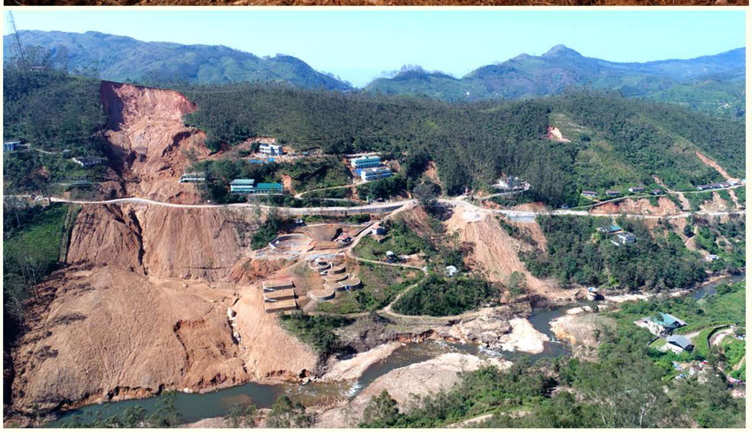
EXECUTIVE SUMMARY OF THE REPORT OF THE

COMMITTEE TO EXAMINE THE CAUSES OF REPEATED EXTREME HEAVY RAINFALL EVENTS, SUBSEQUENT FLOODS AND LANDSLIDES AND TO RECOMMEND APPROPRIATE POLICY RESPONSES

KSCSTE
Kerala State Council for Science Technology and Environment

Submitted to
Kerala State Planning Board



December 2019

EXECUTIVE SUMMARY & RECOMMENDATIONS

OF THE

COMMITTEE TO EXAMINE THE CAUSES OF REPEATED EXTREME HEAVY RAINFALL EVENTS, SUBSEQUENT FLOODS AND LANDSLIDES AND TO RECOMMEND APPROPRIATE POLICY RESPONSES

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Executive Summary

The Kerala State experienced some of the most severe Extreme Rainfall Events (EREs) on record during August 2018 as well as in August 2019. These EREs caused extensive flooding (in most of the river basins) and landslides of high intensity in most districts of the State (specifically along the Western Ghats) resulting in severe damage to both the built and the natural ecosystem. While there were a lot of speculations, theories and scientific perspectives explaining the reasons for occurrence of these phenomena, a concrete and scientific validation was still lacking. These phenomena are a result of various factors ranging from the global climate change to local anthropogenic activities, and required to be investigated comprehensively by a team consisting of interdisciplinary experts. The Committee was entrusted to prepare a quick assessment report, after examining the causes of repeated extreme heavy rainfall events, and subsequent floods/landslides, and suggest recommendations to frame appropriate policy responses. Consequently, the Kerala State Planning Board, Government of Kerala constitute a technical committee. The Committee comprised of an interdisciplinary team of experts from Climate Science, Hydrology, Geology and Civil Engineering disciplines. The Committee was entrusted to prepare a quick assessment report, after examining the causes of repeated extreme heavy rainfall events, and subsequent floods/landslides, and suggest recommendations to frame appropriate policy responses. This document details the summary of the investigations, conclusions and recommendations by the Committee.

The State of Kerala is a narrow strip of land, in the southwestern margin of the Indian Peninsula. It lies between the Western Ghats (WG) in the east and the Arabian Sea in the west. The geographical area of the State is 38,863 square km. The State has a coastal stretch of about 580 km with a width varying from roughly 30 to 120 km. The physiographic profile of the State is classified into three distinct zones: the highlands (elevation > 75 m above mean sea level, and covering the steep and rugged sections of the WG), the lowlands (elevation < 7.5 m above mean sea level, and comprising of the coastal plains), and the midlands (consisting of the undulating hills and valleys) in between.

Kerala frequently experiences flooding and inundation across the low-lying coastal plains, floodplains and broad flat bottom valleys of the river systems and also landslides along with the steeply sloping segments of the Western Ghats. The NCESS has assessed the natural hazard proneness of the State. The assessment indicates that 14.52 per cent of the total geographic area (i.e., 5,643 square km) is prone to flood hazards, with varying proportions as high as 50 per cent for Alappuzha district. A total area of 1848 square km (4.71 per cent geographic area) in the State, extending along the steep slopes of the Western Ghats (i.e., mostly in Wayanad, Kozhikode, Malappuram Idukki, Kottayam and Pathanamthitta districts), is highly prone to the occurrence of landslides. Similar to floods, the occurrence of landslides in the State is mostly triggered by intense rainfall during the extreme rainfall events (EREs).

According to Census 2011, Kerala has a population of 3.3 crores. Kerala is ranked 8th in the population density (859 persons per square km) among the 28 states in India (Census of India, 2011). The distribution of population among the different physiographic units of the State does not show linearity with respect to the areal extent, as the population along the lowlands is much denser compared to the highlands and the midlands.

In August 2018, Kerala experienced two severe EREs, i.e., during August 8th to 9th and August 15th to 17th. According to the India Meteorological Department (IMD), Kerala received a total of 2346.6 mm rainfall from June 1, 2018to August 19, 2018, which is roughly 42 per cent above the normal rainfall. The widespread flooding in August 2018 affected almost 5.4 million people – one-sixth of the State's population. Several districts were inundated for more than two weeks due to the floods. A total of 1,260 out of the 1,664 villages of Kerala were affected. About 341 major landslides were reported from ten districts, where Idukki district was ravaged by 143 landslides, causing a death toll about 104.

Kerala faced yet another ERE between August 7th and 9th, 2019. The State received 'large excess' rainfall to the extent of 123 per cent in August 2019 as compared to 96 per cent excess rainfall received in August 2018. There was 32 per cent deficit rainfall during the months of May, June, and July in 2019. In 2018, there was excess rainfall (8 per cent) during the same period. The antecedent high wetness condition prior to August in 2018 caused a higher level of flooding impact as compared to that in August 2019, which was at a relatively dry antecedent condition. The widespread flooding and landslides across the districts of northern Kerala in 2019 caused severe damage to both the manmade 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 three days (August 8-11, 2019) and the death toll crossed 120.

The repeated EREs, and associated floods and landslides caused damage to infrastructure and resulted in the loss of lives and livelihoods. In the context of recurring EREs and associated damages due to flood and landslides, the Kerala State Planning Board, Government of Kerala constituted a "Committee to examine the causes of repeated extreme heavy rainfall events, subsequent floods, and landslides, and to recommend appropriate policy responses" vide order G.O. (Rt) No. 42/2019/S&TD dated 22-08-2019. The Committee was entrusted to prepare a quick assessment report, after examining the causes of repeated extreme heavy rainfall events, and subsequent floods/landslides, and suggest recommendations to frame appropriate policy responses. The Committee comprised of an interdisciplinary team of experts from Climate Science, Hydrology, Geology and Civil Engineering disciplines.

The Committee addressed the following concerns while preparing the assessment report as per the terms of reference:

1. The reasons for the occurrence of such EREs and their major causative factors;
2. The capability and potential for accurate forecasting of such events with sufficient lead times;
3. Reviewing indicators and methods to locate areas prone to severe landslides during such EREs and remedial measures for minimising such hazards and their consequences;
4. Reviewing current maps of areas prone to flood hazard during such EREs and mitigation measures to minimise such hazards; and
5. To focus on the role of changing land use in these hazards

Methods of Assessment, Review, and Analysis

The Committee conducted field visits in several worst-affected areas (in 2018 and 2019) of floods and landslides in Pathanamthitta, Alappuzha, Kottayam, Malappuram, Kozhikode, Wayanad, Idukki and Kannur districts. The Committee also had several rounds of meetings and discussions with experts, officials, and the local community. The Committee addressed the set objectives on the basis of the survey of previous literature and ancillary information, observations during the field visits, interaction/discussion with scientific experts, administrators at different levels, and community.

The Committee used primary as well as secondary data (either observed or simulated or in combination) for detailed analysis. The daily rainfall data (recorded at meteorological stations and 0.25° x 0.25° gridded data) of the India Meteorological Department (IMD) were used for the analysis of rainfall patterns and spatio-temporal trends across the State. The aerosol particle size distribution data, collected from Munnar Aerosol Observatory (established by IIT Madras) were used for the analysis of the effects of aerosols on EREs. The physical properties of the soil samples from the areas of landslide occurrences (collected by the National Institute of Technology, Kozhikode) were used for the numerical modelling of the landslides. Numerical analysis was performed to evaluate the factor of safety of slopes using Finite Element based Computer Program PLAXIS 2D (PLane strain and AXIal Symmetry). The gauge-discharge data, collected from the Water Resources Department, Government of Kerala, Kerala State Electricity Board (KSEB) Ltd., and Central Water Commission (CWC) through WRIS-India data repository were used for the hydrological analysis. The HEC-HMS, a watershed hydrological model was used to simulate the peak discharge for the actual condition as well as for different scenarios, and the HEC-RAS (2D), a hydrodynamic model was used for the development of flood inundation maps corresponding to different scenarios.

The Committee after detailed deliberations, analysis, and assessment arrived at the following conclusions and recommendations. It is envisaged that the recommendations of the Committee may help the Government to formulate appropriate policies for mitigating the negative impact of such devastating natural hazards in the future.

Conclusions

- The predominant reason for the occurrence of EREs in Kerala in the last two years (2018 and 2019) was the development of deep depression over the northwest Bay of Bengal and neighbourhood, coupled with the influence of the local orographic gradient on the atmospheric circulation, variability in monsoon circulation caused by the transient synoptic-scale and intra-seasonal propagating oscillations. It is to be noted that no noticeable teleconnections of EREs with El Nino Southern Oscillations (ENSO) and Indian Ocean Dipole (IOD) are observed.
- An analysis of the observed southwest monsoon rainfall during 1901-2018 in Kerala, in general, exhibited a decreasing trend over the northern half and along the coastal areas of the State. This observation was significant (at 95 per cent level) in isolated locations in northern parts of the State. The rainfall over the southern region of the State also showed a decreasing (but non-significant) trend. However, the data pertaining to the recent years (1971-2018), showed an increasing trend over most parts of the southern half and some interior areas of central parts of the State with isolated areas showing significant trends. A significant decreasing trend was observed over the northernmost areas of the State.
- There are a large number of predictive models being employed by various agencies across the globe for prediction of EREs, and many of them are being used by the IMD in the Indian context. However, they fail to capture the real mechanism of cloud formation and its impacts on rainfall distribution and pattern during the onset and occurrence of EREs.
- The triggering factor for the occurrence of landslides across Kerala during the EREs in August 2018 and 2019 was the oversaturation of the overburden. Idukki experienced the maximum number of landslides (977 including minor slides) in 2018, whereas Palakkad had the highest count in 2019 (18), followed by Malappuram (11), Wayanad (10) and Kozhikode (8). Generally, steep sloppy areas having slope more than 33 per cent are more vulnerable to landslide, and the majority of the landslides in the State during the last two years occurred in these terrains. The Committee noted that

anthropogenic activities intended for agricultural expansion and water conservation such as terracing, blocking/diversion of stormwater channels and alteration of natural vegetation pattern have amplified the landslide susceptibility of these regions, especially at Kavalappara, Pathar and Puthumala. In addition, soil piping has acted as the triggering factor at a few locations, especially in Northern Kerala.

- The NCESS has prepared a landslide zonation map for Kerala in 2009 on a 1:50,000 scale. The landslides that occurred in the last two years have largely (~80 per cent) fallen in the high hazard zones delineated by the NCESS. There were a few slides in low hazard zones, while some of the high hazard zones were not at all affected during the EREs. This necessitates the inclusion of additional causative factors and refinement of the hazard zonation mapping. It should be performed on a fine resolution (preferably at the cadastral scale). This activity should be followed by the development of landslide risk maps at the cadastral level, which can be used for long term land use planning. The monitoring of ground movement may also be considered as part of long-term research activity.
- The EREs during the last two years were associated with the genesis of deep depression over the northwest Bay of Bengal and nearby areas. An early onset of monsoon along with a large amount of rainfall in June and July 2018 resulted in saturation of the topsoil in most areas. Most of the reservoirs in Kerala had to be filled near the Full Reservoir Level (FRL). The two EREs, subsequently in August 2018 (during August 8th to 10th, and August 14th to 19th), resulted in severe flooding in Kerala. A similar situation, except on the antecedent wetness condition (including reservoir storage), occurred again in August 2019 (during August 8th to 11th) and caused severe flooding in the northern districts of Kerala (north of Ernakulam).
- The floods experienced in the last two years have a large return period (more than 100 years), and the preparedness for such events was less due to their very low probability of occurrence.
- The Committee analysed flood inundation for various scenarios of different reservoir levels and 24-hour 100-year rainfall for the Periyar river basin and developed possible flood inundation maps. Such studies are essential for demarking the flood-prone areas under different conditions and have to be done over all the river basins in the State.
- The existing reservoirs in the State are conservation-oriented and are being operated as per the conditions specified in IS 7323:1994. Accordingly, the policy adopted being "no spilling of water over the spillways will normally be permitted in conservation point of view until the Full Reservoir Level (FRL) is reached. Flood cushion in the reservoirs is limited between the flood control zone, i.e., between FRL and Maximum Water Level (MWL). When any flood occurs, the policy to release the flood water is adhering to the principle that the releases shall not exceed the inflow into the reservoir". Moreover, the

reservoirs harvest water as much as possible to the full capacity during the rainy season. None of them had an operating policy that considered flood control until 2018. After 2018, some of the dams have considered flood control in their revised operation policy. This should be extended to all the reservoirs in the State. Further, the authorities concerned shall explore the possibility of providing some dynamic flood cushion in the conservation zone below FRL for all the reservoirs.

- The Committee recognised the need to define ERE. It was observed that the rainfall value corresponding to the 99th percentile for Kerala is around 120 mm (12 cm). Hence, 24-hr accumulated gridded rainfall ≥120 mm (rainfall of intensity equal to or more than the very heavy rainfall category) can be considered as an ERE.
- There are several natural and anthropogenic drivers of floods in Kerala, among which the prominent are: (1) high-intensity rainfall for prolonged duration, (2) human interventions in the catchment areas, and particularly in the floodplains and riparian zones, (3) unauthorised encroachments leading reduced extent of natural areas and their impaired functionality (4) reclamation of wetlands and lakes that acted as natural safeguards against floods due to urbanisation and development of infrastructure, (5) unexpected EREs and lack of exposure in handling such EREs through reservoir operation and (6) decreased channel capacity due to sedimentation and aquatic vegetation.

Recommendations to mitigate the negative impacts due to:

a) Extreme Rainfall Events

- The current rain gauge network in the State is not sufficient enough to capture the high spatial variability of rainfall because of the orographic barrier, and also in the context of the limited predictive capability of the rainfall forecast models. Therefore, the network density needs to be enhanced to the theoretical level of 1 rain gauge in every 50 square km (approximately 800 numbers). However, considering the varying spatial variability across the different physiographic regions of the State, it is suggested to install a dense network of Automatic Rain Gauges (ARG/AWS; ~ 500 numbers). Priority may be given to regions receiving high-intensity rainfall in short time periods including slopes that have the potential for flash floods. The distribution of the proposed rain gauges can be 50 per cent in the high lands, 35 per cent in the midlands, and the remaining 15 per cent in the low lands and coastal regions.
- It is suggested that a major share (~50 per cent) of the new installations should be Automatic Weather Stations (which can also monitor meteorological parameters such as temperature, pressure, wind direction, wind speed, and sunshine hours)

and all of them be connected to a central location through telemetry. These observations would in the long run help to improve the predictive capabilities of the forecast models on a regional scale.

- The land acquisition for installation of new rain gauges, if required, be done in consultation with IMD and other departments in the State, and be completed at the earliest.
- Identify the rain gauges operated by other agencies in the State and link them to the centralised facility being proposed.
- Facilitate the development of the Regional ERE and Flood forecast system combined with Artificial Intelligence (AI) to predict flash floods and to trigger an advance warning through research studies or start-ups.
- The experts observed that there is a temporal change in the size distribution and circulation pattern of the dust aerosols in the State that have an impact on the changing rainfall patterns. However, this needs further research as it is an emerging area of research worldwide. The significance of forest fires across the WG on the aerosol concentration may also be considered.

b) Landslides

While the devastating landslides in the State during the last two years were primarily initiated by the EREs, the major reason for most of them was the instability of the slopes caused due to various anthropogenic activities. Therefore, preventive measures should certainly include slope stabilisation. The following are some of the possible remedial measures:

- Provide a vegetation cover to the degraded slope by either promoting natural vegetation growth or by planting suitable species that help slope stabilisation (example vetiver). The use of vetiver as a binder in laterite cutting is to be evaluated.
- In areas where clear-felling of trees was done, the deep tap roots should be removed and refilled with the earth. This is to avoid over saturation and decay of the taproot system which will lead to soil piping and landslides.
- In areas where plantation crops are planned, the selection of crops, as well as the soil pits for planting them, needs to be carefully chosen according to the package of practice. Unscientific use of machinery for pit formation may lead to increased disturbance of the overburden and cause additional water-holding, resulting in oversaturation.
- The following activities should be avoided so as to prevent the possibility of landslides:

- Cutting and levelling for construction of houses on the toe region of slopes having more than 25 per cent inclination and a slope length exceeding 100 m.
- Diversion or blocking of stream channels (up to third order) in the upper slopes especially above the settlement.
- Ponding of water in the sloping sections over a 25 per cent slope.
- Soil conservation practices through contour bunding, or terracing in slopes of more than 25 per cent.
- Seasonal cultivation with tilling or pitting activity in the high sloping areas.
- Any activity in those sections where either ground cracks or piping has been initiated.
- Encroachment of stream banks in the highland region for cultivation or settlement.
- Alignment of open irrigation channels on hill flanks with more than 25 per cent slope.
- Construction of roads without adequate engineering design in the unstable slopes especially in those segments having higher soil thickness. The hollow portions are to be treated carefully.
- Construction of dwelling units in the hollow portions which have been filled up with debris.
- Construction of dwelling units on the immediate lower part of a sloping segment that is critically disposed of.

- The following activities can be promoted so as to prevent landslide occurrence:
    - Drainage of excess rainwater from steeper sections of slope through lined predefined channels.
    - Afforestation/ tree crops with no tilling activity in such areas with more than 33 per cent slope.
    - Maintenance of tree belts at suitable intervals in those slopes subjected to seasonal cultivation.
    - Delineate stable and unstable areas in the uppermost catchments of drainage basins.
    - Preservation of existing patches of natural forest cover.
    - Permanent grass cover in extremely sloping sections (> 50 per cent slope).
    - Land zonation at the micro watershed level involving the local community
    - Create awareness among the local population regarding landslides.
- All drainage lines (of all orders) are to be maintained properly, especially during rains. The first and lower order streams get obliterated by agricultural practices such as contour bunding and terracing. These are the areas liable for failures during high rainfall times. The configuration of the basement rock will allow

subsurface water to exhort high pore pressure in these areas, which are known as topographical hollows (places where lower-order streams are located). Therefore, before monsoon, all stream / nallas in the slopes need to be cleaned and opened up for the free flow of stormwater.

- Since the topographic hollows are the areas where the failure takes place, location of the hollows needs to be identified, and new houses/buildings to be allowed at least 50 m from either side of the stream channel / hollow area.
- The Government of Kerala should constitute a Committee to conduct in-depth studies and develop guidelines for best practices for allowing mining activities near topographic hollows. A "codebook" may be developed and strong regulatory system may be enforced. Stone quarries should not be allowed near the topographic hollows with more than 1 m overburden; they should be 200 m away from such localities.
- While constructing village roads in the high sloping areas, care should be taken to ensure the free flow of streams across the roads by providing culverts
- The current practice is that only the critical and high hazard areas are now regulated for activities. Settlements are allowed in the downslope of critical and high hazard areas. These areas are susceptible to high causalities during a landslide event. Therefore, an estimate of the runout distance for landslides needs to be assessed based on slope and overburden volume in the high hazard zones so as to regulate settlements at the downstream of the slopes.
- In many hill-road sections, toppling has occurred during rains where the road cuttings in the laterite are more than 3 m. This will cause disruptions in the traffic movement and destabilisation of the upper slope. Proper protection should be given to these laterite road cuttings with adequate weeping holes. In the unprotected slopes, it is better to give a deep-rooted bio cover like Vetiver (locally known as *Ramacham*) if other methods are not feasible.
- While constructing buildings and houses on the hill slopes, the slope geometry is to be maintained. In other words, the cutting and filling of the slopes for construction in the high slope area should be discouraged.
- The runout zone of the upper unstable area is to be considered while planning any infrastructural development on the lower slopes.
- Artificial impounding of water on slopes should be discouraged. In areas identified as high hazard zones, the construction of swimming pools and theme parks to promote tourism should also be discouraged.
- In long slope areas, the toe part should be protected from development activities. In unavoidable circumstances, any disturbance in the toe area should be accompanied by strengthening/protecting of upper slope areas.

- Provide ditch traps and fencing at a highly hazard zone prone to rock falls. Blasting is not a good option because it may trigger further rock falls. Controlled blasting under the supervision of an expert could be done in case of an emergency.
- Unstable slopes can be modified by re-grading, geotextile mats, vegetation and bio-engineering and geotechnical measures such as soil nailing, and wire machine. Anthropogenic activities that can cause saturation of the soil are to be strictly regulated in critical/prone areas. However, in locations where exceptionally deteriorated conditions of moderate dimensions already exist, the slope geometry needs to be scientifically changed to reduce the stress on the unstable mass. This may be done by providing restraining structures to increase the resistance to slide movements. These include providing a buttress, shear keys, retaining walls, rock bolts, and piles. Grouting and electro-osmosis can also be resorted to in very specific cases.
- The Government should encourage people to secure insurance coverage for their assets in high-risk areas.
- The Government should identify (construct if needed) multipurpose shelters designed by qualified architects for temporarily rehabilitating the affected people before and during an event. These shelters in normal times could be used for other purposes such as marriage or meeting for generating funds for its maintenance. These shelters should be at locations that are safe from both floods and landslides.
- Modify the existing landslide-prone area maps (prepared by NCESS) by considering additional causative factors and past occurrences of landslides. A cadastral level mapping with micro watershed boundaries may be desirable in the high hazard zones. In case of an area which is yet to be covered under cadastral survey, maps in a 1:5,000 scale may be prepared based on topographical maps, high-resolution image, and aerial photographs.
- The risk level of the landslide occurrence should be estimated and depicted on the refined hazard zonation maps at the cadastral level by incorporating vulnerability that considers population data, land use, infrastructure, assets, etc.
- Locations of current landslide incidences should be mapped in the hazard zonation maps prepared by NCESS (1:50,000 scale) for ready reference.
- Initiate studies that can help develop rainfall intensity-based probability for landslide occurrences.

c) Flood

The floods of 2018 and 2019 have a large return period (more than 100 years). To fully alleviate the impacts of such floods is practically difficult because any structural measure would not have considered such a high return period of floods due to their very low probability of occurrence. However, mitigation measures and preparedness can be planned to reduce the negative impacts of such calamities. The following are some of the suggestions to reduce the impact of flood in the future:

- As the catchment area of most of the reservoirs of the State drains forest areas, they do not experience heavy silting unlike the reservoirs in other parts of India, especially the ones in Himalayan Rivers. However, the storage capacity of most of the reservoirs in the State might have been reduced to varying extents as there was no periodic desilting action performed in the past decades. This capacity reduction would certainly have lowered the originally designed efficiency of the system. Therefore, the committee recommends that the storage capacity of all the reservoirs shall be evaluated at periodical intervals, say 10-20 years, to determine the amount of siltation on a priority basis, and desilting be planned accordingly if required.
- Several rivers that have reservoirs did not have larger flows in the past as the reservoir releases were minimal. Therefore, the concept of floodway and flood fringe can be introduced for flood zoning. The floodway is the high-risk area, which should be kept free of any construction to allow free movement of floodwater. The level of risk can be determined based on factors like depth and velocity of floodwater, duration of flooding, available flood storage capacity, or rate of rising of floodwater. In the flood fringe area, constructions may be permitted under certain conditions. In regulated rivers, this can be ensured by the controlled release of water (may be of magnitude corresponding to a 2-5-year return period of the virgin catchment) on specified intervals (example, once in 2-3 years) during active monsoon season. Such actions would ensure no encroachment into the river beds immediate downstream of dams.
- Buffer zones are to be demarcated on both the banks of the rivers (50-100 m from the bank) based on the geomorphological characteristics, where no construction is to be allowed. However, the cultivation of seasonal crops can be permitted in these buffer zones. Riverbank maps prepared under River Bank Protection and Sand Auditing project being executed by the Institute of Land Development and Management (ILDM), Revenue Department, Government of Kerala may be used for this purpose. In fact, agencies involved in riverbank mapping and sand auditing projects may be entrusted with this job of buffer zone demarcation.
- The Committee observed several obstructions in the flow channels (including rivers), which caused reduction/restriction of flow downstream resulting in the accumulation of water upstream. This was noted at different locations (Mukkom, etc.) in the 2019 floods. This was specifically observed in the Kallayi River, where

sediment accumulation resulted in an island formation that obstructed the river flow by almost 80 per cent. In addition, dumping of construction debris was observed in the river bed at many locations, that also caused restriction to the free flow of floodwater. Therefore, a smooth passage for the flood flow needs to be maintained in rivers. This can be done by periodical monitoring and clearing of river channels/drainage lines. This will reduce the bed roughness of rivers and ensure sufficient conveyance capacity. River cross-section data generated under river bank mapping and sand auditing projects under ILDM may be used for this purpose. River rejuvenation programme as initiated for a couple of rivers like Killi Ar, Karamana may be encouraged and executed throughout the state involving local people, and local self-government departments (LSGDs).

- The existing reservoirs in the State are conservation-oriented, and the policy is to harvest water as much as possible to the full capacity during the rainy season. None of them had an operating policy that considered flood control until 2018. After 2018, some of the dams have considered flood control in their revised operation policy. In the case of other reservoirs, it is suggested to revisit the rule curves by considering the dams as multi-purpose and multi-reservoir water resources systems, and develop integrated reservoir operation policies so as to maintain the balance between flood control and other objectives, such as hydropower generation, irrigation and drinking water uses. In addition, a relook at increasing the flood cushion in most of the reservoirs can be attempted.
- Wetlands such as rice fields, ponds, and lakes used to play a major role in flood control. While there are a large number of wetlands in the State, most of them have deteriorated or been abandoned or reclaimed and have become ineffective in their primary role. Therefore, it is suggested to restore the wetlands in the State on priority.
- Most of the river beds and flood plains have been deposited with sediments during the last two major floods. This has caused a further reduction in carrying capacity. Therefore, rejuvenation of the rivers to their original capacity is required.
- Wherever feasible, consider constructing levees and floodwalls. This should be done after a proper scientific feasibility study.
- It appears that a zonation of flood hazard has not been done for most of the rivers. What is available is only the flood-prone area map, which would only help in planning developmental activities. Flood impact mitigation requires the flood zones corresponding to different return period floods or return period rainfall. Since the floods are mostly caused by the EREs, it is recommended to simulate and demarcate the flood inundation zones corresponding to different rainfall return periods (example 10, 25, 50, 100, 150 years). In addition, such maps can be

prepared for different ensemble magnitudes of rainfall (without assigning any return period), and a library can be built using the simulations. During the onset of EREs, case-based reasoning can be performed on this library to approximate the possible flooding areas, which can be used for evacuation/mitigation. Such models, when developed, can also be used on a real-time basis to demarcate the approximate flooding zones.

- In addition to the flood hazard zone mapping through simulation, flood risk maps should also be developed. Flood risk maps will show the possible adverse consequences to people, health, livestock, economic activity, the environment, and cultural heritage in the event of floods. The map should show at least the risk to the potentially affected people (during day-time and night-time) including the indicative number of transitory people (example, tourists), aspects of economic activity, protected areas and natural environment, and where present, the facilities causing accidental pollution should they be flooded.
- An effective flood warning system is to be developed and implemented on priority. Since the predictive capability of the rainfall forecast models is limited, the flood warning systems cannot be fully dependent on the rainfall forecasts. Therefore, flood warning systems that depend on flood discharge at upstream locations and the time of travel to a downstream location may be planned and developed. This kind of warning system will mitigate human/livestock casualties. Telemetry systems can be effectively utilised for this purpose.
- Develop operation and maintenance manuals for flood gates and shutters. Perform maintenance, operation, and monitoring during the pre-monsoon period, and rectify the issues at regular intervals. Trials and test operational procedures should be performed at defined intervals. Ensure timely gate operations during flood events.
- It is noted by the Committee that flood accumulation in the lower Kuttanad region was mostly due to insufficient capacity to discharge the flood water to the ocean. Therefore, it is suggested to clear the sandbars near the Thottappalli Spillway on a regular basis and ensure the original width of the channel (downstream of the spillway) for smooth flow of the floodwater. Also, an increase of the width (~to 300 m) of the lead channel to the Thottappalli spillway is recommended.
- It is noted that the dwellings in the lower Kuttanad region are scattered and are aligned along the bunds. This reduces the effectiveness of evacuation in case of a severe flood event. Therefore, it is suggested to facilitate settlement at identified clusters.
- Since forests cover the majority of the catchment area of the rivers of the State, research studies may be carried out to understand the significance of forested watersheds in flood hydrological response.

d) Recommendation for Sustainable Housing in Hazard Zones

In the flood-prone areas of the State, building controls are not stand-alone solutions to mitigate flood risk. Instead, they need to be implemented in conjunction with other flood mitigation measures. Building controls are important to reduce damage to buildings and their contents. Setting the minimum floor levels for residential buildings and other structures in flood risk areas can reduce the frequency and extent of flood damage. The minimum floor level should be determined from the flood levels derived from significant historical flood events or floods of specific annual exceedance probabilities.

- Erection of fences/compound walls, whether solid or open, can affect the flood flow behaviour and flooding pattern by altering flow paths. The impact of such structures will depend on the type of fence and its location relative to the flow path. Hence, controls should be considered in relation to the type of fencing permitted, or to limit its location or height depending on the geographic area. In general, solid fencing, especially to ground level, should not be erected across flow paths where it might act as a dam. Open fencing is preferable.
- Flow velocities, flow depths and associated debris loads can affect the structural soundness. Hence, the structural soundness of the buildings in the flood-prone areas needs to be considered for the local hydraulic conditions.
- Emergency services (for example, water treatment and distribution, power generation and distribution, and communication services) might be disrupted during floods. Hence, the vulnerability of the emergency services to floods must be minimised. Service providers should also consider the emergency response and recovery planning for floods for key assets.
- Landslides lead to the complete destruction of houses and buildings that fall directly in the path of the flow. Moreover, it was seen that the walls of the buildings that are constructed with load-bearing masonry walls and reinforced concrete slabs were completely destroyed and the slab collapsed as a whole (pancaking type failure). It is difficult to design buildings that are resistant to landslides or floods. Nevertheless, it is recommended that all buildings in areas prone to landslides and floods be designed as per the norms of seismic zone 3, though the region is not in a seismic area. The justification is that the provisions for design in seismic zone 3 regions will lead to better lateral resistance and ensure that the pancaking collapse does not occur. Further, the foundations will also be such that there is better resistance against the force of mud and water.
- Habitations in flood plain, if unavoidable, could be designed as in the case of buildings in the coastal areas that are prone to tsunamis; i.e., the same regulations as in the case of tsunamis could be followed.

- Habitations in steep terrains could be designed such that the slopes are reinforced/strengthened by soil nailing. Further, the design should follow the provisions of design for seismic zone 3. As far as possible, the steep slopes should not be disturbed; if inevitable the building design should be made in such a way that the slopes need not be altered.
- Model structures may be constructed by following the existing provisions for coastal areas taking into account the effects of scouring, lateral impact of boulders and mud, and the maximum expected flood levels.

e) General Suggestion

- The Committee has analysed spatial and non-spatial data collected from different agencies and departments. Therefore, an important suggestion is that a centralised facility/ repository to store and share data may be created. The facility should be a single point contact, where all the data collecting departments should submit the data related to natural/man-made resources and data related to various hazards. This will (a) eliminate the generation of redundant data, (b) bring uniformity to data from different sources, and (c) ensure data quality. A policy should also be developed for sharing the data between different departments or academic and research organisations.
- During interactions with the survivors of landslides, the Committee observed that the traditional/ancestral knowledge of environmental and biological signals has been used to cope with natural hazards, which helped them to forecast the hazards. Hence, the Committee suggests to carry out research investigations to understand the scientific background behind these kinds of linkages. This may be helpful for developing early warning systems.

Recommended Action Plans

Based on the recommendation of the Committee, the following action plans are suggested to the government. The action plans envisage policy developments, detailed scientific assessment/studies, and ground-level plans for different sectors as detailed in the following section.

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
Policy	Sharing data from different departments to the central facility/ repository which will store and share data related to the natural/man-made resources	Restrict disturbances at the locations of topographical hollows which falls under landslide-prone areas	Restrict settlements in the landslide run-out areas	Minimise/remove relief funds for property loss during hazards in high hazard-prone areas for the individuals who deny the mitigation measures of the government
	Restrict quarrying/ mining activities at high landslide-prone areas. Appropriate regulations also need to be made for quarrying/ mining activities at low landslide-prone areas	Conduct a mandatory environmental impact assessment for new developmental projects in the high flood/ landslide hazard-prone areas.	Develop integrated reservoir operation policies so as to maintain the balance between flood control and other system objectives, such as hydropower generation, irrigation and drinking water uses.	Restrict financial aids from the government for construction/activities in the high hazard-prone areas.
Scientific	Identify and map regions with potential disasters like heavy rainfall areas, flood-prone areas, landslide-prone areas,	Prepare flood inundation maps at 1:4000 scale	Hazard zonation and mapping of entire Kerala at 1:4000 scale • Flood hazard zonation	Prepare action plans for various levels of public administration/LSGDs to manage various

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
	etc.		• Landslide hazard zonation • Dam release/breach hazard zonation	situations/hazards and preparation of documents to guide the public about action required during emergencies.
	Identify potential locations of topographical hollows	Prepare landslide hazard area and runout area maps at a 1:4000 scale. Initiate in-situ observations of aerosol microphysical properties (such as size distribution) including bio-aerosols, utilising educational/ research institutions at least in three representative locations; in the plains, on the slopes, and at higher altitudes in the Western Ghats.	Study to determine the model parameters specific to Kerala for physics-based models used in prediction of rainfall as well as the river flow	Studies on understanding the long-term trend of atmospheric aerosols over Kerala, specifically the fine mode aerosols relevant for the cloud and precipitation forming processes, using high-resolution satellite data.
	Conduct detailed Studies on the impact of climate change in land use planning, considering the increasing frequency of EREs and	Conduct studies on improving the predictability of EREs	Studies on the threshold intensity of rainfall by incorporating more automatic rain gauges. Initiate studies on debris flow	Modelling studies to primarily understand the role of aerosol on cloud and rain formation.

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
	associated floods and landslides.		runout.	
	Studies on the amount of sand carried by all the rivers in the State and the allowable extraction from its bed	Develop risk maps of landslide and flood possibility for the entire state.		
Land Use Management	Identify and mark buffer zones near the banks of rivers where only seasonal cultivation can be done with no construction and any obstruction for flow.	Prepare special land use planning for areas with slopes more than 20°.	In the unprotected slopes, plant a deep-rooted bio cover like Vetiver (*Ramacham*)	Introduce the concept of floodway and flood fringe for flood zoning. In the flood fringe area, constructions may be permitted under certain conditions.
	Removal of deep tap roots after clear-felling of trees and refill with earth (with minimal soil disturbances) to avoid over saturation and decay of tap root system which will promote soil piping and landslides.			
Water Resources	Conduct periodical monitoring and clearing of river channels/ drainage lines	Plan controlled the release of high flow (2- or 5-year return period) at least once in 2-3	Implement measures such as re-enforcement of embankments, lowering the	Consider providing a dynamic flood cushion in the reservoirs, when advance

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
	thus ensuring a smooth flow of water by reducing the bed roughness of the rivers and to ensure sufficient conveyance capacity.	years in all rivers to demarcate their boundaries.	floodplain area, widening the floodplain by re-location and lowering of embankments, and development of flood bypasses.	warning of extreme rainfall events are available
	Install dense network of Automatic Rain Gauges (ARG/AWS; ~500) with special emphasis on regions receiving high-intensity rainfalls in short time periods including slopes that have the potential for flash floods	Install weather stations for monitoring meteorological parameters (temperature, pressure, wind direction, wind speed, etc. ~50) in high time and spatial resolution; more importantly over the slopes of Western Ghats	Rejuvenate stagnant water bodies such as isolated channels, rivulets, and oxbows in the floodplain.	Perform maintenance, operation, and monitoring during the pre-monsoon period, and rectify the issues at regular intervals. Trials and test operational procedures should be performed at defined intervals. Ensure timely gate operations during flood events.
	Give priority to flood control over irrigation requirements and/or power benefits, especially during ERE forecasts	Create a State level ERE forecast system combined with Artificial Intelligence (AI) to predict flash floods and trigger an advance warning alerting the authorities.	Develop operation and maintenance manuals for flood gates and shutters.	
Construction	Set minimum floor levels for new residential buildings and	Introduce construction standards (including	Construct multipurpose shelters at safe locations	Construction of levees/ floodwalls and restoration of

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
	other structures in flood-prone areas	materials) and building codes for floodplains and landslide-prone areas.		wetlands.
	Introduce designs of flood resilient buildings	Plan for proper traffic access in the flood hazard zones.	Demonstration of model flood-resilient buildings at various locations	Investigate the structural soundness of the buildings in the flood-prone areas for the local hydraulic conditions.
Revenue		Identify the flood plains and flood levels of 10-, 50- and 100-year return period floods. This needs to be done with the help of scientific studies	Propose one-time financial aid for people residing in the floodplains (high flood-prone areas) to relocate.	
Agriculture	Regulate agricultural activities which allow saturation of the soil in critical/prone areas of landslide.	Restrict cultivation on slopes based on hazard risk; promote cultivation along the contours with provisions for drainage of water.		
Dam/ Reservoir Management		Revisit the rule curves of the reservoirs by considering the dams as multi-purpose and multi-reservoir water resources systems and giving the provision of flood cushion	Desilt the reservoirs. Priority should be given to basins having cascading reservoirs and reservoirs whose capacities have reduced due to silting.	Improve flood warning system with integrated real-time reservoir operation

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
Data Management	Install a proper hazard warning dissemination system both for administration and the public.	Develop a centralised facility/ repository to store and share data related to the various hazards and natural/man-made resources in the potential hazard areas	Update the centralised facility/repository at regular intervals	
Social/Awareness	Create awareness and communicate to the public about the risk of living in certain areas especially in flood and landslide-prone areas.	Encourage interaction between LSGD and local people about the hazard risk in their area and possible prevention measures.	Train and empower the locals in disaster management activities.	Encourage people in flood- and landslide-prone areas to cover people / properties / agriculture / industries under insurance
	Provide emergency contact details to people	Conduct Workshops, and awareness programs (at educational- and community-levels). Scientific and technical meetings are essential to actively involve and engage stakeholders. Dedicated websites or social media may be used to provide information to the general public and publish		

Type of measure	Immediate (6 Months)	Short Term	Medium Term	Long Term
		surveys and summary reports		