Government of India
Central Water Commission
Hydrological Studies Organisation
Hydrology (S) Directorate

STUDY REPORT

KERALA FLOODS OF AUGUST 2018

September, 2018

Contents

Kerala Flood of August 2018

1.0 Introduction

Kerala State has an average annual precipitation of about 3000 mm. The rainfall in the State is controlled by the South-west and North-east monsoons. About 90% of the rainfall occurs during six monsoon months. The high intensity storms prevailing during the monsoon months result in heavy discharges in all the rivers. The continuous and heavy precipitation that occurs in the steep and undulating terrain finds its way into the main rivers through innumerable streams and water courses.

Kerala experienced an abnormally high rainfall from 1 June 2018 to 19 August 2018. This resulted in severe flooding in 13 out of 14 districts in the State. As per IMD data, Kerala received 2346.6 mm of rainfall from 1 June 2018 to 19 August 2018 in contrast to an expected 1649.5 mm of rainfall. This rainfall was about 42% above the normal. Further, the rainfall over Kerala during June, July and 1st to 19th of August was 15%, 18% and 164% respectively, above normal. Month-wise rainfall for the period, as reported by IMD, are given in Table-1.

Table-1: Month wise actual rainfall, normal rainfall and percentage departure from normal

Period	Normal Rainfall	Actual Rainfall	Departure from normal
	(mm)	(mm)	(%)
June, 2018	649.8	749.6	15
July, 2018	726.1	857.4	18
1-19, August, 2018	287.6	758.6	164
Total	**1649.5**	**2346.6**	**42**

Due to heavy rainfall, the first onset of flooding occurred towards the end of July. A severe spell of rainfall was experienced at several places on the 8th and 9th of August 2018. The 1-day rainfall of 398 mm, 305 mm, 255 mm, 254 mm, 211 mm and 214 mm were recorded at Nilambur in Malappuram district, Mananthavadi in Wayanad district, Peermade, Munnar KSEB and Myladumparain in Idukki district and Pallakad in Pallakad district respectively on 9 August 2018. This led to further flooding at several places in Mananthavadi and Vythiri in Wayanad district during 8-10, August 2018. Water was released from several dams due to

heavy rainfall in their catchments. The water levels in several reservoirs were almost near their Full Reservoir Level (FRL) due to continuous rainfall from 1st of June. Another severe spell of rainfall started from the 14th of August and continued till the 19th of August, resulting in disastrous flooding in 13 out of 14 districts. The water level records at CWC G&D sites for some of the rivers in Kerala are given at **Annex-I**. As per the rainfall records of IMD, it has been found that the rainfall depths recorded during the 15-17, August 2018 were comparable to the severe storm that occurred in the year 1924.

1.1 Earlier floods in Kerala

The 1924 witnessed unprecedented and very heavy floods in almost all rivers of Kerala. Heavy losses to life, property and crops etc. had been reported. The rainstorm of 16-18, July 1924 was caused by the South-west monsoon that extended to the south of peninsula on 15th July and caused rainfall in Malabar. Under its influence, heavy rainfall occurred in almost entire Kerala. The area under the storm recorded 1-day maximum rainfall on 17th of July, 2-day maximum rainfall for 16-17, July 1924 and 3-day maximum rainfall for 16-18, July 1924. The centre of the 1-day and 2-day rainstorm was located at Devikulam in Kerala which recorded 484 mm and 751 mm of rainfall respectively. The centre of 3-day rainstorm was located at Munnar in Kerala which recorded a rainfall of 897 mm in 3 days.

The fury of 1924 flood levels in most of the rivers was still fresh in the memory of people of Kerala, the year 1961 also witnessed heavy floods and rise in the water levels of reservoirs. Usually in the State, heavy precipitation is concentrated over a period of 7 to 10 days during the monsoon when the rivers rise above their established banks and inundate the low lying areas. But in 1961, floods were unusually heavy not only in duration, but also in the intensity of precipitation. During the year 1961, the monsoon started getting violent towards the last week of June and in the early days of August, the precipitation was concentrated on most parts of the southern region of Kerala. By the first week of July, the intensity gradually spread over the other parts of the State and the entire State was reeling under severe flood by the second week of July. The worst affected area was Periyar sub-basin and it also impacted other sub-basins. Many of the important infrastructures like highways etc were submerged. After a brief interval, by the middle of July, the monsoon became more violent, affecting the northern parts of the State. The average rainfall was 56% above normal. The maximum daily intensities recorded at four districts in 1961 are given in Table-2.

.**Table-2: Recorded 1-day rainfall in different districts of Kerala in 1961**

Sl. No.	District	Rainfall(mm)
1	Calicut	234
2	Trivandrum	136
3	Cochin	189
4	Palakkad	109

The damage caused by the floods had been severe and varied. It is understood that 115 people lost their lives due to floods and landslides. Over 50,000 houses were completely and partly damaged and about 1,15,000 acres of paddy were seriously affected.

2.0 District wise rainfall realised during 1 June 2018 to 22 August 2018

District wise rainfall realised in Kerala as per IMD records is presented in Table-3, where it can be seen that the rainfall departure in Idukki is the highest viz. 92%.

Table-3:District wise rainfall realised during 1 June 2018 to 22 August 2018

Districts	Normal Rainfall (mm)	Actual Rainfall (mm)	Departure from Normal (%)	
Kerala State	1701.4	2394.1	41	Excess
Alappuzha	1380.6	1784	29	Excess
Kannur	2333.2	2573.3	10	Normal
Ernakulam	1680.4	2477.8	47	Excess
Idukki	1851.7	3555.5	92	Large Excess
Kasaragode	2609.8	2287.1	-12	Normal
Kollam	1038.9	1579.3	52	Excess
Kottayam	1531.1	2307	51	Excess
Kozhikode	2250.4	2898	29	Excess
Malappuram	1761.9	2637.2	50	Excess
Palakkad	1321.7	2285.6	73	Large Excess
Pathanamthitta	1357.5	1968	45	Excess
Thiruvananthapuram	672.1	966.7	44	Excess
Thrissur	1824.2	2077.6	14	Normal
Wayanad	2281.3	2884.5	26	Excess

3.0 Analysis of rainfall data

To analyse the August 2018 flooding phenomenon of Kerala, daily rainfall data from 1 June 2018 to 20 August 2018 has been obtained from IMD. The data consist of rainfall records of 67 rain gauge stations spread across the entire State covering both plain and hilly regions. At some of the stations, rainfall records were missing for a particular date and the same have been completed using the rainfall records of nearby stations. On scrutiny of data it has been found that cumulative rainfall realised during 15-17, August 2018 was quite significant, with

more than 800 mm rainfall at Peermade rain gauge station followed by more than 700 mm at Idukki. The rain gauge stations used for the present study are shown in Fig.1.

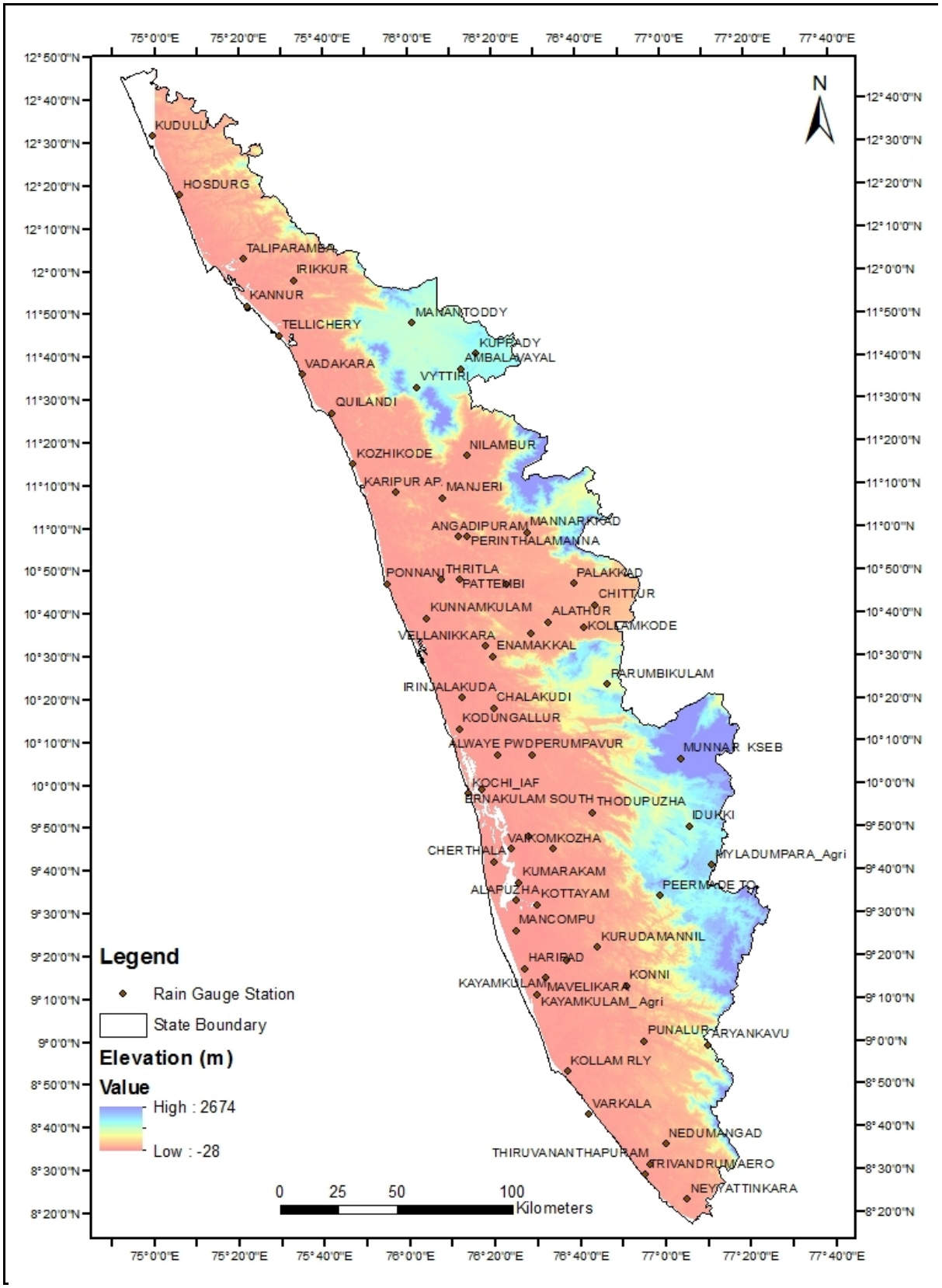


Fig.1: Rain gauge stations of Kerala used for rainfall analysis

3.1 Analysis of rainfall records of 15-17, August 2018

The storm of 15-17, August 2018 was spread over the entire Kerala with eye centred at Peermade, a place between Periyar and Pamba sub-basins. The storm was so severe that the gates of 35 dams were opened to release the flood runoff. All 5 overflow gates of the Idukki Dam were opened, for the first time in 26 years. Heavy rains in Wayanad and Idukki caused severe landslides and left the hilly districts isolated. On August 15, Kochi International Airport, India's fourth busiest in terms of international traffic, and the busiest in the State, suspended all operations until August 26, following flooding of its runway. As per the reports in media, the flooding has affected hundreds of villages, destroyed several roads and thousands of homes have been damaged. The Kerala State Disaster Management Authority placed the State on a red alert as a result of the intense flooding. A number of water treatment plants were forced to cease pumping water, resulting in poor access to clean and potable water, especially in northern districts of the state. A number of relief camps were opened to save the people from the vagaries of flood. The situation was regularly monitored by the State Government, Central Government, and National Crisis Management Committee which also coordinated the rescue and relief operations.

In order to estimate the rainfall variability at different places and rainfall depths realised in different river sub-basins, the 1-day, 2-day cumulative, and 3-day cumulative rainfall raster have been prepared from the point rainfall data. At some places maximum rainfall was recorded on 15th of August, while at other places the same was recorded on 16th of August. Hence, 1-day rainfall raster has been prepared for both 15 August 20181 and 16 August 2018 rainfall. The 1-day, 2-day, and 3-day rainfall raster for 15-17, August 2018 rainfall are given at **Annex-II**. Using the shape files of the sub-basins, the rainfall depths realised in different sub-basins and rest of the Kerala is given in Table-4.

Table-4: Rainfall depths realised in different sub-basins and rest of the Kerala in storm of 15-17, August 2018

Sl. No.	NAME	AREA (Sq Km)	15 Aug 2018	15-16, Aug2018	15-17, Aug 2018	16 Aug 2018
			1 Day (mm)	2 Day (mm)	3 Day (mm)	1 Day (mm)
1	Rest of the Kerala	26968	132	279	364	155
2	Kallada	1139	129	208	289	83
3	Pamba	1620	176	397	538	217
4	Periyar	4035	198	452	588	248
5	Bharathapuzha	5784	114	297	373	182
6	Chaliyar	1992	128	256	331	141
7	Valapattanam	1019	180	263	336	83

The severity of the storm has been compared with the storm of 16-18, July 1924 centred at Devikulam in Kerala in Table-5. The rainfall isohyets of 1-day, 2-day and 3-day rainfall of Devikulam storm are given at **Annex-III.**

Table-5: Comparison of rainfall depths realised in different sub-basins and rest of the Kerala during 15-17, August 2018 storm with Devikulam storm of 16-18, July 1924

Sl. No.	NAME	AREA (Sq Km)	16 July 1924	16-17, July 1924	16-18, July 1924	15Aug 2018	15-16, Aug2018	15-17, Aug 2018
			1-Day (mm)	2-Day (mm)	3-Day (mm)	1-Day (mm)	2-Day (mm)	3-Day (mm)
1	Rest of Kerala	26968	155	260	362	132	279	364
2	Kallada	1139	165	268	415	129	208	289
3	Pamba	1620	202	423	551	176	397	538
4	Periyar	4035	280	502	604	198	452	588
5	Bharathapuzha	5784	161	291	378	114	297	373
6	Chaliyar	1992	267	490	599	128	256	331
7	Valapattanam	1019	232	420	512	180	263	336

From the above analysis, it can be seen that the 2-day and 3-day rainfall depths of 15-17, August 2018 rainfall in Pamba, Periyar and Bharathapuzha sub-basins are almost comparable to the Devikulam storm of 16-18, July 1924. For the entire Kerala the depth of rainfall realised during 15-17, August 2018 is 414 mm, while the same during 16-18, July 1924 was 443 mm.

3.2 Reservoirs in Kerala

Kerala is having 57 large dams out of which 4 dams are operated by Government of Tamil Nadu. The total live storage capacity under these dams is 5.806 BCM. This is equal to 7.4% of annual average runoff of all 44 rivers in Kerala, which is about 78 BCM *(ref: Water Resources of Kerala 1974)*. Out of the above, only 7 reservoirs are having a live storage capacity of more than 0.20 BCM and they constitute 74% of the total live storage in Kerala. These reservoirs are given in Table-6.

Table-6: Major Reservoirs in Kerala

Sl.No.	Name of Reservoir	Live Storage Capacity (MCM)
1.	Idukki	1460
2.	Idamalayar	1018
3.	Kallada	488
4.	Kakki	447
5.	Parambikulam (for use of TN)	380
6.	Mullaperiyar (for use of TN)	271
7.	Malampuzha	227

4.0 Volume of runoff generated during 15-17, August 2018 rainfall

In order to estimate the runoff volume generated in the rainfall event of 15-17, August 2018, the sub-basins where severe flooding occurred have been analysed and estimated runoff volume compared with the discharge records of CWC observation sites. For the analysis, the drainage area of sub-basins, have been estimated up to terminal G&D site of CWC. Volumetric analyses have been carried out for Periyar, Pamba, Chalakudi, Bharathapuzha and Kabini sub-basins.

4.1 Runoff computations for Periyar sub-basin

The Periyar, 244 km in length, is the longest river of Kerala. The total drainage area of the basin is 5389 sq.km out of which nearly 98 % lies in the Kerala State. The State wise distribution of the drainage area is given in Table-7.

Table-7: State wise area distribution of Periyar sub-basin

Name of State	Drainage Area (Sq.km)	Percentage of Total Drainage Area
Tamil Nadu	114	2
Kerala	5284	98
Total	5398	100

The river originates at the forest land of Sivagiri peak 80 km South of Devikulam at an elevation of 2438 m above MSL and traverses the steep mountainous terrain before it is joined by the Mullayar, 16 km downstream. The river then turns westwards and continues to flow in that direction for about 16 km on a sandy bed. After a winding course of about 13 km, the river reaches Vandiperiyar and passes through a second narrow gorge below which it is joined by Perumthura. Further down, it is joined by six tributaries after which the important tributary Edamala joins Periyar. Passing Malayattur and thereafter taking a meandering course, the river reaches Alwaye where it divides itself into two branches. The upper branch joins the Chalakudi river at Punthenvelikara and then expands into a broad sheet of water at Munambham. The other branch taking a southerly course is broken up into a number of small channels which fall into the Vembanad lake (as Varapuzha). There are two Hydrological Observation Stations maintained by CWC on this river i.e at Neeleswaram & Vandiperiyar.

The Periyar river has a drainage area of 4,033 sq km upto CWC gauging station at Neeleshwaram. The dams with significant storage in Periyar sub-basin are Mulla Periyar,

Idukki and Idamalayar. The catchment area of river at Mulla Periyar dam is about 637 sq.km. The free catchment between Mulla Periyar and Idukki dam is about 605 sq.km. The catchment area intercepted by Idamalayar dam is about 472 sq.km. A catchment area map of Periyar river upto CWC G&D site at Neeleshwaram is given in Fig.2.

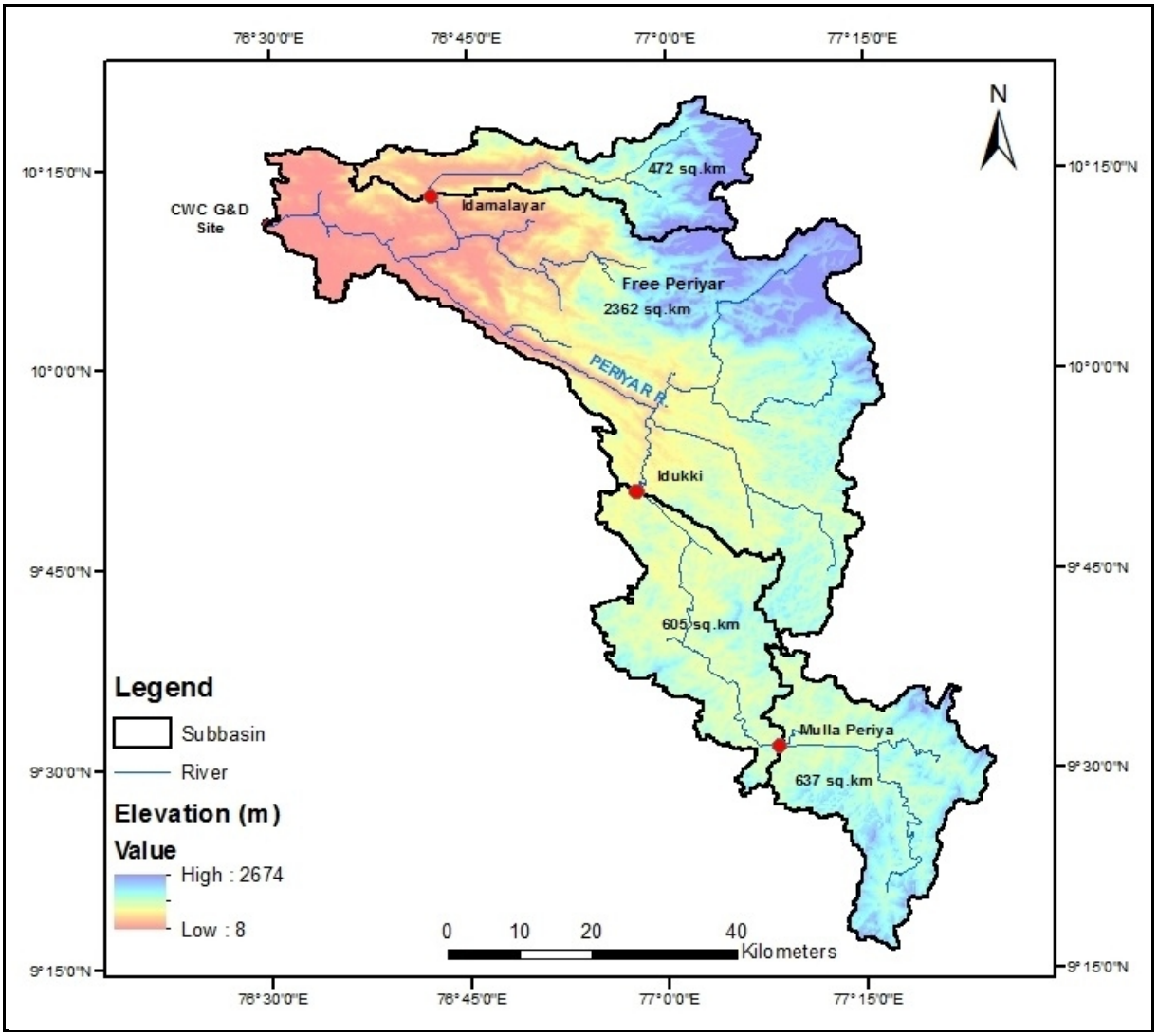


Fig.2 Drainage area map of Periyar river up to Neeleshwaram G&D Site

During rainfall event of 15-17, August 2018 the rainfall depths realised in Mulla Periyar, Idukki and Idamalayar catchments and remaining part of the sub-basin along with estimated runoff during the same period are given in Table-8.

Table-8: Rainfall and runoff in Periyar sub-basin up to CWC G&D Site

Catchment	Area	Rainfall depth 15 Aug 2018 (1-day)	Rainfall depth 15-16, Aug 2018 (2-day)	Rainfall depth 15-17, Aug 2018 (3-day)	Runoff 15Aug 2018 (1-day)	Runoff 15-16, Aug 2018 (2-day)	Runoff 15-17, Aug 2018 (3-day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Free Periyar	2362	203	459	589	374	845	1084
Between Idukki and MullaPeriyar	605	240	523	682	123	269	351
MullaPeriyar	637	196	415	536	106	225	290
Idamalayar	472	179	394	496	72	158	199
Total	4076	190	454	584	675	1498	1925

From the computation shown in Table-8, the estimated areal rainfall of Periyar sub-basin is about 190 mm, 454 mm and 584 mm respectively for 1-day, 2-day and 3-day rainfall of 15-17, August 2018. The runoff volume of 1-day, 2-day and 3-day have been estimated as 675 MCM, 1498 MCM, and 1925 MCM respectively.

The estimated runoff has been compared with the discharge data of Neeleshwaram G&D site of CWC. The plot of flood hydrograph of Neeleshwaram G&D site is given in Fig.3.

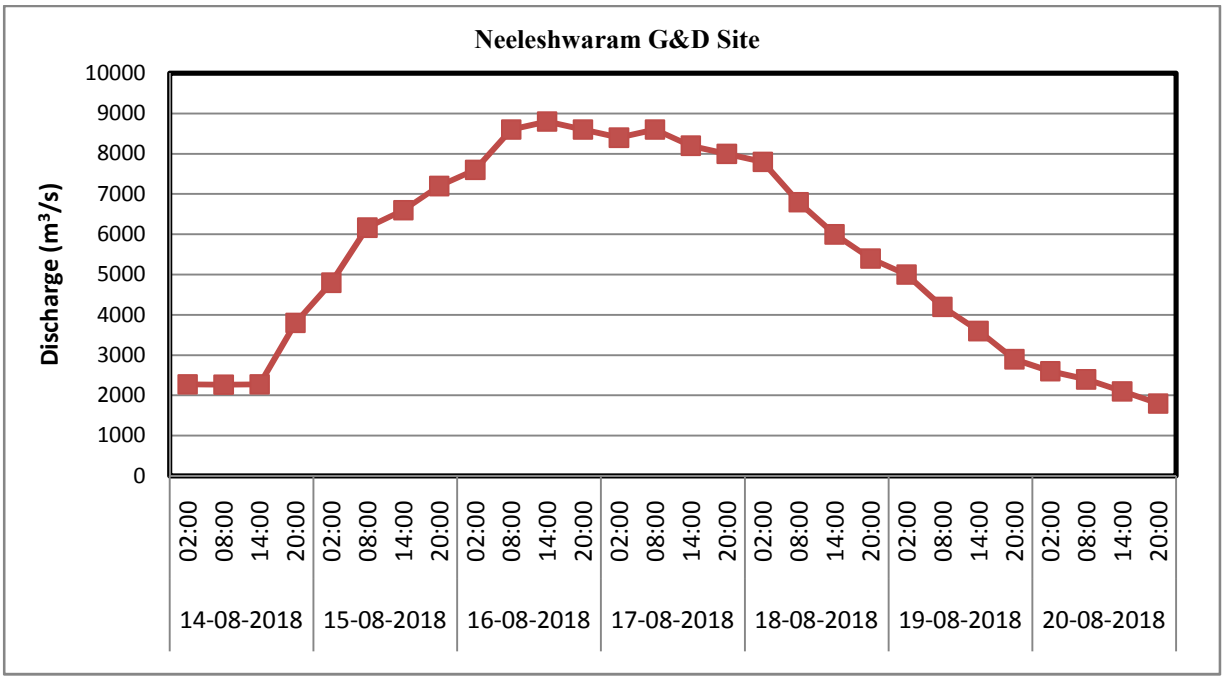


Fig.3: Discharge data of Periyar river at Neeleshwaram G&D site

The maximum discharge at Neeleshwaram G&D site was about 8800 cumec on 16th August 2018 at 14:00 hours. The cumulative runoff for 15-17, August 2018, computed from the

Neeleshwaram G&D records is about 1.93 BCM, while the estimated runoff from IMD rainfall is about 1.925 BCM for a runoff coefficient of 0.78 for free catchment and 0.85 for catchments tapped by dams.

Periyar sub-basin consists of about 50% of the total live storage of the State that is about 2.92 BCM. The reservoirs with substantial live storage capacity in Periyar sub-basin are Idukki, Idamalyar and Mulla Periyar. During the rainfall event of 15-17, August 2018, the total release during three days from Idukki reservoir was about 345 MCM (spill) and 30 MCM (power house going to Muvattupuzha river) against the inflow volume of 435 MCM. Hence, about 60 MCM of flood runoff was absorbed by Idukki reservoir during 15-17 August.

The average release from Idukki reservoir on 15 August 2018 was about 1100 cumec with peak release of 1500 cumec against the average inflow of 1640 cumec. Idukki reservoir received an average 533 cumec discharge from Mulla Periyar on 15 August 2018 with a peak discharge of 760 cumec. The average release from Idukki reservoir on 16 August 2018 was about 1400 cumec with peak release of 1500 cumec against the average inflow of about 2000 cumec. Idukki reservoir received an average 650 cumec discharge from Mulla Periyar on 16 August 2018 with a peak discharge of 760 cumec. The average release from Idukki reservoir on 17 August 2018 was about 1460 cumec with peak release of 1500 cumec against the average inflow of about 1440 cumec. Idukki reservoir received an average 390 cumec discharge from Mulla Periyar on 17 August 2018 with a peak discharge of 590 cumec.

4.1.1 Reservoir operation of Idukki

Idukki reservoir lies in the State of Kerala on Periyar river. It has a gross storage of about 1997 MCM at FRL of 732.43 m. It has a gross storage of about 537 MCM at MDDL of 694.94 m. The live storage between FRL and MDDL is about 1460 MCM.

On 10 August 2018 at 00:00 hrs, the level in Idukki dam was 731.82 m i.e. 0.61 m below FRL. The extra flood cushion available (below FRL) was about 40 MCM only. The inflow into reservoir at that time was about 649 cumec and spill from dam was about 50 cumec (in the river) and 115 cumec power house release (going to Muvattupuzha river). As a result, the water level in the reservoir kept on rising. At 12:00 noon the level touched 732.16 m. To contain the level within FRL, the spill from the reservoir was increased to 750 cumec (plus 118 cumec power house release) by 17:00 hrs on 10 August 2018 against similar inflows.

After that, inflows into reservoir dropped a bit and were in the range of 500 – 700 cumec. The reservoir releases were maintained at higher levels (spill 750 cumec + 115 cumec power house release) until 18:00 hrs on 13 August 2018 in order to make space in the live storage zone to accommodate possible higher floods that might come. As a consequence, the reservoir level dropped to 730.80 m increasing the extra flood cushion below FRL to about 90 MCM.

The inflows into the dam started rising from 18:00 hrs on 14 August 2018 when the level in the reservoir was 730.88 m (i.e. an extra flood cushion of about 85 MCM. The outflows from the dam were increased to about 1615 cumec (1500 cumec spill + 115 cumec power house release) by 18:00 hrs on 15 August 2018 and continued until 03:00 hrs on 16 August 2018. The peak inflow of about 2532 cumec into dam occurred at 22:00 hrs on 15 August 2018 when the corresponding release from the dam was of the order of 1614 cumec (1500 cumec spill + 114 cumec power house release). Thus, the peak was attenuated from 2532 cumec to 1500 cumec (an attenuation of about 41% downstream of Idukki). The reservoir touched FRL of 732.43 m at 01:00 hrs on 17 August 2018. The inflow, outflow and water level at Idukki reservoir are given in Fig.4.

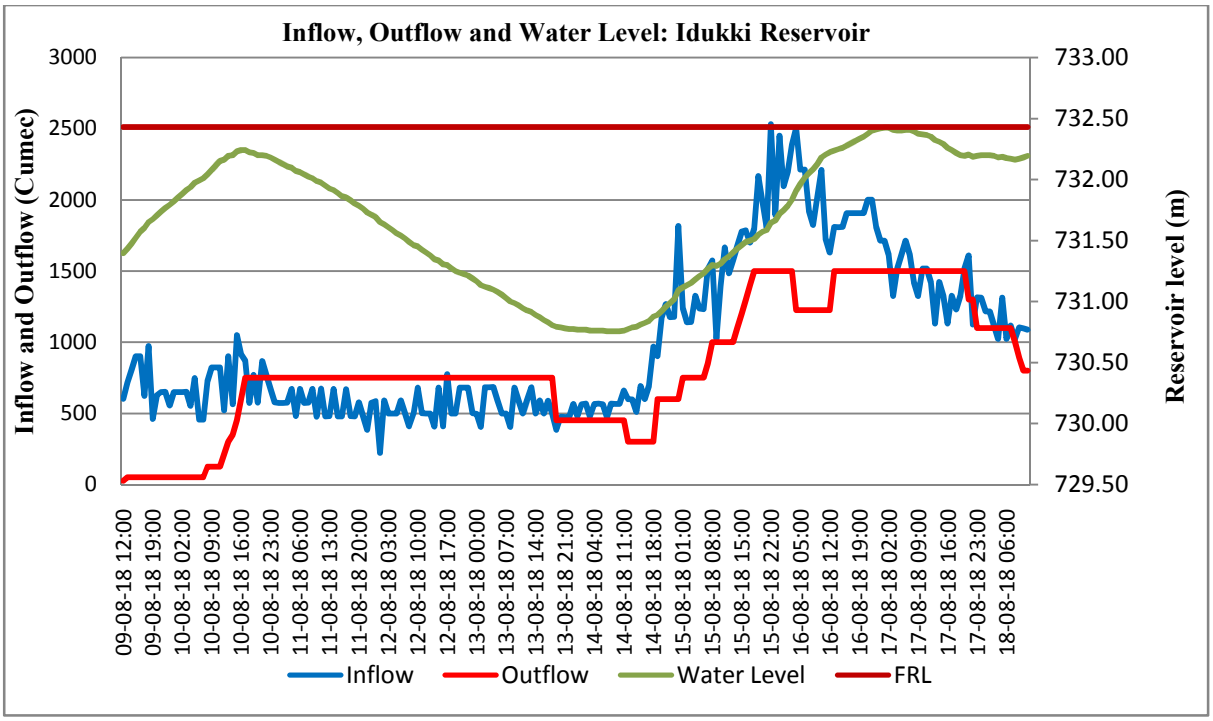


Fig.4: Inflow, outflow and water level at Idukki reservoir

It may be noted that a flood peak of about 8800 cumec was observed at Neeleswaram G&D site. That means apart from a release of about 1500 cumec from Idukki reservoir, the flood peak generated in the downstream free catchment was of the order of about 7300 cumec. Even if there was no or very little release from Idukki reservoir (a hypothetical situation in the wake of floods of such a magnitude), the downstream areas would still have received a peak of about 7500-8000 cumec. Therefore, it can be concluded that Idukki reservoir's contribution to the overall flooding situation downstream was a miniscule. It had, in fact, provided an attenuation of flood peak by about 1,030cumec when peak inflow impinged the reservoir.

4.1.2 Reservoir operation of Idamalayar

The Idamalayar Dam is located on the Idamalayar river, a tributary of the Periyar river in Kerala. Its live storage is about 1018 MCM. The water level in Idamalayar reservoir on 8 August 2018 was 168.06 m i.e. just 1 m below FRL. The reservoir was nearly 97% full in terms of live storage. The dedicated flood space between FRL (169 m) and MWL (170.3 m) is about 60 MCM only. There were no spills till 8 August 2018. The inflow, outflow and water level at Idamalayar reservoir (showing no attenuation after 9 August 2018) are given in Fig.5.

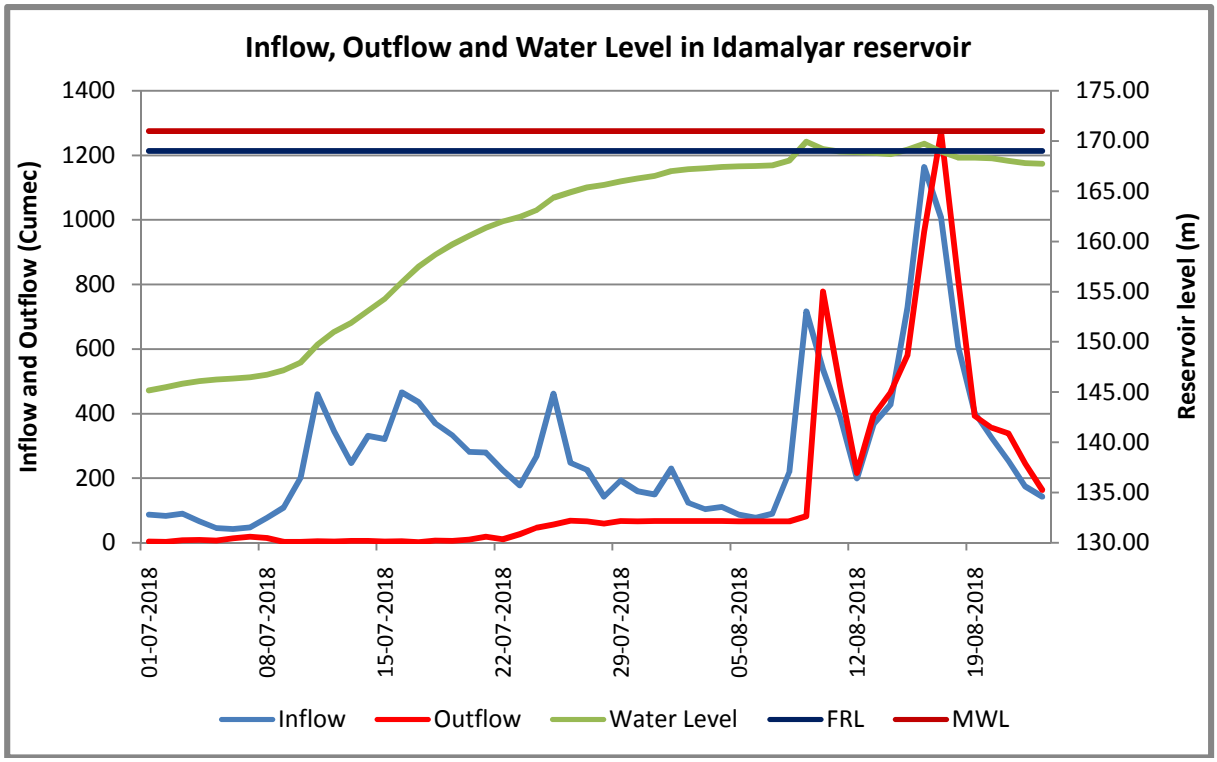


Fig.5: Inflow, outflow and water level atIdamalyar reservoir

As per dam site rainfall records, during 8-17 August, 2018 there was a rainfall of about 1,100 mm in its catchment with maximum 1-day rainfall of 230 mm occurring on 16 August 2018. The inflow into the dam started rising from 8 August 2018 and attained its peak of 1164 cumec on 16 August 2018. The average spill from the reservoir was 1271 cumec. It can be seen that in case of Idamalayar reservoir, there was no attenuation of peak owing to two reasons: heavy rainfall; and reservoir being too close to FRL prior to the onset of flood event.

4.2 Runoff computations for Pamba sub-basin

The Pamba, 176 km in length is the third longest river in Kerala. It is formed by the confluence of the Pamba Aar, Kaki Aar, Arudhai Aar, Kakkad Aar and Kall Aar. The Pamba Aar rises in the Peermedu Plateau at an elevation of 1670 m. A drainage area map of river Pamba and Manimala is shown in Fig.6.

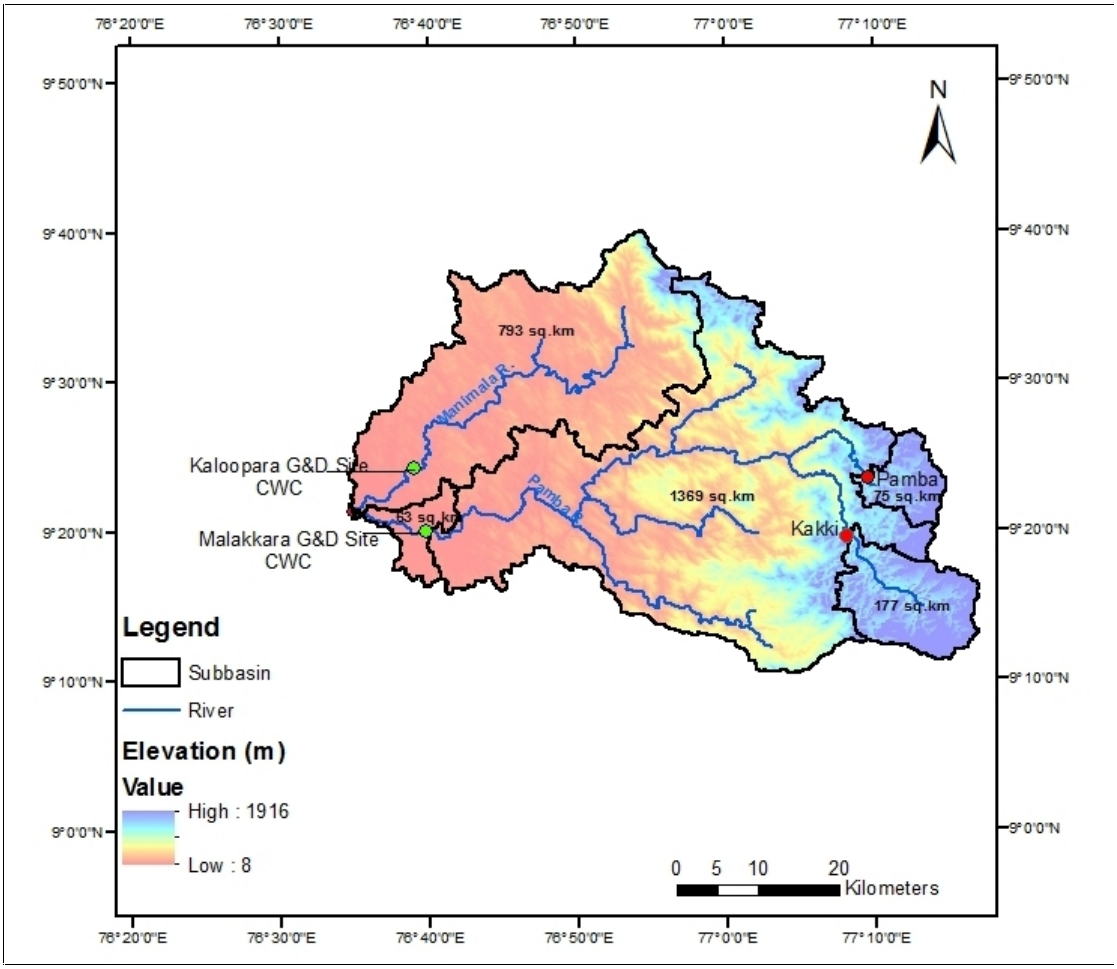


Fig.6: Drainage area map of Pamba and Manilmala rivers

The Kaki Aar, which forms the major tributary of the Pamba river, is a much larger stream at the beginning than the main river. The Pamba river, after receiving the Kaki Aar flows in a

Westerly direction till it is joined by the Arudhai Aar. At Narayanamuzhi, it turns and follows a south-easterly direction until the Kakkad Aar joins it. Beyond the confluence, the river flows in a Southerly direction up to Vadasserikkara where it is joined by the Kallar which has its origin in the Valanjakkatti Malai.

There are two Hydrological Observation stations maintained by CWC on this river/Tributary i.e at Kalloppara on river Manimala & Malakkara on river Pamba. The major reservoir project in Pamba basin is Kakki dam. At Pandanad the river bifurcates, one branch taking a westerly course. The Manimala joins the Pamba in its Neeretupuram branch. The river, thereafter, flows northwards and falls into the Vembanad lake through several branches, the important ones being the Pallathuruthy Aar and the Nedumudy Aar. The Pamba basin experiences good rainfall, moderate temperature and humid atmosphere. The South West and North East monsoon have great influence over the climatic condition of the basin. Even though the coastal regions of the basin experience hot with high humidity, the hilly region is generally cold. The average annual rainfall varies between 2276 mm to 4275 mm.

During rainfall event of 15-17, August 2018 the rainfall depths realised in Kakki dam, Pamba dam and remaining part of the sub-basin along with estimated runoff during the same period are given in Table-9.

Table-9: Rainfall and runoff in Pamba sub-basin up to CWC G&D Site

Catchment	Area	Rainfall depth 15 Aug 2018 (1 day)	Rainfall depth 15-16, Aug 2018 (2day)	Rainfall depth 15-17, Aug 2018 (3 day)	Runoff 15Aug 2018 (1 day)	Runoff 15-16, Aug 2018 (2 day)	Runoff 15-17, Aug 2018 (3 day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Manimala G&D to confluence	700	175	388	526	92	204	276
Manimala G&D site to confluence	93	175	388	526	12	27	37
Pamba dam	75	207	449	586	12	25	33
Kakki dam	177	196	394	522	26	52	69
Catchment up to Malakkara G&D site	1369	181	409	551	185	420	566
Catchment between Malakkara G&D site and Manimala confluence	63	110	197	280	5	9	13
Total	2477	179	397	537	297	663	894

From the computation shown in Table-9, the estimated areal rainfall of Pamba sub-basin is about 179 mm, 397 mm and 537 mm respectively for 1-day, 2-day and 3-day rainfall of 15-17, August 2018. For Manimala river up to CWC G&D site, the runoff volume of 1-day, 2-day and 3-day have been estimated as 92 MCM, 204 MCM, and 276 MCM respectively assuming a runoff coefficient of 0.75 corresponding to three day observed runoff of 277 MCM at Kallooppara G&D site. The same runoff coefficient has also been adopted for Pamba sub-basin with estimated 1-day, 2-day and 3-day runoff of 223 MCM, 497 MCM and 668 MCM upto Malakkara G&D site. From the flood hydrograph of Malakkara G&D site total runoff in 3 days is about 533 MCM. The difference in volume may be attributed to retention of overtopped water over river banks in nearby areas.

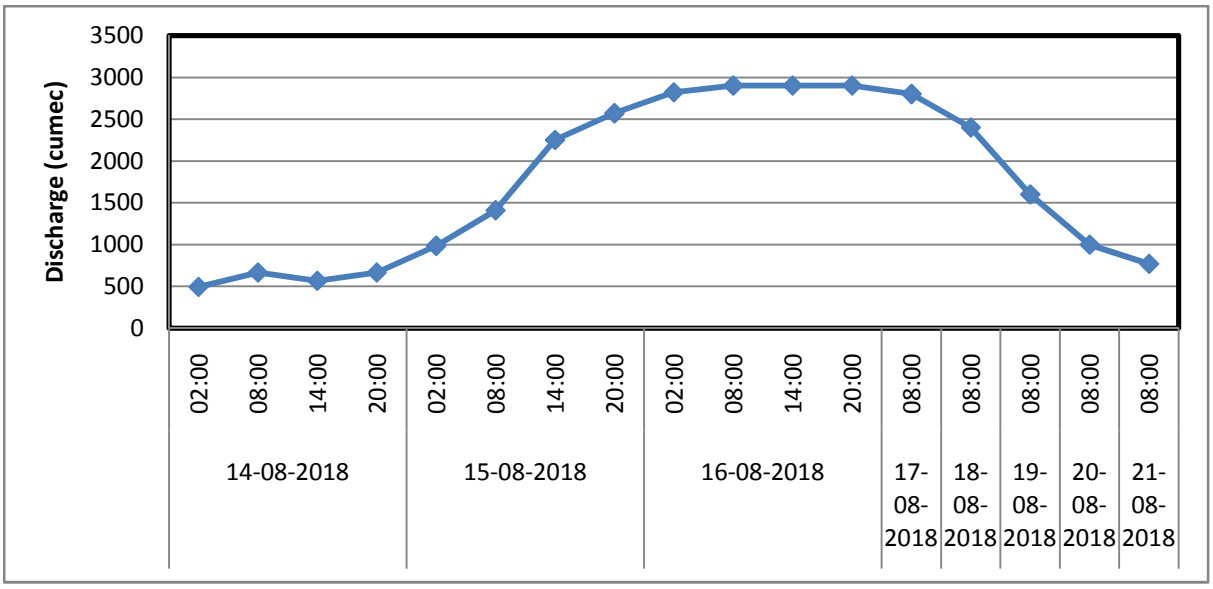


Fig.7: Discharge data of Malakkara G&D site on Pamba River

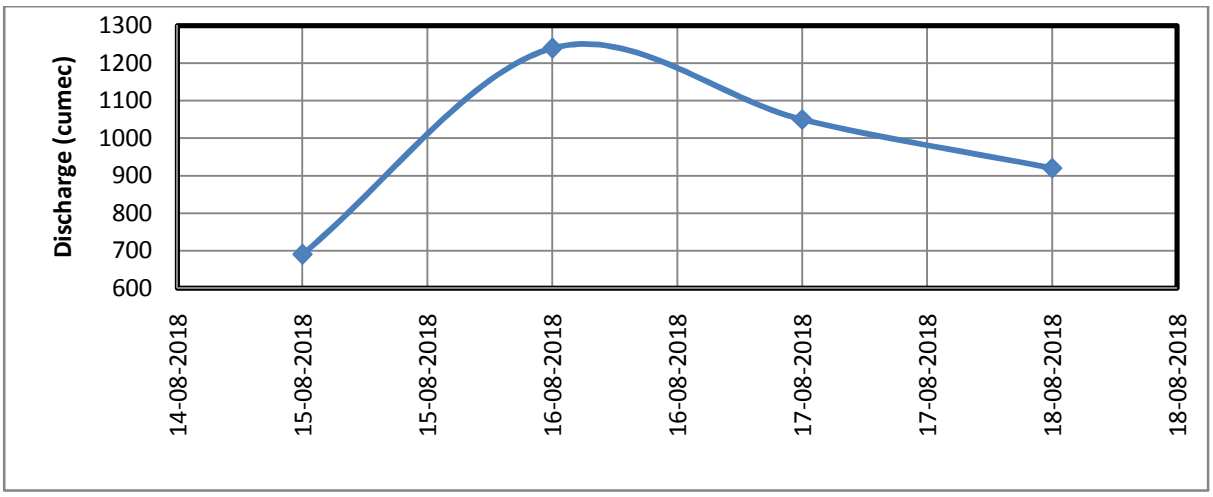


Fig.8: Discharge data of Kallooppara G&D site on Manimala River

In Pamba sub-basin there are 8 dams and one barrage. The total live storage capacity is 487 MCM, which is 10.5% of the average annual runoff of 4.64 BCM (4640 MCM). Out of the total live storage capacity only Kakki with the 447 MCM live storage has a significant storage. The Kakki storage is about 92% of the total live storage in Pamba sub-basin. Next to Kakki storage is the Pamba storage (live storage only 31 MCM). The total live storage of all other reservoirs and barrages is only 9 MCM.

4.2.1 Reservoir operation of Kakki

Kakki reservoir is built across the river Kakki, a tributary of Pamba river in Kerala. It has a gross storage of about 450 MCM at FRL of 981.46 m and storage of 7.6 MCM at MDDL of 908.3 m. The live storage of Kakki reservoir is about 442 MCM. On 8 July 2018 the reservoir level was 965.05 m i.e. 16.41 m below FRL. In terms of storage volume, the live storage was 226 MCM i.e. 51% of total live storage capacity. Subsequently, there was continuous rain during 9-27, July. As the reservoir was only half-full prior to this spell of rains, there were no spills and reservoir level rose to 979.04 m on 28 July 2018 with a live storage of about 403 MCM. The reservoir was now 91% full. So, the Kakki reservoir absorbed this heavy spell of rain fully. However, as a result, it got very close to FRL in July itself with only 39 MCM extra flood cushion available below FRL. The releases from Kakki reservoir could not be made to deplete water level in Kakki reservoir, as at that time the below MSL areas in Kuttanad region were already experiencing heavy inundation and any release would have added to the misery of people living in that region. Moreover, there is a Thottapalli spillway at Vembanad lake that receives waters from Pamba, Achenkovil, Meenachil, and Manimala rivers, out of which only Pamba basin is having a control structure namely Kakki dam. The other three are uncontrolled rivers. The Thottapalli barrage spillway has a discharging capacity of around 630 cumec. Therefore, the waters take time to pass through the barrage and get accumulated in the low-lying areas around Vembanad lake. So, the discharge from Kakki reservoir, when the low lying areas in Kuttanad region are already experiencing inundation, makes it a tricky situation i.e. in deciding whether to hold water in Kakki dam to save Kuttanad from further flooding or to release water anticipating possible future flood events.

If Kuttanad region was not flooded prior to the second spell of extreme rains, ideally, when this spell of rain once subsided, the reservoir level could have been brought down to some

extent to moderate any future extreme flood events that might impinge the reservoir in the monsoon month of August. Unfortunately, this happened 11 days later.

On 9 August 2018, the reservoir level was 981.25 m and it was nearly with and no spills from the dam. Now, any flood event could have been moderated between the space available between FRL (981.46 m) and MWL (982.16 m). Only about 20 MCM dedicated flood space is available between FRL and MWL. As per dam site rainfall record, the rainfall during the second event that occurred during 9-20 August 2018 was 1724 mm with 590 mm rainfall in just two days i.e. 15-16, August 2018. The maximum inflow in the reservoir was 835 cumec with a corresponding release of 938 cumec. As there was no space left in the reservoir, it could not provide any flood attenuation during this second event and the space between FRL and MWL was quickly exhausted. The inflow, outflow, water level attained at Kakki reservoir are given in Fig.9.

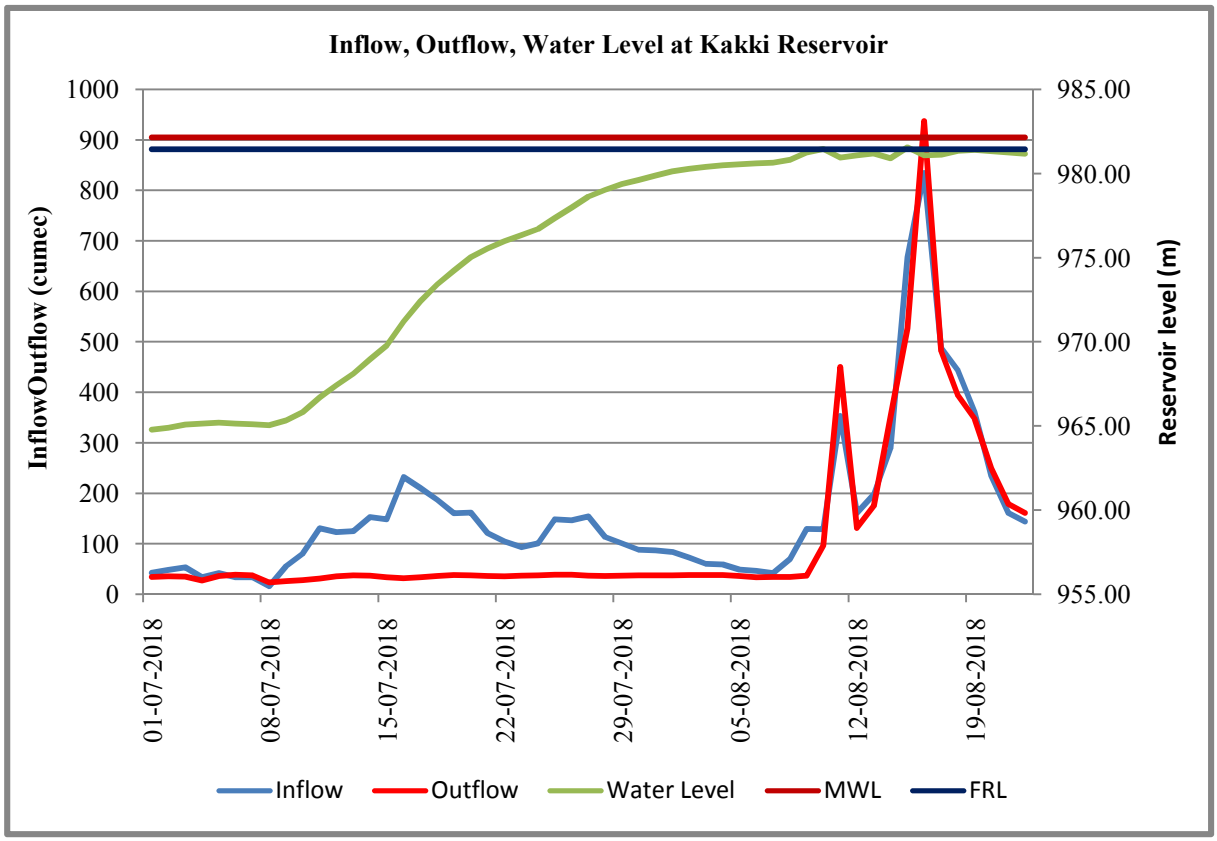


Fig.9: Inflow, Outflow and Water Level attained at Kakki reservoir

It may also be noted that this was an extreme flood event. The total flood peak observed in Pamba sub-basin was of the order 2900 cumec. Even if there was just 500 cumec release from Kakki, the downstream flood peak would still have been about 2400 cumec.

4.2.2 Combined runoff of Pamba, Manimala, Meenachil and Achenkovil rivers

Four major west flowing rivers namely Achenkovil, Pamba, Manimala and Meenachil drain directly into the southern part of Vembanad Lake while a southern branch of Periyar (further north of Muvattupuzha) drains into Cochin Kayal and finally into the Arabian sea through Kochi outlet. The Vembanad Lake is bordered by Alappuzha (Alleppey), Kottayam and Ernakulam districts of Kerala covering an area of about 200 sq km and extending 80 km in a NW-SE direction from Munambam in the north to Alleppey in the south. The width of the lake varies from 500 m to 4 km and the depth from 1m to 12m. An index map of Vembanad lake is given in Fig.10.

Fig.10: Index map of Vembanad Lake

Manimala, Meenachil, Pamba and Achenkovil flow into the lake south of Thanneermukkom. While Muvattupuzha river flows into the Cochin backwaters north of Thanneermukkom barrage. Kuttanadu is a marshy delta in the southern part of the lake, formed by four river network namely, Pamba, Manimala, Achankoil and Meenachi together with the backwaters in and around the Vembanad lake. Large parts of the vast estuary lie below the sea level up to a depth of about 2.5 m, waterlogged for most part of the year subject to flood and inundation during the monsoons and saline water intrusion during the summer months. The Vembanad lake was declared as a Ramsar Site in November 2002. A catchment area map of Pamba, Manimala, Achankoil and Meenachi river systems up to Vembanad lake is given in Fig.11.

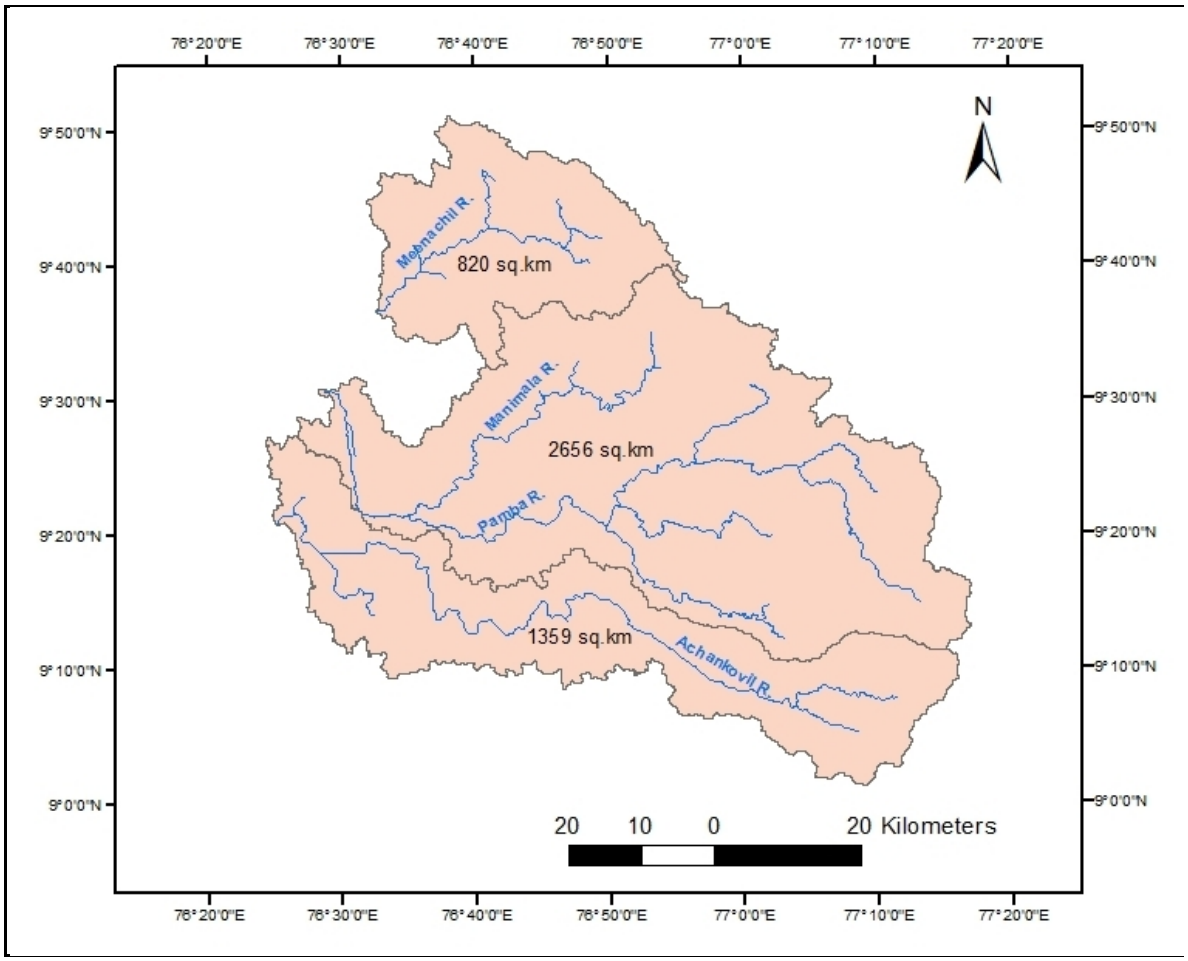


Fig.11: catchment area map of Pamba, Manimala, Achenkoil and Meenachi river systems

The estimated runoff for a runoff coefficient of 0.75 from Pampa, Manimala, Achankoil and Meenachi river systems up to vemabanad lake during 15-17, August 2018 is given in Table-10.

Table-10: Rainfall and runoff in Pamba, Manimala, Achankoil and Meenachi river systems up to Vembanad lake

River	Catchment Area	Rainfall depth 15 Aug 2018 (1 day)	Rainfall depth 15-16, Aug 2018 (2day)	Rainfall depth 15-17, Aug 2018 (3 day)	Runoff 15Aug 2018 (1 day)	Runoff 15-16, Aug 2018 (2 day)	Runoff 15-17, Aug 2018 (3 day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Achankovil	1359	122	231	329	124	235	336
Pamba and Manimala	2656	173	382	517	346	762	1030
Meenachil	820	146	327	437	90	201	268
Total	**4835**	**441**	**940**	**1283**	**560**	**1198**	**1634**

As per July 2008 report of Planning Commission, the water carrying capacity of the system is reported to have reduced to an abysmal 0.6 BCM from 2.4 BCM as a result of land reclamation. The Pamba reservoir (31 MCM) and Kakki reservoir (447 MCM), in the Pamba sub basin can hardly regulate 10.5% of the average annual flow in the Pamba River. All other storages in Pamba river are very small ones having no appreciable storage capacity. The other three rivers Manimala, Meenachil and Achenkovil have no storages on them. The Thottappally spillway Constructed in 1954, as part of Kuttanadu development scheme for relieving flood condition in Kuttanadu, by diverting flood waters of Pamba, Manimala, Achenkovil and Meenachil directly to the sea. The Thottappally spillway consists of a leading channel 1310 m long 365 m wide with a bridge cum regulator across the spillway channel. The bridge cum regulator is 365 m along with 40 vents, each having 7.6 m clear span. Though the original discharge capacity of the spillway was about 1812 cumec, it is reported that at present the average maximum discharge passing through the spillway is limited to 630 cumec, which is almost 1/3rd of the design capacity of the spillway.

The runoff generated from Pamba, Manimala, Achenkovil and Meenachil rivers during 15-17 August rainfall was about 1.63 BCM (1630 MCM) against the 0.6 BCM (600 MCM) carrying capacity of Vembanad lake. Further, the discharging capacity of 630 cumec of Thottappally spillway was other major constraint for the disposal of runoff. Considering the lake carrying capacity of about 600 MCM and discharging capacity of 630 cumec of Thottappally spillway and about 1706 cumec present discharging capacity of Thaneermukkom barrage, it can be concluded that out of 1.63 BCM the runoff generated during the 15 to 17 August 2018 rainfall, only about 0.605 BCM runoff was possible to drain out of the Vembanad lake. The remaining runoff volume of about 1 BCM created the rise of the water level in the lake and

nearby areas. This continuous rising of lake water may be one of the reason of overall change in the river hydrodynamics of Pamba, Manimala, Meenachil and Achenkovil river systems resulting higher water level for a particular discharge in these rivers. Considering the high rainfall during 15-17, August 2018, the absence of appreciable storage reservoirs in the upstream on the above rivers, shrinkage of carrying capacity of Vembanad Lake and reduction of the capacity of Thottappally spillway may have worsened the flooding in the Kuttanad region and the backwater flows to the low-lying areas in the upper reaches of the lake. This may be the reason of the heavy flooding experienced in the low-lying areas closer to the Vembanad lake in the Pathnamthitta, Kottayam and Alapuzha districts.

4.3 Runoff computations for Chalakudy sub-basin

Chalakudy River is the fifth longest river in Kerala. The Chalakudy river is formed by the confluence of five streams, Parambikulam, Kuriarkutty, Sholayar, Karappara and Anakkayam, all of them originating in the Anamalai Hills of the Western Ghats. Out of these, Parambikulam and Sholayar rivers originate from the Coimbatore district of Tamil Nadu. Karappara and Kuriarkutty rivers originate from the Palakkad district in Kerala. At about 470m above M.S.L. the Parambikulam joins the Kuriarkutty river. Further 9 km down, the river is joined by the Sholayar. The Karappara joins the main river at about 455m above M.S.L. The Anakkayam joins the main river 8 km further down at 365m above M.S.L. In the initial course, the river passes through thick forests and its flow is broken by many falls till it reaches the plains at Athirapally.

The Chalakudi river basin is bounded by the Karuvannur sub-basin on the north and the Periyar sub-basin on the south. The basin consists of about 30,000 ha of wet lands. The basin receives and average rainfall of about 3000 mm. The total drainage area of the river is 1704 sq.km and out of this 1404 sq.km lies in Kerala and the rest 300 sq.km in Tamil Nadu. The length of the river is about 130 km.

The famous waterfalls, Athirappilly falls and Vazhachal falls, are situated on this river. The hydro electric projects on Chalakudy River are Sholayar and Peringalkutthu Hydro Electric Projects. For irrigation purposes Thumboormoozhy weir is constructed across this river. It merges with the Periyar River near Elenthikara, adjacent to Manjali North Paravur in Ernakulam district and finally joins Kodungallur backwaters and Arabian Sea at Azhekode. The Parambikulam Dam has been built on the Parambikulam river, one of its four tributaries. The river finally empties into the right arm of the Periyarat Elanthikkara in

Puthenvelikara village of Ernakulam district. The river derives its name from Chalakudy town which is an important town in the basin. The river flows through Palakkad, Thrissur and Ernakulamdistricts of Kerala. A drainage area map of Chalakudy river up to CWC G&D site at Arangali is shown in Fig.12.

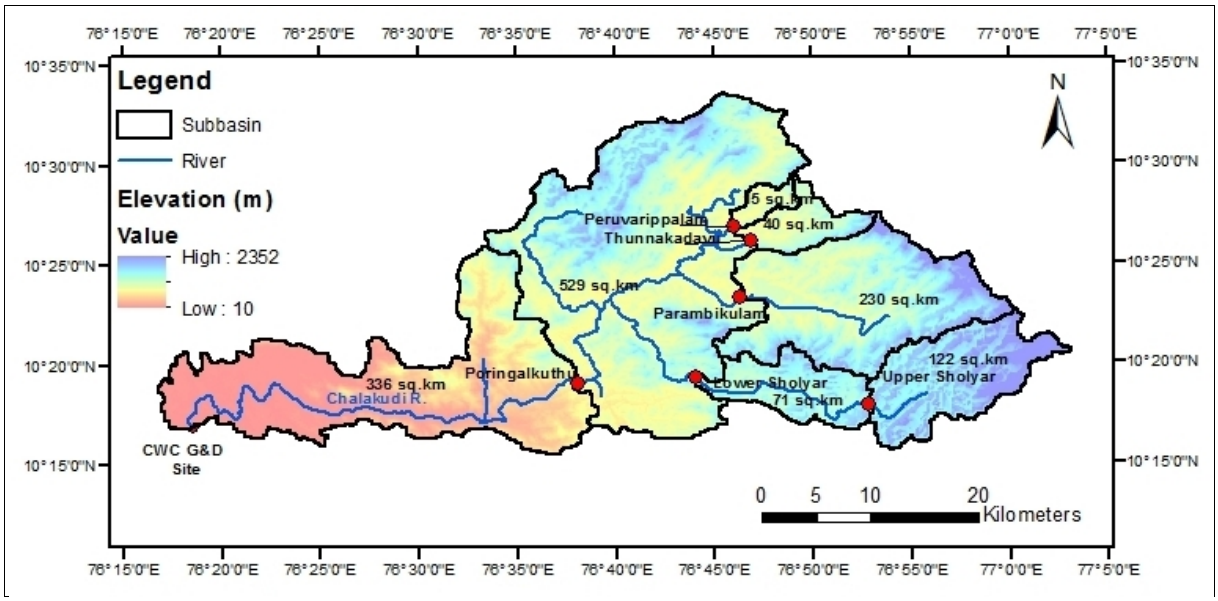


Fig.12: Drainage area map of Chalakudy river up to Arangali G&D Site of CWC

During 15-17, August 2018, rainfall depths realised in Parambikulam, Lower Sholyar, Upper Sholyar, Peruvarippalam, Thunnakadavu and remaining part of the sub-basin i.e. Chalakudi Free along with estimated runoff during the same period for a runoff coefficient of 0.9 (because of very steep terrain), are given in Table-11.

Table-11: Rainfall and runoff in Chalakudysub-basin up to CWC G&D Site

Catchment	Area	Rainfall depth 15 Aug 2018 (1 day)	Rainfall depth 15-16, Aug 2018 (2day)	Rainfall depth 15-17, Aug 2018 (3 day)	Runoff 15Aug 2018 (1 day)	Runoff 15-16, Aug 2018 (2 day)	Runoff 15-17, Aug 2018 (3 day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Upper Sholyar	122	170	356	447	19	39	49
Lower Sholyar	71	160	333	424	10	21	27
Parambikulam	230	152	308	391	31	64	81
Peruvarippalam	15	133	275	352	2	4	5
Tunakadavu	40	137	278	353	5	10	13
Poringalkuthu	529	136	313	405	65	149	193
Chalakudi Free	336	123	346	467	37	104	141
Total	**1343**	**140**	**324**	**421**	**169**	**391**	**508**

From the computation shown in Table-11, the estimated areal rainfall of Chalakudy sub-basin is about 140 mm, 324 mm and 421 mm respectively for 1-day, 2-day and 3-day rainfall of 15-17, August 2018. The runoff volume of 1-day, 2-day and 3-day has been estimated as 169 MCM, 391 MCM, and 508 MCM respectively.

The estimated runoff has been compared with the discharge data of Arangaly G&D site of CWC. The plot of flood hydrograph of Arangaly G&D site is given in Fig.13.

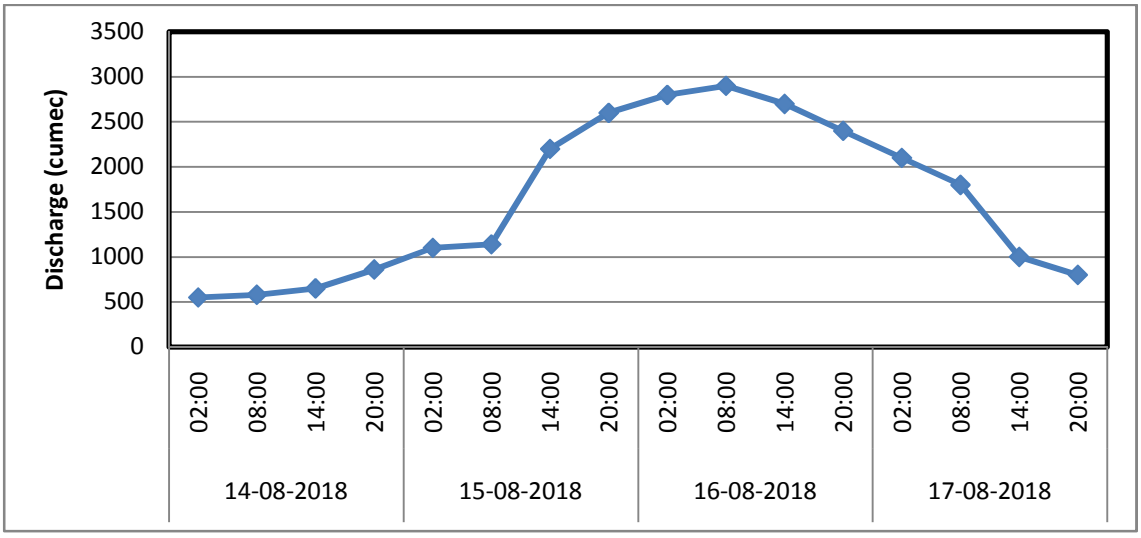


Fig.13: Discharge data of Chalakudy river at Arangaly G&D site

The maximum discharge at Arangaly G&D site was about 2900 cumec on 16.08.2018 at 08:00 hours. The cumulative runoff for 15-17, August 2018, computed from the Arangaly G&D records is about 525 MCM, while the estimated runoff from IMD rainfall is about 508 MCM for a runoff coefficient of 0.9.

The Chalakudy sub-basin has a total of 6 reservoirs, out of these 1 reservoir is located in Tamil Nadu and rest 5 reservoirs are in Kerala. Chalakudy is the steepest river of Kerala. The total drainage area of the river is 1704 sq.km, out of this 1404 lies in Kerala and the rest 300 sq.km lies in Tamil Nadu. The average annual runoff is about 3121 MCM. All the 6 reservoirs in the system have a combined Live Storage of 719 MCM, which enables the reservoirs to store 23% of the average annual runoff. The biggest reservoir in this system is the Parambikulam with a Live Storage of 381 MCM. In these six reservoirs, three reservoirs situated in Kerala along with TN-Sholayar reservoir, are being operated by the Govt of Tamil Nadu under the Parambikulam-Aliyar Project system. The remaining two, Kerala-Sholayar and Poringalkuth reservoir are being operated by KSEB Limited. The Thumboormoozhy weir

located downstream of Poringalkuth reservoir is the origin point of the canals of Chalakudy irrigation project.

The runoff from the spill of Kerala Sholayar, Parambikulamand, Tunakadavu comes into the Chalakudy river. The Kerala Sholayar, Parambikulam and Tunakadavu reservoirs were at FRL on 14 August 2018. Releases from Kerala Sholayar, Parambikulam and Tunakadavu reservoirs are given in Table-12 and 13.

Table-12: Inflow and outflow from Kerala Sholayar reservoir

Kerala Sholayar *FRL 811.68 m, Live storage 150 MCM*			
Date	Water level (m)	Inflow (MCM)	Spill (MCM)
13-08-2018	811.68	11.93	11.93
14-08-2018	811.68	32.39	32.39
15-08-2018	811.68	41.99	41.99
16-08-2018	811.68	36.25	36.25
17-08-2018	811.38	23.07	23.07
18-08-2018	811.38	33.36	30.53
19-08-2018	811.07	20.41	14.89

Table-13: Inflow and outflow from Kerala Sholayar reservoir

Parambikulam reservoir *FRL - 556.26 m, Live storage - 381 MCM* ***Tunakadavu*** *FRL -539.50 m, Live storage - 9 MCM*				
Date	Inflow (MCM)	Spill Parambikulam (MCM)	Spill Tunacadavu (MCM)	Total Spill (MCM)
13-08-2018	14.86	11.50	0.00	11.50
14-08-2018	27.23	19.57	0.00	19.57
15-08-2018	61.99	63.60	0.00	63.60
16-08-2018	73.09	67.96	13.46	81.41
17-08-2018	36.93	19.06	14.86	33.92
18-08-2018	20.47	9.79	9.70	19.49
19-08-2018	12.95	9.71	1.84	11.56

From the inflow and release data, it can be seen that release from Kerala Sholayar reservoir was almost same as that of inflow during 15-17, August 2018, while release from Parambikulam system was about 8 MCM more than the inflow of 16 August 2018. The 8 MCM more release from Parambikulam system on 16 August 2018 would have slightly affected the flow in river when compared with 222 MCM overall runoff generated in the sub-basin on the same date.

Poringalkuthu reservoir is having free catchment area of about 529 sq.km. Its live storage capacity is about 30 MCM. Its FRL is at EL 424 m and crest level of spillway is at EL 419.4 m. The discharging capacity of the spillway is 2265 cumec. Apart from its free catchment this reservoir also receives the spills from Parambikulam, Kerala Sholayar and Tunakadavu dams. As per rainfall data of 16 August 2018 of Kerala Sholayar dam site and power house site, Idamalayar dam site, about 293 mm rainfall occurred in the free catchment area of Poringalkuthu. The total inflow estimated into this reservoir on 16 August 2018 is about 258 MCM against the discharging capacity of spillway of 196 MCM, resulting overtopping of the dam.

4.4 Runoff computations for Bharathapuzha sub-basin

Bharathapuzha is the second longest west flowing river that drains into the Arabian Sea in Kerala. This sub-basin is bounded in the east by the Cauvery basin, in the west by the Arabian Sea. The catchment area of Bharatpuzha at Kumbidi G&D site of CWC is about 5787 sq.km. The drainage area map of Bharatpuzha at Kumbidi G&D site is given in Fig.14.

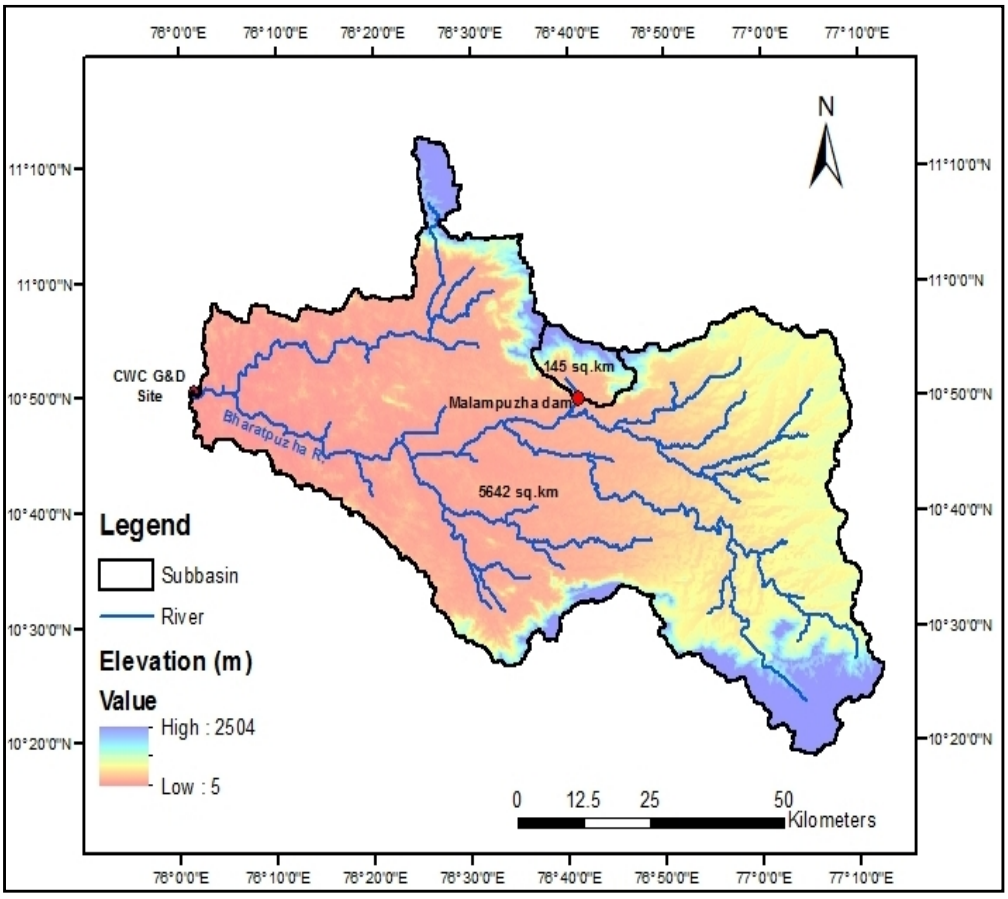


Fig.14: Drainage area map of Bharathapuzha up to Kumbidi G&D Site

Its total drainage area is about 6186 sq.km out of which 71% lies in Kerala and rest 21% in Tamil Nadu. The basin is elongated in shape. There are five Hydrological Observation Stations on this river maintained by CWC at Kumbidi, Pulamanthole, Mankara, Pudur & Ambarampalayam. The Bharathapuzha or Ponnani river as it is called in the lower reaches, rises in the Eastern slopes of Anamalai hills of the Western Ghats at an elevation of 2,250m above MSL and flows in the North-Westerly direction in Pollachi taluk of Coimbatore district in Tamil Nadu.

At about 45 km downstream of its origin, it is joined by a tributary namely the Palar on its right bank. Traversing another 15 km westwards, it enters the Palakkad district of Kerala through Palakkad gap. At about 100 km downstream of its origin, it is jointed by the Kalpathipuzha on the right bank. Traversing another 109 km in the Westward direction through Palakkad and Malapuram districts, it finally discharges into the Arabian Sea near Ponnani town. The total length of the river is about 209 km. The upper reaches of the river is called as the Aliyar. When it enters Kerala, it is called as Kannadipuzha till it meets the Kalpathipuzha. After confluence with the Kalpathipuzha, it is known as Bharathapuzha or Ponnani River. It is joined by Gayathripuzha on the left bank and Pulanthode on the right bank as it flows down to the Arabian Sea. It also receives a large number of small streams and rivulets. The Gayathripuzha, Kalpathipuzha and Pulanthode, are the three major tributaries. All the three tributaries rise in the Western slopes of the different ranges of the Western Ghats and drains a major parts of the Palghat, Trichur and Malapuram districts.

During rainfall event of 15-17, August 2018 the rainfall depths realised in Free Bharathapuzha and Malampuzhadam catchments along with estimated runoff are given in Table-14.

Table-14: Rainfall and runoff in Bharathapuzhasub-basin up to CWC G&D Site

Catchment	Area	Rainfall depth 15 Aug 2018 (1 day)	Rainfall depth 15-16, Aug 2018 (2day)	Rainfall depth 15-17, Aug 2018 (3 day)	Runoff 15Aug 2018 (1 day)	Runoff 15-16, Aug 2018 (2 day)	Runoff 15-17, Aug 2018 (3 day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Bharathapuzha Free	5642	107	288	362	435	1170	1472
Malampuzha dam	145	60	232	304	7	27	35
Total	**5787**	**106**	**287**	**361**	**442**	**1197**	**1507**

From the computation shown in Table-14, the estimated areal rainfall of Bharathapuzhasub-basin is about 106 mm, 287 mm and 361 mm respectively for 1-day, 2-day and 3-day rainfall of 15-17, August 2018. The runoff volume of 1-day, 2-day and 3-day has been estimated as 442 MCM, 1197 MCM and 1507 MCM respectively.

The estimated runoff has been compared with the discharge data of Kumbidi G&D site of CWC. The plot of flood hydrograph of Kumbidi G&D site is given in Fig.15.

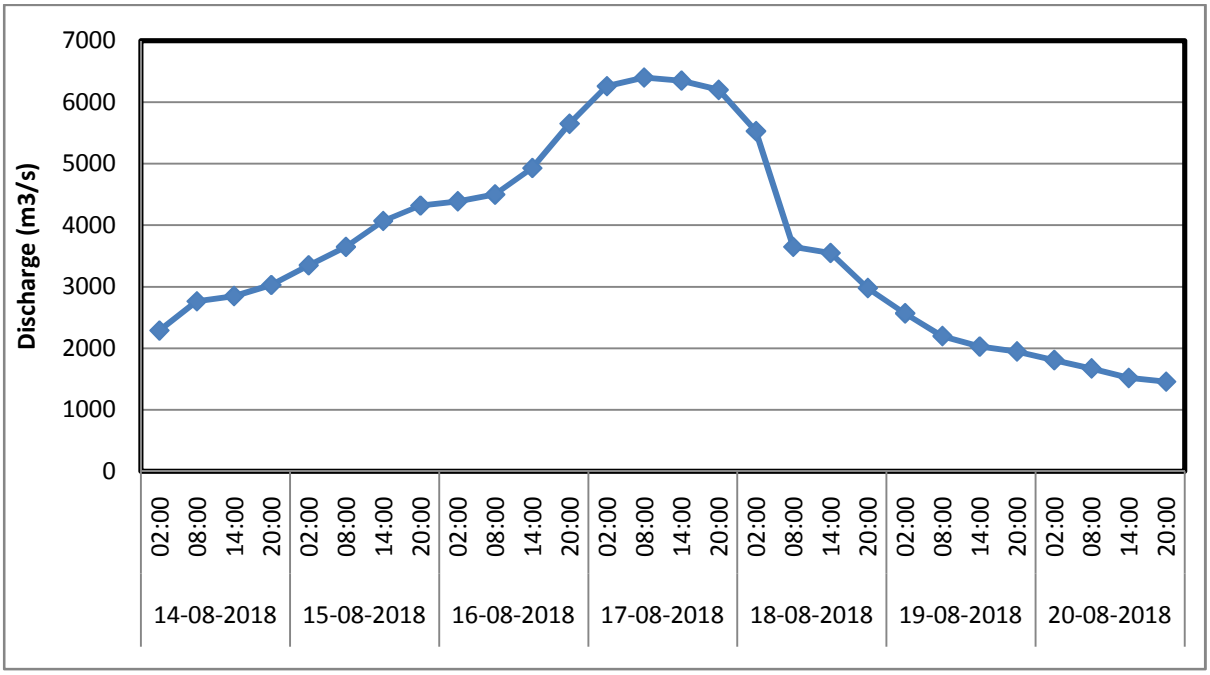


Fig.15: Discharge data of Bharathapuzha River at Kumbidi G&D site

The maximum discharge at Kumbidi G&D site was about 6400 cumec on 17.08.2018 at 08:00 hours. The cumulative runoff for 15-17, August 2018, computed from the Kumbidi G&D records is about 1.51 BCM, while the estimated runoff from IMD rainfall is about 1.507 BCM for a runoff coefficient of 0.72 for free catchment and 0.80 for catchments tapped by dam.

The major reservoir in Bharatpuzha sub-basin is Malampuzha. The inflow and outflow graph of Malapuzha reservoir is presented in Fig.16. From the plot it can be seen that during 8-9, August 2018 the total inflow into the reservoir was about 97 MCM against the release of 48 MCM. During 8-9, August 2018, the reservoir absorbed about 49 MCM of flood water and thus resulting less flooding in downstream area. During 15-17, August 2018 the total inflow

into the reservoir was about 53 MCM against the release of 66 MCM, hence the released volume was about 13 MCM more than the inflow, which is insignificant in comparison to estimated runoff of 1510 MCM from the basin.

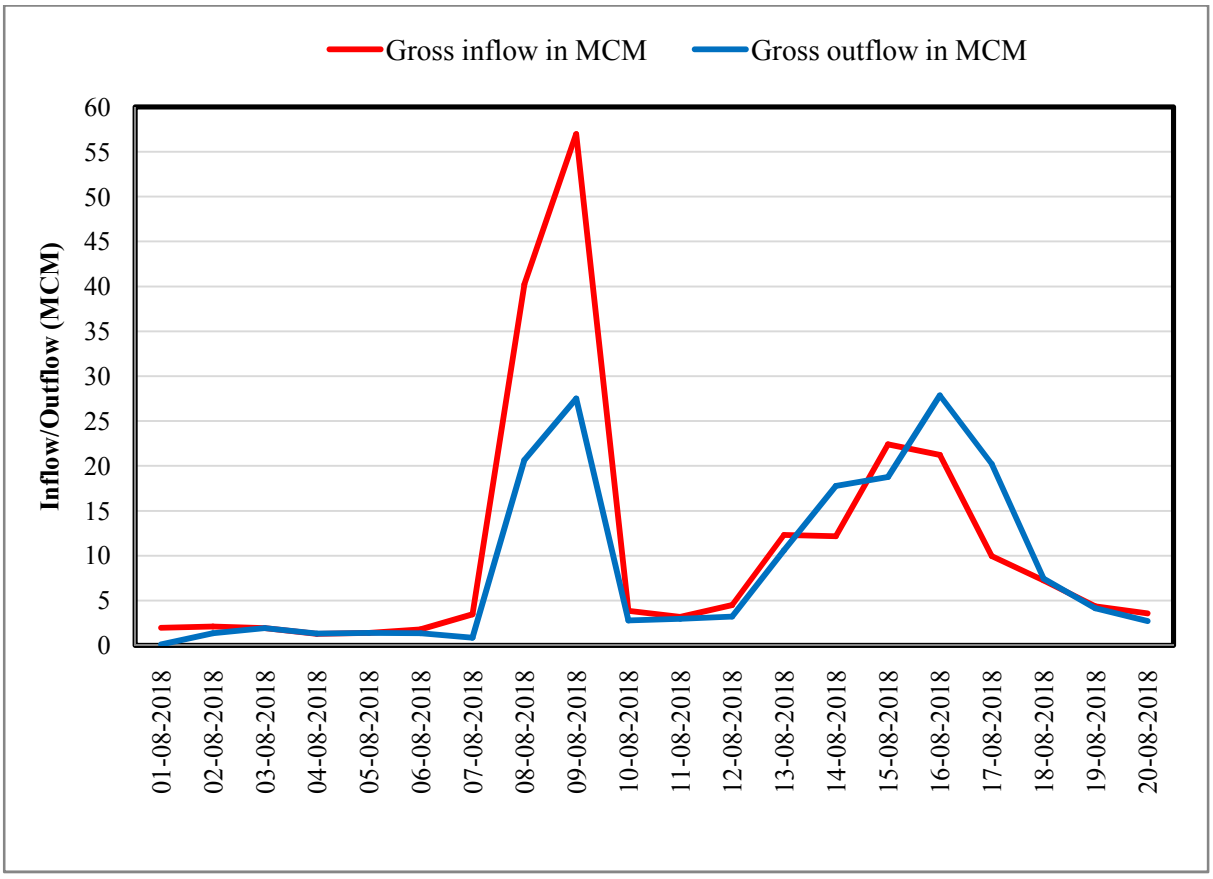


Fig.16: Inflow and outflow from Malapuzha reservoir

4.5 Runoff computations for Kabini sub-basin

River Kabani is one of the major tributaries of Cauvery river in southern India. It originates in the Western Ghats of Wayanad district of Kerala by the confluence of Panamaram and Mananthavady rivers. It flows eastwards to join the Cauveryriver at Tirumakudalu, in Karnataka. The Banasura Sagar Dam is a stone masonry constructed on Karamanathodu tributary of the Kabini river. A canal from Banasura Sagar reservoir supplies the water to Kakkayam hydro electric power project and meets the demand for irrigation and drinking water in the region. Karapuzha dam is constructed on Karapuzha river, another tributary of the Kabini river. The total drainage area of the Kabini sub-basin upto CWC G&D site at Muthankera is 1546 sq.km. The total drainage area of the Kabini river in Kerala is about 1920 sq.km. The drainage area map is given in Fig.17.

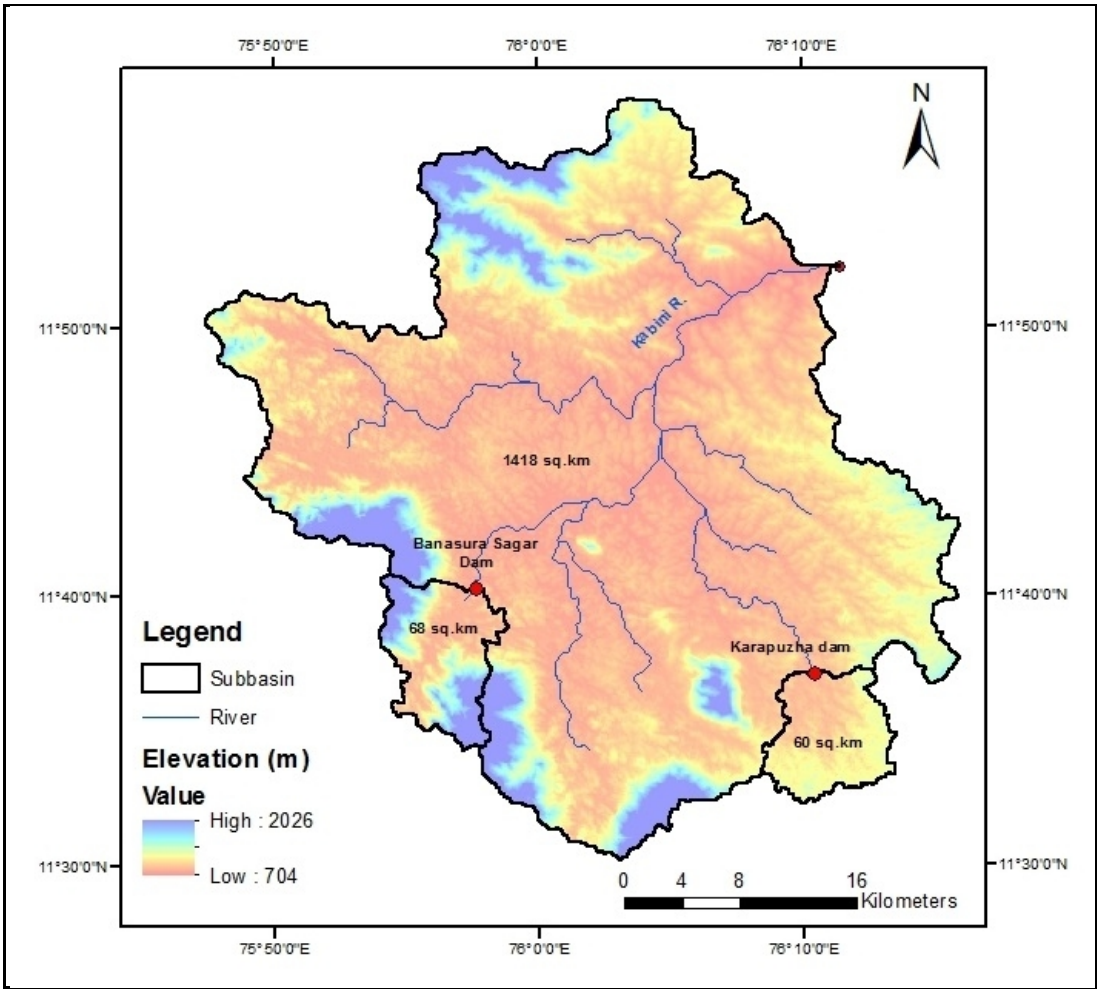


Fig.17: Drainage area map of Kabini river up to Muthankera G&D Site

During rainfall event of 8-10, August 2018 the rainfall depths realised in Karapuzha, Banasura Sagar and Free Kabini catchments along with estimated runoff during the same period are given in Table-15.

Table-15: Rainfall and runoff in Kabinisub-basin up to CWC G&D Site

Catchment	Area	Rainfall depth 8 Aug 2018 (1 day)	Rainfall depth 8-9, Aug 2018 (2day)	Rainfall depth 8-10, Aug 2018 (3 day)	Runoff 8 Aug 2018 (1 day)	Runoff 8-9, Aug 2018 (2 day)	Runoff 8-10, Aug 2018 (3 day)
	(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
Free Kabini	1418	104	280	313	103	278	311
Karapuzha dam	60	77	194	209	3	9	9
BanasuraSagar (Rainfall as per dam site data)	68	278	721	882	14	37	45
Total	**1546**	**104**	**279**	**311**	**121**	**323**	**365**

From the computation shown in Table-6, the estimated areal rainfall of Kabini sub-basin is about 104 mm, 279 mm and 311 mm respectively for 1-day, 2-day and 3-day rainfall of 08-10, August 2018. The runoff volume of 1-day, 2-day and 3-day has been estimated as 123 MCM, 329 MCM and 367 MCM respectively.

The estimated runoff has been compared with the discharge data of Muthankara G&D site of CWC. The plot of flood hydrograph of Muthankara G&D site is given in Fig.18.

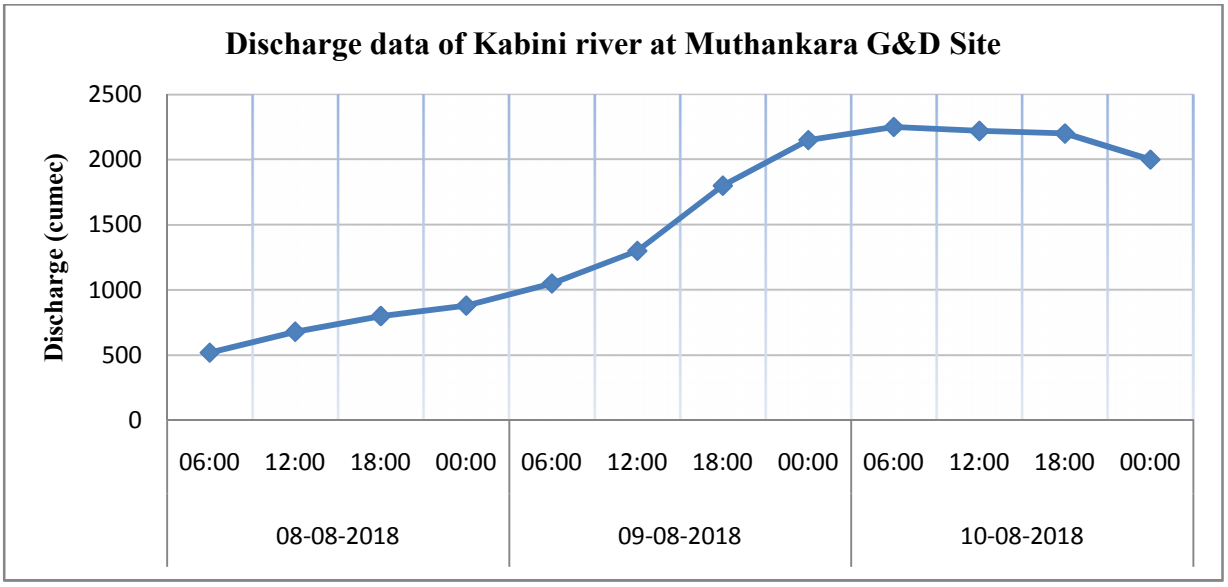


Fig.18: Discharge data of Kabini River at Muthankara G&D site

The maximum discharge at Muthankara G&D site was about 2235 cumec on 10 August 2018 at 12:00 hours. The cumulative runoff for 8-10, August 2018, computed from the Muthankara G&D records is about 367 MCM, while the estimated runoff from IMD rainfall is also about 367 MCM for a runoff coefficient of 0.70 for free catchment and 0.75 for catchments tapped by dams.

Bansaura Sagar reservoir with gross storage of 209.25 MCM was on its FRL at EL 775.60 m since 16 July 2018. Since then, whatever inflow came into the reservoir, the same was released. On 8th and 9th of August 2018 rainfall records of dam site show a rainfall of 278 and 443 mm respectively with consequent inflow 11.32 MCM and 19.67 MCM respectively. Since reservoir level was at FRL, entire inflow was released from spillway. The inflow, outflow and recorded rainfall at dam site is given in Table-16.

The average release on 8th, 9th and 10th of August were 131 cumec, 228 cumec and 113 respectively, while the observed maximum discharge at CWC G&D site were about 880 cumec on 8 August 2018, 2150 cumec on 9 August 2018 and 2250 cumec on 9 August 2018. Hence, major runoff was generated from untapped catchments of Kabini river.

Table-16: Inflow and Outflow and rainfall records of Bansura Sagar reservoir

Date	Reservoir level	Rainfall	Gross Inflow	Spill
	(m)	mm	MCM	MCM
7-Aug-18	775.6	79.20	1.21	1.21
8-Aug-18	775.60	278.40	11.32	11.32
9-Aug-18	775.60	442.60	19.67	19.67
10-Aug-18	775.60	160.90	9.75	9.75
11-Aug-18	775.60	46.50	6.08	6.08
12-Aug-18	775.60	75.00	6.59	6.59
13-Aug-18	775.60	151.70	8.10	8.10
14-Aug-18	775.60	205.40	14.50	14.50
15-Aug-18	775.60	304.90	18.48	18.48
16-Aug-18	775.00	343.90	17.99	18.59
17-Aug-18	774.60	182.30	14.19	14.59
18-Aug-18	775.60	161.60	4.24	3.24
19-Aug-18	774.50	77.40	0.00	2.21
20-Aug-18	774.65	88.00	2.36	2.21
21-Aug-18	774.80	60.30	1.61	1.46
22-Aug-18	774.85	80.40	0.79	0.74

5.0 Rainfall depths realised for entire Kerala during 15-17, August 2018 and estimated runoff

Using 1-day, 2-day and 3-day rainfall raster, estimated rainfall and runoff for entire Kerala are presented in presented in Table-17. Considering the saturated ground condition and estimated runoff coefficient in different sub-basins, a runoff coefficient of 0.75 has been adopted for the entire Kerala.

Table-17: Estimated rainfall and runoff for entire Kerala during 15-17, August 2018

Area	**Estimated rainfall**			**Estimated runoff**		
	15 August 2018	**15-16, August 2018**	**15-17, August 2018**	**15 August 2018**	**15-16, August 2018**	**15-17, August 2018**
(sq.km)	(mm)	(mm)	(mm)	(MCM)	(MCM)	(MCM)
38863	140	316	414	4081	9211	12057

From the estimated quantity of runoff, it can be said that this huge runoff generated within a short period of 3 days was beyond the carrying capacity of most of the rivers in Kerala, resulting overbank flows from most of the rivers. Further, total catchment area tapped by

dams in Kerala excluding barrages is about 6610 sq.km. Taking a runoff coefficient of 0.8, the runoff generated from the catchment tapped by the dams during the 3 days rainfall of 15-17, August 2018 has been estimated about 2.19 BCM, out of total runoff of 12 BCM for entire Kerala. The total live storage of Kerala is about 5.8 BCM. Even with 20% of the live storage availability of 14 August 2018, the available flood moderation extent would have been only 1.16 BCM against the estimated inflow of 2.19 BCM. It shows that in any case, it was essential to make releases from reservoirs.

6.0 Findings of CWC Study

From analysis of rainfall data of IMD, discharge data of CWC G&D sites and inflow/outflow data of reservoir received from Government of Kerala, the findings are as under:

i. Kerala terrain is a linear one with elevation varying from about -2 m to 1500 m in a stretch of about 80 to 100 km across the State. The Western Ghats terrain has steep slopes, while the rest of terrain is rolling/plains. The time of concentration (the time required to travel the water from farthest point of project catchment to the project catchment outlet) of most of the reservoirs in the region is about 2 to 3 hours only.

ii. During the August 2018 flood 13 out of 14 districts of the State were severely affected from flood due to heavy rainfall. As per IMD, Kerala received about 2346.6 mm of rainfall during 1 June 2018 to 19 August 2018 against the normal rainfall of 1649.5 mm, which was 42% above the normal. During 1 August 2018 to 19 August 2018 total rainfall occurred in Kerala was about 758.6 mm against the normal of 287.6 mm, which was 164% above normal.

iii. A one day rainfall of 398 mm, 305 mm, 255 mm, 254 mm, 211 mm and 214mm respectively was recorded at Nilambur in Mallapuram district, Mananthavady in Wayanad district, Peermade, Munnar and Myladumpara in Idukki district and at Pallakad district respectively on 9 August 2018. The severe rainfall in Wayanad district resulted in heavy flooding at Mananthavadi and Vythiri during 8-10, August 2018.

iv. As per analysis carried out by CWC, the rainfall of 15-17, August 2018 having eye of storm near Peermade between Pamba and Periyar sub-basins, was almost of the same order as that of rainfall of Devikulam, Kerala which occurred during 16-18, July

1924. As per the historical records severe most flooding had occurred in Kerala during the year 1924. The average cumulative rainfall of 15-17, August 2018 is about 414 mm for entire Kerala. The consequent cumulative runoff of three days for the entire Kerala (area about 38,800 sq.km) is about 12 BCM (12,000 MCM) for a runoff coefficient of 0.75.

v. Further, total catchment area tapped by dams in Kerala excluding barrages is about 6610 sq.km. Taking a runoff coefficient of 0.8 the runoff generated from the catchment tapped by the dams during the 3 days rainfall of 15-17, August 2018 has been estimated about 2.19 BCM, out of total runoff of 12 BCM for entire Kerala. The total live storage of Kerala is about 5.8 BCM. Even with 20% of the live storage availability on 14 August 2018, the available flood moderation extent would have been only 1.16 BCM against the estimated inflow of 2.19 BCM. It shows that in any case, it was essential to make releases from reservoirs.

vi. Out of 758.6 mm rainfall from 1 August 2018 to 19 August 2018, about 414 mm rainfall occurred in just three days viz 15-17, August 2018, which created severe flooding in the State. Due to severe rainfall from 15-17, August 2018, the gates of about 35 dams were also opened due to extremely large inflow of water in the reservoirs. During August 2018, the reservoirs were either at FRL or only few feet below the FRL.

vii. During 15-17, August 2018, the 3-day rainfall depths realised in Periyar, Pamba, Chalakudi and Bharathapuzha sub-basins were 588 mm, 538 mm, 421 mm and 373 mm respectively and these depths are of the same order as that of 1924 rainfall.

viii. As per CWC's Neeleswaram G&D site (Periyar sub-basin) records, the maximum discharge passed in Periyar river was 8800 cumec on 16 August 2018 at 15:00 hrs and maximum water level attained was at EL 12.4 m. The earlier HFL was recorded on 27 July 1974 at EL 11.105 m. The major storages in Periyar basin are Idukki (live storage 1.4 BCM) and Idamalayar (LS 1.1 BCM). The peak release on 16 August 2018 from Idukki was 1500 cumec against a peak inflow of 2532 cumec achieving a flood moderation of 1032 cumec. The release from Idamalayar on 16 August 2018 was 963 cumec against an inflow of 1164 cumec. The discharge in Periyar river at Neeleswaram G&D site on 17 August 2018 was recorded as 8600 cumec and release

from Idukki and Idamalayar were 1500 cumec (inflow 1610 cumec) and 1272 cumec (inflow 1007 cumec). On analysis of data it has been found that the releases from these dams were the controlled releases, as the discharging capacity of these dams are 5013 cumec (Idukki) and 3012 cumec (Idamalyar).

ix. The maximum discharge in Pamba river at CWC, G&D site (Malakkara) was 2900 cumec on 16 August 2018 with corresponding water level at EL 9.58 m. The earlier recorded HFL was 8.2 m. The major reservoir in Pamba sub-basin is Kakki and release from this reservoir was 488 cumec (15th of August), 899 cumec (16th of August), 443 cumec (17th of August), 356 cumec (18th of August), 309 cumec (19th of August) against the spillway capacity of 1788 cumec. The reservoir was at EL 980.91 m on 14 August 2018, against the FRL at EL 981.46 m. The maximum reservoir level attained on 19 August 2018 was 981.4 m.

x. From the analysis it has been found that the dams in Kerala neither added to the flood nor helped in reduction of flood, as most of the dams were already at FRL or very close to FRL on 14 August 2018, due to more than normal rainfall in the months of June to July 2018. It may be noted that, had the reservoir been a few feet below FRL, the flooding conditions would have not changed much, as the severe storm continued for 3 days and even for 4 days at majority of the places, and in any case it would have been necessary to release from the reservoirs after 1st day of the extreme rainfall.

xi. Nevertheless, it is essential to review the rule curves of all the reservoirs in Kerala. The rule curves need to be meticulously drawn particularly for the reservoirs having the live storage capacity, of more than 200 MCM in order to create some dynamic flood cushion for moderating the floods of lower return periods particularly in the early period of monsoon.

xii. The runoff generated from Pamba, Manimala Achenkovil and Meenachil rivers during 15-17, August 2018 rainfall was about 1.63 BCM against the 0.6 BCM carrying capacity of Vembanad lake. Further, the discharging capacity of 630 cumec of Thottappally spillway was the other major constraint for the disposal of runoff. Considering the lake carrying capacity of about 600 MCM and discharging capacity of 630 cumec of Thottappally spillway and about 1706 cumec present discharging capacity of Thaneermukkom barrage, it can be concluded that out of 1.63 BCM the

runoff generated during the 15-17, August 2018 rainfall, only about 0.605 BCM runoff was possible to drain out of the Vembanad lake. The remaining runoff volume of about 1 BCM created the rise of the water level in the lake and nearby areas. This continuous rising of lake water may be one of the reason of overall change in the river hydrodynamics of Pamba, Manimala, Meenachil and Achenkovil river systems resulting higher water level for a particular discharge in these rivers. Considering the high rainfall during 15-17, August 2018, the absence of appreciable storage reservoirs in the upstream in the above rivers along with the shrinkage of carrying capacity of Vembanad Lake and reduction of the capacity of Thottappally spillway worsened the flooding in the Kuttanad region and the backwaters flows to the low lying areas in the upper reaches of the lake.

xiii. The worst affected districts noticed were Wayanad (Kabini sub-basin), Idukki (Periyar sub-basin), Ernakulam (Periyar and Chalakudi) sub-basins, Alleppey and Pathanamthitta (both in Pamba sub-basin).

xiv. In a nutshell, it can be concluded that August 2018 flood in Kerala was due to severe storm occurrences during 8-9, August 2018 and 15-17, August 2018. The storm of 15-17, August 2018 resulted in heavy flooding in Periyar, Pamba, Chalakudi and Bharatpuzha sub-basins of Kerala. The rainfall during 15-17, August 2018 was almost comparable to the historical 16-18, July 1924 rainfall of Kerala, particularly in Periyar, Pamba, Chalakudi and Bharatpuzha sub-basins.

xv. The release from reservoirs had only minor role in flood augmentation as released volume from the reservoirs were almost similar to inflow volumes. In fact Idukki reservoir absorbed a flood volume of about 60 MCM during 15-17, August 2018. Even, with the 75 percent-filled reservoir conditions, the current flood could have not been mitigated as 1-day rainfall in majority of the area was more than 200 mm and severe rainfall continued for 3 to 4 days.

7.0 Recommendations

i. It is essential to review the rule curves of all the reservoirs in Kerala. The rule curves need to be formulated for both conservation as well operations during the flood,

particularly for the reservoirs having the live storage capacity of more than 200 MCM in order to create some dynamic flood cushion for moderating the floods of lower return periods particularly in the early period of monsoon.

ii. For efficient discharge of flood runoff from Vembanad lake, the approach channels to Thottappally spillway and the passage of the Thaneermukkom barrage should be widened taking into consideration the lake hydrology, ecology, saline water intrusion, etc based on scientific and engineering inputs.

iii. In basins like Periyar, Pamba and Achenkovil basins, Kerala should explore the possibilities of creating suitable storage reservoirs, wherever feasible, for flood moderation and other multipurpose uses.

iv. The Poringalkuthu dam should be inspected by DSRP panel and design flood, spillway capacity of Poringalkuthu dam must be reviewed.

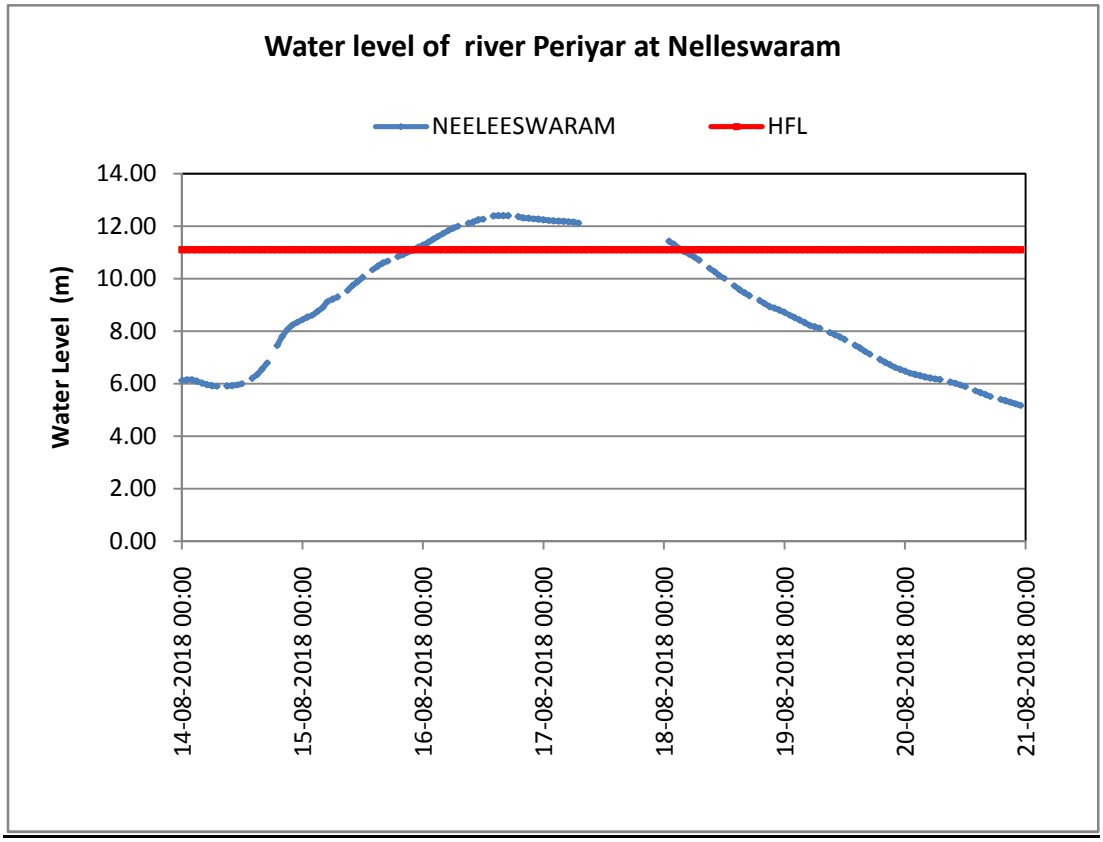
8.0 Limitations

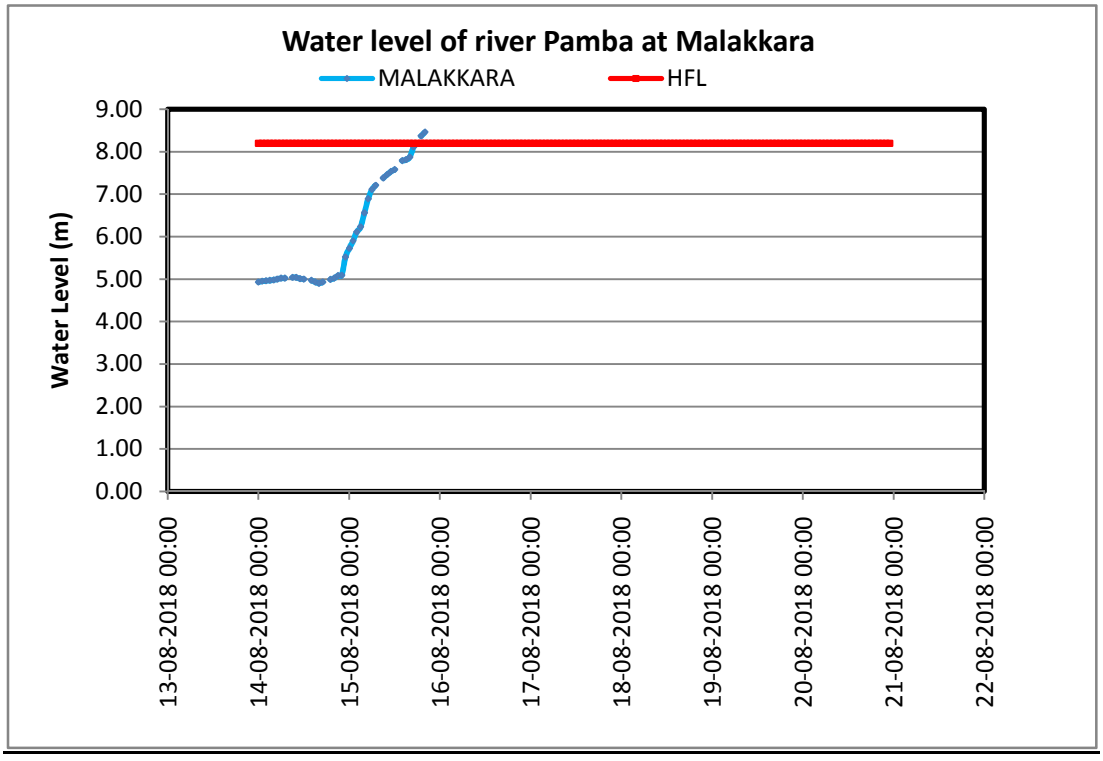
i. The rainfall analysis carried out in the present study is based on the rainfall records of 67 rain gauge stations of IMD spread across the entire State covering both plain and hilly regions. In hilly terrains of Chalakudy, Periyar, Pamba, Kabini and other sub-basins, rainfall records of some more rain gauge stations may provide a further finer estimate of rainfall and also the inflow volume into the reservoirs.

ii. The gauge records at some of the CWC G&D sites could not be observed on 16th and 17th of August 2018 because of inaccessibility of site due to severe flooding. Hence, the estimated discharge may differ from the one that actually occurred.

iii. Some of the observations regarding the discharging capacity of Thottappally and Thanneermukkom barrages, carrying capacity of Vembanad lake etc are based on the reports of the other institutions.

Annex-I


Water level of river Periyar at Nelleswaram
NEELEESWARAM
HFL
Water Level (m)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
18-08-2018 00:00
19-08-2018 00:00
20-08-2018 00:00
21-08-2018 00:00


Water level of river Pamba at Malakkara
MALAKKARA
HFL
Water Level (m)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
13-08-2018 00:00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
18-08-2018 00:00
19-08-2018 00:00
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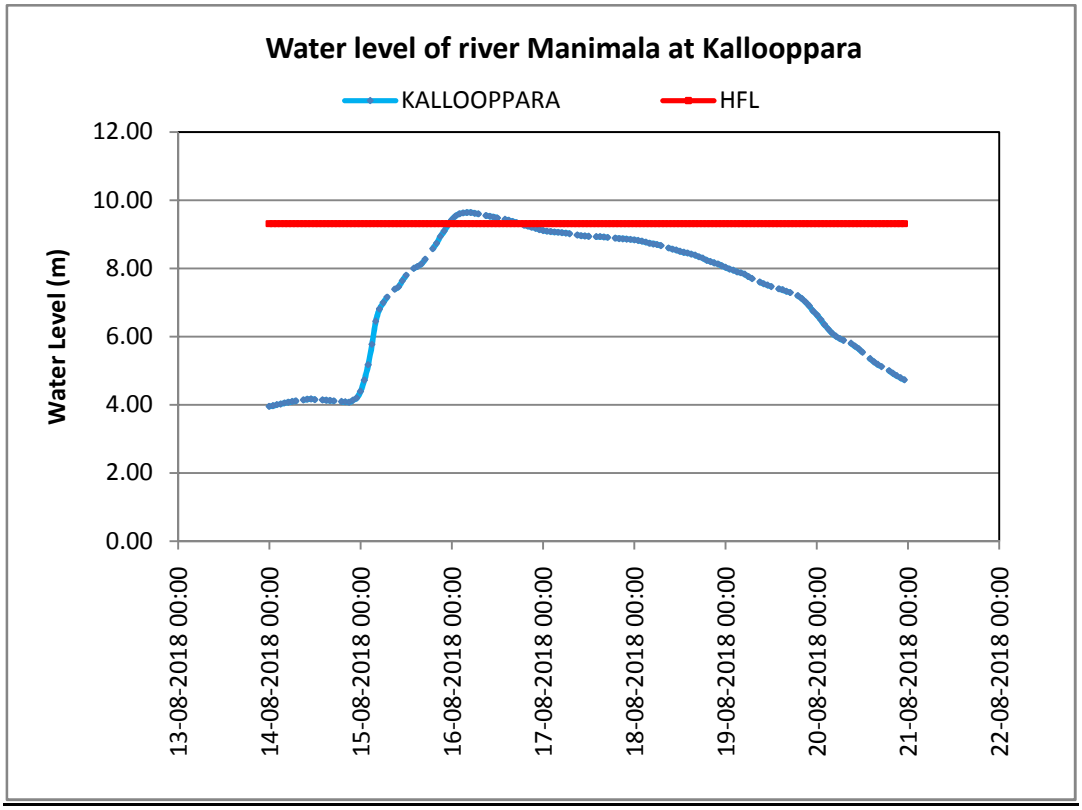
21-08-2018 00:00
22-08-2018 00:00


Water level of river Manimala at Kallooppara
KALLOOPPARA
HFL
Water Level (m)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
13-08-2018 00:00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
18-08-2018 00:00
19-08-2018 00:00
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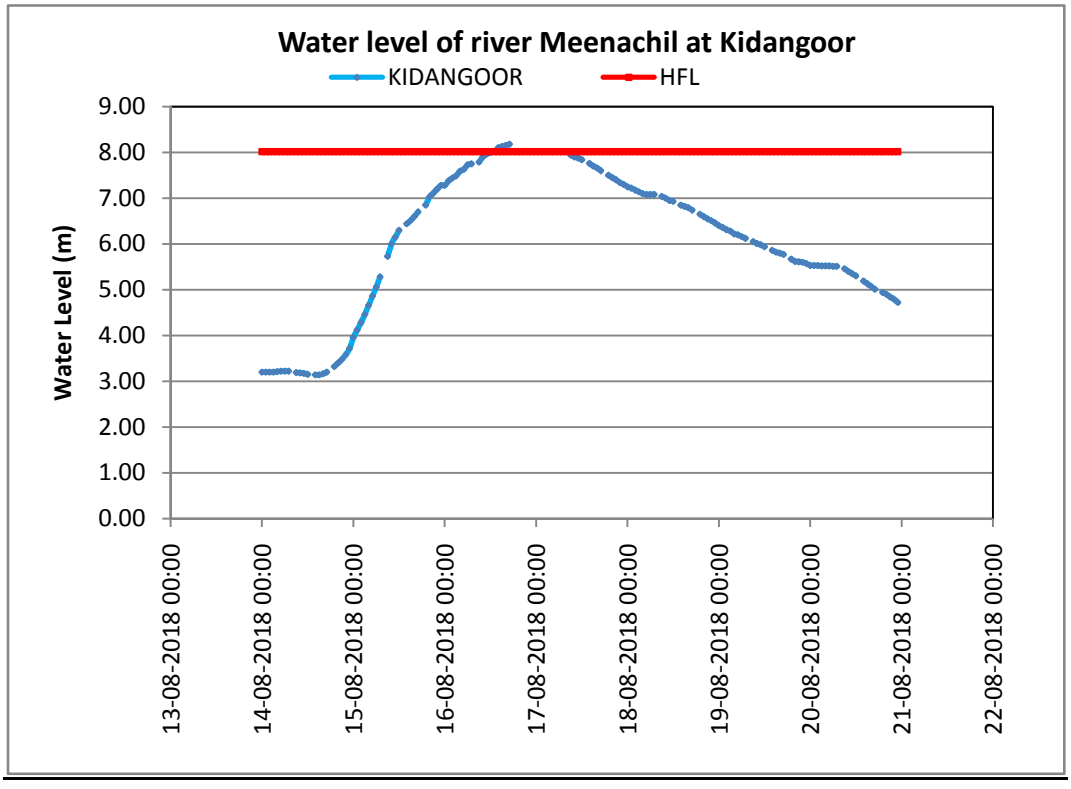
21-08-2018 00:00
22-08-2018 00:00


Water level of river Meenachil at Kidangoor
KIDANGOOR
HFL
Water Level (m)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
13-08-2018 00:00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
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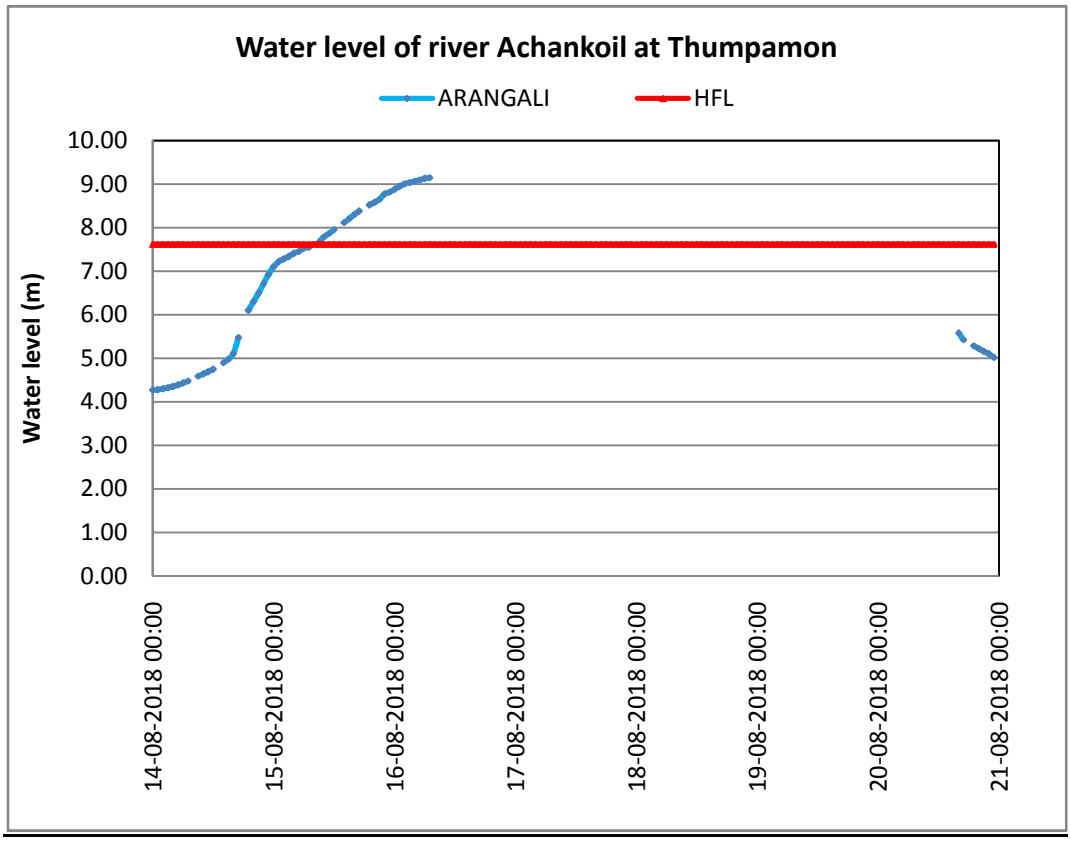
22-08-2018 00:00


Water level of river Achankoil at Thumpamon
ARANGALI
HFL
Water level (m)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
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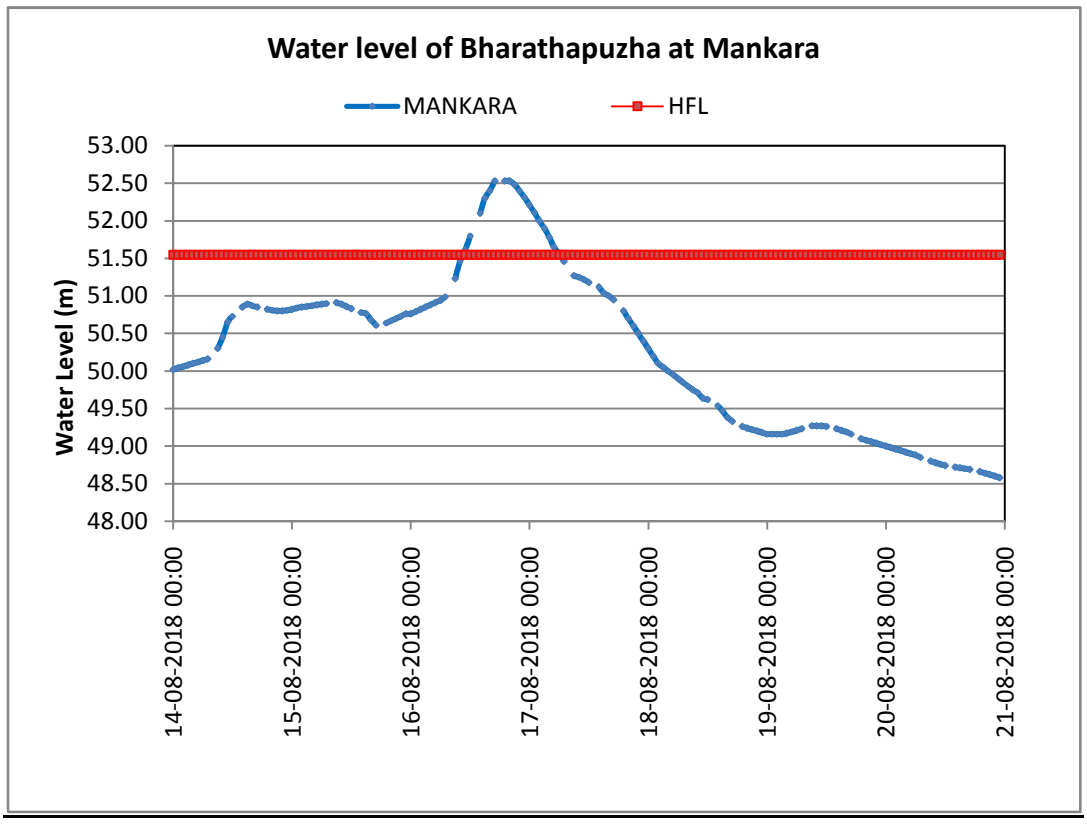
21-08-2018 00:00


Water level of Bharathapuzha at Mankara
MANKARA
HFL
Water Level (m)
53.00
52.50
52.00
51.50
51.00
50.50
50.00
49.50
49.00
48.50
48.00
14-08-2018 00:00
15-08-2018 00:00
16-08-2018 00:00
17-08-2018 00:00
18-08-2018 00:00
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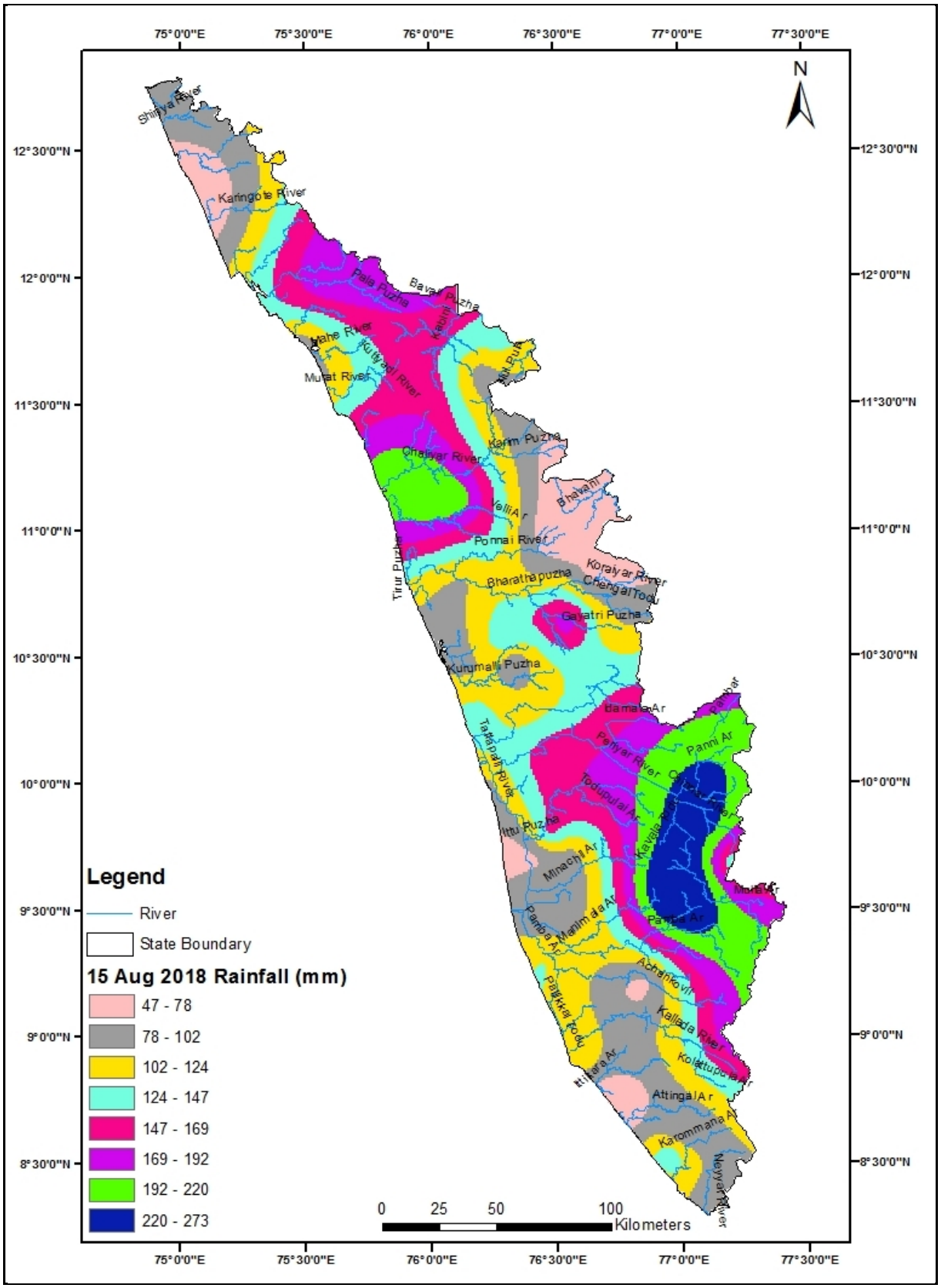
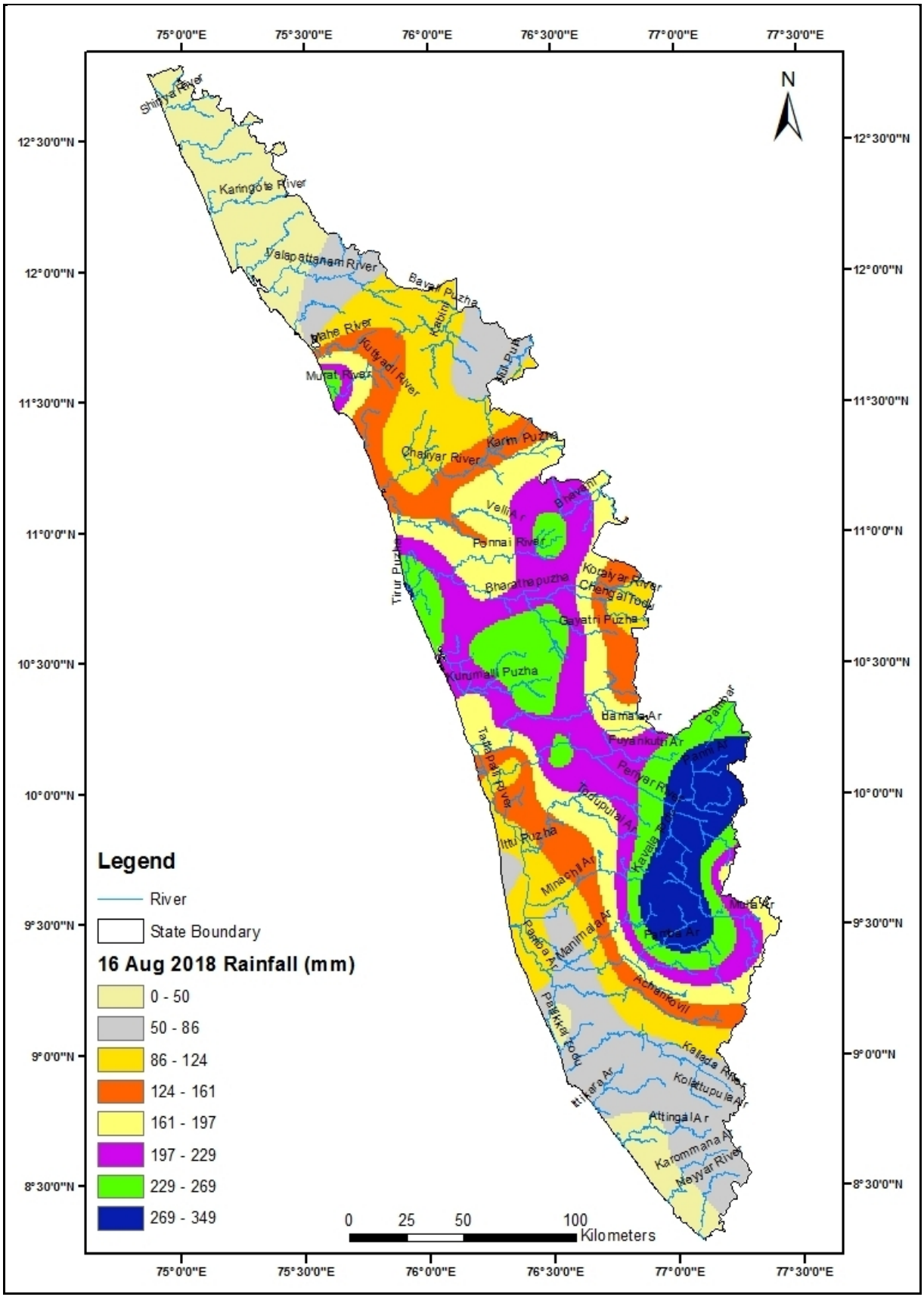
20-08-2018 00:00
21-08-2018 00:00

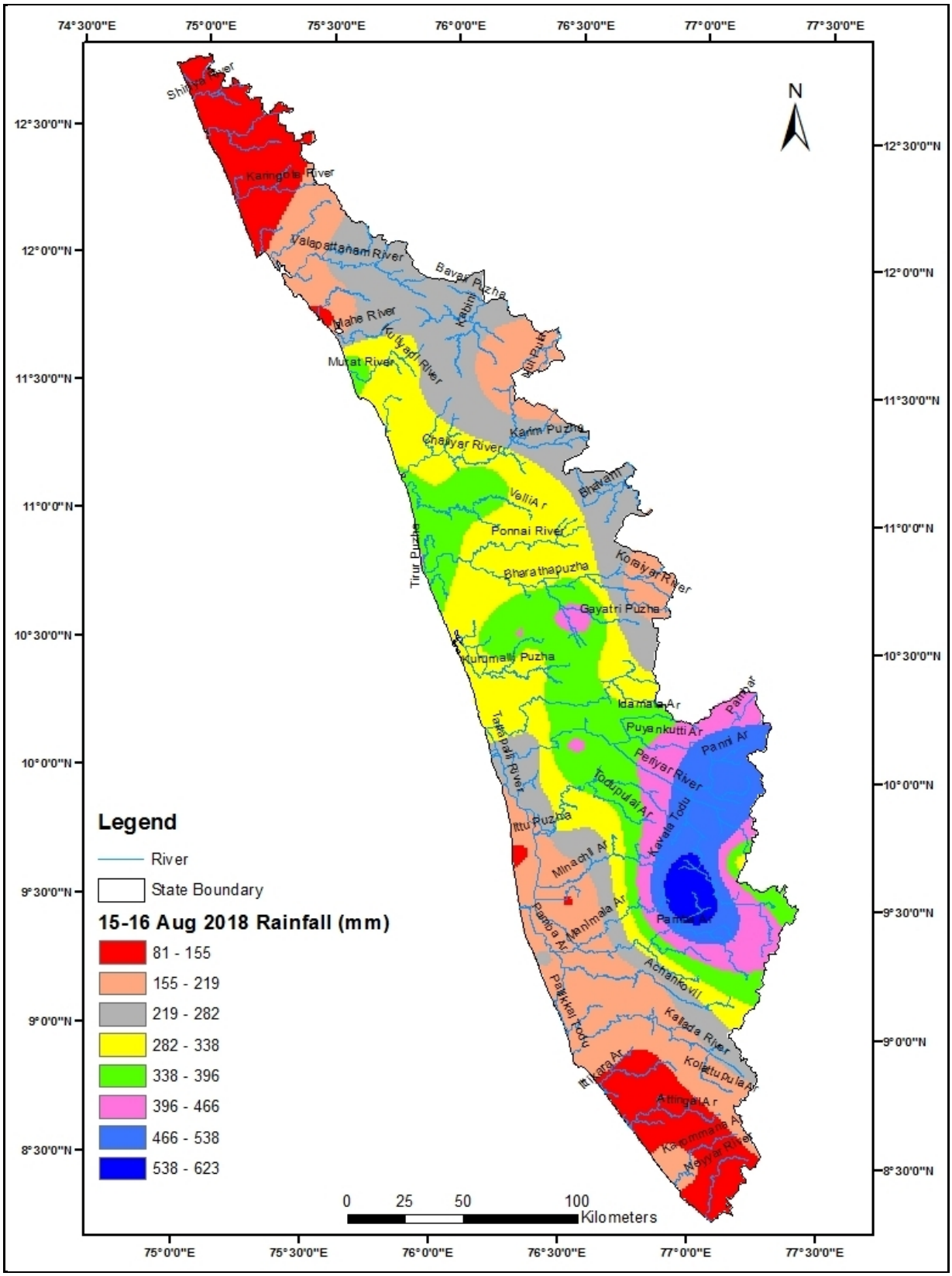
Annex-II



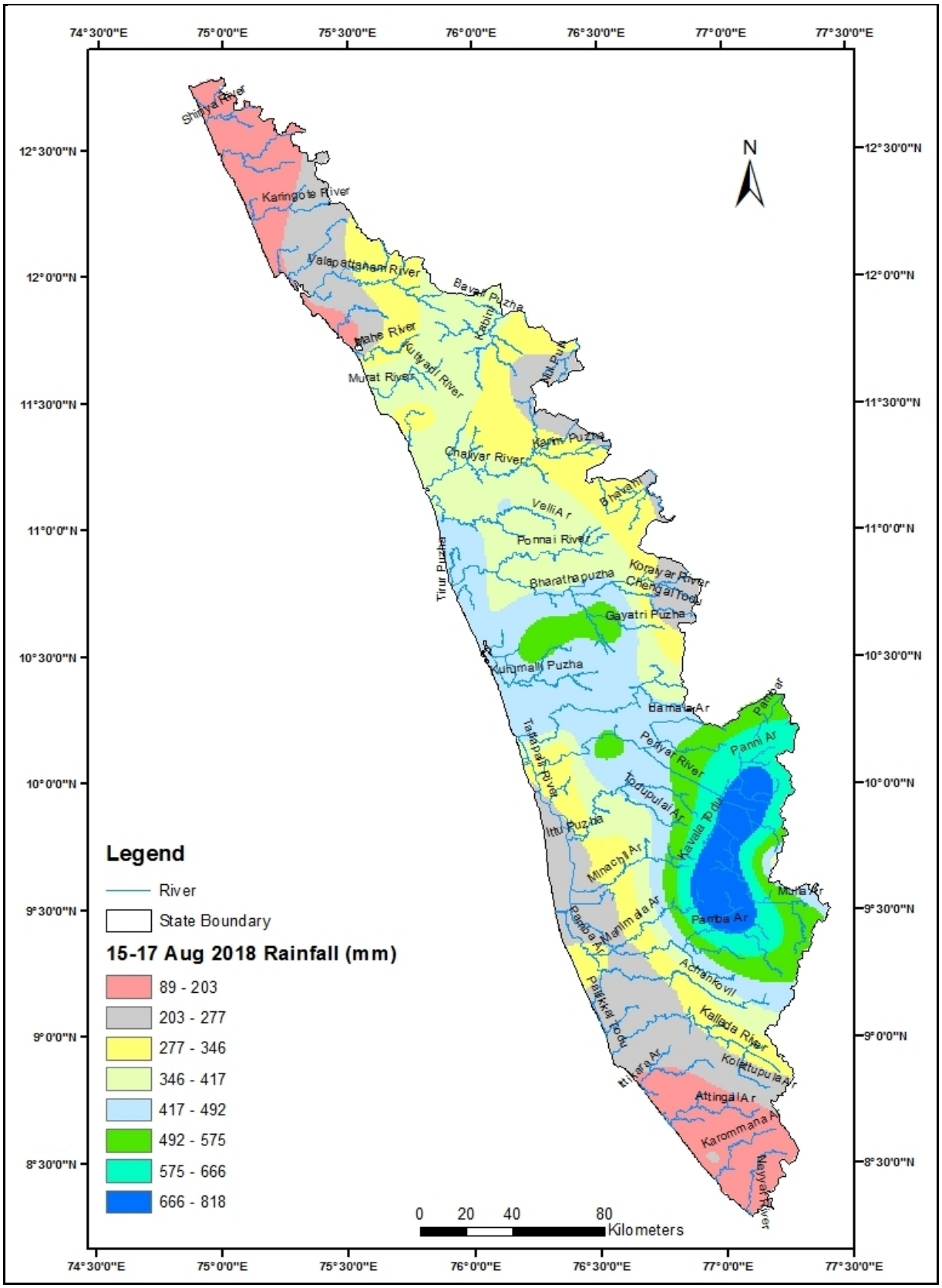
1 day rainfall of 15 August 2018



1 day rainfall of 16 August 2018

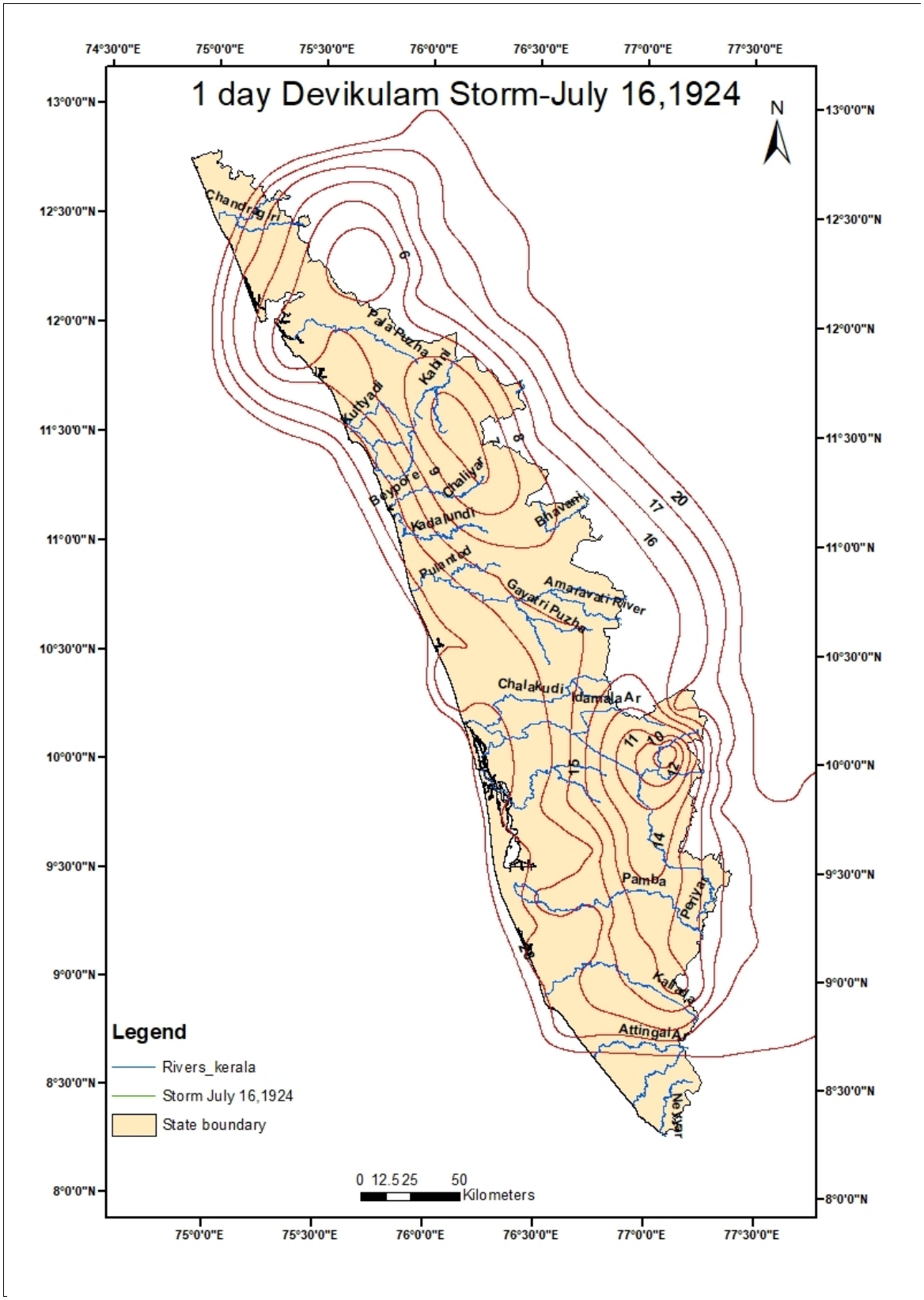


2 days cumulative rainfall of 15-16, August 2018

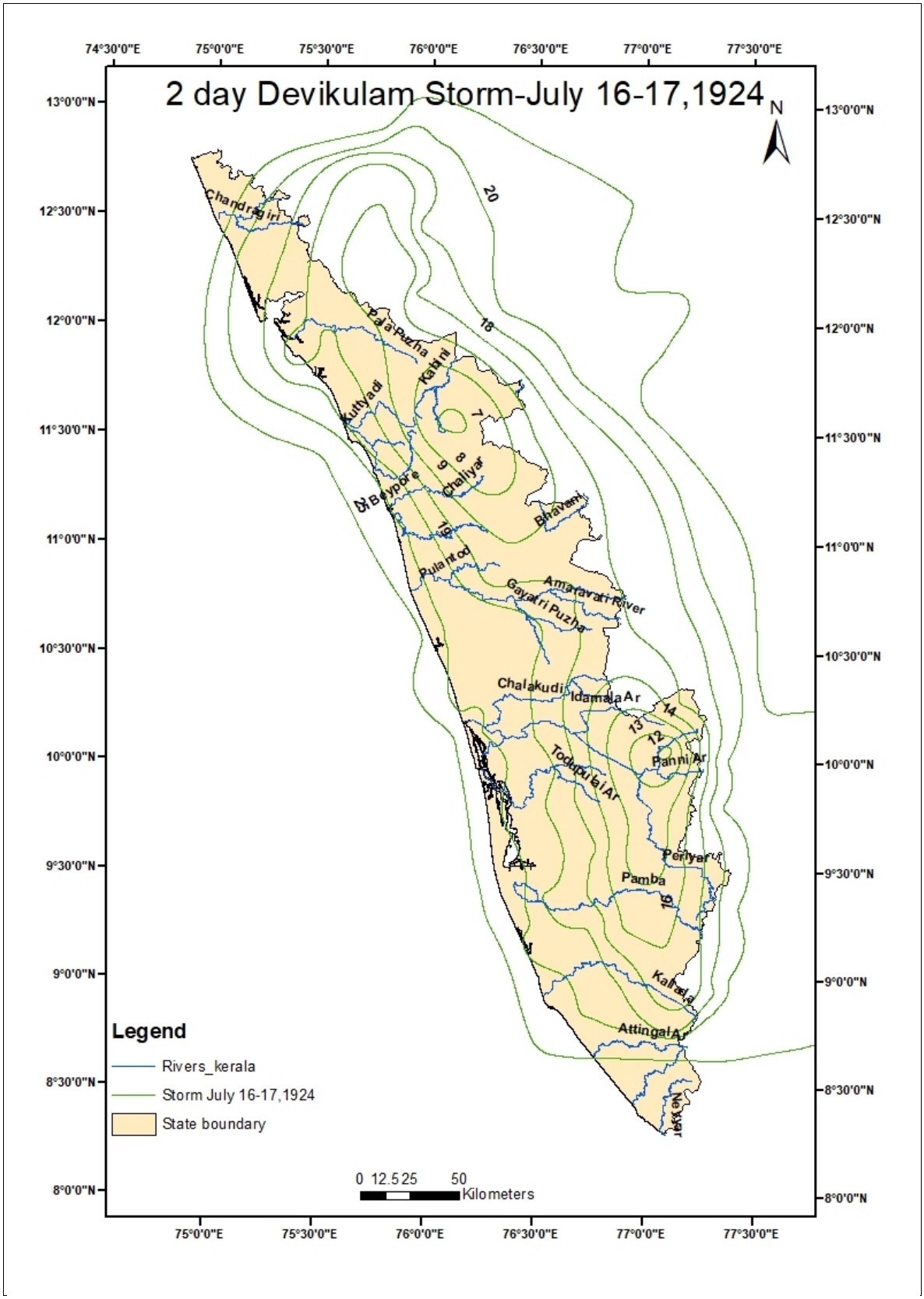


3 days cumulative rainfall of 15-17, August 2018

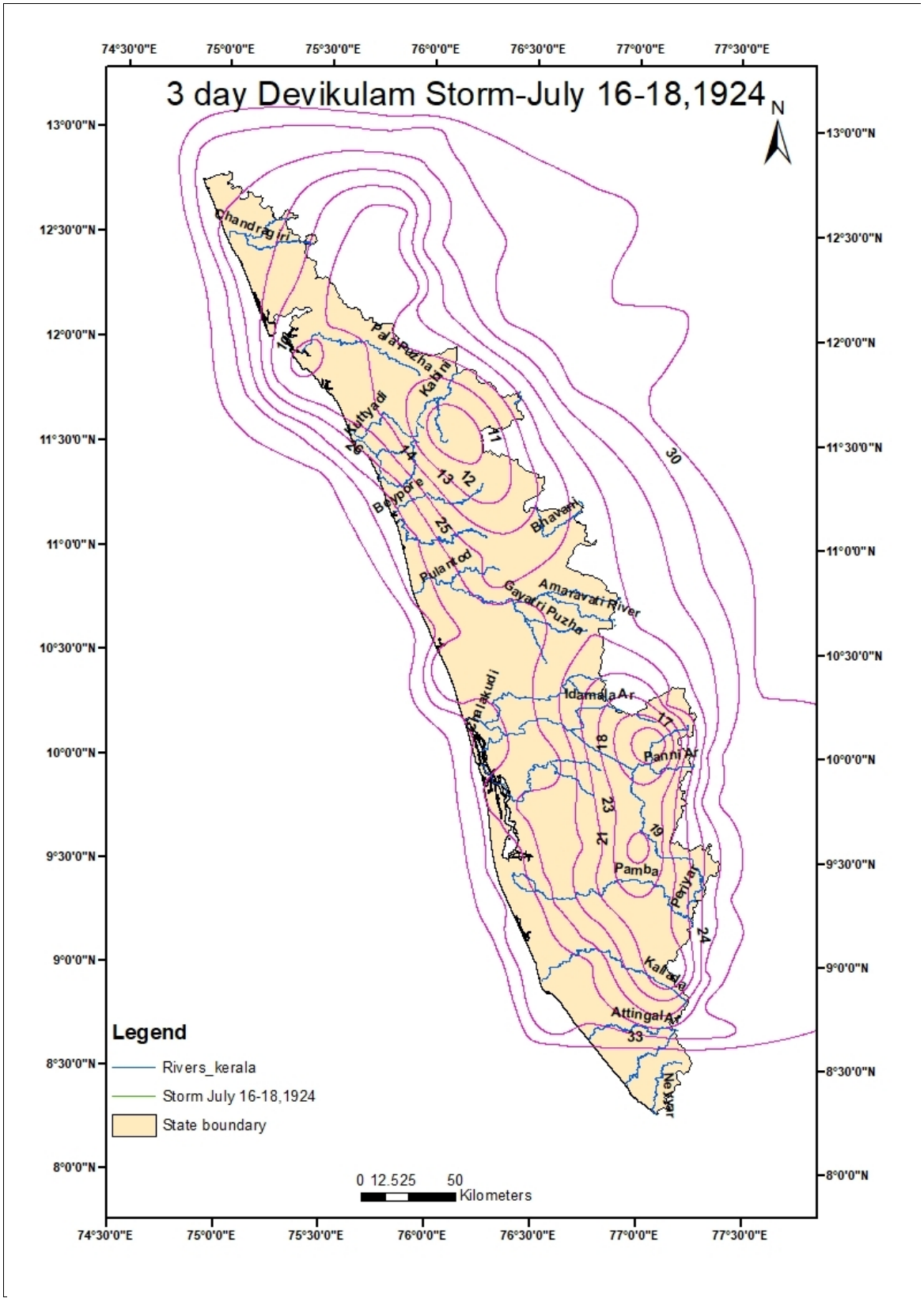
Annex-III



Note: Storm isohyets are in cm



Note: Storm isohyets are in cm



Note: Storm isohyets are in cm