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Short communication

Frequented Extreme Climatic Events in Kerala - Evolving Sustainable Management Paradigm

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Climate change is a much-deliberated global phenomenon in the present era. Increased frequency of extreme climatic events is a prominent indicator of climate change. Agriculture is one of the essential sectors in India that contributes appreciably to its national economy. At the same time, this sector is increasingly vulnerable to climate change, is an important concern for the planners and policymakers. The impact of climate change on agriculture sector is multi-dimensional. Crop diversity, its climate resilience, change in yield, availability of water for irrigation, etc. are all indicators of these multi-dimensional parameters. About 60% of the total cultivated area in India is rainfed. Any substantial change in rainfall has therefore a direct impact on the GDP component of the agriculture sector.

Changes in climate are believed to impinge on hydrological balances, input supplies, livestock production, and other components of agricultural systems. However, the nature of these impacts and the responses of human beings to them is uncertain and complex. These changes even may also change the type, frequencies, and intensities of various crop and livestock, pests, the availability and timing of irrigation water supplies, and the severity of soil erosion (MoEF, 2012). Habitually, agriculture in the coastal states in India like Kerala will be impacted severely.

Mainstreaming of Climate Change Adaptation and Disaster Risk Reduction (CCA & DRR) in the development proposals are getting progressively more recognized today. The monsoon seasons in India over the years have become nightmarish due to the extreme precipitation and flood events with high spatio-temporal variabilities. Untimely and unevenly distributed precipitation events are on the increasing side in India during the last few decades and are likely to be so further under the climate change scenario. In this short communication, we are highlighting the need for evolving a sustainable management paradigm for the extreme climatic events taking a case study of Kerala floods of 2018 and 2019.

Kerala, an immensely popular destination in the world tourism map and a state of high population density in southern peninsular India, had undergone a devastating flood in August 2018. The state of Kerala with its unique geographical and topographical features and well renowned as the God's own country is likely to lose this title in the light of the extreme climatic events in recent years. The rainfall in the state is controlled by the south-west and north-east monsoons that collectively provide an average annual precipitation of about 3000 mm (KSPB, 2020). About 90% of the rainfall occurs during the six monsoon months (June to November). There are reports on incidents of extreme climatic events and consequent hazardous situations in Kerala in earlier decades as well. The year 1924 witnessed unprecedented and extremely heavy floods in almost all rivers of Kerala with heavy losses to life, property, and land. 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 heavy rainfall in almost entire Kerala. A recurrence of similar heavy floods was witnessed in the year 1961 leading to the rise of water levels in the reservoirs.

After a long spell of nearly fifty-seven years, during August 2018, Kerala state experienced one of the most severe rainfall events on record devastating the entire land enough as to demand a rebuild of the entire state. Extensive flooding and landslides were reported across many districts, causing severe damage to both the built-up and natural ecosystems. According to the India Meteorological Department (IMD), the westerly flow across the southern peninsula strengthened due to formation and movement of 3 Depressions (D) over the north Bay of Bengal (BOB), *viz*., (i) D over northeast BOB during 10-11 June, (ii) D over northwest BOB during 21-23 July and (iii) D over northwest BOB during 7-8 Aug 2018. Low-level merging of strong, moist winds from the southeast Arabian sea and orographic lifting led to extreme rainfall over the Western Ghats belt and the pouring effect of such persistent activity for a few days in a belt during all the three major rainfall weeks [(i) 7-13 June, (ii) 12-18 July, and (iii) 9-15 Aug 2018] turned out catastrophic (IMD, 2018).

On an average, Kerala received significantly high monsoon rainfall from 1 June 2018 to 19 August 2018 (2346.6 mm) (CWC, 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 were 15%, 18% and 164% above normal, respectively. Out of 758.6 mm rainfall during 1-19 August 2018, 414 mm occurred during the three days 15-17 August 2018. 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 one-day rainfall of 398 mm, 305 mm, 255 mm, 254 mm, 211 mm and 214 mm was recorded at Nilambur in Malappuram district, Mananthavadi in Wayanad district, Peerumed, Munnar and Myladumparai in Idukki district and Palakkad in Palakkad district, respectively on 9th 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. Month wise rainfall for the period, as reported by IMD, is presented in Table 1 along with its graphical representation in Fig. 1.

The extreme rainfall and the exceedingly high population density of 860 persons per km^2, made the deluge significantly affecting a population of 1.2 million. About 400 persons lost their lives and the basic infrastructure facilities were seriously damaged. UN Secretary General referred to the Kerala floods to highlight the urgency of the climate crisis. Cochin international airport had to suspend all operations for a fortnight, following runway floods. Among the different districts of the state, Idukki received the maximum rainfall, which was almost 100% excess compared to the normal rainfall (3555 mm against the normal 1852 mm). During the first 19 days of August 2018, Kerala

Table 1. *Month wise actual rainfall, normal rainfall, and percentage departure from normal (CWC 2018)*

Period	Normal rainfall in mm	Actual rainfall in mm	% Departure from normal
June 2018	649.8	749.6	15
July 2018	726.1	857.4	18
1-19 Aug 2018	287.6	758.6	164
Total	1649.5	2346.6	42

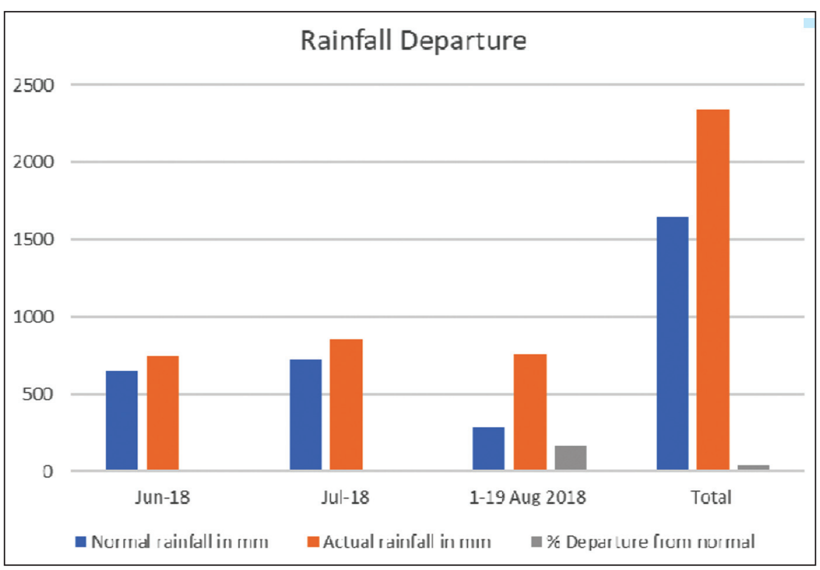

Fig. 1. *Rainfall and its departure from normal*

received 164% above normal rainfall, of which the major share was from two extreme rainfall events during 8-10 and 14-19. The two rain gauge stations that realized maximum cumulative rainfall during 15-17 August 2018 were Peerumed (>800 mm) and Idukki (>700 mm), both belonging to Idukki district in the Western Ghats.

CWC (2018), Mishra *et al*. (2018) and Sudheer *et al*. (2019) have done extensive analysis of extreme rainfall event during August 2018 by comparing its intensity with the occurrences in 1924 and 1961. Table 2 below presents a comparison of different methodologies used in the extreme rainfall analysis performed by various agencies. They have estimated the return period of 2-day maximum rainfall as about 200 years. At the same time, the estimated return period of extreme rainfall on the upstream catchments of large reservoirs was more than 500 years. But in general, the overall return period of more than 100 years has been confirmed in this analysis.

The study by Mishra *et al*. (2018) analyzed the return period of extreme rainfall and the potential role of reservoirs in the recent flooding in Kerala. They showed that Kerala experienced 53% above normal rainfall during the monsoon season (till August 21st) of 2018. Moreover, 1, 2, and 3 - day extreme rainfall in Kerala during August 2018 had return periods of 75, 200, and 100 years. Six out of seven major reservoirs were at more than 90% of their full capacity on August 8, 2018, before extreme rainfall in Kerala. Therefore, above normal seasonal rainfall (before August 8, 2018), high reservoir storage, and unprecedented extreme rainfall in the catchments where reservoirs are located worsened the flooding in Kerala. They suggested that reservoir operations need be improved using a skillful forecast of extreme rainfall at the longer lead time (4-7 days). However, the argument that high reservoir storage worsened the flooding was later counterargued and defeated in the invited referee comments and public domain discussions of this paper. As the inflow to KWRD reservoirs during peak flood was 696 Mm^3 and the release from those reservoirs was only 700 Mm^3, it is true that they could not absorb the flood, but they never worsened the flooding on the downstream sides.

Another study by Sudheer *et al*. (2018) answered whether the early release of the water stored in the reservoirs would have attenuated the flood peaks, and if so, what would have been the extent of this attenuation? The study area chosen was one of the worst affected basins, Periyar River Basin (PRB), which received a 145-year return period rainfall. This study reports the results and analysis of a modelling exercise using HEC-HMS to simulate and analyze the role of dams, as well as reservoir operations, on the flood of August 2018. The results indicated that the role of releases from the major reservoirs in the PRB resulting in the flood havoc was less. The analysis suggested that reservoir operations could not have helped in avoiding the flood situation as only 16-21% peak attenuation was possible by emptying the reservoir in advance. The bulk of runoff to the flooding was also contributed by the intermediate catchments without any reservoirs

Table 2. *Extreme rainfall event analysis - data types and methodologies (Source: Padikkal and Joshy, 2019)*

Governmental Agency / Researcher	Data type	Methodology
Central Water Commission (CWC)	1-day, 2-day cumulative, and 3-day cumulative rainfall raster prepared from the point rainfall data	Direct computation of 1 day, 2 days cumulative and 3 days cumulative
Kerala Water Resources Department (KWR)	Actual measured rainfall at reservoir sites	Direct computation of 1 day, 2 days and 3 days cumulative
Sudheer *et al*. (2019)	Half hourly cumulative gridded precipitation datasets of Integrated Multi-satellite Retrievals for GPM (IMERG) from 1st June to 31st August 2018 available at a spatial resolution of 0.1 x 0.1 (NASA, 2018)	IMERG-based cumulative monthly rainfall
Mishra *et al*. (2018)	Daily observed rainfall data from India Meteorological Department (IMD) at 0.25° for the period 1901-2018 (till 21st August)	Generalized extreme value distribution

to control. As the contribution from uncontrolled catchments was significant, existing reservoirs had little role in controlling the flood. To put it precisely, all the experts have concurred that unprecedented rainfall was the cause of the flood.

Any calamity is generally followed by lots of arguments, controversies, and unauthorized information sharing. People struggle to comprehend what happened and how to cope. The actual causes of Kerala floods are being debated by the broader public including politicians, water resource engineers and science researchers. The role of different parameters like extreme rainfall event, changed land use pattern and the dam operation modalities are widely discussed. In addition to the unprecedented rainfall, ill-thought-about development plans that have affected the sustainability of the Western Ghats, construction of airport on fields and wetlands adjacent to river, dam operations in the late hours after reaching full capacity, etc are debated upon as the reasons for the calamity. However, the post-disaster publications in the scientific journals and international conferences have categorically rejected the theory that flood was dam induced. Nevertheless, the debate has opened the need for a sustainable management paradigm for extreme climatic events.

The highland physiography of Kerala supports numerous dams and reservoirs, which are predominantly designed for hydroelectric power generation as well as irrigation purposes. Dams and reservoirs can be effectively used in flood moderation. This is done by temporarily storing the flood volume and releasing it later. The most effective method of flood control is accomplished by an integrated water management plan for regulating the storage and discharges of each of the main dams located in a river basin. Each dam is operated by a specific water control plan for routing floods through the basin without damage. This means lowering of the reservoir level to create more storage before the rainy season. This strategy eliminates flooding. However, this can be done only when the dam is built mainly for flood control.

All the major reservoirs in Kerala were filled to more than 90% of their maximum capacity just before the occurrence of the extreme climatic event by July. Table 3 gives the storage capacities of major reservoirs in Kerala during peak floods. As the major reservoirs were filled, naturally their flood absorption capacity was very much limited. But all these reservoirs are basically built with an objective of water conservation. Therefore, keeping these reservoirs at 90% of its storage capacity is fully justifiable from the dam management perspective. Moreover, the extreme climatic event happened during the last one-third stretch of the southwest monsoon period. Southwest monsoon being the prominent one for this region, maximum water conservation in this monsoon season becomes mandatory.

When a dam is built for water conservation, there may be many other challenges associated with the water conservation paradigm making it practically impossible to lower the reservoir levels. The number of dams and their water control management plans is established by comprehensive planning for economic development and with public involvement. Flood control is a significant purpose for many of the existing dams and continues as the main purpose for some of the major dams of the world currently under construction. But Kerala has no flood control dams which must be factored importantly in the evolution of a new management paradigm for extreme climatic events. Flood moderation and downstream impact reduction are believed to be manageable with science-based decisions on dam operations. The safety of the dam gets an utmost important consideration during any disaster and naturally, the dam operators focus mainly on this aspect. It illustrates the extremely limited scope of flood management using large dams with a storage capacity of 100 Mm^3 or lesser when

Table 3. *Major reservoirs' storage before flood (CWC 2018; Padikkal and Joshy, 2019)*

Dam	% of FRL storage	Reservoir water spread area at FRL in km^2
Idukki	92.5	59.83
Idamalayar	97.3	28.30
Parambikulam System	99.0	28.54
Kallada	90.5	23.00
Kakki	97.3	17.51

extreme rainfall events with a return period of 100 years or more happen. The challenges in dam management for larger dams with more than 100 Mm^3 capacities which are built and operated with a primary objective of water conservation should also be considered. In the case of Kerala catchments with typically very small-time intervals of concentration, reliable longer lead forecast of climatic events becomes very crucial.

The state of Kerala is now on a massive mobilization drive to rebuild a new Kerala. The state government with the support of the line departments, other service agencies has initiated steps to rehabilitate the affected group and to enable them to cope with the hazardous situation. A Post Disaster Needs Assessment (PDNA) was initiated on September 18, 2018 for a period of three weeks with the engagement of over 100 people from government, international agencies, and civil society. Ten UN agencies have supported the PDNA. According to the PDNA report, the policy framework to build a new Kerala rests on four pillars, of which, the major emphasis is on the two aspects: integrated water resources management (IWRM) and eco-sensitive and risk-informed approaches to land use and settlements. The aim is to break existing inter-sectoral barriers to establish a holistic framework for coordination. It helps to identify best practices that safeguard the environment, economics, urban planning, and sustainability principles to achieve healthy and hassle-free river ecosystems.

Draft sector plan for water resources management which conforms to the IWRM framework is now being actively deliberated in Kerala at various levels. One of the most important aspects discussed in the sector plan is improving the data and knowledge management systems, including reliable monitoring systems (water level, water quality, water use) with adequate spatial and temporal coverage. Kerala Water Resource Information System (KWRIS) as it has been christened aims to address all the data related issues pertaining to the development of strategic water sector plans.

Even though dam management did not worsen the flooding as it is established with corroborative evidence, one of the major lessons learned from managing these floods is the urgency of developing a fully functional water resources information system for Kerala. Fundamental to water management is the need for a reliable, accurate, and accessible water information system. High-quality and timely water data need to be built up to support planning and decision making. Limited availability of data results from the inadequate hydro-met system, including lack of sampling stations, low density of gauges, broken equipment, etc. This leads to poor quality data that is inadequate for sound decision making.

Overall, there is a lack of detailed systematic information on water resources conditions that are required for scientific analysis to properly manage water resources and plan measures to make more productive use and mitigated water-related risks (floods, droughts, sediment, etc.). Regular collection and analysis of data relating dynamics of floods, erosion, sedimentation is required for time series analysis of the potential impacts and to support forecasts/predictions.

An equally challenging problem is the limited accessibility of data, which negatively affects the ability of agencies to access information for planning and management of water resources. This is due to several factors, including inadequate information systems and restrictions to data. Available data are scattered across several agencies (e.g., Irrigation Department, CWRDM, KSEB, etc.) and often access to data is restricted hampering sharing of information across agencies. Laborious data requests are often subject to long delays, and information is often not digitized or in digestible formats. Limited open public access to even basic data in analysis-ready formats and tools for analytic insights relating to water resources and associated fields, is also limiting the contribution of academia, private sector, research agencies, and the general public to contribute to, and benefit from a shared vision in the planning and management of water resources. Without both available and accessible data, it is simply not possible to responsibly manage and develop water resources in the state.

The PDNA by the UN agencies has recommended IWRM as one of the major pillars of disaster recovery and risk reduction. IWRM is well discussed in Kerala but practically no steps have been taken for translating this idea into a reality. There exists no water resource information system is one of the major challenges in taking up IWRM.

KWRIS is envisaged to effectively resolve the prevailing issues in the water sector such as:

1. Lack of facility to predict the shifts in hydrological extremes such as drought and flood.
2. Shortfall in the identification of effective and optimum locations for surface water recharge.
3. Inappropriate water balancing, water audit and groundwater estimation methods.
4. Inadequacy in mapping and management of aquifers.
5. Lack of facilities to identify locations of severe water stress especially in case of groundwater depletion.
6. Inefficient water distribution and canal management in case of irrigation projects.
7. Alarming increase in pollution levels of water bodies.
8. Shrinking and vanishing of water bodies due to the rising encroachments.
9. Improper management of assets in the water sector/ water conservation structures.
10. Lack of availability of water-related data in a single platform.

Proposed solution architecture and the framework of KWRIS is schematically presented in Figure 2.

Extreme climatic events, either flood or drought, will have a direct impact on coastal agriculture. In the August 2018 floods in Kerala, crops were most heavily affected, contributing to 88% of the total loss and damage to the sector. The total impact of Kerala floods on Agriculture and Allied sector (crops, livestock and fisheries) are ₹7,154 crores (KSPB, 2020). Anticipated production losses in the crop sub-sector are at ₹3,558 crores across 89.6 thousand hectares which is 4.44% of the net cropped area.

The monsoon caused significant loss in banana accounting for 40% of total crop losses, followed by pepper (19%) and paddy (14%). About 36.74% of the net cropped area of Wayanad and 17.59% of that in Alappuzha was damaged. Perennial and annual crops, such as banana, coconut, arecanut, pepper and coffee were the most impacted. Seasonal crops, such as rice, vegetable, tapioca, and other tuber crops also suffered significant losses.

The structural interventions in the irrigation sector must be integrated with the flood and drought management, especially in the backdrop of frequented extreme climatic events. Strategically designing the irrigation infrastructure for flood and drought management, community micro-irrigation schemes with significantly improved water use efficiency, ecosystem-based disaster risk reduction including the nature-based solutions are some of the important tools to be applied in mitigating the impact of extreme climatic events on coastal agriculture.

The possibilities of having flood control dams in river basins must be explored together with other non-structural interventions. More real-time flood forecasting facilities must be developed and collaborative effort by authorities in related line departments of the state at critical times of weather extremes must be ensured by incorporating appropriate institutional arrangements like River Basin Conservation and Management Authority

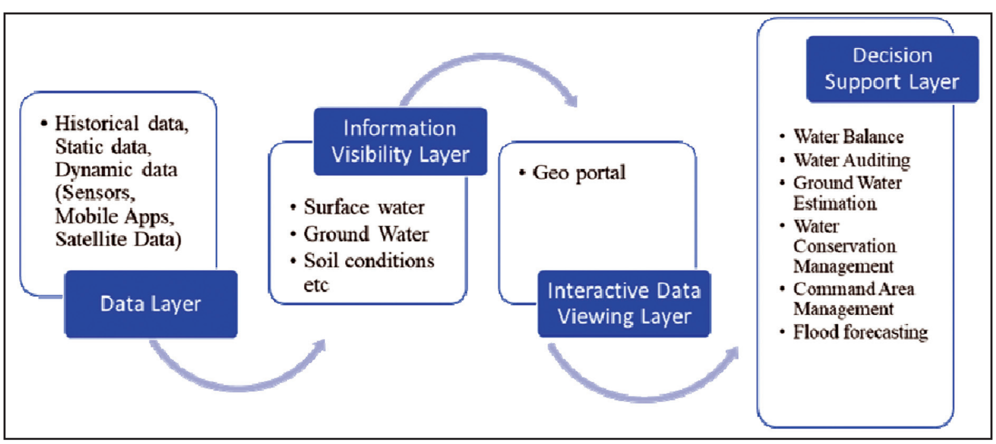

Fig. 2. *KWRIS-Solution Architecture and Framework*

(RBCMA). Under the RKI program, the state has already initiated action on important steppingstones like KWRIS and RBCMA. Together with this, the proposals for flood control dams are revisited in the background of modified Probable Maximum Flood (PMF). Nonstructural interventions like mainstreaming of Disaster Risk Reduction and Climate Change Adaptation (DRR & CCA) in the development plans under RKI are also importantly recognized now. Selected gramapanchayats have already commenced Local Action Plan on Climate Change (LAPCC). These interventions, both structural and non-structural in a balanced manner, must shape up the sustainable management paradigm for extreme climatic events.

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