Supplementary Material 1: Recent floods across Kerala

Kerala is the south-western State of India extending between 8° 18' - 12° 48' N latitude and 74° 52' - 77° 22' E longitude. The Arabian Sea borders the state in the west and the Western Ghats in the east. The state experiences mesoscale circulations during pre-monsoon and monsoon seasons, aggravated by local orographic disturbances due to the elevation gradient of the Western Ghats. The state receives an average annual precipitation of about 3,000 mm (CWC-Report, 2018), 70% of which is contributed by the Indian summer monsoon.

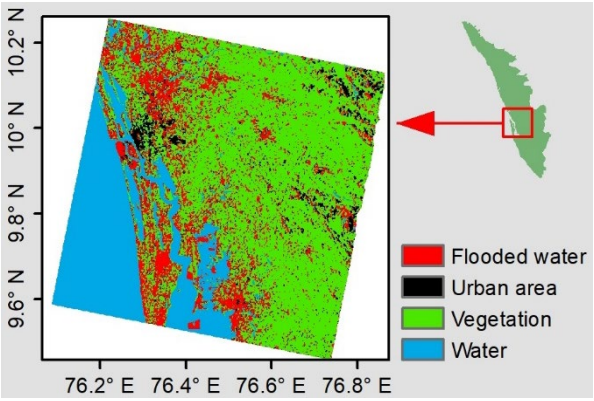

Fig S1: Flood-affected areas during the August 2018 floods over Kerala derived from the SENTINEL 1 SAR images.

The consecutive floods of large return periods over the state during 2018, 2019 and 2020 show an alarming situation of the rising EREs. Contrary to the long-term rainfall trends, Kerala experienced a remarkably higher amount of rainfall during the first half of the Indian summer monsoon season in 2018. During August 2018, the state experienced two severe EREs on record. During the first ERE (8 - 10 August 2018), a few meteorological stations of the state received more than 50% of the normal monthly rainfall in just three days. However, most of the state exceeded the normal monthly rainfall by 50% in the second ERE (15 - 17 August 2018), causing widespread flooding affecting almost 5.4 million people (KSCSTE-Report, 2019). Several districts were inundated for more than two weeks due to the floods. The analysis of SENTINEL-1 Synthetic Aperture Radar (SAR) data collected from NASA's Alaska Satellite Facility Distributed Active Archive Centre gives a visual perspective of the flood over central Kerala (Fig. S1). Comparison of pre- (16 July 2018) and post-flood (21 August 2018) SAR images reveal that roughly 22% (925 km^2) of the analysed area was inundated. About 341 major landslides were reported from ten districts during the EREs of August 2018, where 143 landslides ravaged the Idukki district.

The ERE occurred during August 2019 in Kerala was the result of the formation of a low-pressure system and later a depression over the northwest Bay of Bengal off north Odisha-West Bengal coasts on 6 August 2019. The widespread flooding and landslides across the districts of northern Kerala caused severe damage to both the built and natural ecosystems. The low-lying areas of

the major river systems were inundated, and more than 2 lakh people were displaced. Kerala witnessed 80 landslides in eight districts over the three days (August 8-11, 2019) as the death toll crossed 120. However, the most devastating landslide witnessing the highest ever recorded casualty occurred during the EREs in 2020 in Pettimudy, Idukki. While most of the landslides in the state during recent years were primarily triggered by the EREs, anthropogenic interferences also contributed to the instability of the slopes (KSCSTE-Report, 2019). However, most recent landslide events show no significant changes in land use, suggesting the significant role of the extraordinary rainfall events (Martha et al., 2019)

Supplementary Material 2: Wind Trajectory computations

The wind trajectory vectors were analysed to understand the wind patterns and aerosol transport pathways over Kerala using the PC-Windows-based NOAA HYSPLIT model (Rolph et al., 2017; Stein et al., 2015). Seven days backward trajectories were computed every hour at 850 hPa from a central location (10.5◦N, 76.3◦E) over Kerala. These trajectories were then clustered to an optimal number of clusters based on the total spatial variance explained by the clusters (Fig. S2). The analysis was performed for 2001 and 2018 using the 2.5◦ NCEP reanalysis data.

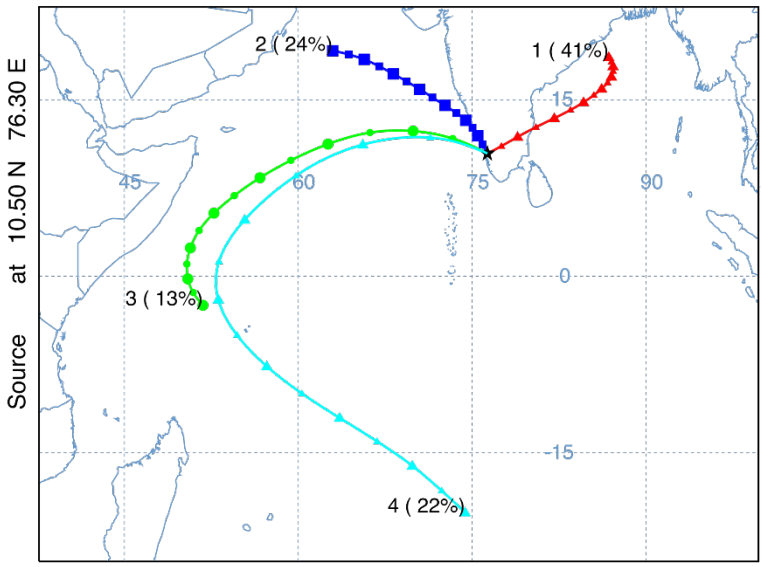

***Fig S2*:** Wind trajectory clusters from a central location (10.5◦N, 76.3◦E) over Kerala during 2001

Supplementary Material 3: Aerosol variation over Kerala

The atmospheric aerosols with hygroscopic properties act as CCN over which water condenses, and hence their variation can impact cloud formation and further precipitation. The time-series of the AOD over Kerala as observed from the MODIS is shown in Fig. S3. The Mann-Kendall trend test indicates a significantly increasing AOD over the region since the beginning of the 21st century, implying the increasing concentration of aerosols. Various researchers reported such observations in Thiruvananthapuram (Kerala) using ground-based measurements (Moorthy and Satheesh, 2000). They observed a peak AOD during the monsoon season and reported its primary contribution from sea-salt aerosols with occasional contributions from transported desert dust. They also noted an increasing trend in AOD due to an increase in urbanisation and other anthropogenic sources.

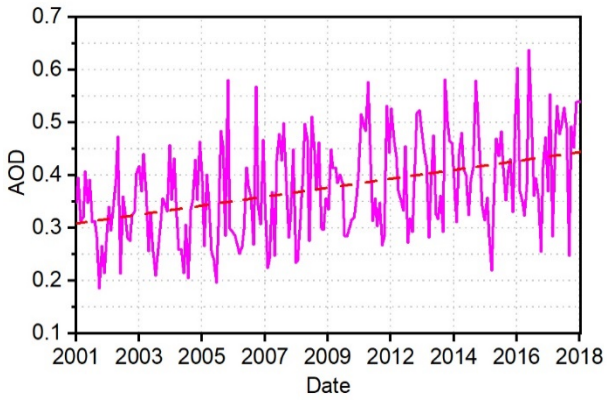

***Fig S3*: Temporal variation of AOD over Kerala from 2001 to 2018.**

References

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