.38	2.03	0.71	13.90	11.90	30.66	20.61	8.69	3.96	67.82	187.59	205.68	11	112.03	2:00pm	14.09.2017
	207.4	395.6	22.0	32.4	7.9	453.2	115.4	506.4	288.1	53.5	185.7	647.2	2914.7	3361.1		58.66	11:00pm	31.05.2008
6 Ellagawa R.B. 3	78.23	183	40	31.00	20.66	64.49	90.21	790.05	351.32	95.48	216.21	600.03	2561.43	3341.00	59	1622.96	4:00pm	27.05.2017
	281.0	289.7	104.5	101.2	44.2	233.0	144.8	749.6	276.0	187.3	385.3	555.2	3351.6	3716.8		2620.00	4:00am	19.05.2003
7 Galgamuwa R.B. 95	0.41	1.32	0.69	0.71	0.60	0.59	0.31	0.26	0.07	0.00	0.01	0.02	5.00	49.37	27	2.42	7:00am	20.12.2016
	62.7	204.0	112.8	190.8	55.7	153.2	73.7	92.3	32.5	59.1	42.8	141.0	1220.7	1294.4		159.25	1:00pm	19.11.2006
8 Giriulla R.B. 102	5.54	27.13	5.60	4.17	3.04	7.02	9.63	8.46	10.91	6.66	6.98	17.57	112.71	1134.37	16	245.21	4:00am	02.11.2016
	169.4	265.8	26.1	116.1	34.9	247.0	99.9	263.6	276.8	111.3	212.6	412.9	2236.5	2672.3		1690.50	4:00pm	26.12.2014
9 Glencourse R.B. 1	157.67	321.90	92.10	50.28	28.10	143.86	171.58	491.58	427.93	190.95	338.50	632.56	3047.01	3919.40	68	1589.09	4:00pm	26.05.2017
	252.8	330.8	36.2	52.3	11.4	354.7	223.6	653.7	329.3	169.7	340.4	531.1	3286.0	3626.5		3500.00	10:00am	04.06.1989
10 Hanwella R.B. 1	116.16	274.82	78.28	62.44	40.72	123.66	137.27	554.68	374.42	129.87	220.17	639.25	2751.74	4324.21	32	1448.92	9:00pm	26.05.2017
	246.5	346.9	40.9	67.5	15.5	347.6	226.6	673.9	315.2	165.5	312.9	570.7	3329.7	3718.6		2745.58	8:00am	05.06.1989

STREAM FLOW DATA - WATER YEAR 2016/17

Upper line : Runoff in MCM

Lower line : Basin Rainfall in mm

Name of station & River Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annul Runoff & Annual Basin Rainfall 2016/17	Long-term Average of Annual Runoff & Basin Rainfall up to 2015/16		Peak Flood for 2016/17 & Observed Maximum Flood Peak up to 2015/16		
														value	yrs	cumecs	Time	Date
11 Holombuwa R.B. 1	2.09	12.82	0.95	0.48	0.18	7.86	11.92	12.39	14.51	3.75	3.79	24.42	95.16	261.30	52	167.85	12:00am	13.09.2017
	153.9	265.9	31.5	43.0	5.6	326.6	245.7	368.9	259.1	71.0	177.1	434.4	2382.7	3112.1		644.47	7:00am	03.06.1989
12 Horowpothana R.B. 67	3.32	12.19	5.70	28.14	4.84	6.92	2.89	2.77	2.37	1.96	3.93	3.86	78.89	174.55	55	193.00	5:00am	28.01.2017
	75.6	338.8	67.5	189.6	20.8	121.5	7.0	58.3	0.6	158.5	180.3	88.8	1307.1	1445.9		-1	4:00pm	26.12.1957
13 Katharagama R.B. 26	17.37	16.88	17.33	16.76	15.18	17.14	16.74	17.15	16.15	16.20	16.09	15.72	198.71	218.74	71	8.14	5:00pm	04.04.2017
	98.0	159.7	90.3	122.7	73.0	195.2	78.3	98.9	12.9	44.8	63.5	71.2	1108.4	1552.4		1365.00	1:00pm	25.12.1957
14 Kithulagala R.B. 1	78.62	76.95	57.63	39.72	20.17	30.19	35.41	74.25	90.36	65.99	125.16	145.99	840.44	1155.26	68	279.17	8:00am	26.05.2017
	180.7	215.9	33.6	34.9	12.0	268.5	146.6	563.6	266.6	151.3	374.5	358.7	2606.9	3443.9		2157.00	5:15pm	30.05.1989
15 Manampitiya R.B. 60	1.34	24.86	14.16	134.23	13.63	60.19	9.19	4.52	2.92	2.84	3.30	1.05	272.23	4732.30	62	623.90	1:00pm	25.01.2017
	116.7	182.3	90.3	163.5	93.9	244.9	86.9	259.1	136.6	87.4	192.2	219.8	1873.6	2337.8		-1	11:00am	26.12.1957
16 Millakanda R.B. 3	55.27	247.19	69.01	45.07	25.22	67.86	115.51	583.37	263.52	102.31	165.71	503.20	2243.24	2127.41	26	1233.16	2:00am	27.05.2017
	237.4	427.2	190.6	122.9	60.4	307.2	253.3	1104.0	331.6	173.6	366.1	588.7	4163.0	4307.2		1155.41	12:00mn	01.06.2008
17 Nakkala R.B. 31	11.43	15.24	12.23	23.77	15.21	31.08	18.06	15.41	10.46	10.37	12.24	10.70	186.20	-1		87.81	6:00am	25.01.2017
	122.4	137.2	50.0	175.8	80.1	229.9	96.0	155.1	14.0	91.6	183.8	55.2	1391.0	-1		-1	-1	-1
18 Nawalapitiya R.B. 60	47.69	54.66	30.26	19.59	12.98	24.36	25.23	59.75	95.67	56.45	110.09	101.17	637.90	491.64	28	239.21	7:00am	26.05.2017
	198.7	232.4	19.0	47.9	28.9	317.5	136.4	526.1	344.7	191.7	458.5	423.9	2925.7	3700.1		360.20	4:00am	28.06.1993
19 Norwood R.B. 1	4.88	8.60	5.21	4.26	3.52	9.30	7.99	14.43	13.06	7.22	9.32	11.56	99.35	135.65	31	44.49	5:00pm	08.05.2017
	57.4	166.2	48.7	44.1	14.0	205.5	167.4	309.9	82.6	47.6	138.9	170.9	1453.0	2584.6		180.98	6:00pm	13.05.2013
20 Padiyathalawa R.B. 54	0.21	4.19	1.41	17.25	7.94	10.48	0.95	0.67	0.22	0.11	0.47	0.44	44.35	151.10	32	168.96	11:00pm	24.01.2017
	69.4	322.8	208.7	349.7	147.1	202.2	27.2	102.1	32.3	74.2	170.8	155.3	1861.7	2136.3		972.30	9:00am	26.12.2014

Note :-Missing data is denoted by '-1'

STREAM FLOW DATA - WATER YEAR 2016/17

Upper line : Runoff in MCM
Lower line : Basin Rainfall in mm

Name of station & River Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annul Runoff & Annual Basin Rainfall 2016/17	Long-term Average of Annual Runoff & Basin Rainfall up to 2015/16		Peak Flood for 2016/17 & Observed Maximum Flood Peak up to 2015/16		
														value	yrs	cumecs	Time	Date
21 Peradeniya R.B. 60	86.00	114.89	77.29	42.24	29.92	46.80	70.42	77.71	158.18	154.79	155.54	180.99	1194.77	1814.19	68	253.75	8:00pm	30.05.2017
	101.0	169.9	83.6	104.5	66.1	338.1	98.0	329.8	227.8	118.9	298.8	261.5	2198.0	2934.9		-1	2:30am	15.08.1947
22 Pitabeddara R.B. 12	9.91	48.99	39.11	24.60	11.32	15.29	30.77	170.85	41.77	18.71	23.87	43.84	479.02	505.37	36	1559.58	4:00am	26.05.2017
	172.4	397.6	248.6	153.2	20.3	153.9	142.3	588.2	179.2	87.9	169.7	320.9	2634.1	2916.3		1292.80	12:20am	18.05.2003
23 Putupaula R.B. 3	168.15	313.75	184.03	184.81	145.53	190.12	206.16	1150.07	480.81	175.18	217.12	771.10	4186.83	6071.62	72	2334.82	10:00am	28.05.2017
	266.8	353.5	130.3	121.2	46.6	253.3	200.2	845.4	291.8	176.8	357.9	595.2	3638.9	3205.2		2829.00	9:30am	16.08.1947
24 Rathnapura R.B. 3	35.28	57.75	19.96	16.74	11.87	27.11	31.08	257.47	91.07	39.29	80.29	168.32	836.23	1027.57	10	689.03	8:00pm	26.05.2017
	295.4	277.4	94.5	115.8	41.5	233.3	153.6	789.4	262.4	193.2	379.9	482.8	3318.9	3127.9		814.10	12:00nn	31.05.1989
25 Siyambanduwa R.B. 36	0.00	0.00	0.12	3.70	0.41	3.24	0.26	0.01	0.00	0.01	0.02	0.00	7.77	134.44	25	54.80	1:00am	27.01.2017
	44.3	125.9	155.8	239.1	114.2	169.7	116.6	125.7	21.7	104.0	78.4	27.2	1322.3	1728.8		889.27	4:00pm	12.01.2007
26 Thanamalwila R.B. 22	1.86	5.06	1.06	1.59	0.26	21.56	21.84	18.69	1.47	0.18	0.40	0.79	74.76	261.95	29	238.08	9:00pm	03.04.2017
	73.4	172.2	74.2	106.3	66.0	281.4	142.4	149.2	20.1	26.2	49.4	48.3	1209.1	1605.4		824.70	3:00am	24.11.2012
27 Thanthirimale R.B. 22	2.24	18.71	10.46	13.09	7.34	15.54	5.84	10.04	3.27	2.00	4.82	10.96	104.31	-1		34.80	12:00pm	14.03.2017
	79.6	213.9	52.2	127.2	30.1	101.4	62.2	148.5	7.0	14.6	120.1	173.3	1129.9	-1		-1	-1	-1
28 Thawalama R.B. 9	25.12	97.75	59.03	41.09	21.65	60.57	65.12	230.40	92.07	51.19	70.25	120.90	935.13	1049.21	36	1023.46	12:00nn	26.05.2017
	196.0	520.8	250.5	261.5	45.2	383.8	322.1	911.4	193.5	180.3	307.4	480.2	4052.7	4003.2		1339.07	5:00am	18.05.2003
29 Urawa R.B. 12	1.04	7.45	4.58	3.35	1.57	2.30	3.09	17.97	6.22	2.39	2.56	5.66	58.21	81.28	16	196.88	1:00am	26.05.2017
	184.4	451.4	222.0	198.4	35.1	196.2	193.6	673.2	135.0	66.9	167.9	319.5	2843.6	3125.4		-1	-1	17.05.2003
30 Wellaway R.B. 22	2.35	4.19	2.23	2.48	1.31	15.33	17.99	20.21	4.54	2.24	3.27	3.45	79.59	120.73	28	247.95	5:00pm	03.04.2017
	73.0	113.2	74.5	87.1	48.1	301.8	165.0	137.1	33.1	36.7	68.1	33.4	1171.1	2054.9		634.50	8:00pm	21.10.2012

Note :-Missing data is denoted by '-1'

RUNOFF RAINFALL RATIOS

RUNOFF RAINFALL RATIOS - 2016/17

Name of River Basin	Station	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff / Rainfall ratio (%)	Long term average of Runoff / Rainfall ratio (%) up to 2015/16
Kelani Ganga	Norwood	1453	1028	71	47
Kelani Ganga	Kithulgala	2607	2194	84	82
Kelani Ganga	Deraniyagala	4451	2608	59	68
Kelani Ganga	Holombuwa	2383	614	26	55
Kelani Ganga	Glencourse	3286	1909	58	69
Kelani Ganga	Hanwella	3330	1544	46	62
Kalu Ganga	Rathnapura	3319	1387	42	49
Kalu Ganga	Ellagawa	3349	1839	55	64
Kalu Ganga	Millakanda	4163	2875	69	65
Kalu Ganga	Putupaula	3639	1612	44	60
Gin Ganga	Thawalama	4053	2480	61	71
Gin Ganga	Baddegama	3849	2575	67	76
Nilwala Ganga	Urawa	2844	987	35	45
Nilwala Ganga	Pitabeddara	2634	1624	62	59
Kirindi Oya	Wellawaya	1171	462	39	36
Kirindi Oya	Thanamalwila	1209	100	8	21
Heda Oya	Siyambanduwa	1322	26	2	25
Maduru Oya	Padiyathalawa	1862	279	15	42
Mahaweli Ganga	Peradeniya	2198	1023	47	45
Mahaweli Ganga	Manampitiya	1874	37	2	29
Yan Oya	Horowpothana	1307	110	8	18
Mee Oya	Galgamuwa	1221	17	1	7
Maha Oya	Giriulla	2236	98	4	37
Maha Oya	Badalgama	2152	241	11	40
Aththanagalu Oya	Dunamale	2915	1228	42	40

MONTHLY DISCHARGES IN MAJOR RIVERS

MONTHLY DISCHARGES IN MAJOR RIVERS (in MCM)

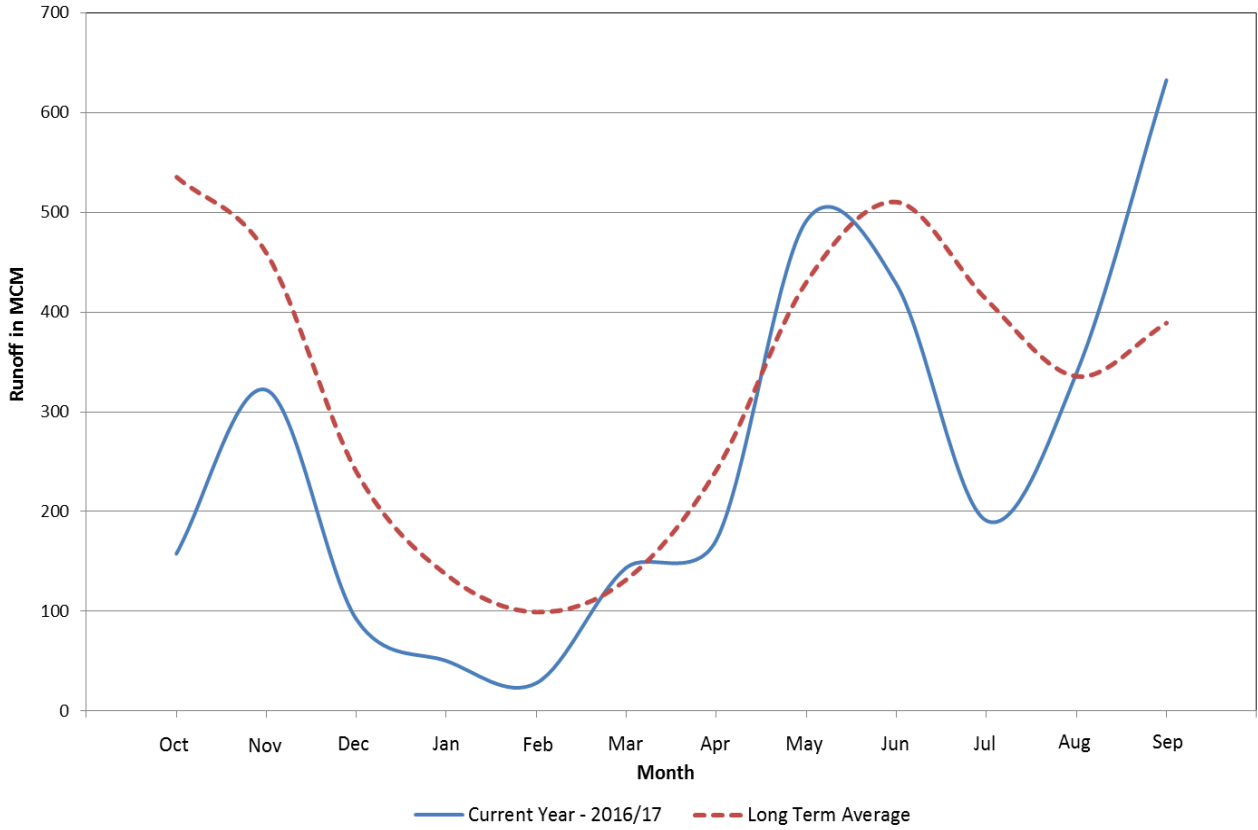
Upper line : Current year 2016/17

Lower line : Long term average

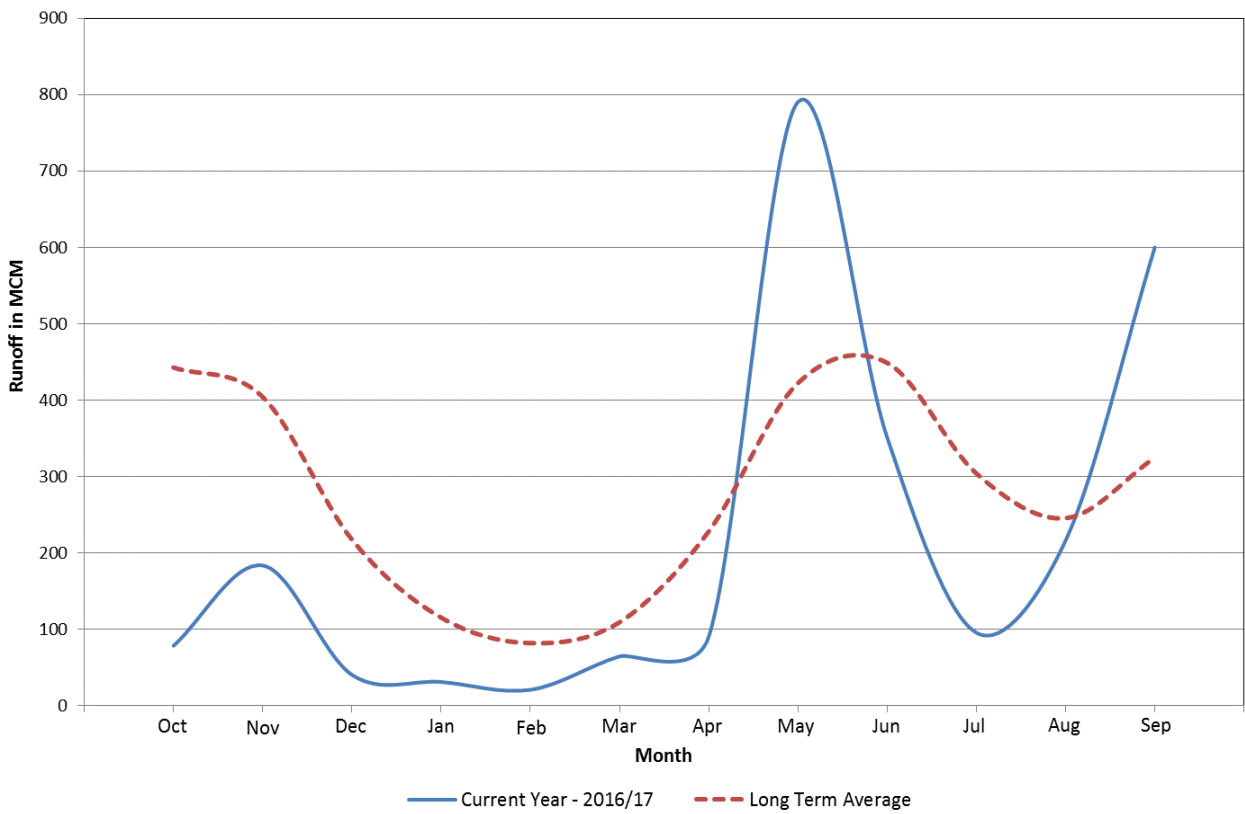
Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Kelani Ganga at Glencourse	157.67	321.90	92.10	50.28	28.10	143.86	171.58	491.58	427.93	190.95	338.50	632.56	3047.01
	535.08	458.51	239.32	136.43	99.25	131.92	241.84	430.22	510.16	412.31	335.45	388.90	3919.40
Kalu Ganga at Ellagawa	78.23	183.47	40.28	31.00	20.66	64.49	90.21	790.05	351.32	95.48	216.21	600.03	2561.43
	442.63	404.08	217.23	114.89	81.45	108.80	227.69	422.10	448.67	303.77	245.14	324.55	3341.00
Kalu Ganga at Putupaula	168.15	313.75	184.03	184.81	145.53	190.12	206.16	1150.07	480.81	175.18	217.12	771.10	4186.83
	800.15	717.85	446.69	276.40	204.08	262.09	414.20	721.22	772.32	510.91	414.20	531.50	6071.62
Gin Ganga at Thawalama	25.12	97.75	59.03	41.09	21.65	60.57	65.12	230.40	92.07	51.19	70.25	120.90	935.13
	123.91	131.06	93.00	52.55	38.20	47.46	84.34	123.02	117.64	80.13	66.94	90.95	1049.21
Gin Ganga at Baddegama	111.24	236.68	112.78	109.81	84.37	128.52	138.16	389.61	181.29	99.88	119.91	213.65	1925.91
	257.25	274.03	215.96	102.35	96.93	120.37	170.40	240.32	206.83	137.17	119.76	184.62	2125.98
Nilwala Ganga at Pitabeddara	9.91	48.99	39.11	24.60	11.32	15.29	30.77	170.85	41.77	18.71	23.87	43.84	479.02
	55.76	74.93	57.75	32.99	23.71	24.59	38.45	54.61	50.26	31.35	25.22	35.76	505.37
Kirindi Oya at Thanamalwila	1.86	5.06	1.06	1.59	0.26	21.56	21.74	18.69	1.47	0.18	0.40	0.79	74.66
	20.88	56.85	48.39	23.71	14.57	19.44	40.15	26.80	5.23	2.16	1.51	2.27	261.95
Mahaweli Ganga at Peradeniya	86.00	114.89	77.29	42.24	29.92	46.80	70.42	77.71	158.18	154.79	155.54	180.99	1194.77
	221.55	218.83	156.64	86.58	54.39	47.55	77.03	130.84	210.56	223.63	206.36	180.21	1814.19
Mahaweli Ganga at Manampitiya	1.34	24.86	14.16	134.23	13.63	60.19	9.19	4.52	2.92	2.84	3.30	1.05	272.23
	317.73	555.54	986.32	812.37	479.15	286.66	240.22	232.39	209.14	210.56	204.40	197.82	4732.30

* Discharge at Manampitiya has been gradually reduced due to construction of Moragahakanda reservoir. Generally all rivers have discharged lesser annual flow during 2016/17.

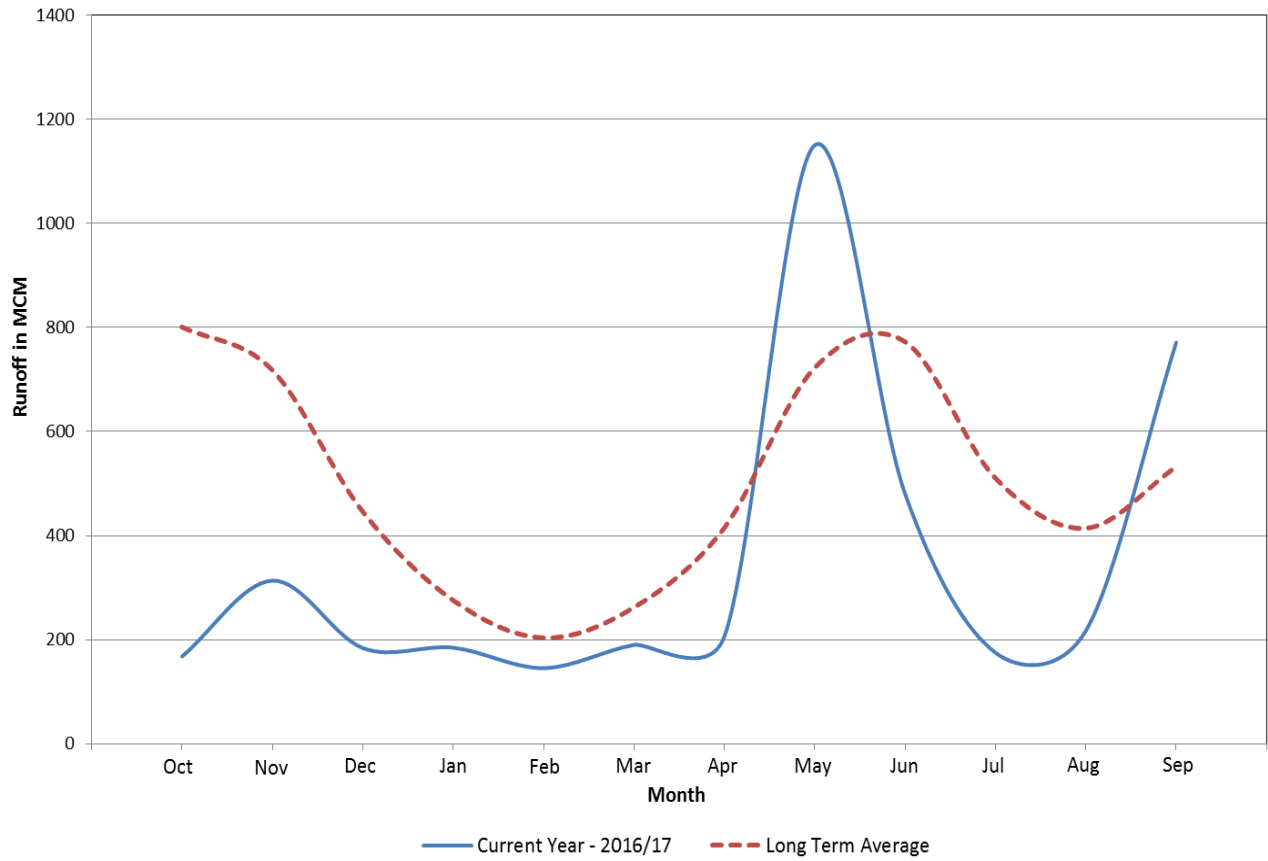
MONTHLY DISCHARGE IN KELANI GANGA AT GLENCOURSE



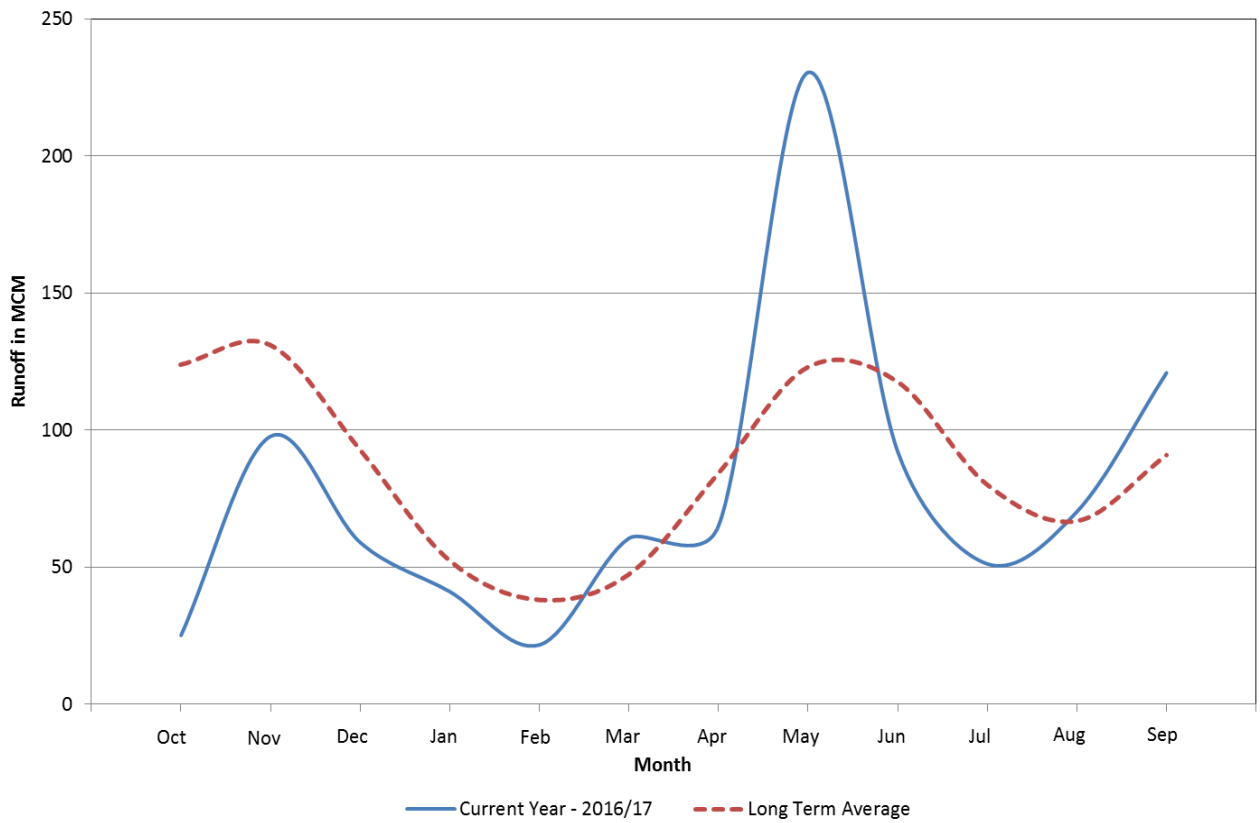
MONTHLY DISCHARGE IN KALU GANGA AT ELLAGAWA



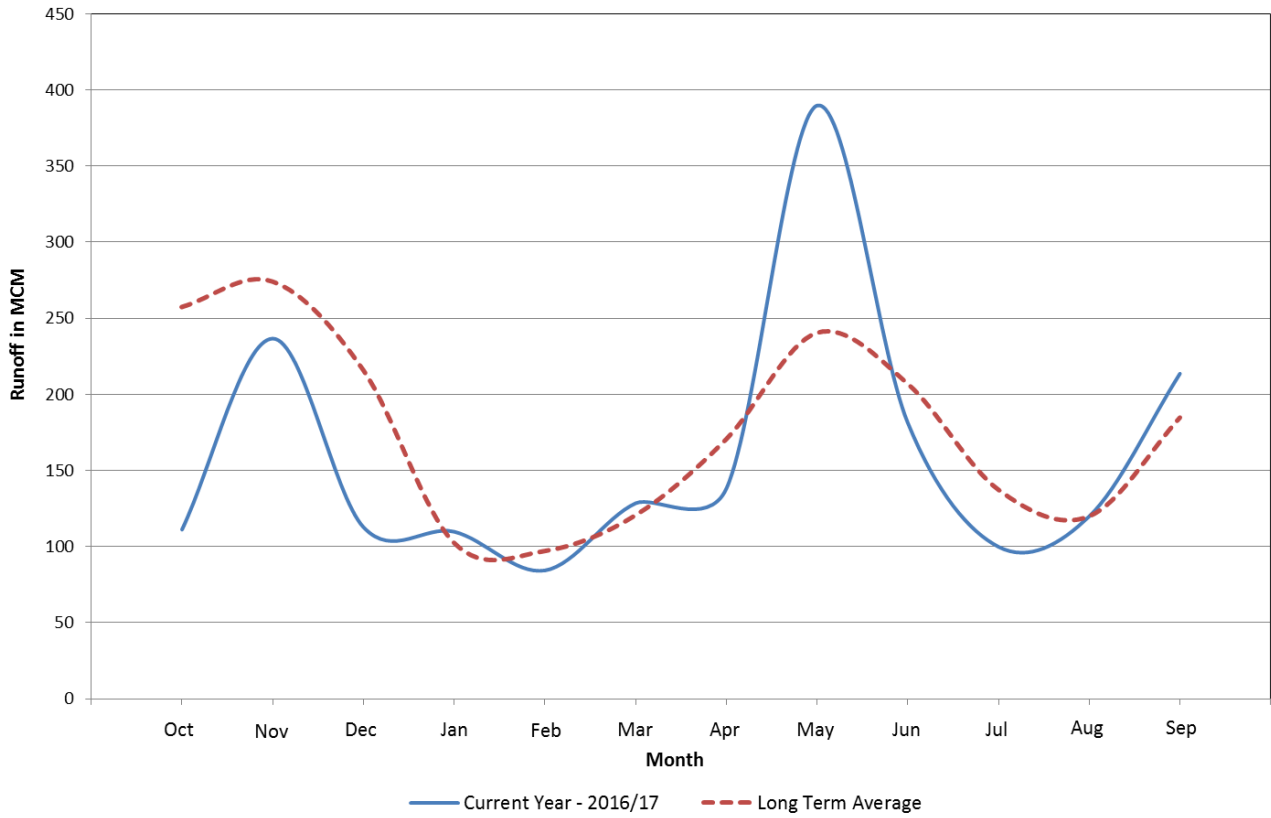
MONTHLY DISCHARGE IN KALU GANGA AT PUTUPAULA



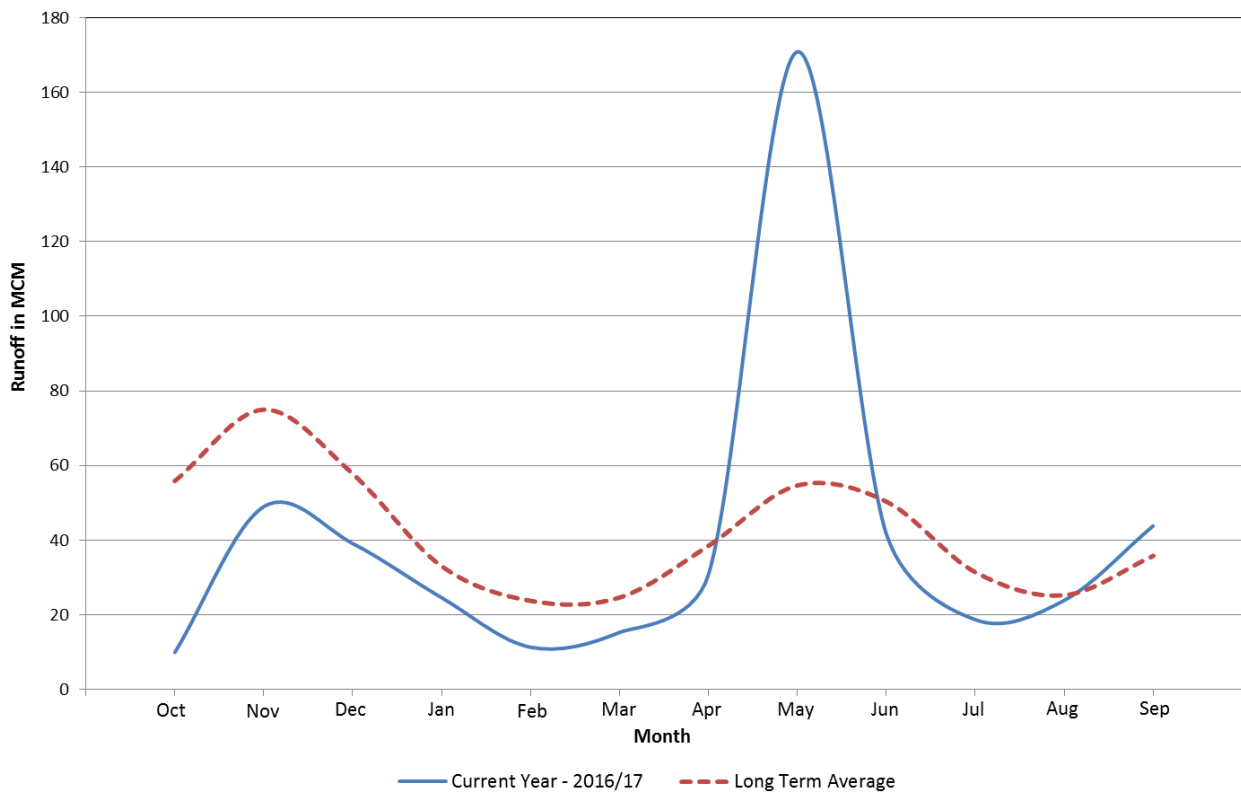
MONTHLY DISCHARGE IN GIN GANGA AT THAWALAMA



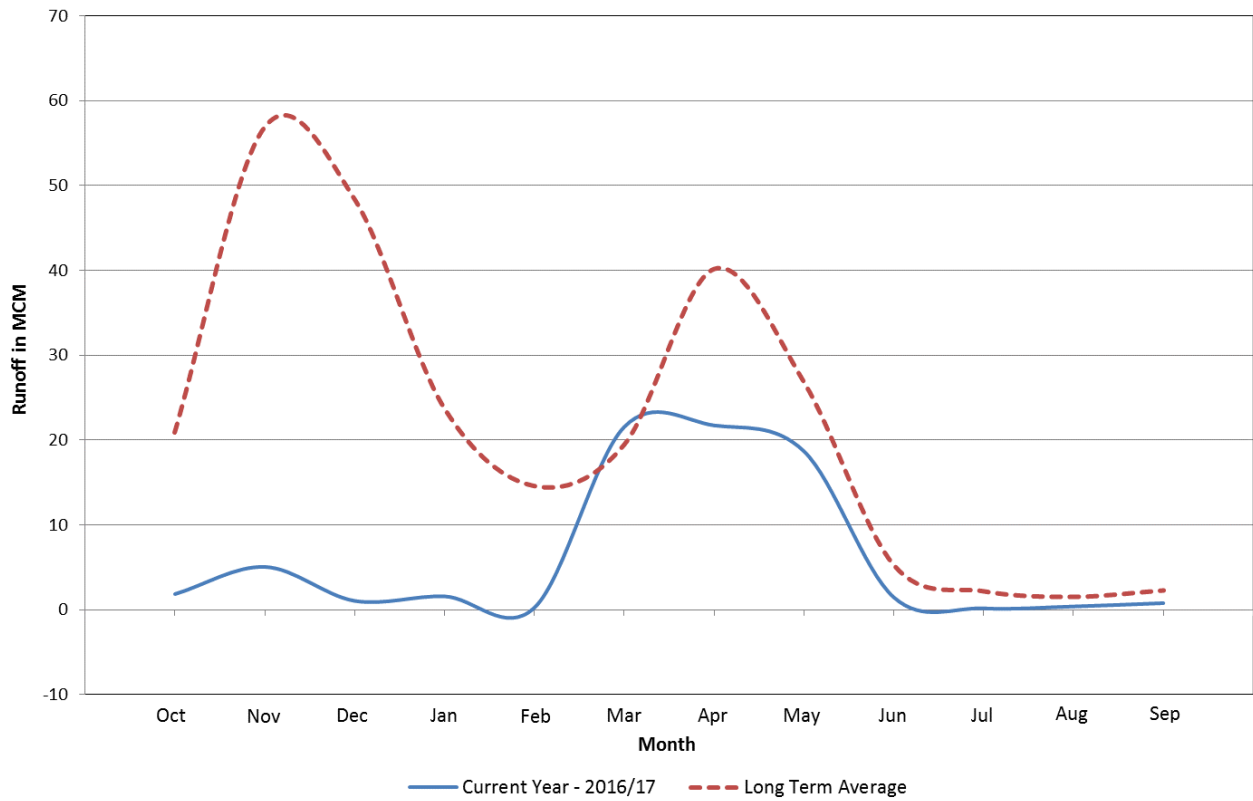
MONTHLY DISCHARGE IN GIN GANGA AT BADDEGAMA



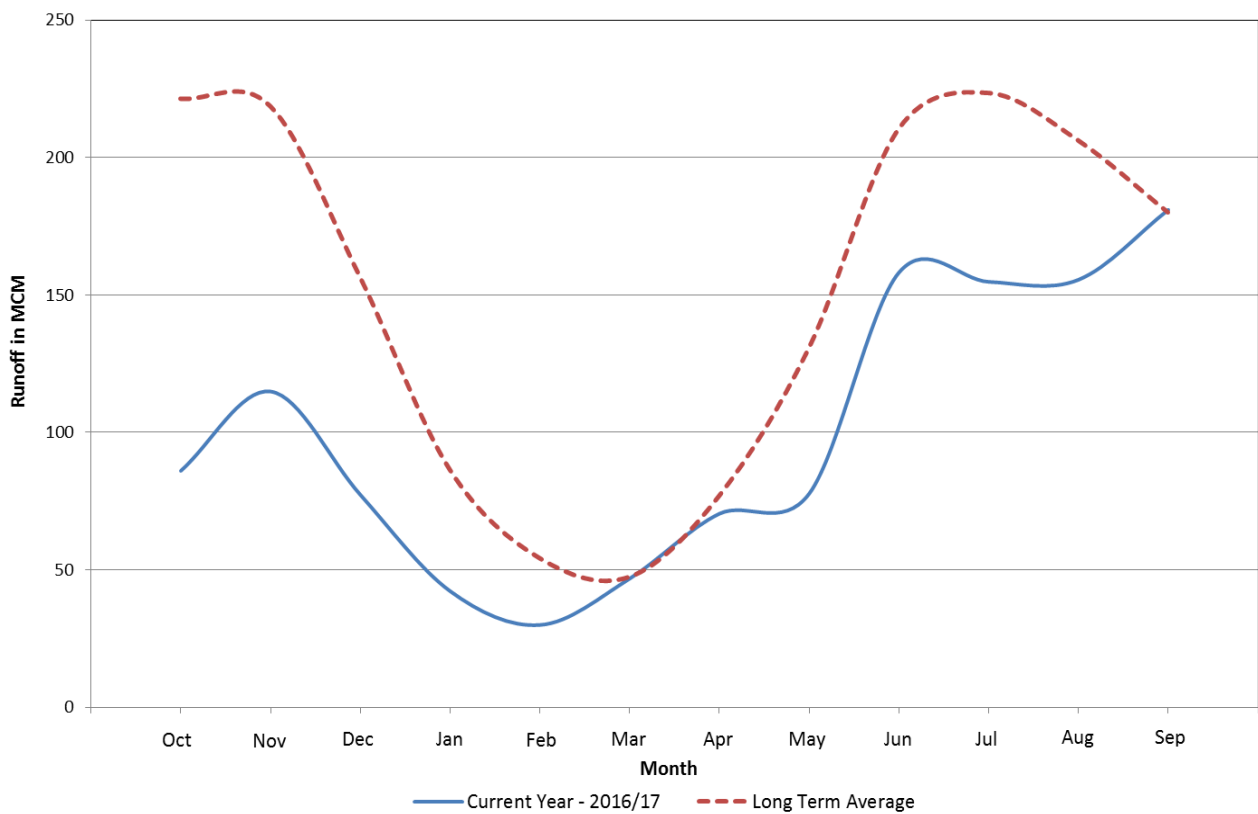
MONTHLY DISCHARGE IN NILWALA GANGA AT PITABEDDARA



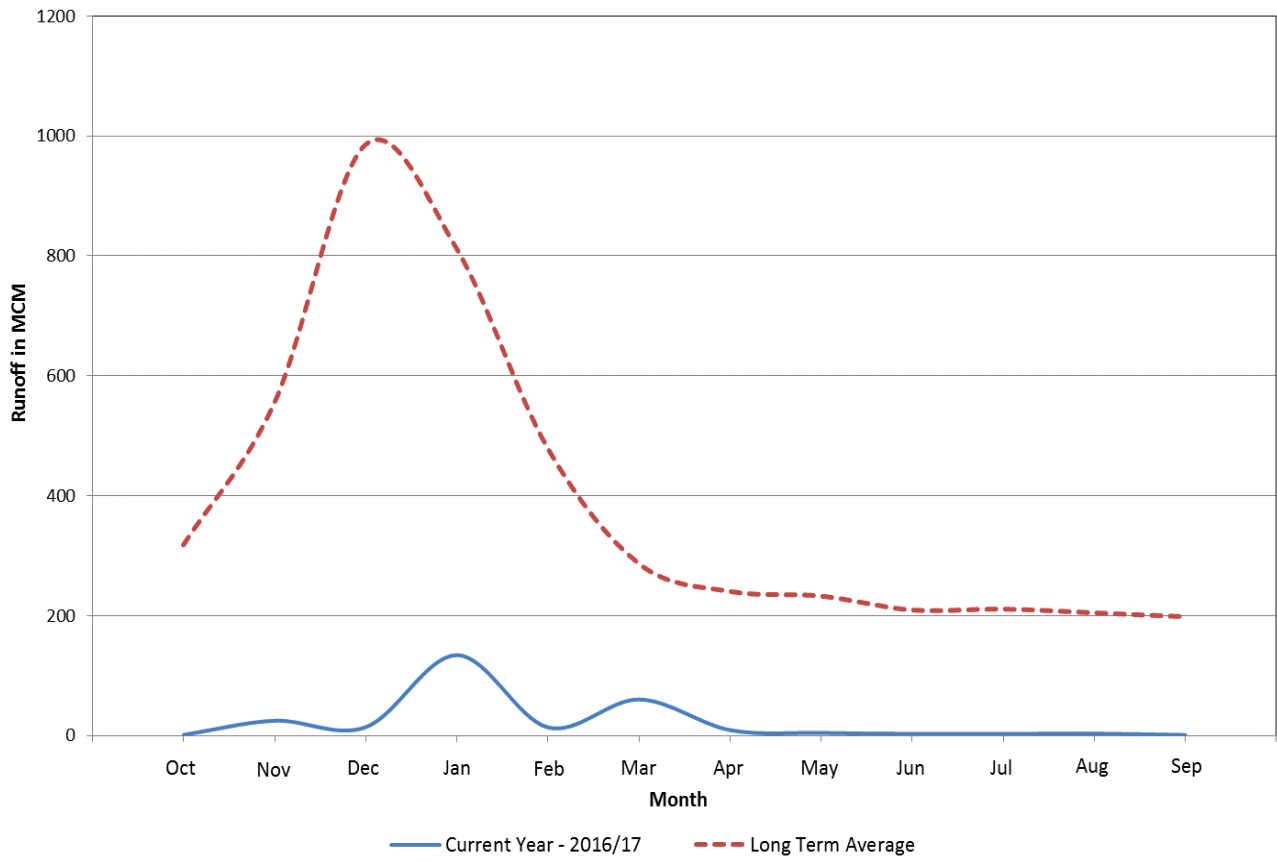
MONTHLY DISCHARGE IN KIRINDI OYA AT THANAMALWILA



MONTHLY DISCHARGE IN MAHAWELI GANGA AT PERADENIYA

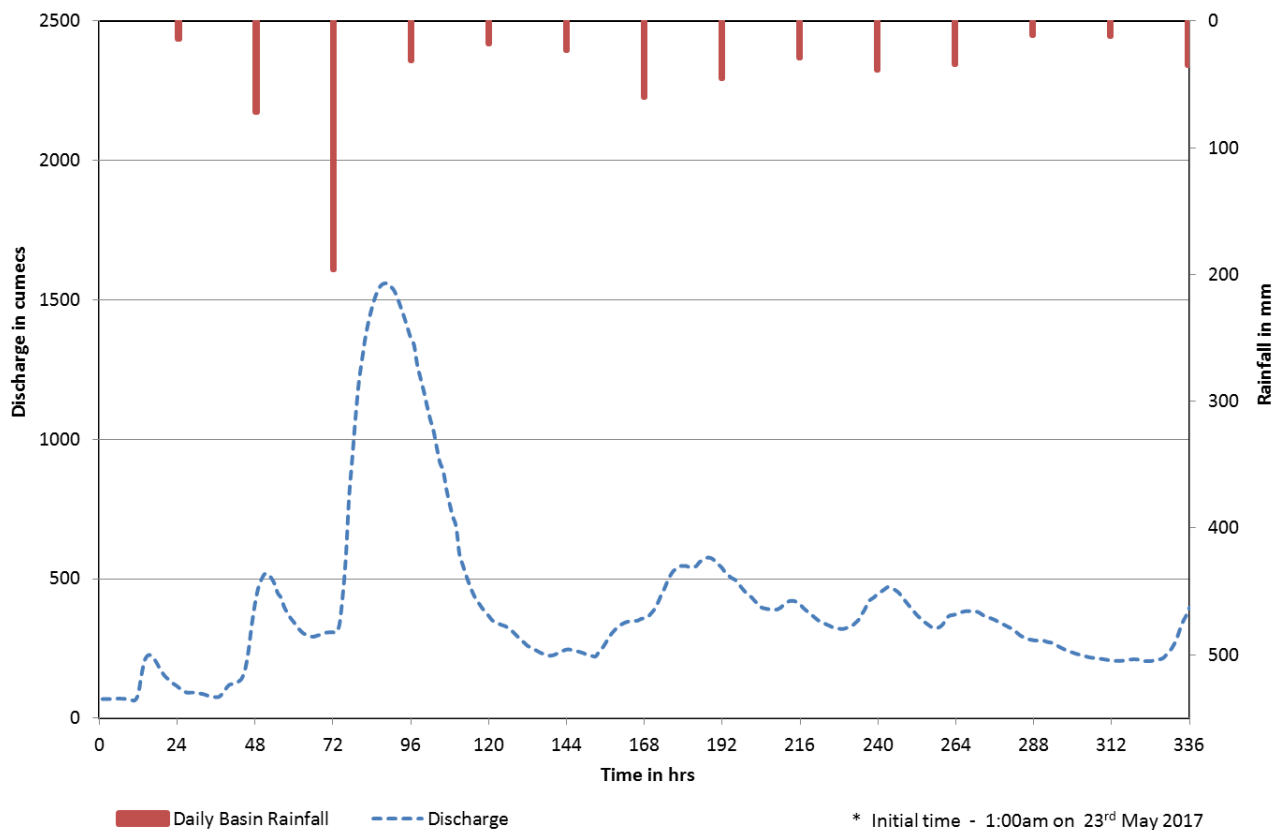


MONTHLY DISCHARGE IN MAHAWELIGANGA AT MANAMPITIYA

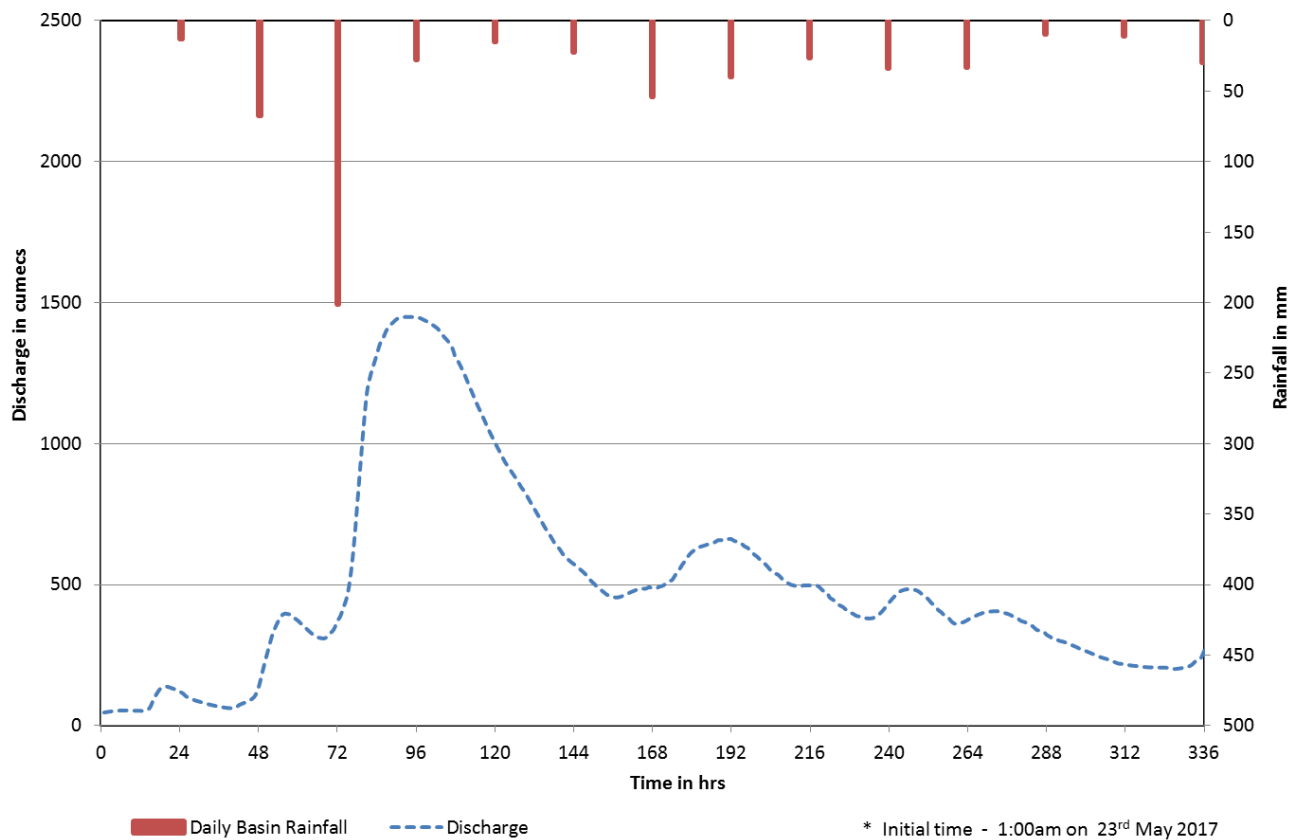


FLOOD HYDROGRAPHS

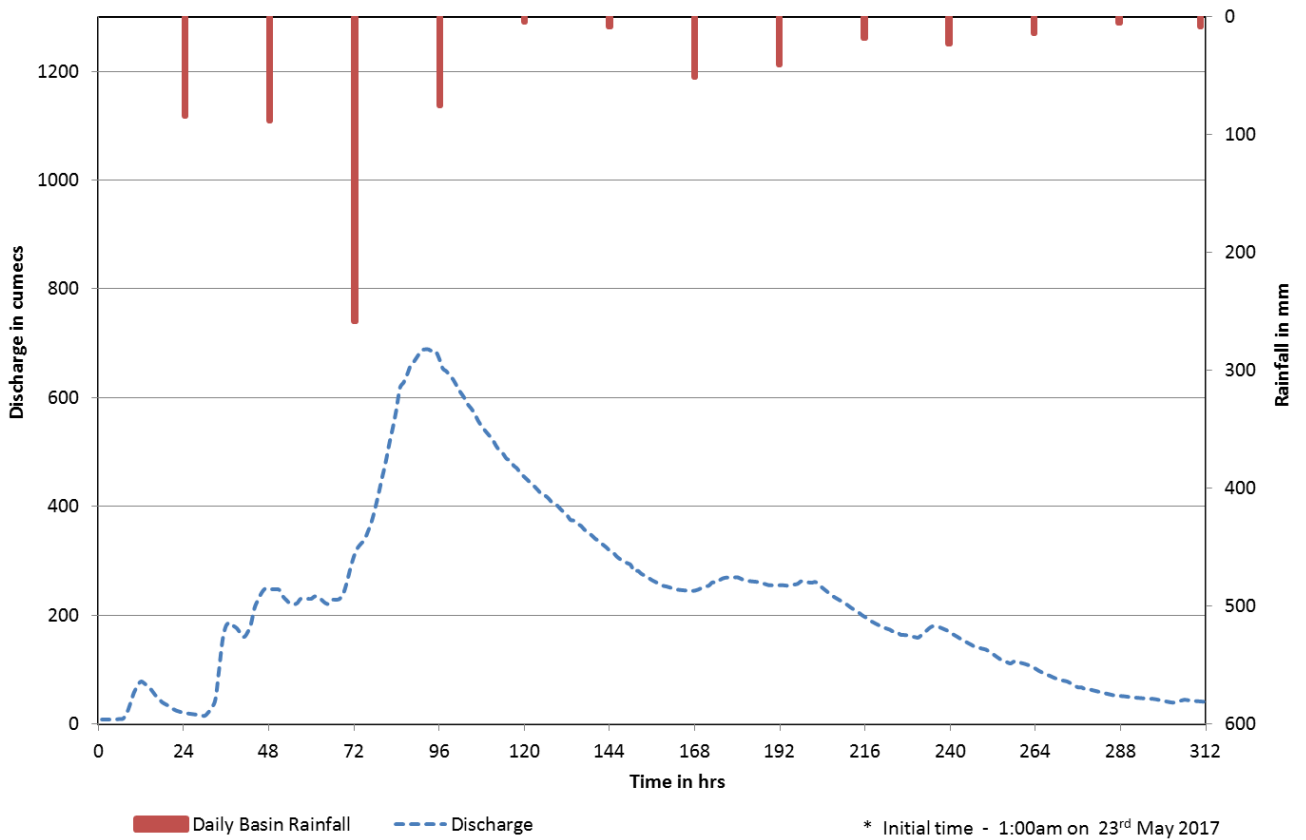
**Maximum Flood During 2016/17
Kelani Ganga at Glencourse
May 2017**



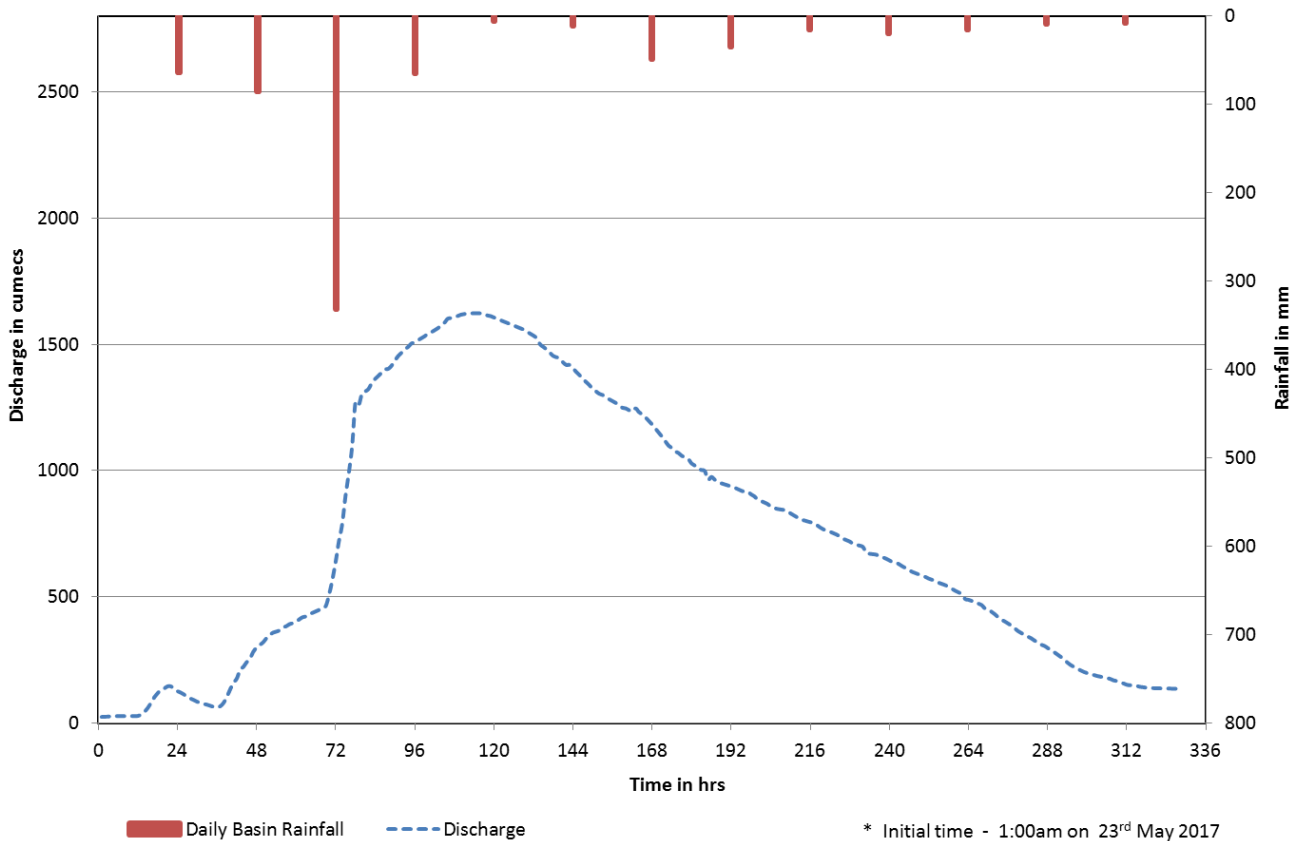
**Maximum Flood During 2016/17
Kelani Ganga at Hanwella
May 2017**



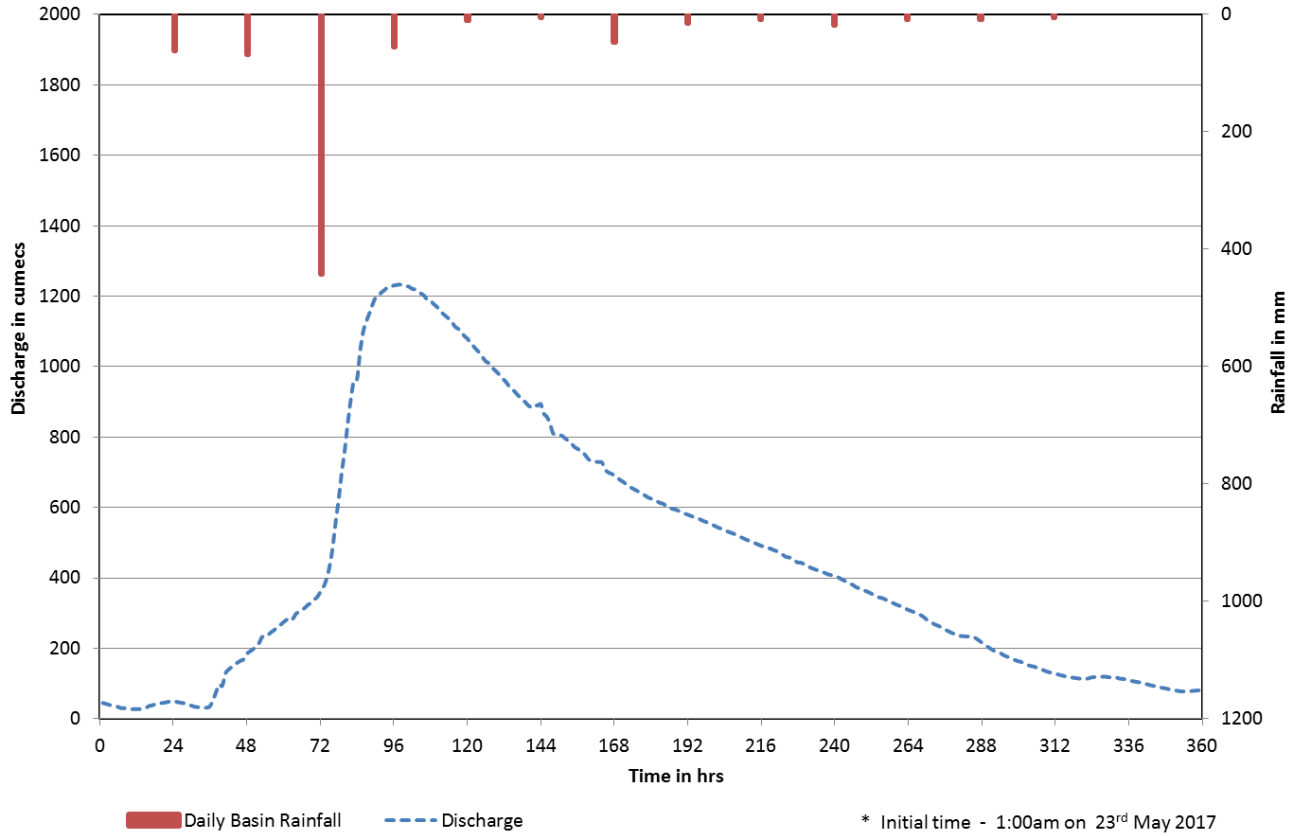
**Maximum Flood During 2016/17
Kalu Ganga at Rathnapura
May 2017**



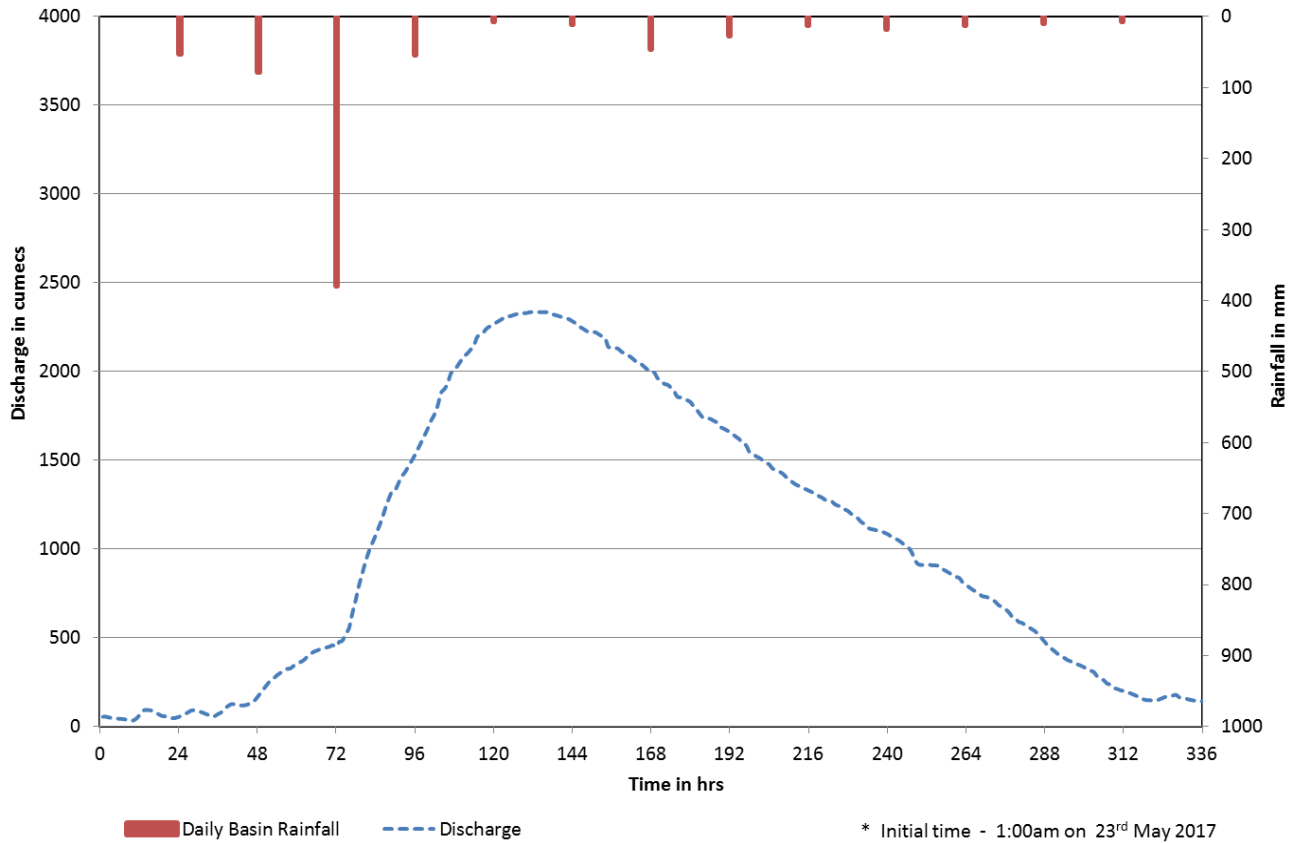
**Maximum Flood During 2016/17
Kalu Ganga at Ellagawa
May 2017**



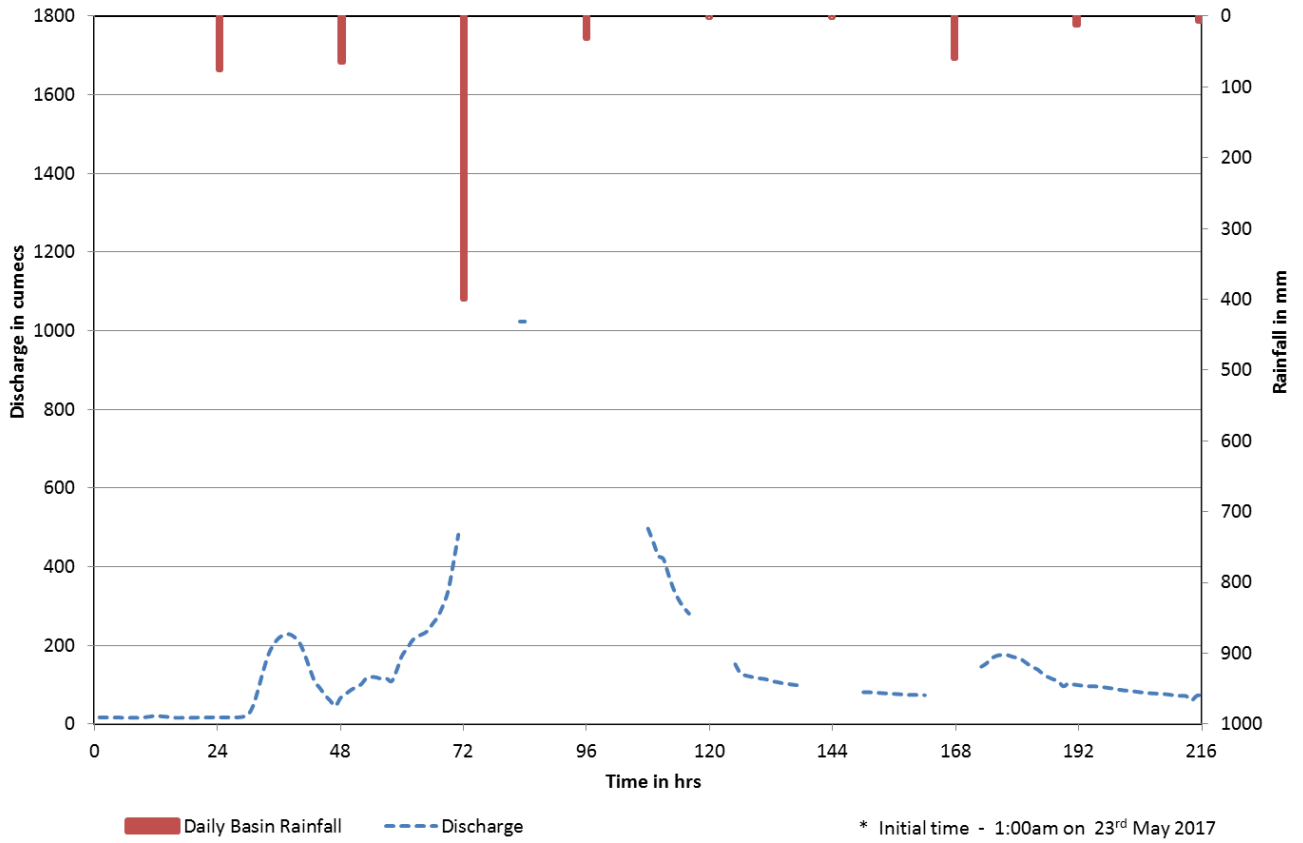
**Maximum Flood During 2016/17
Kuda Ganga at Millakanda
May 2017**



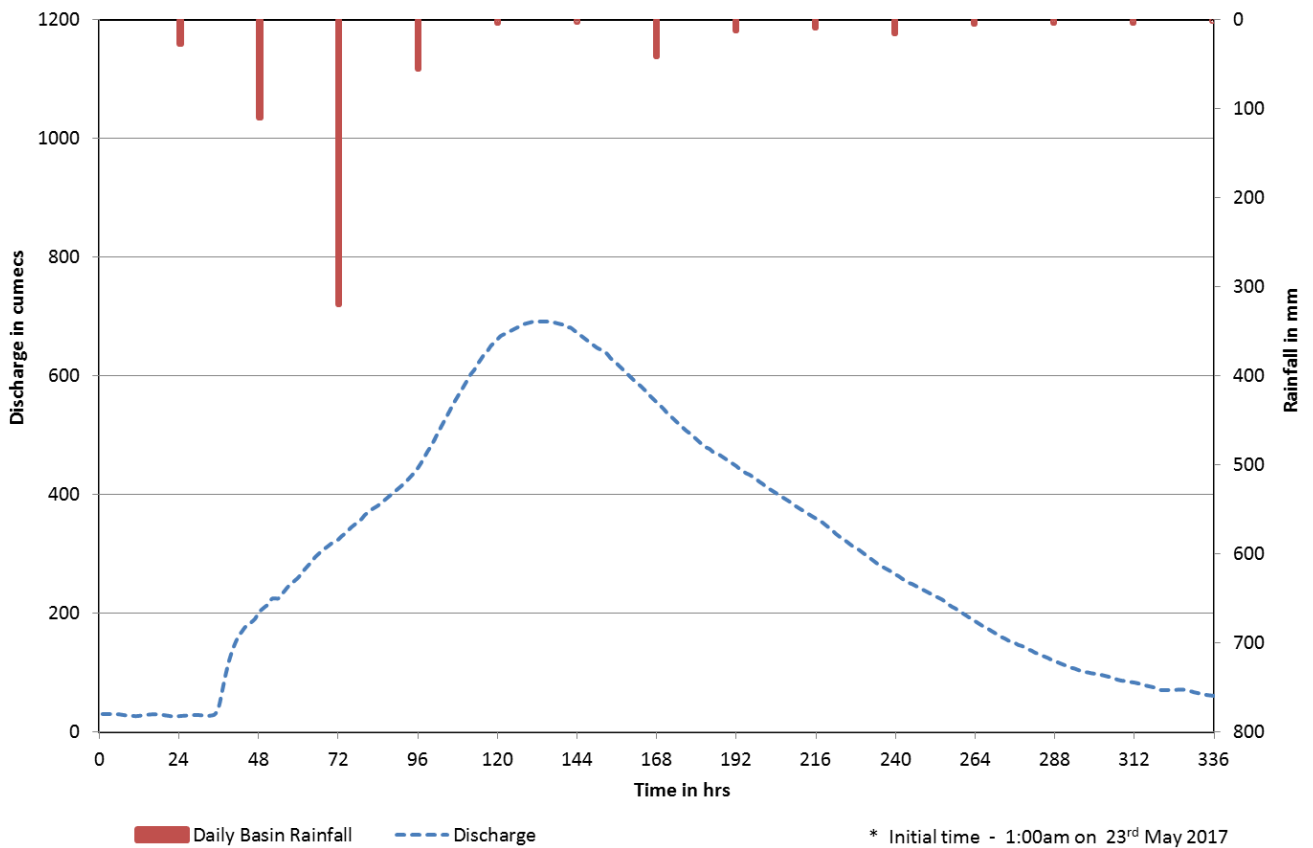
**Maximum Flood During 2016/17
Kalu Ganga at Putupaula
May 2017**



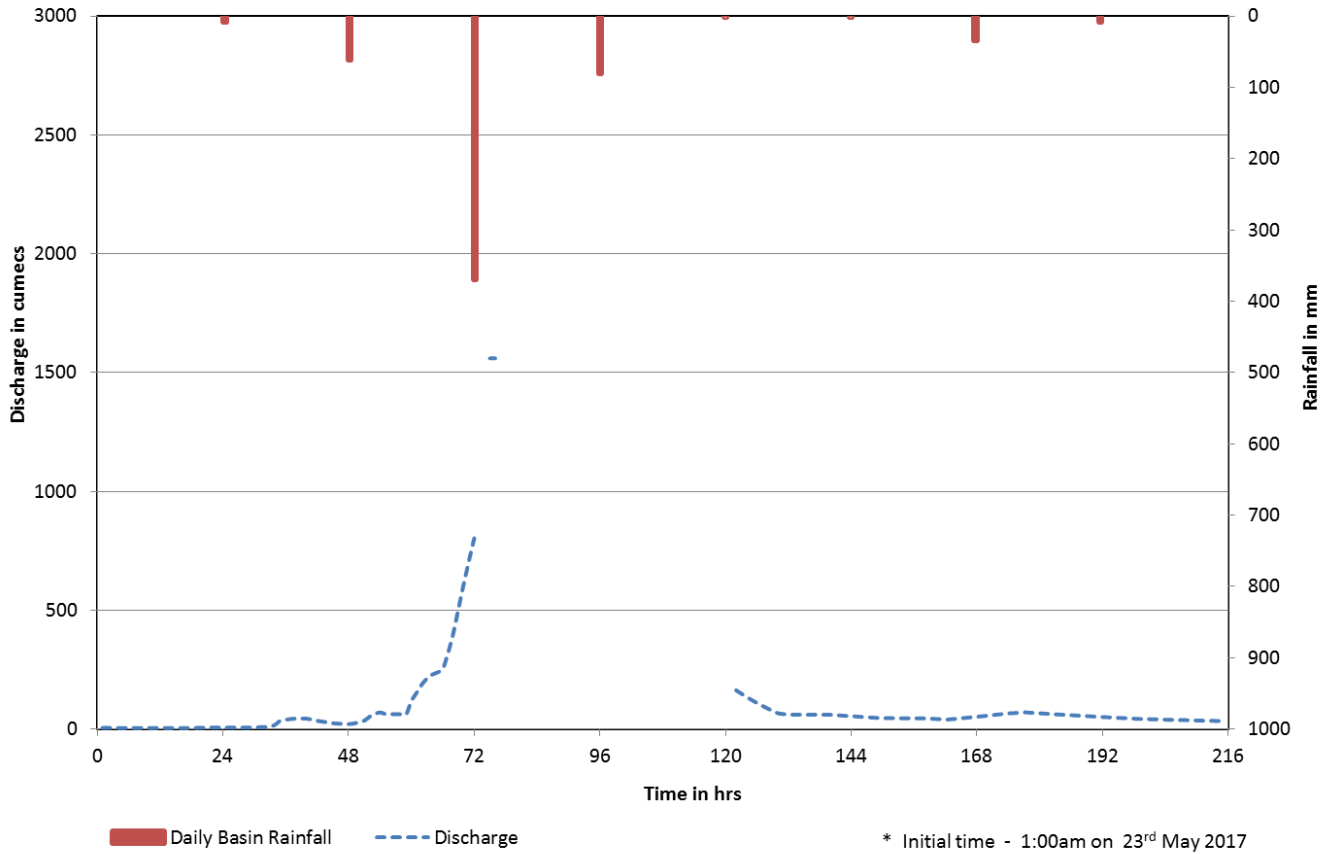
**Maximum Flood During 2016/17
Gin Ganga at Thawalama
May 2017**



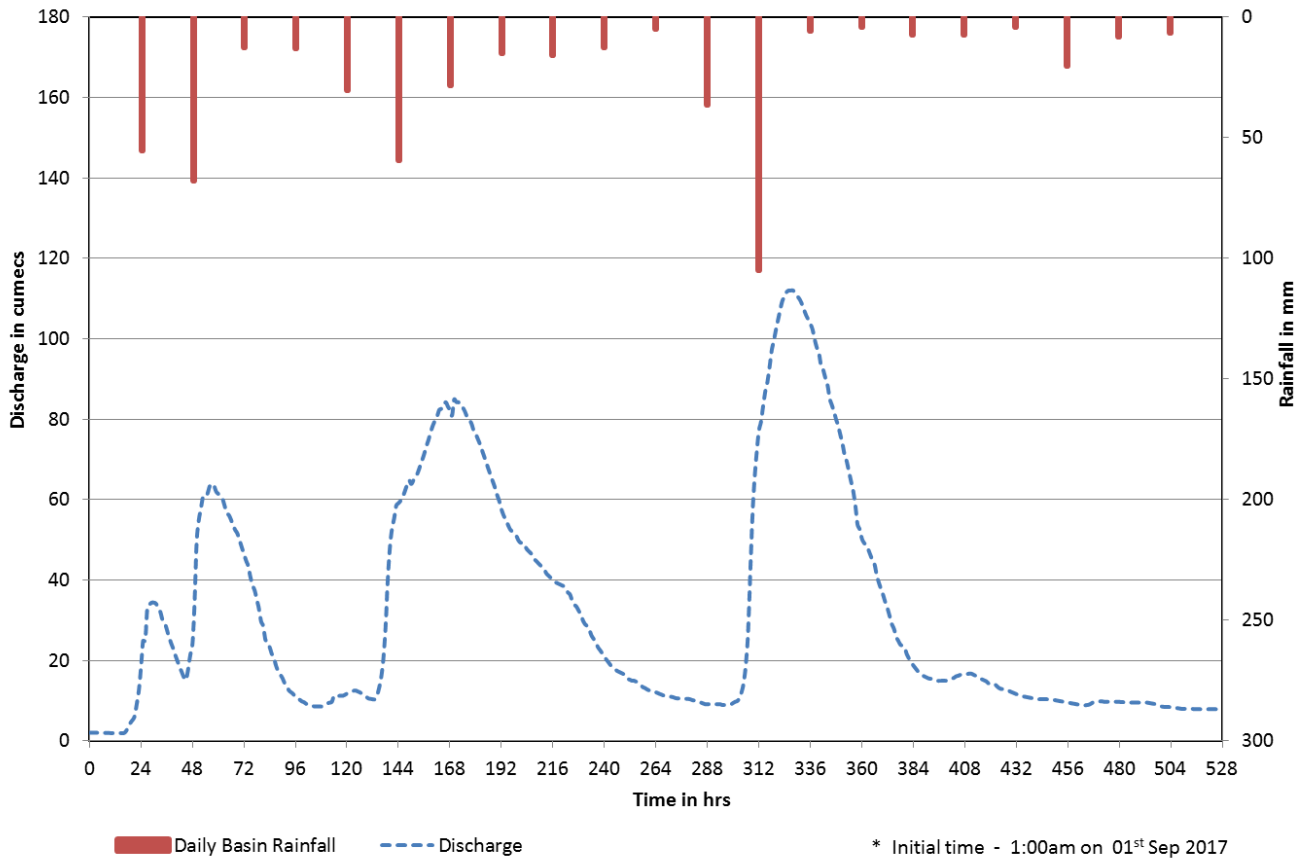
**Maximum Flood During 2016/17
Gin Ganga at Baddegama
May 2017**



**Maximum Flood During 2016/17
Nilwala Ganga at Pitabeddara
May 2017**



**Maximum Flood During 2016/17
Aththanagalu Oya at Dunamale
September 2017**



PART III

- **Experience during the Floods in May 2017 in the Wet Zone of Sri Lanka**
- **Mapping surface water with Remote Sensing**

**Experience during the Floods in
May 2017 in the
Wet Zone of Sri Lanka**

Experience during the Floods in May 2017 in the Wet Zone of Sri Lanka

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Abstract

With the onset of South – West monsoon, on 25th May 2017, Sri Lanka had to face severe weather condition causing floods and landslides over 7 administrative districts Colombo, Gampaha, Kaluthara, Ratnapura, Galle, Matara and Hambantota. The highest rainfall recorded was 646.6 mm (24 hr) at Kukule Hydrometric Station in the Kalu Ganga upper catchment while some other stations in the same catchment and the Gin Ganga catchment reporting rainfalls over 500 mm. Being situated at the middle of the affected area, the Kalu Ganga basin suffered most severely claiming 147 lives (84 and 63 in Ratnapura and Kalutara districts respectively) and heavy damages to properties. In addition to that 53 people were reported missing according to the sources of Disaster Management Centre. Total death count, from all affected districts, was 206 and the number of people affected was reported as 650,000.

Among the past records, an event somewhat similar to this flood could be found in May 2003. However, the flood levels at the lower reaches of Kalu Ganga (at Putupawla), Gin Ganga (at Baddegama) and the Nilwala (at Pitabeddara and Panadugama) in 2017 were higher than the recorded values of the previous event. This paper analyses the hydrological aspects related to these events with the observations made during the recent flood and the past records. Managing this type of situation is a rare experience and it is vital for managing such events in future and also for planning and designing of flood control works with respect to the affected river basins.

1. Introduction

Sri Lanka is a tropical country which experiences heavy rainfalls during the South-West (May, June and July) and the North-East (November, December, January) monsoon periods. Normally the South-West monsoon affects the south-western quadrant of the country which includes major river basins of Aththanagalu, Kelani, Kalu, Gin and the Nilwala Rivers. During the North – East monsoon, entire country get heavy rains. The smaller river basins in between and adjacent to those rivers (Bolgoda, Benthara, Madu Ganga, Polwaththe Ganga and a part of Kirama Oya & Urubokka Oya) and some coastal basins are also affected. These areas belong to Western, Southern and Sabaragamuwa provinces which are highly populated and developed.

This part of the country normally experiences floods in May, June months at the beginning of South-West monsoon or in late October with the onset of North-East monsoon. Occasionally it has been subjected to extreme floods due to tropical cyclones which may occur at any time of the year.

Out of these river basins, the Kalu river faces floods most frequently while the Kelani floods are associated with heavy damages. The lower basins of the Gin, Nilwala and the Kelani have been protected against the minor and medium floods by constructing levees either side of the rivers. The Kalu Ganga is the largest among all (2840 km² of catchment) and releases the highest discharge (average annual discharge over 6000 MCM) to the sea. So far this water hasn't been used extensively for any economic purpose even though there is ample potential for producing hydropower and trans-basin diversion to the dry zone.

2. River Basins information

All affected river basins, except the Kirama Oya and Urubokka Oya, are situated in the Wet Zone of the country. Some of the important information pertaining to major rivers is summarized in Table I.

Name of the River	Total Catchment Area km ²	Lower Most River Gauging Station (GS)	Catchments above Gauging Station km ²	Average Annual Rainfall (for catchments above GS)	Average Annual Discharge (at GS)
Aththanagalu Oya	811	Dunamale	153	3352	197
Kelani Ganga	2340	Hanwella	1782	3709	4164
Kalu Ganga	2839	Putupaula	2598	3186	6134
Gin Ganga	932	Baddegama	681	3422	2347
Nilwala Ganga	971	Pitabeddara	333	3058	511

Table 1: Information on Affected Major River Basins

Water resources of the Kelani River have been harnessed for domestic water and hydropower development by constructing several reservoirs while the other rivers still remaining in their virgin status.

3. Hydrometric Network

When compare to the other parts of the country the Hydrology Division of Irrigation Department is maintaining relatively denser network of hydrometric stations on these rivers, mainly for the purpose of flood forecasting. Station at Nagalagam Street on the Kelani River is the oldest river gauging station in the country. It has continuous record of water levels since 1924. Several other stations on these rivers also have historical data for periods more than 50 years.

Recently a project was started for expansion and modernization of hydro-meteorological information system (HMIS) of the country with the financial support of the World Bank. Total number of hydro-meteorological stations (of the country) will reach to (168) by completion of this project. The major part of the project had been completed by the time of 2017 flood and online data from some of those stations were available during the flood time. Those data were extremely useful for river modeling and flood forecasting during the flood period.

4. Experience of Managing 2017 Flood

Irrigation Department (ID) is the mandated organization for flood management in Sri Lanka. It is responsible for implementing structural and non-structural measures for mitigation of the riverine floods and the reservoir induced floods. Hydrology Division (HD) of the Irrigation Department (ID) has been assigned with the responsibility of flood forecasting and early warning with respect to major rivers. HD has long term experience, knowledge and trained technical staff in this regard and comprehensive hydro-meteorological observation network covering the entire Island. This Division is continuously monitoring the water levels of the rivers and rainfalls of the catchments throughout the year. In addition to that HD is always being vigilant on the meteorological forecasts issued by the Department of Meteorology.

4.1 Situation Prior to the Flood Event

First part of the year, up to mid of May, was dry and the Dry Zone of the country faced severe shortage of water. Water levels of the reservoirs reached minimum causing crop failures in the Northern, North-Central and Eastern provinces of the country where extensive paddy cultivation is practiced. Wet Zone Rivers, Kelani, Kalu, Gin and Nilwala, were also at low stages up to the third week of May 2017.

4.2 Meteorological Forecast for 25th May 2017

The Department of Meteorology (DOM) predicted heavy rains in the Wet Zone of the Island with the onset of South – West monsoon which was expected around 25th of May. According to the 10 day forecast (experimental) of the DOM (Fig. 1), heavy rains up to 200 mm were predicted in Kaluthara and Galle districts and somewhat less rains in the adjacent (Colombo, Ratnapura and Galle) districts.

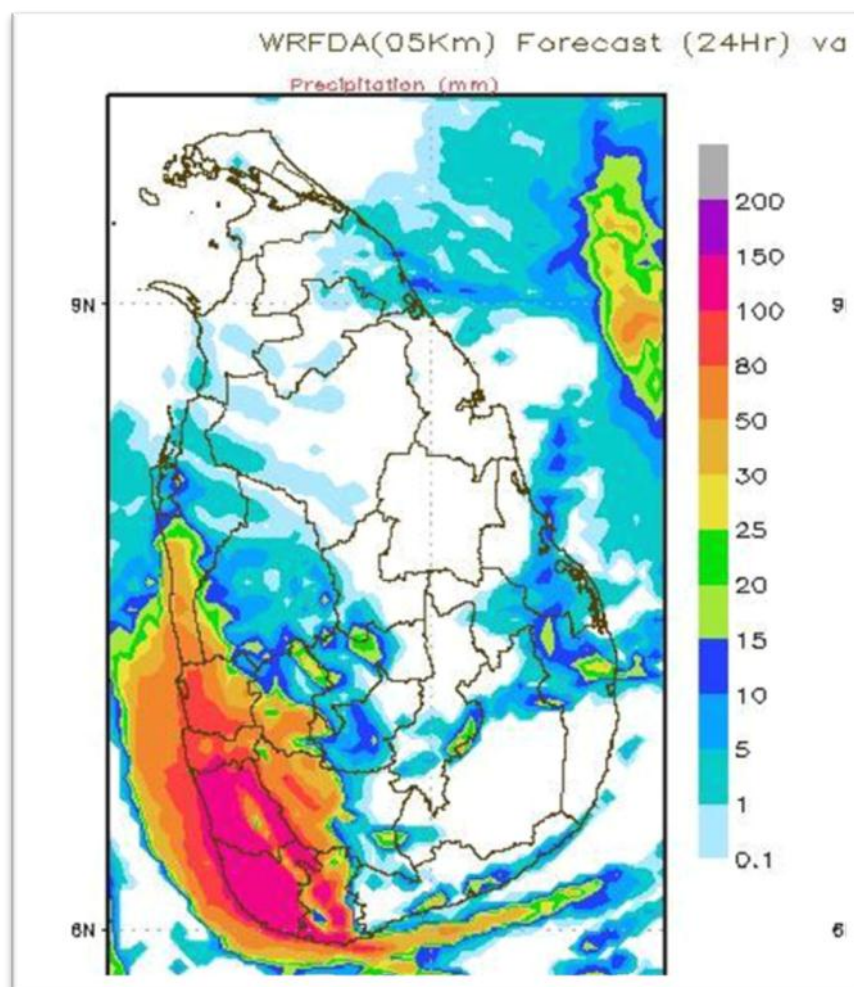


Fig. 1: Experimental Forecast issued by the Department of Meteorology for 25th May 2017.

4.3 Initial Preparations

Hydrology Division took following precautionary actions for monitoring and forecasting flood levels and lessening flood hazards in the river basins which were expected to be flooded.

1. Arranged several discussions among the stakeholder organizations (Irrigation Department, National Water Supply and Drainage Board, Sri Lanka Navy etc.) and reduced the level of Salinity Barrier at Ambatale on the Kelani River by removing temporary part of the structure before flood. This structure caused a significant rise in flood level (nearly by 60 cm) during the previous flood in May 2016, causing severe damages to the area upstream.
2. Cancelled the leave of all officers attached to Hydrology Division and advised them to be vigilant on the water levels and rainfalls of all manual and automated hydrometric stations.
3. Took prompt actions to attend the repairs and maintenance works of hydrometric stations (automated and manual) to ensure proper functioning of them during the rainy period.
4. Prior arrangements were made for current metering at the newly established gauging stations under the 'Hydro – meteorological Information System' (HMIS) project in order to prepare rating curves.
5. Hydrological (HEC-HMS) and Hydrodynamic (MIKE 11) models were calibrated for the four rivers (Kelani, Kalu, Gin and Nilwala) and kept ready for flood forecasting and early warning purposes.

4.4 River Stages and Rainfalls on the Previous Day

Hydrology Division monitors the Island wide water level situation in major rivers and compares with the predefined alert levels at gauging points as a routing and reports to the all relevant organizations. The same report is published in the Web Site of the Irrigation Department. According to that the river stages of all major rivers were normal up to 9.00 am of 24th May 2007. Somewhat heavy rains had been reported at Tawalama (146 mm) on the Gin Ganga and at Malwala (111.7 mm) on the

Kalu river on the previous day (23rd May). Water level at former station rose to minor flood level and at the latter to Alert level during the day time on 24th. First warning was issued based on that. However, the river stages at both stations were reported falling by 3.00 pm in the same day. There was no significant rainfall during the day time. The office was closed in the evening.

However, some heavy rains were reported in the Kaluganga upper catchment by 9.00 pm of the same day (24th May) from the automated raingauges under HMIS (93.8 mm at Ratnapura, 202.7 mm at Malwala, 105.9 mm at Dela and 159.8 at Banagoda). Based on that, a warning message was issued to the people of Ratnapura area through Disaster Management Center (DMC) by 9.30 pm. Immediate actions were taken to open the office of Hydrology Division (by 10.30 pm) and keep on getting observations from the field stations, reporting real time situation, river modeling and issuing forecasting throughout the night. Unfortunately it was not possible to get continuous observations from the automated stations due to some technical problems but the manual stations were in operation. According to the report issued at 11.30 pm Ratnapura station had reached to alert level (5.2 m) and the water level was rising further.

By 3.00 am of 25th May, Baddegama Station on the Gin Ganga also became alert (3.5 m) and the situation was reported to DMC. Based on the model results warning was issued to Ratnapura area to expect minor flood situation and the people of vulnerable areas of the Gin, Nilwala, Kalu and Kelani river basins were also advised to be on alert.

By 6.00 am on 25th May Ratnapura (Kalu Ganga), Baddegama on Gin Ganga and Panadugama on the Nilwala were at alert levels and none of the stations had reached flood levels. Based on the model results (using the observed rainfalls as input) minor flood situations were forecasted for all four river basins.

Water level situation by 9.00 hours of 25th May is summarized in Table 2 below.

River	Gauge Station	Situation	Water Level Rising / Falling
Kelani Ganga	All Stations	Normal	-
Kalu Ganga	Ratnapura	Alert	Stable
	Millakanda	Normal	-
	Other stations	Normal	-
Gin Ganga	Baddegama	Alert	Rising
	Tawalama	Normal	-
Nilwala Ganga	Panadugama	Alert	Rising
	Pitabeddara, Urawa	Normal	-

Table 2: Water Level Situation at 9.00 hrs. on 25th May

Heavy rains (over 100 mm per day) had been reported from the following stations as per the observations from manual rain gauges.

River Basin	Station	Rainfall mm
Kelani Ganga	Norton	128.0
	Canyon	132.0
	Lakshapana	148.0
	Deraniyagala	134.0
Kalu Ganga	Millakanda	161.5
Gin Ganga	Baddegama	211.9

Table 3: High Rainfalls (over 100 mm) on the previous day (24 hours ended by 9 am on 25th May)

As per above all the catchments were in the wet condition and the river stages were fairly high by the end of the previous day.

4.5 Experience during the Flood Period

Severe rainfalls causing floods were occurred on 25th May 2017. Engineers of Project Management Unit (PMU) were able to repair and managed to receive continuous data from HMIS stations by this time. Heavy rainfalls (over 500 mm) were recorded at several stations. Spatial

distribution of the rainfalls over the affected area is illustrated in following Figures. This was copied from the HMIS Web Portal in the Morning of 26th May which illustrated rainfalls of last 24 hours.

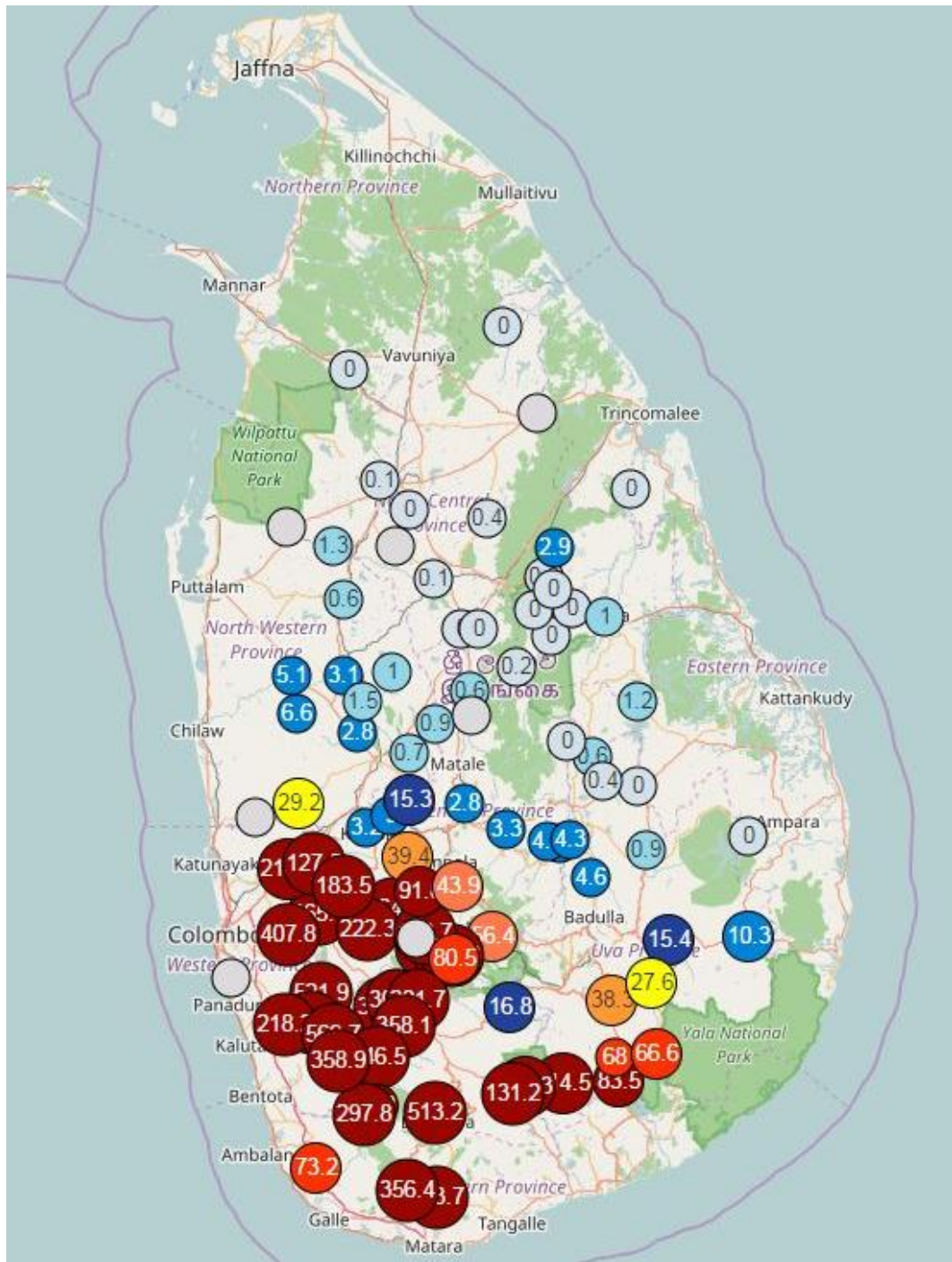


Fig. 2: Spatial distribution of rainfalls on 25th May over the affected area

Similar performances were observed from the other stations and the comparison between manual and automated rainfalls at Hanwella and Glencourse is shown in Table 5.

Date	Hanwella		Glencourse	
	Manual	HMIS	Manual	HMIS
23th May	0.0	0.8	23.8	23
24th May	62.8	13.0	55.6	45.3
25th May	350.4	406.6	245.9	264.3
26th May	15.3	14.7	14.0	16.3
27th May	1.0	1.0	2.2	3.2
28th May	19.2	17.9	37.6	42.5
29th May	19.3	17.8	40.8	60
30th May	21.4	19.1	26.6	34.7
31st May	15.4	16.6	7.8	15.4
1st June	19.0	11.3	6.8	9.9
2nd June	33.6	41.6	25.3	36.4
3rd June	5.9	4.8	0.3	0.9
4th June	6.6	6.0	20.0	19

Table 5: Differences of Rainfalls from the Manual and HMIS stations, Kelani Ganga.

Fairly better match was observed with the water level observations at Ratnapura station on the Kalu Ganga as depicted in Figure 4.

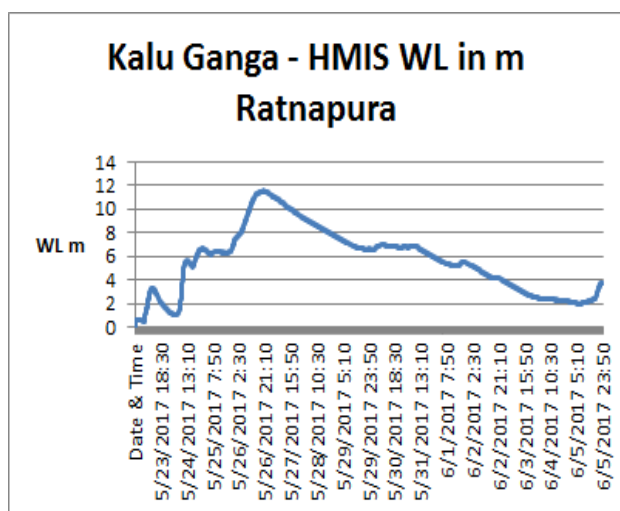


Fig. 4a: HMIS data, Ratnapura

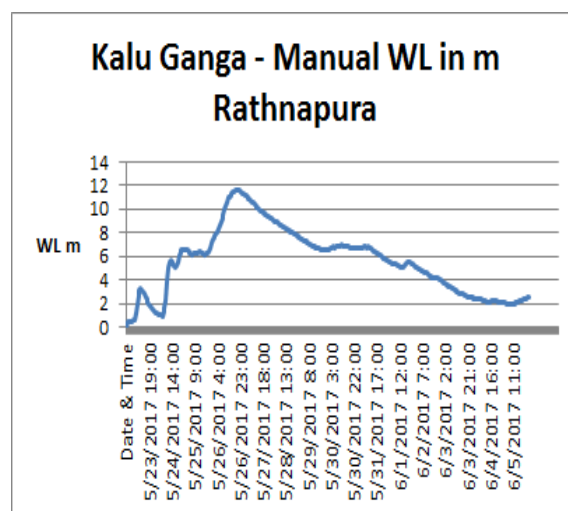
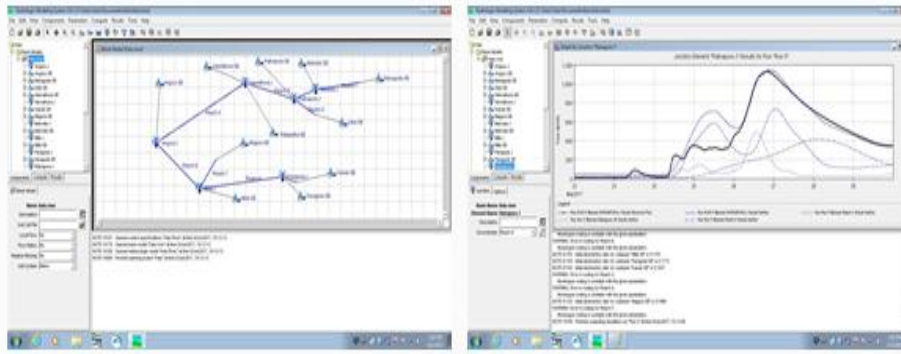


Fig. 4b: Manual Water Levels Rathnapura

5. Flood Forecasting with Mathematical Models

HEC HMS software was used to forecast flood levels during the flood time. Even though there were some discontinuities in the data, we were able to get field data from the automated hydrometric stations during the flood time. Manual stations at Panadugama and Pitabeddara were inundated and some other stations had to be abandoned due to the risk of being isolated.

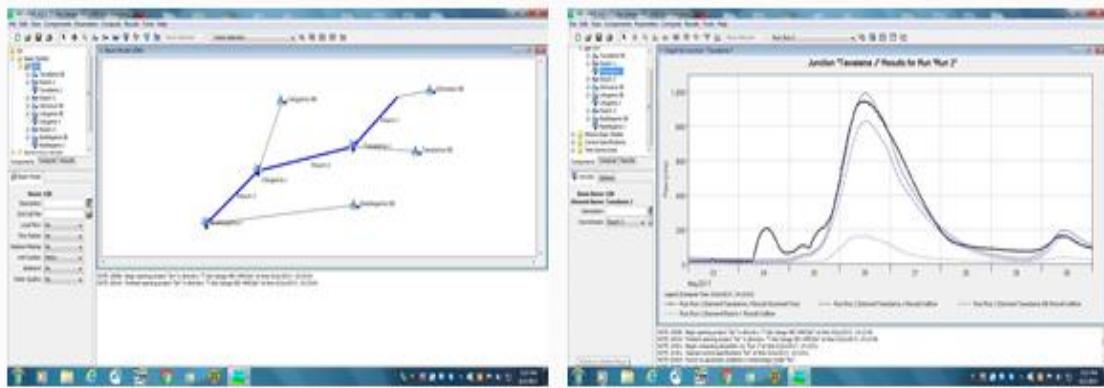
HEC HMS is a simple hydrological model which can be used in these types of situations where several river basins are affected simultaneously. Following figures show predicted flood levels and observed flood levels during the flood period at different stations on the four rivers affected.



Basin Model

Ratnapura

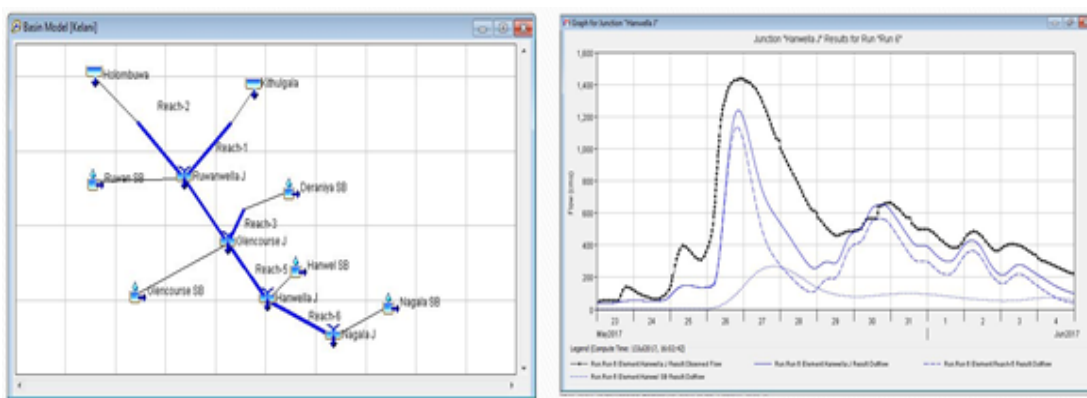
Fig. 5a: HEC-HMS Model Output, Kaluganga at Ratnapura



Basin Model

Tawalama

Fig. 5b: HEC-HMS model output, Gin Ganga at Tawalama



Basin Model

Hanwella

Fig. 5c: HEC-HMS model output, Kelani Ganga at Hanwella

Performance of the model was generally satisfactory and it was possible to issue early warning with sufficient lead time for most of the areas. As mentioned in the earlier chapters, the first warning for Ratnapura was issued at 3.00 am on 25th May. All other stations were issued warning by 6 am on the same day. The times of starting minor floods and respective lead times are shown in Table 6. However,

it is not possible to assure weather these messages were reached to the people of affected areas in time. Since there are several organizations involved in the forecast dissemination, delays and misinterpretations may occur. Precautions have to be taken to avoid such gaps in the future cases of flooding.

River	Station	Start time of minor flood	Lead time of warning
Kalu River	Ratnapura	1 am on 26th	18.5 hrs
	Ellegawa	3 am on 26th	20.5 hrs
	Millakanda	3 am on 26th	20.5 hrs
	Putupaula	9 am on 26th	26.5 hrs
Kelani River	Nagalagam St.	1 pm on 26th	30.5 hrs
	Hanwella	9 am on 26th	26.5 hrs
	Glencourse	8 am on 26th	25.5 hrs
	Deraniyagala	6 am on 26th	23.5 hrs
Nilwala River	Urawa	5 pm on 25th	10.5 hrs
	Pitabeddara	2 pm on 25th	7.5 hrs
	Panadugama	1 pm on 25th	6.5 hrs
Gin River	Tawalama	12 pm on 24th	-
	Baddegama	2 pm on 25th	7.5 hrs

Table 6: Start times of flooding and lead times of warning

Model performance could be further improved by the field observations received online. Hydrology Division was able to issue reliable warnings (commence of major flood, peak flood level and time to peak etc.) with adequate lead time throughout the flood period. However several areas in the upper catchments received flashfloods without getting sufficient time for evacuation of people and properties or taking safety measures. This is a common problem in the small basins with steep terrain where catchment lag is short. Intense rainfalls further reduced the lead time. The floods with lead time less than 6 hours are generally considered as flash floods in which meteorological (rainfall) forecasting can play a vital role. However the accuracy and the resolution (time and special) of quantitative rainfall forecasts in Sri Lanka is still not sufficient to use in flood forecasting.

6. Post Evaluation

The recent (2017) flood is classified as a critical flood with respect to most of the affected basins according to the impact based flood level classification used in the Hydrology Division. This kind of floods is occasional and the experience gained is very important in controlling future flood events. Therefore, post-evaluation of the hydrological and socio-economic aspects of the flood is vital for the safety of people of flood prone areas.

6.1 Comparison with Previous Floods

Flooding is the most common natural disaster in all the wet zone of the country. However, only few records with respect to previous critical floods are available (at HD). The recent flood is comparable to 2003 flood with spatial distribution but the flood peaks on the Kalu, Gin and Nilwala were somewhat higher than the 2003 flood. Similarly 2016 flood affected the Kelani basin very severely. Flood levels of Kelani Basin in the recent flood are considerably less the 2016 flood. Following tables give the comparison of three floods. Some of the gauging stations were not in operation by the times of previous floods.

River Basin	Station	Max 24 hour Rainfall (2017) mm	Max one day Rainfall (2003) mm	Max one day Rainfall (2016) mm
Kalu	Kukule	646.6	246.0	-
	Paragoda	569.7	-	-
	Millakanda	428.5	220.3	-
	Ratnapura	368.5	347	-
Ginganga	Thawalama	297.8	193.5	-
	Baddegama	199.0	146.7	-
	Deniyaya	513.2	730.0	-
Nilwala	Panadugama	356.7	-	-
	Sapugoda	351.7	-	-
	Pitabeddara	343.1	-	-
Kelani Ganga	Hanwella	407.0	-	169
	Deraniyagala	303.0	-	355.6
	Avissawella	265.0	-	240.4

Table 7: Comparison of rainfalls with previous Flood Events

River Basin	Station	Highest Flood Level (2017)	Highest Flood Level (2003)	Highest Flood Level (2016)
Kaluganga	Millakanda	12.88 m MSL	14.04 m MSL	-
	Ratnapura	23.46 m MSL	23.57 m MSL	-
	Putupawla	6.92 m	6.09 m	-
Ginganga	Thawalama	12.6 m	14.78 m	-
Nilwala	Pitabeddara	10.77 m	9.7 m	-
Kelani Ganga	Avissawella	18.22 m MSL	-	19.81 m MSL
	Hanwella	9.92 m MSL	-	10.51 m MSL
	Nagalagam Street	6.00 ft MSL	-	7.65 ft MSL

Table 8: Comparison of Flood Levels with Previous Flood Levels

6.2 Return Periods of 2017 Floods

Return period of the flood is become an enthusiastic question after a severe flood event. This is normally computed by statistical analysis of discharges. Water Levels also can be used in the absence of discharges. Particularly it is not possible to establish unique relationship between river stage and discharge at the gauging stations in coastal areas (Eg. Nagalagam Street) due to tidal influence. In such cases water levels are used for the flood frequency analysis. In both cases it is necessary to find a mathematical function closely fit with the observed data series. In this case, Gumble Extreme Value distribution was found suitable for most of the data series. Similarly Log Pearson Type III distribution was selected for Tawalama (Gin Ganga) and Pitabeddara (Nilwala) stations. The results obtained are summarized in Table 8. According to that the Nilwala, Gin and Kalu rivers have experienced the floods of high return periods while the Kelani River experiencing floods of low return period. Also, according to (Impact based) flood level classification the Kelani flood can be categorized as a minor flood.

River Basin	Station	Highest Flood Level (2017)	Maximum Discharge(cumec)	Return Period (yrs.) Based on Q or WL	Mathematical Function Used
Kaluganga	Millakanda	12.88 m MSL	1127	40 (based on Q)	Gumbel EV1
	Ratnapura	23.46 m MSL	674	25 (based on Q)	Gumbel EV1
	Putupawla	6.9 m MSL	2335	50 (based on Q)	Gumbel EV1
Ginganga	Tawalama	43.9 m MSL	1152	50 (based on Q)	Log P III
	Baddegama	7.44 m	-	40 (based on WL)	Gumbel EV1
Nilwala	Pitabeddara	10.776 m	1558	75 (based on Q)	Log P III
Kelani	Avissawella	18.22 m MSL	1569	5 (based on Q)	Gumbel EV1

	Hanwella	9.92 m MSL	1445	10 (based on Q)	Gumbel EV1
	Nagalagam St.	6.00 ft MSL	-	5 (Based on WL)	Gumbel EV1

Table 9: Return Periods of floods at different locations on four Major River Basins

7. Conclusion and Recommendations

The floods in 2017 May was the most severe hydrological hazard recorded in the recent history, mainly affected to the wet-zone river basins of the country. This is comparable to 2003 May flood with respect to spatial distribution but somewhat higher in the magnitude. Flood damages were also higher than the former event, particularly in the Kalu Ganga basin.

Return periods of the floods were varying from 5 year to 75 year with respect to different locations of affected river basins. According to that this seems a rare event, but the damage, especially the death toll, is extremely high. As per the flood level classification, the Nilwala, Kalu and Gin Ganga experienced 'Critical Floods'. The Kelani catchment also received high rainfalls (even higher than the rainfalls of 2016) as shown in Table 6. The flood levels were controlled, to some extent, due to the precautionary actions (removal of sand bagged part of Salinity Barrier at Ambatale) taken before the flood. However, the permanent part of the same structure still obstructs the flood flow significantly.

Flood control and disaster management authorities have to be prepared for these types of disasters with regards to all river basins vulnerable for flooding. Flood control structures as well as the non-structural measures (such as flood warning, zoning and land use planning, adaptation to natural conditions etc.) can play a vital role in regulation of floods and mitigation of damages. Man-made structures such as narrow bridges, salt water exclusion structures and buildings in the flood plain (sometimes projected to river) cause retardation of flood flow and increase of damages. This has to be controlled by imposing laws and regulations on development activities in the riverine environment.

Automated data collection and transmission system of HD is extremely useful for the implementation of effective flood forecasting and warning system. It is very essential to ensure proper maintenance of this system in a sustainable manner. These data should be utilized effectively in flood forecasting and early warning. Mathematical models are used for flood forecasting in Hydrology Division but still there is a shortage of trained staff. Secondly, the line agencies related to disaster management have made arrangements to function their offices, round the clock, throughout the year considering the urgency of this work. Hydrology Division is also functioning during weekends and public holidays. However, still there are no proper arrangements for night duties. During flood periods, night duties are arranged in an ad hoc manner. This should be regularized by arranging shift duties or by introducing suitable incentive scheme for extra works.

Mapping surface water with Remote Sensing

Mapping surface water with Remote Sensing

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Abstract

Surface water is the most accessible source of water for humans. It is affected by both climate change and anthropogenic activities. In situ data are not regularly available for detecting the changes in surface water. Satellite remote sensing and GIS techniques facilitate the investigation of surface water changes and to overcome the lack of in situ data. In this study, images of Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) were used to map surface water during the period from 1987 to 2016 with supervised image classification for Milingimbi Island, Northern Territory, Australia. Most of the wet season images were affected with cloud cover and the extraction of inundation area during the wettest moments was limited. During this study historical surface water inundation was mapped and the frequency of inundation on the island was identified.

Keywords

Surface water, Remote sensing, Supervised classification, NDWI, MNDWI

1. Introduction

Surface water is the most accessible component of the water cycle for human population (Pekel et al., 2016). The availability of surface water has been vital for the development and the existence of human civilization (Lawford, 2008). As well it is equally important for the sustainability of the ecosystem (Huang et al., 2016). Surface water is affected by both climate change and anthropogenic activities (Pekel et al., 2016, Lawford, 2008). The change in surface water has many impacts on the human social behavior related to domestic needs, agricultural production, urbanization, water management and eco system balance.

In-situ data are the best reliable source in analysing the impacts on surface water. Sometimes in-situ data are collected through specific studies and not regularly available due to lack of technology (Lawford 2008). Satellite remote sensing augments ground-based data, with earth surface observations for many decades. It has overcome the time-consuming traditional manual work and high cost in detecting the spatial distribution of water. During the last twenty years, Satellite remote sensing has been widely used to monitor the distribution and the changes in surface water (Gao et al. 2016; Wang et al. 2011).

Many researchers have studied long term changes in surface water bodies in a local area and surface water detection during floods in different countries using remote sensed data. Pekel et al. (2016) have studied the changes in global surface water using Landsat satellite images for 32 years and found that during the period from 1984 to 2015, permanent surface water in an area of approximately 90,000 square kilometres has disappeared and new permanent surface water bodies of an area of 184,000 square kilometres have formed in the world. These changes are possible as loss of surface water can occur with long term drought conditions, damming, river diversions, and extensive withdrawals while the increase of surface water can occur due to new constructions of water bodies, or new inundations affected by changing climate.

2. Remote sensing of water

Remote sensing is a technology of observing objects at distance by the sensors that are not in direct contact. In satellite remote sensing Earth objects are observed with electromagnetic radiation captured by the sensors in the satellite and resulting products are images. The information about the ground objects is extracted by analysing and interpreting these images (Jensen 2014). Both optical and radar remote sensing are used to detect surface water. Landsat satellite images (optical) are widely

used in literature for water detection as the images are comparatively high in both spatial and temporal resolution and provide continuous data for long-term analysis (Martinis et al. 2015).

In optical remote sensing, reflected solar radiation is captured by the sensors usually in visible, near infra-red (NIR) and middle infrared (MIR) regions of the electromagnetic spectrum (Fig 1).

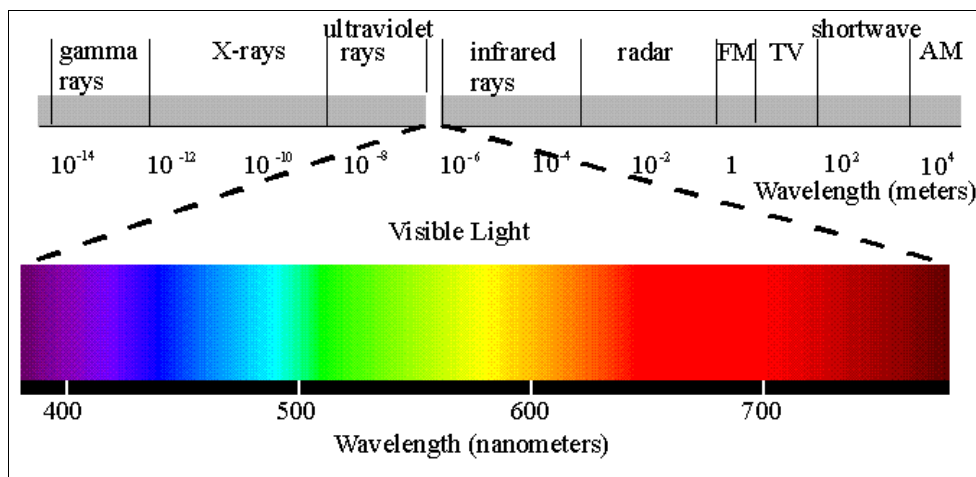


Figure 1 : Electromagnetic spectrum

When the radiation from the sun (E_{Sun}) reaches a water body, a part of the radiation is reflected from the water surface (L_s). Some of the radiation penetrates the air-water interface, interacts with the constituents in the water and exits the water surface (L_v). Some radiation penetrates the water, reaches the bottom, and then propagates back and exits the water-air interface (L_b). Some radiation is scattered in the atmosphere without reaching the water surface (L_p). Figure 2 illustrates the water radiance interaction. The energy L_s carries spectral information about the surface characteristics. L_v has the characteristics of water column. L_b is important in bathymetric mapping of water bodies (Jensen 2014).

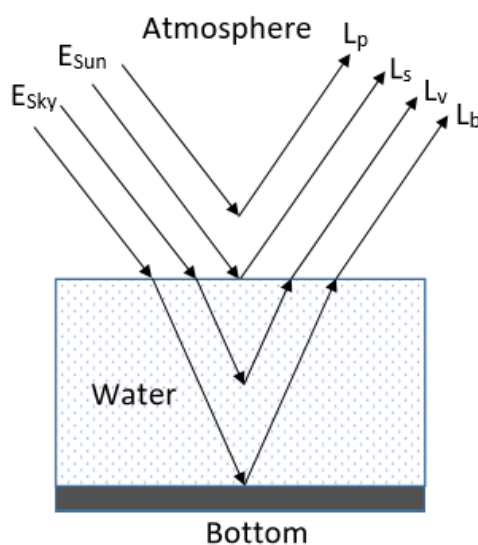


Figure 2 : Interaction of radiance and water features (Jensen 2014)

In remote sensing of water, the radiance recorded by the remote sensor records the energy from all four sources L_s , L_v , L_b and L_p . The electromagnetic radiation is changed due to scattering and absorption by aerosols and gases when transmitting through the atmosphere from the Earth surface to the satellite sensor. The atmospheric effect is different in different wave bands, as both Rayleigh and Mie scattering depends on the wavelength.

Recorded image data by sensors contains geometric and radiometric errors. Image pre-processing is done for corrections before an image is used for classifications. Geometric errors are caused by the relative motion of the satellite, scanners and the earth, and curvature of the earth (Richards & Jia 1998). For the geometric corrections a standard geographic coordinate system is used to develop the geometric relationship with the image by selecting geometric ground control points on the image (Du, Teillet & Cihlar 2002) and typically corrected by the vendor.

Radiometric error is the change in measured brightness value of the pixel due to effect of the atmosphere, variations in the solar illumination angles, Earth-sun distance and the instrumentation used for recording data (Chen, Vierling & Deering 2005). There are two methods of radiometric corrections as absolute and relative. Absolute radiometric correction (atmospheric correction) uses sensor calibration data and an atmospheric correction algorithm based on modelling the atmospheric attenuation at the time of image acquisition to convert the image data in Digital Numbers (DN) to the reflectance at the surface (Du, Teillet & Cihlar 2002). Accurate measurements of the atmospheric optical properties at the time of image acquisition are required for the correction of the atmospheric effect and these measurements are frequently unavailable (Richards & Jia 1998). Relative radiometric correction uses a base image to adjust the radiometric properties of the other images to reduce the atmospheric effect among multiple images. It is an image based method, which can correct the noise due to the atmosphere, sensor and other sources in one process and is simpler than the absolute method (Chen, Vierling & Deering 2005).

3. Spectral characteristics of water

The reflectance of solar radiation depends on the objects on the ground. In optical remote sensing, objects are distinguished with the spectral reflectance pattern of the objects. Therefore, identifying spectral characteristics of different land cover types is important to distinguish water from other land features such as vegetation, soils, and buildings. The spectral reflectance curve gives the percentage of energy that an object reflects in different wavelengths. Figure 3 shows the spectral reflectance pattern of water, grass and soil taken from the ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) spectral library. Figure 4 shows spectral reflectance curves of common ground objects extracted from Landsat ETM⁺ by Wen and Yang (2011). The spectral curves show that water absorbs most of the radiation and show very low reflections in all wavelengths compared to other objects.

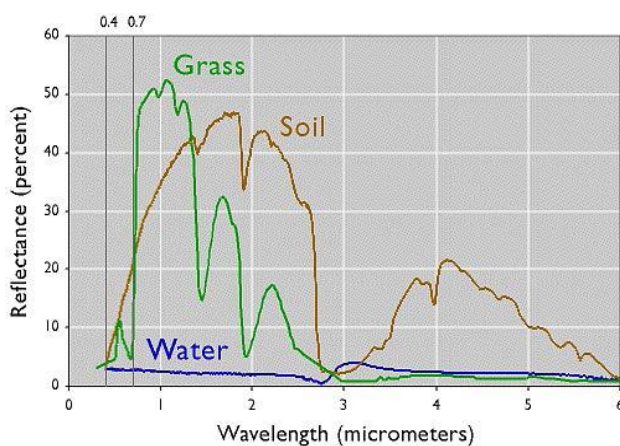


Figure 3 : Spectral reflectance pattern of water, soil and grass observed by ASTER sensor (<https://www.e-education.psu.edu> 2017)

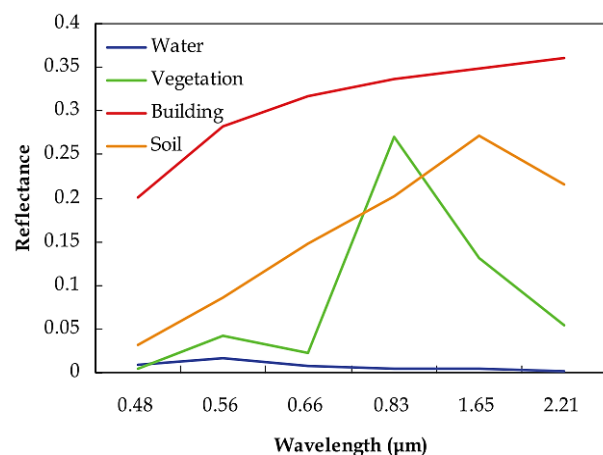


Figure 4 : Spectral reflectance curves of different objects on the ground extracted from Landsat ETM⁺ image (Wen & Yang 2011)

The spectral reflectance of water changes due to the constituents in water. Organic and inorganic constituents of water especially near the surface, dramatically increase the NIR radiance leaving the water surface. Algae floating near the water surface reflect highly in NIR.

4. Methods of water detection with satellite remote sense images

According to the literature, there are multiple methods available for water body extraction, such as thematic image classification methods of supervised and unsupervised classifications, single band thresholds, spectral relationship methods, and water index methods (Li et al. 2016; Zhou et al. 2017).

Image classification is the method used to categorise all the pixels in an image into themes or land cover types using a numerical basis for the spectral pattern of the data for each pixel. The method for a particular classification depends on the nature of the data and the applications of the classified data (Lillesand, Kiefer & Chipman 2004). For the supervised classification, prior knowledge of the ground features is required. The pixels of water features are identified on the image and a classification model is built to enable the computer to automatically identify the pixels with the same spectral characteristics. The water and other land cover classes are classified based on the spectral signatures of the selected training pixels. Some researchers, such as Haibo et al. (2011), use the supervised classification image as the base map to compare other classifications. However, it is a time consuming method when compared to the water index methods.

The band ratio methods use the ratio of the reflections in visible bands, such as green or red, to the NIR and MIR bands. Soil and terrestrial vegetation show high reflectance in NIR band thus are suppressed with the band ratio. Open water bodies are enhanced as the reflectance in NIR band is low.

Threshold based water detection and water index methods have undergone a succession of evolutions and many techniques and methods for water extraction are investigated by researchers. Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Water Ratio Index (WRI) are some of water indices widely used for water body extraction.

$$\text{NDWI} = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}$$

$$\text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}}$$

$$\text{WRI} = \frac{\text{Green} + \text{R}}{\text{NIR} + \text{MIR}}$$

Green, NIR, MIR and R are the reflectance of the Green band, Near Infrared band, Middle Infrared band and Red band.

The review of literature for detecting the surface water features using satellite images shows that the performance of each method depends largely on the background environment and water constituents such as sediment, salinity, and phytoplankton.

5. Accuracy assessment

Once an image classification is completed, it is necessary to assess the accuracy of the image to check the degree of confidence of the result. Classification accuracy is the main measure of the quality of the map prepared by applying various image classification techniques on remote sense images. The accuracy is assessed by comparing the sample pixels of the classified map against the reference ground data (Lillesand, Kiefer & Chipman 2004).

The most widely used methods for assessing the accuracy of image classification are based on the error matrix (Comber et al. 2012; Congalton 1991; Foody 2002). The comparison of the ground data and the classification is given in a tabular form, which is referred to as confusion or error matrix. Error matrix shows the number of correctly identified pixels and the number of erroneously identified pixels for each class in the classified map. Kappa coefficient is another technique used for the accuracy assessment. It is a discrete multivariate technique which is a statistical test done on the error matrix.

It is important to define the minimum level of required overall accuracy in order to reduce the potential for subjective post classification evaluation in thematic mapping with remote sensed images. In literature, an accuracy value of over 85% has been widely used as the target for overall accuracy and explicitly as a standard for thematic mapping with remote sensed imagery. However Foody (2008) argues that the target accuracy is a function of variables, such as spatial and spectral resolution of remotely sensed data, the number of classes defined in the classification, and the users' requirements, such as tolerance to error and impacts of variations due to severity of the error. In assessing the acceptability of the map, the map accuracy is compared with the target accuracy.

6. Study

Images of Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) were used to map surface water during the period from 1987 to 2016 in Milingimbi Island, Northern Territory, Australia. On the island, the spatial distribution of shallow surface water inundation of salty land is changing frequently. Unsupervised and supervised classifications and water indices of NDWI and MNDWI were applied on 13 satellite images of both wet season and dry season to detect surface water.

The accuracy assessment was done by developing the error matrix by extracting ground data from the images by visual inspection. The spectral resolutions of Landsat TM and OLI image are sufficient to distinguish water surface and land features visually on the true colour image. Ground points were selected by random sampling and excluding the training area to avoid the bias. Based on the error matrix, Overall Accuracy and Kappa values for each classification were estimated. Considering the behaviour of Overall Accuracy and Kappa values for the different classifications on the Landsat images, the best suitable classification for the study area was selected.

The supervised classification showed the best accuracy of water detection. Therefore, surface water area was mapped by supervised classification from 24 images for both wet season (Dec- April) and dry season (May- Nov) in Milingimbi Island.

7. Results

The map in Figure 5 showing the inundation area during the wet season was prepared by stacking nine thematic maps of the wet season. Fifteen thematic maps of the dry season were used to prepare the dry season inundation map shown in Figure 6. The frequency of inundation was assigned to each pixel with the ratio of number of times water was observed in the pixel compared to the total number of times of observations.

8. Discussion

In the dry season, the cloud cover over the study area does not affect most of the images showing surface inundation. Therefore, remote sensed images of Landsat could be used to extract dry season inundations. During the wet season, cloud cover has affected almost all the wet images and the possibility to extract inundation areas during the wettest moments was limited.

Remote sensed images from many satellites give excessive amount of data and many methods are used today to extract information to detect the surface water. Cloud cover during rainy seasons and flood events is crucial in optical remote sensing as it affects the data acquisition and detection of the extent of water surface (Idol, Haack & Mahabir 2015). Finding cloud free image concurrent with the water occurrence could be challenging in water detection with optical remote sensed images. Landsat TM/ETM+ images have relatively high spatial resolution even though the temporal resolution with 16 day return cycle is not adequate to capture the dynamic changes in water surface during a rainfall and flood events. Landsat satellite images could be used for detection of historical changes in water surface as continuous data is available for decades in the Landsat archive.

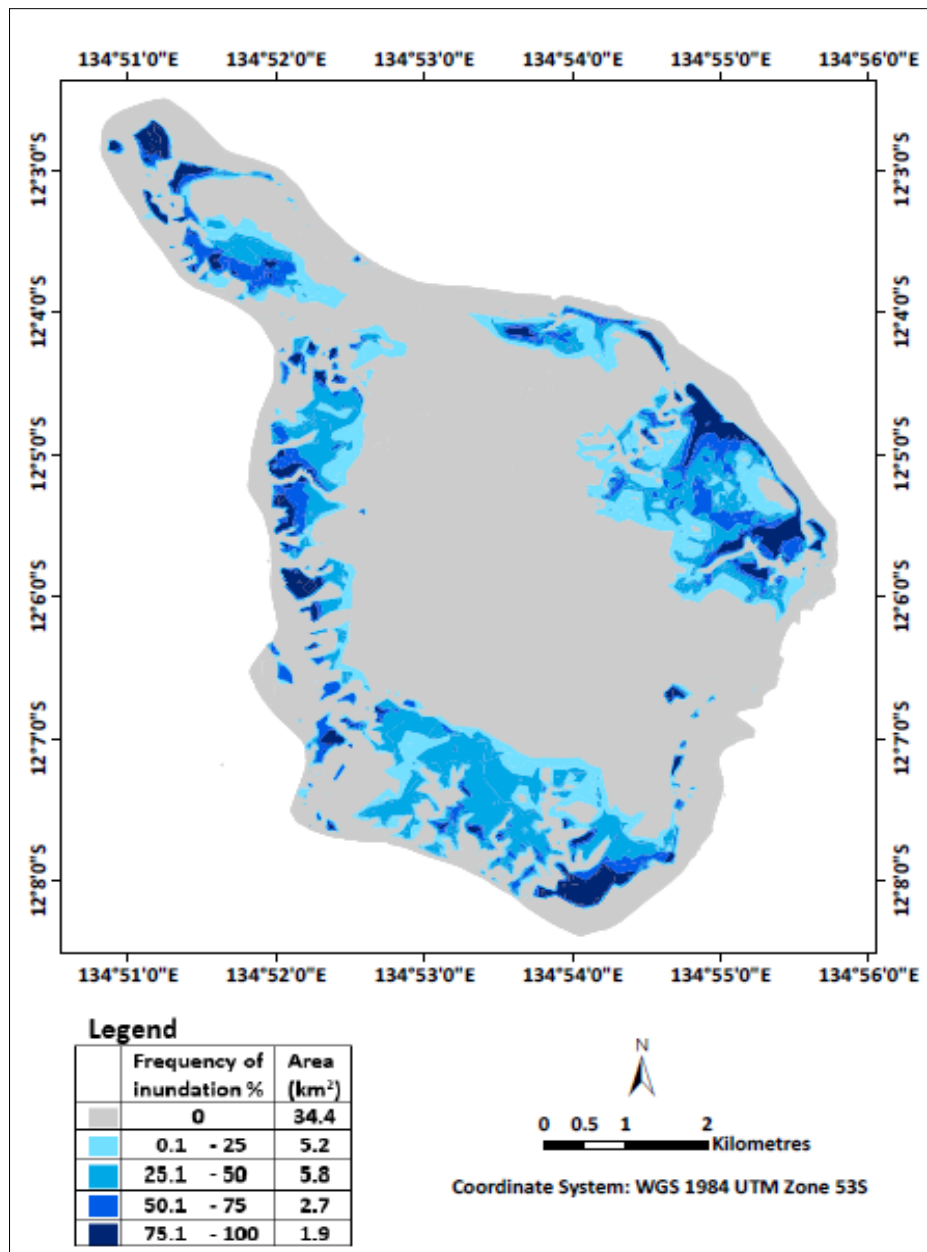


Figure 5 : Wet season inundation areas and the frequency of wet season inundation mapped with nine images

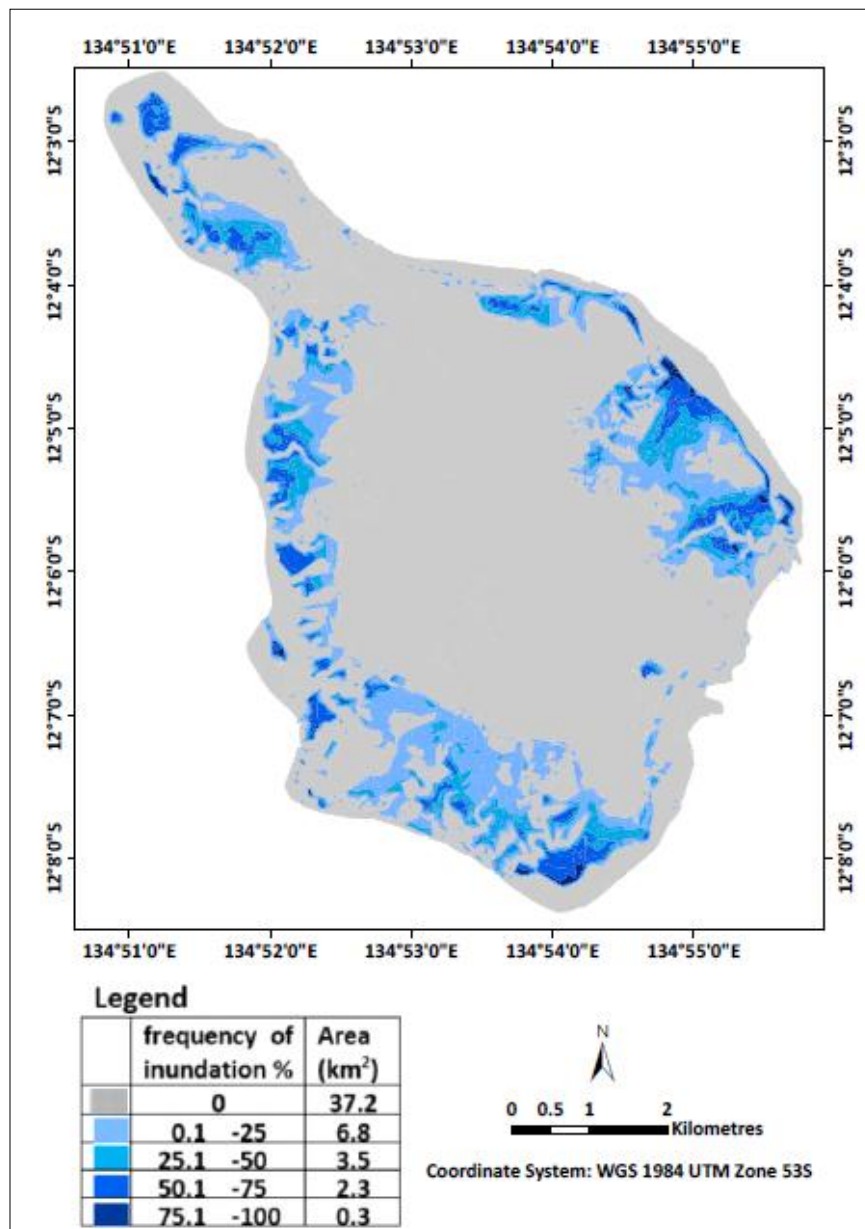


Figure 6 : Dry season inundation areas and the frequency of dry season inundation mapped with fifteen images

9. Applications of remote sensing in Water Resources Management

Remote sensing is widely used in environmental resource mapping and modeling. Images of different sensors are used for extracting information for different purposes. Applications in water resources management can be considered in different categories such as mapping watersheds and features, estimation of hydrological parameters, estimation of hydrological variables and water quality monitoring.

Mapping surface water bodies, such as reservoirs, rivers and wetlands, floodplains, coastal areas, flood inundation and disaster areas, are some applications in mapping features. Most common applications in estimation of hydrological parameters include generating land cover, vegetation cover and impervious surface cover. Variables in the land surface water balance such as precipitation, evapotranspiration, soil moisture, terrestrial water, snow and ice are observed with remote sensing. Water quality parameters such as turbidity, suspended sediments, chlorophyll-a, and algae blooms in water bodies are monitored with sensors of high spectral and spatial resolution. However, this is not an exhaustive list of applications of the remote sensing techniques in water resources management.

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