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Article

Standard Operating Procedures (SOP) towards Effective Flood Response and Environmental Management in Kelani and Deduruoya River Basins, Sri Lanka

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Abstract: Standard Operating Procedures (SOPs) for a river catchment improve the efficiency and effectiveness of flood response and environmental management by providing a structured framework for coordinated actions. This paper examines Standard Operating Procedures (SOPs) in enhancing the efficiency and effectiveness of flood response and environmental management. Considering the two major river basins in Sri Lanka, the applicability of the well-established Standing Operating Procedure (SOP) of the Kelani River Basin (KRB), in mitigating flood impacts in the Deduruoya River Basin (DRB) was studied. DRB is affected by intermittent flash floods. Flood-affected administrative units (Divisional Secretariat Divisions) were identified and mapped using the Desinventar Database. Subsequent surveys and stakeholder interviews were held, revealing critical gaps in current flood management strategies. The integration of environmental management principles into SOPs is explored in relation to safeguarding ecosystems, preventing contamination, and promoting sustainable recovery. The study underscores the importance of regularly updating SOPs to incorporate technological advancements, data analytics, and community input. It also advocates for a collaborative, multi-stakeholder approach to flood response, where SOPs are continuously rehearsed and refined to ensure timely and coordinated actions. Findings emphasize that the adoption of dynamic and inclusive SOPs can significantly reduce flood-related damages, enhance environmental resilience, and contribute to long-term recovery. This study calls for the integration of SOPs into national and local disaster management strategies, offering a valuable tool for both government agencies and practitioners to build more resilient communities and protect natural ecosystems from future flood risks.

Keywords: River Basin; Standard Operating Procedures (SOP); Flood Response; Environmental Management; Resilience

1. Introduction

This paper discusses "Standard Operating Procedures" (SOP) towards Effective Flood Response and Environmental Management. Effective flood response and environmental management require a proactive, collaborative, and adaptive approach. By following this, stakeholders can significantly reduce the impact of floods, protect the environment, and build resilient communities [1]. Emergency Operating Procedures (EOPs) outline stakeholder responsibilities for incident response and recovery, while local administrations determine the specific organizational structures and operating details [2].

Establishment of detailed common disaster management standard for Sri Lanka has been accelerated after the devastating 2004 Asian Tsunami, to create an emergency management standard for the government activities. The central government is establishing a national emergency management system with standardized plans and procedures for all stakeholders in Sri Lanka, as described later in this paper. The study emphasizes the importance of pre-defined guidelines for flood preparedness, early warning systems, resource allocation, evacuation planning, and post-flood recovery. It highlights how SOPs facilitate inter-agency collaboration, optimize resource utilization, and ensure timely decision-making during emergencies. This paper cites case studies from Sri Lanka, an island country in South Asia, located between latitudes 5°55′10″–9°50′06″ North, and longitudes 79°31′19″–81°52′36″ East. Total land area of the country is 65,610 km^2 [3,4]. Two major river basins (Kelani River and Deduru-oya) in Sri Lanka are studied. **Figure 1** shows the selected two river basins (DRB and KRB); shaded within District map of Sri Lanka. **Figure 2** shows different climatic zones in Kelani River basin (KRB) and **Figure 3** shows different climatic zones in Deduru-oya River basin (DRB). **Table 1** compares hydrological data for the two basins.

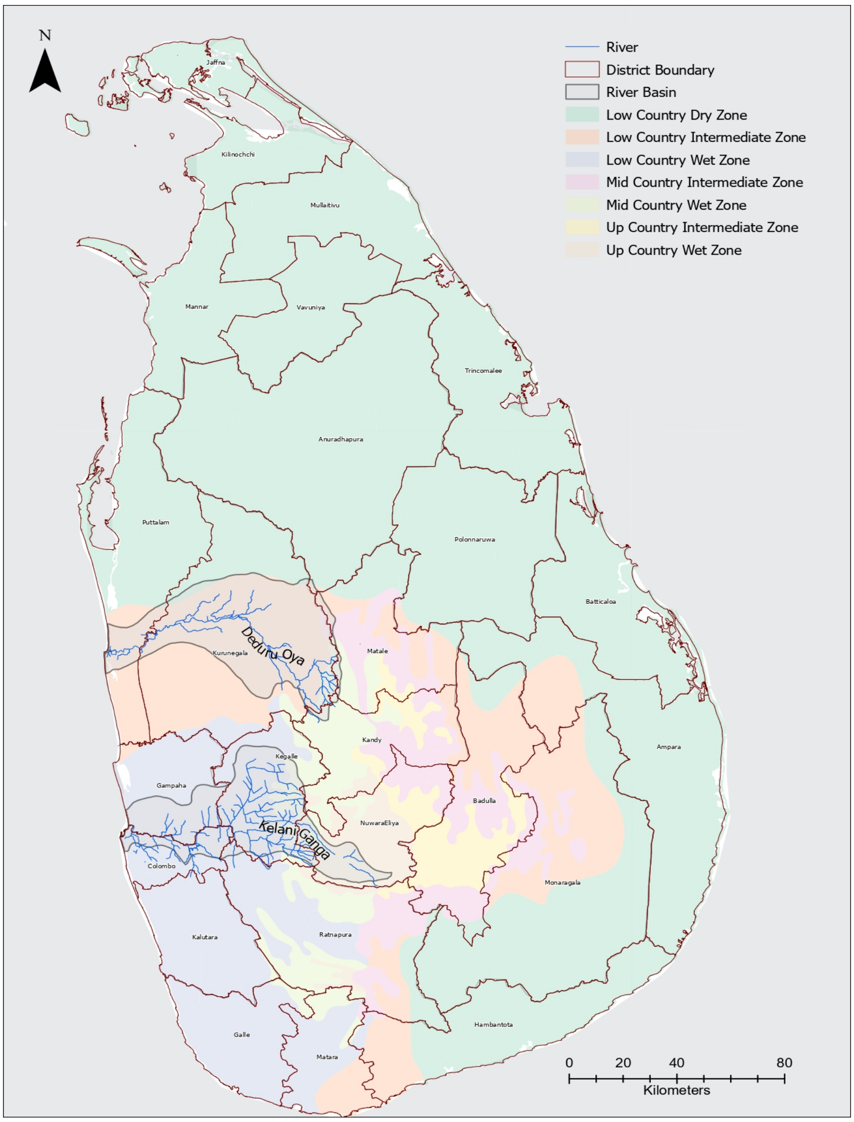


Figure 1. Selected two river basins (DRB and KRB); shaded within District map, Sri Lanka.

Note: latitude range 5°55′10″–9°50′06″ N, longitude range 79°31′19″–81°52′36″ E.

Table 1. Deduru Oya Basin (DOB) and Kelani River Basin (KRB) comparative data [5,6].

Parameter	Kelani River Basin (KRB)	Deduru-oya River Basin (DRB)
Basin description (approximate values)	Seventh largest in the country in extent of watershed and third largest in water resources aspect (4,225 million cubic meters (MCM) average annual discharge). Of the 7,860 MCM annual rainfall (3,450 mm); 43%; discharges into the Indian Ocean.	Fifth largest catchment, whose upper reaches are situated in the intermediate zone of the country, and the lower (1,150 km^2) in the dry zone. Sixth longest river. Of the 4,258 MCM annual rainfall; 37%; discharges into the Indian Ocean.
Headwater/Length of river	Originating near Adam's Peak, the river flows 145 km to the sea at Colombo (commercial capital).	Originating in western slopes of Kandy-Matale hills river flows 142 km to the sea north of Chilaw.
Basin area	2,340 km^2 being 3.6% of total area of the country.	2,623 km^2 being 4% of the country.
Population (2011 Census)	2,981,491, approximately 14% of country's population.	1,038,779, approximately 5% of country's population.

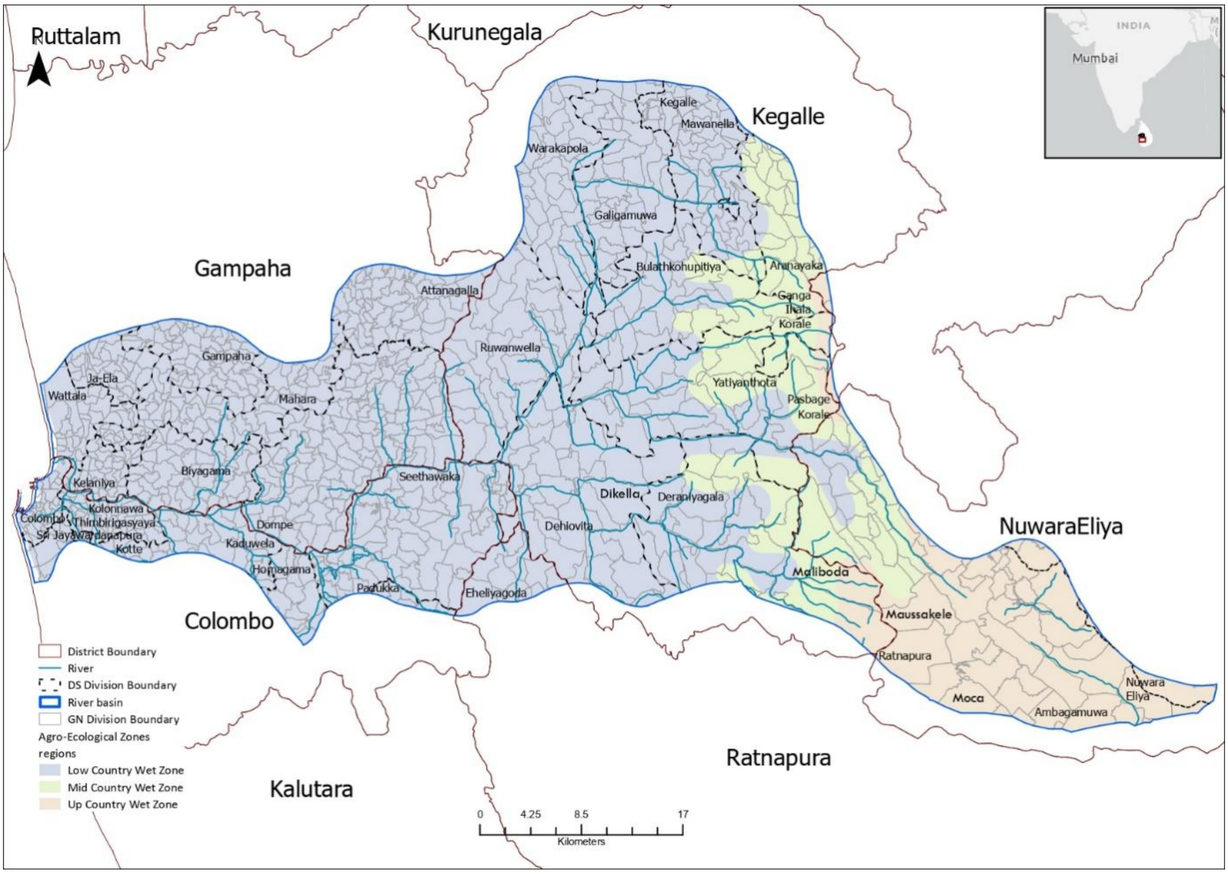


Figure 2. Map of different climatic zones in Kelani River basin (KRB) in Sri Lanka.

Note: Basin Boundaries: approximately 6°47′ N–7°15′ N and 79°50′ E–80°45′ E.

National Emergency Operation Plan (NEOP) in Sri Lanka serves as the master plan for response phase of the disaster management cycle, as stipulated by the Sri Lanka Disaster Management Act in 2005 [7]. District governments play key roles in all phases of the disaster management cycle to reduce disaster risks within their territory and enhancing their capability of disaster risk reduction (**Figure 4**). Most accepted standards of emergency management, e.g., the USA National Incident Management System (NIMS), define items that must appear in emergency management plans. As it does not specify the level of detail required, Takaaki Kato et al. [2] suggested adding more supporting references.

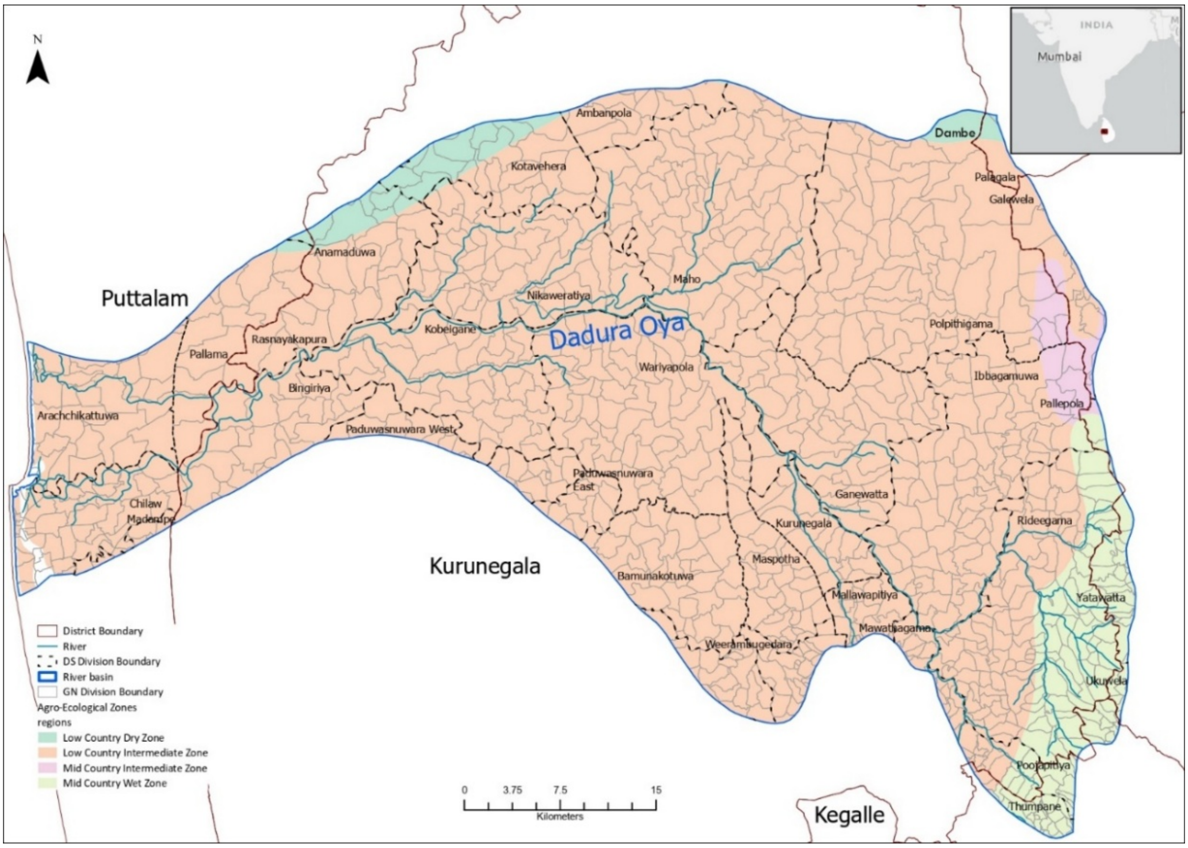


Figure 3. Map of different climatic zones in Deduruoya River basin (DRB) in Sri Lanka.

Note: Basin Boundaries: approximately 7°19′ N–7°52′ N and 79°47′ E–80°35′ E.

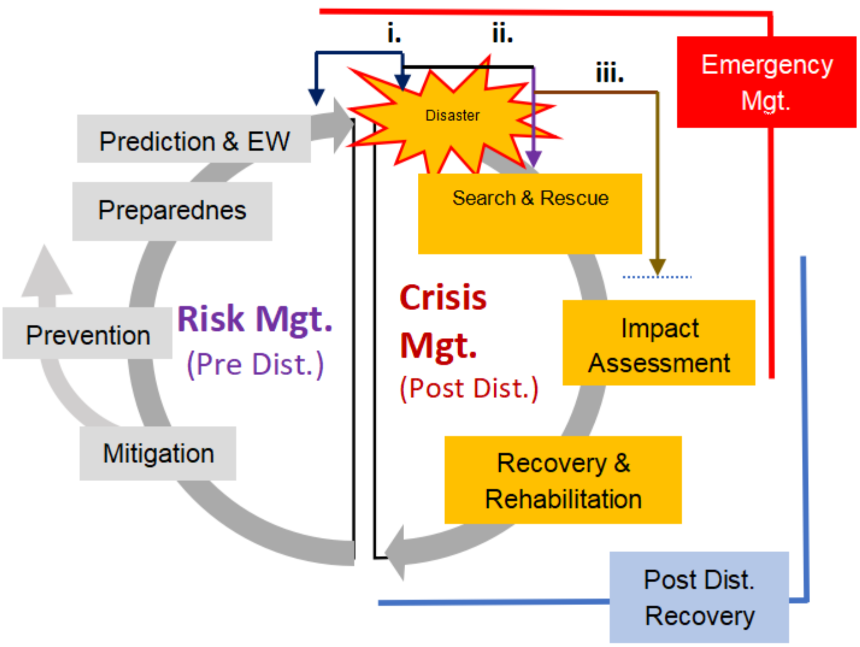


Figure 4. Two spheres of Disaster Management-Cycle (Crisis Management and Risk Management) and its three phases. i.) Pre-incident: Early-warning and evacuation to ensure that people will not be affected. ii.) During the incident: evacuation/rescue may continue. iii.) Early recovery stage [8].

The increasing frequency and intensity of flood events due to climate change, urbanization, and environmental degradation, necessitate the implementation of robust response mechanisms to mitigate their impact.

Impact of the floods can be widespread, including temporary relocation of people, damage to civic amenities, deterioration of water quality and risk of epidemics, landslides, etc. Recent experiences of high rainfall intensity have caused intermittent floods, inundating habitats from a few hours to several days, causing many difficulties both to the community and to the administrative infrastructure.

This paper looks at several flood disaster incidents in Deduru-oya basin to assess whether proper Standard Operating Procedures (SOPs) could serve as the management base of the flood disaster response process. The approach keeps a baseline comparison with the Kelani River flood response SOP (**Supplementary Materials**, **Table S1**) [9]. The Kelani River SOP prescribes guidance and assigns responsibility for adopting various executive actions, to ensure prompt response to address all (disaster) management aspects during flood disasters including environmental management.

1.1. Standardised Operations

Emergency management plans and related training to familiarize them among stakeholders are essential to optimize the merit of mitigation activities. Emergency Operation Procedures (EOP) have a series of tasks that stakeholders need to perform to fulfil emergency functions, usually as annexures. This includes standard operating procedures (SOPs) defining specific procedures and steps for achieving disaster management tasks [2]. In performing specific tasks or processes consistently and efficiently, Standard Operating Procedures (SOPs) are helpful as step-by-step instructions guiding individuals or teams, to conduct routine operations. SOPs serve as a cornerstone for organizational operations, ensuring quality output and uniformity of performance, and compliance across all activities, while reducing miscommunication and failure to comply with industry regulations. The military uses the term standing (rather than standard) operating procedure because a military SOP refers to a unit's unique procedures, which are not necessarily standard to another unit. "Standard" implies that only one (standard) procedure is to be used across all units.

How to do it instruction, work instruction, desk instruction, procedure, protocol standard and routine processes, are not expected to cover every eventuality that may happen. Communications should be given due attention to ensure the success of the entire environmental management system (EMS) [10]. A simple matrix approach can map individual communication requirements in a logical, structured manner. **Figure 5** shows the SOP development framework used to standardise the process [11].

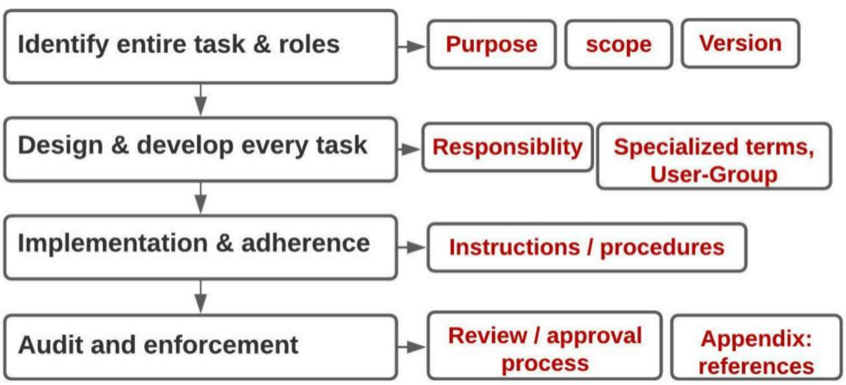


Figure 5. SOP development framework used to standardise the process [11].

For rivers, SOPs are considered a soft mitigation countermeasure (like insurance, foreign aid, support to small businesses; early warning, land-use planning, etc.), which are useful to reduce the disaster risk. River SOPs have some unique characteristics versus hard solutions like dikes, upstream dams, reinforced buildings, etc. SOP of the flood starts from the Advisory issued on heavy rainfall, followed by impact-based Early-warning issued to each River-basin. **Supplementary Materials Table S2** shows different response steps of a river basin SOP. Warning bulletins issued by the Irrigation department are based on the rainfall received by the river-basins, the area covered by the Standing Orders and several features such as flood bunds, roads, etc. [9].

The patterns of land use in the Kelani River basin have changed due to numerous developments and the high land-value closer to the commercial capital city of Colombo [12]. Based on Harvard's proposals (1922–1924) on protection against floods by structural means, building of flood protection embankments were started by the Department of Irrigation (DoI), which maintains the 7.6 km long Flood Protection Bund on the right bank of the Kelani River [9].

Objectives of the SOP are to disseminate the flood Early-Warning efficiently to the public, by giving timely and accurate information with sufficient lead time to minimize damage to life and property. Due to the multitude of organizations involved in response activities during a flood, their coordination becomes complex. Therefore, to operate flood protection works in an efficient and coordinated manner to mitigate floods, SOP covers a procedure that is undertaken by more than one person (or organisation), defining how 'ownership' 'chain of custody' is passed on, particularly across teams.

Having realized the necessity for timely preparedness for flood mitigation in the commercial capital city of Colombo, the TAG (technical advisory group) prepared guidelines (for Kelani River) to be adopted by various institutions, both public and private, in case of floods in Colombo and the suburbs. As several principal state agencies are involved with flood forecasting and mitigation, the TAG recognizes the activities of the relevant state institutions, which must be activated during a flood to meet the set objectives. Cabinet sub-committee decided the Provincial Administration (District Secretaries and Divisional Secretaries), must set up voluntary vigilance groups (VVG). Naval commitment is defined in respect of communication facilities and rescue duties in the Colombo and outer Districts during floods (operation cloud burst) [12]. **Figure 6** shows the Scheme of stakeholders in Standing Orders before the flood and during the flood. In **Figure 6**, "Tanks" refer to cascade of irrigation reservoirs in the tributary rivers.

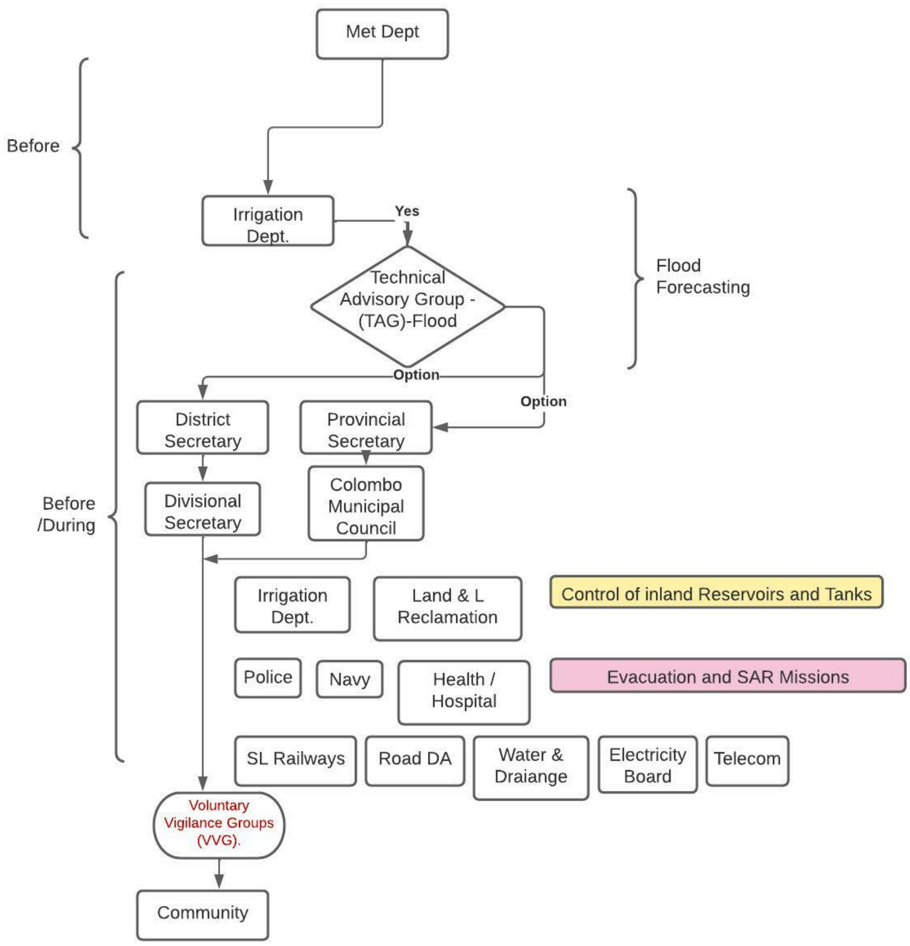


Figure 6. Scheme of Stakeholders in Standing Orders [12].

1.2. Deduru-oya Basin

Kelani River Basin (KRB) SOPs are adopted for Deduru-oya River Basin (DRB). KRB SOP was developed over the past 200 years, due to the commercial and strategic value, and larger population of the Kalani basin. These two river basins represent two different climatic regions of the country (as shown in **Figures 2** and **3**).

The Deduru-oya River Basin (DRB) in Sri Lanka is an important ecological and socio-economic zone, supporting agriculture, water supply, and biodiversity. Managing the environment in this river basin involves addressing challenges related to water resources, land use, pollution, and climate change. Deduru-oya originates in mountains of the Matale District, and it discharges to the sea at Chilaw after flowing about 142 km. As given in **Table 1**, Deduru-oya is the fifth largest river basin in the country with 2,623 km^2 of the catchment area, spread over three climatic zones in Sri Lanka (94% belongs to Intermediate Zone, while 5% and 1% belongs to the Wet and the Dry Zones respectively). In terms of administrative boundaries, 97% of the basin area is covered by the Northwestern Province (Kurunegala and Puttalam Districts) and uppermost 3% by the Central Province (Kandy and Matale Districts).

Four major reservoirs and approximately 3,000 small and medium size "tanks" (cascading irrigation reservoirs) in the Deduru-oya basin provide irrigation and domestic water requirements. The river basin recorded the highest tank density (one irrigation tank per 1.2 km^2) in Sri Lanka [13]. More runoff is generated at upper parts of the basin located in the Wet Zone. Middle and lower parts of the basin are in the Intermediate Zone, which usually faces water shortages in the dry periods. Available surface water in the DRB includes direct rainfall, recharged stream flow in the headwater regions, surface water storage in reservoirs and regional and local groundwater flow. There is significant spatial and temporal variation in annual rainfall (averaged to 1,628 mm). The total basin population is approximately one million [6]. Water use for irrigation and agriculture sector is high compared to domestic, industrial and commercial sectors [14].

Figure 7 shows the locations of principal rainfall and stream gauging stations used in flood forecasting in DRB. Deduru-oya river is affected by intermittent flash floods but suffers from long periods of very low flows during January to March and June to September. Some drought periods endured in the area extended for nearly 7 to 9 months creating an acute water shortage [14]. The rainfall in the basin follows the bimodal pattern with two peaks in the months of April/May and October/November and the minima in January/February and August (See **Table 2** and **Figure 8**). The rainfall runoff ratio is high in August and the low in June [15,16]. Floods are caused by heavy monsoon rains which exceed the capacity of the rivers and drainage system. Also, floods can be caused if dams of water reservoirs are damaged.

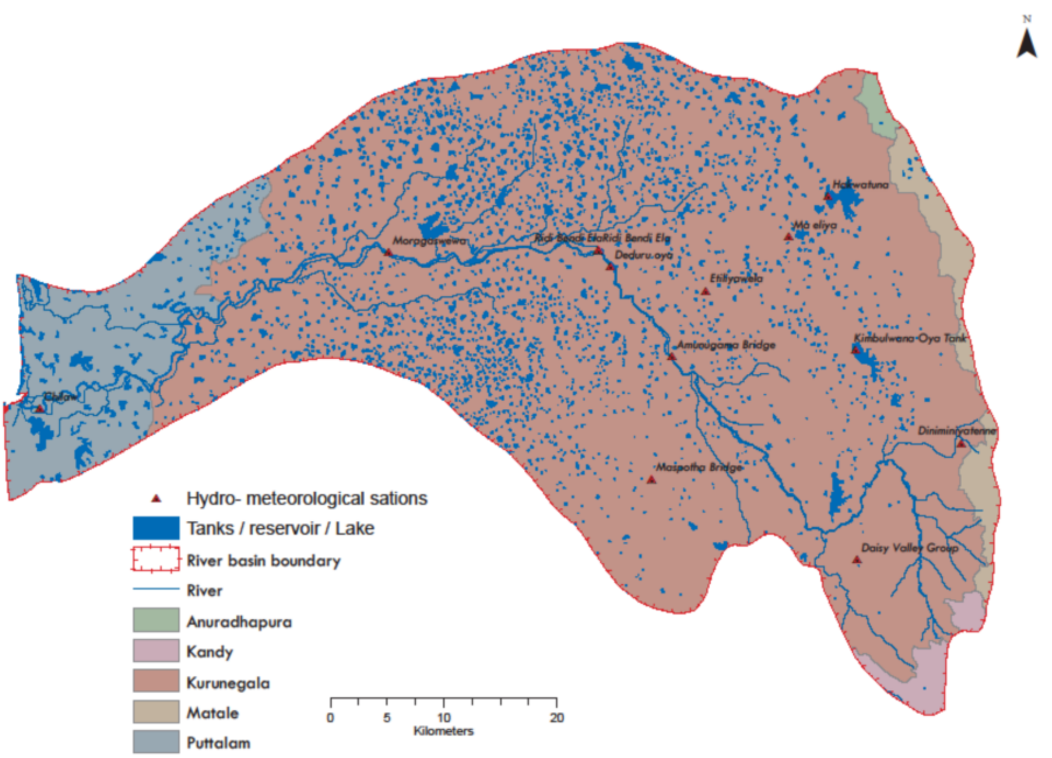


Figure 7. Distribution of River-gauges and Rain-gauges in Deduru-Oya River-Basin (DRB).

Note: Administrative Districts are shown in colour.

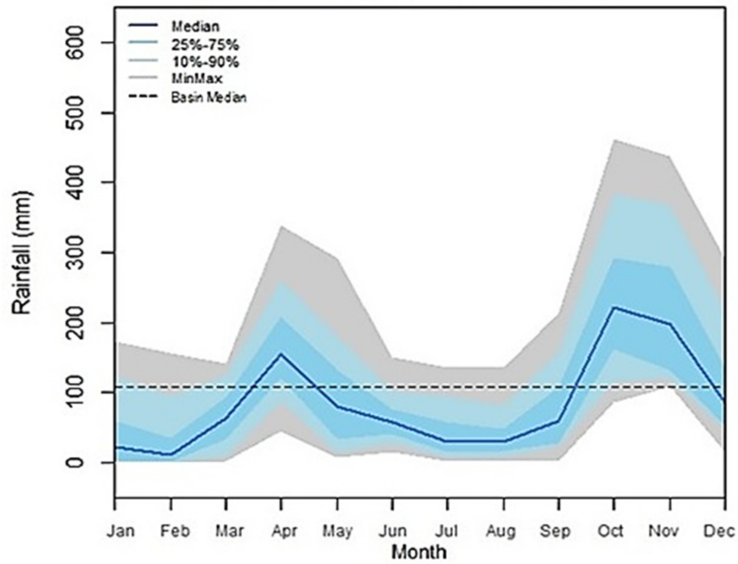


Figure 8. Monthly rainfall variation—DRB-Deduru-oya River Basin [17].

Table 2. Four rainfall seasons (within one year) in Deduru-oya-Basin.

Month	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov
Annual Monsoon Rainfall Season	Northeast monsoon (NEM) "Maha" season			First Inter-monsoon (IM-1)		Southwest monsoon (SWM) "Yala" season					Second Inter-monsoon (IM-2)	

Note: Low intensity rain—light blue, High intensity rain—dark blue.

Floods in lower valley of Deduru-oya are caused by heavy rainfall, particularly in the upper catchment of the river. **Table 2** shows the four distinctive rainfall seasons (within one year) in the Deduru-oya-Basin. Observed critical flood levels are given in **Figure 8** (and DRB flood data in **Table 3**). There is a high potential of great floods of the same magnitude in future.

Table 3. Significant flood incidents in DRB and affected numbers [18].

Year District	Deaths	Missing	Houses Destroyed	Houses Damaged	Number of Affected Families	Affected People
1978 November						
Kurunegala	23	0	34	226	3,916	19,608
Puttalam	0	0	75	175	6,600	28,306
2000 December						
Kurunegala	0	0	5	30	35	177
Puttalam	0	0	35	301	1,445	7,225
2010 November						
Kurunegala	0	0	71	165	1,274	5,053
Puttalam	0	0	3	19	2,796	12,360
2014 December						
Kurunegala	2	0	52	129	3,181	11,142
Puttalam	1	0	0	0	8,010	26,170
2016 May						
Kurunegala	4	0	21	98	2,816	9,645
Puttalam	4	0	21	78	8,931	33,872
2018 May						
Kurunegala	3	1	43	286	3,677	12,688
Puttalam	3	0	60	660	15,903	41,575

Note: 2012 flood data which was a major flood in this river basin is not included.

Figure 8 shows variation of intensity of rainfall in DRB. Also see **Table 1** for discharge data of the catchment.

In a river basin flood response context, proposed institutional reforms required for sustainable management of water resources in DRB for irrigated agriculture, and other general uses, adopt a multidisciplinary and multi-analytic approach [19]. **Figure 9** shows the flood inundation map (of May 2018) with administrative institution (Divisional Secretariat) boundaries superimposed.

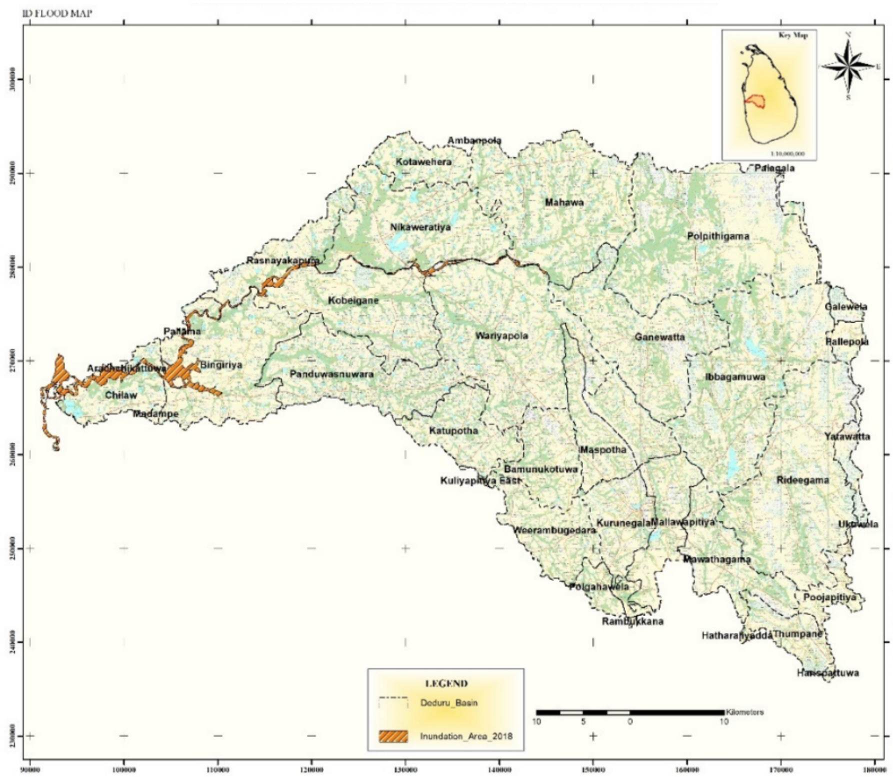


Figure 9. Administrative boundaries of Divisional Secretariat Divisions of Deduru-oya river-basin in flood inundation map of May 2018. Shaded intensity indicated the frequent flood affected Area.

Source: General flood warning, Irrigation Department, 2018.

Supplementary Materials Table S3 gives data of "Frequently Flood Affected" DS Divisions in DRB. **Table 3** shows significant flood incidents in DRB and affected numbers of families & people.

Flood pattern and related environmental impacts are assessed on the above areas, considering **Figure 10**, which shows the cascade of flood flow.

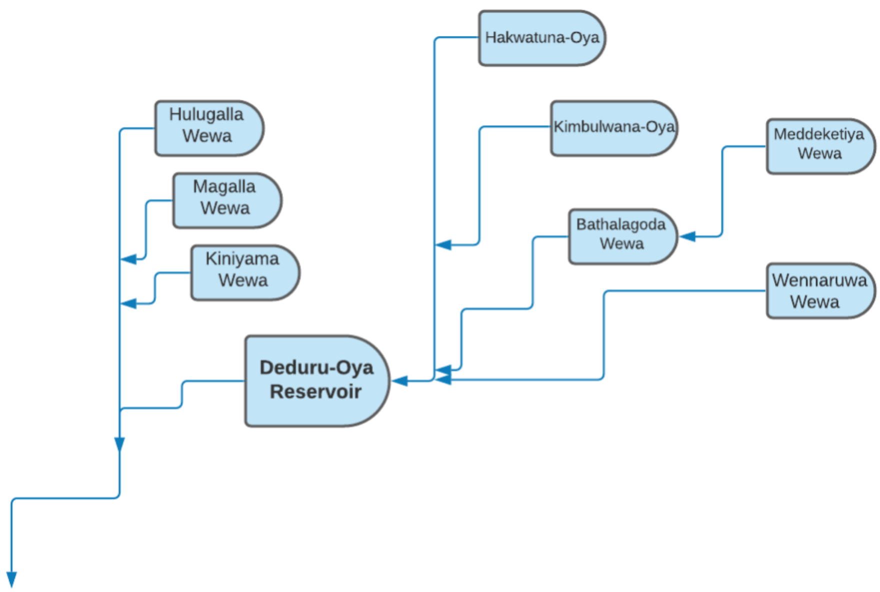


Figure 10. Schematic diagram of the flow of the main irrigation reservoirs in DRB.

Note: "tank" or "wewa" are local terms for irrigation reservoir.

Sri Lanka, an island nation with 103 river basins, faces various environmental challenges in its key rivers. Main river basins, originating from the central highlands in Sri Lanka, face many environmental challenges due to geographical & hydrological reasons, and human activities. **Table 4** lists the main environmental problems associated with some major river basins.

Table 4. Major environmental problems observed in key river basins in Sri Lanka.

Major Environmental Problems	Affected Main River Basins
1. Pollution	• Industrial Waste: Effluents from industries located near river basins, especially in Kelani River Basin, are a major source of water pollution. These include chemicals, heavy metals, and untreated wastewater. • Agricultural Runoff: Excessive use of fertilizers and pesticides in Mahaweli River Basin leads to nutrient runoff, resulting in water contamination and eutrophication. • Domestic Sewage: Unregulated disposal of untreated sewage is a widespread issue, particularly in urbanized river basins.
2. Deforestation and Land Degradation	• Clearing forests for agriculture, settlements, or infrastructure development in watersheds (e.g., in the Kalu Ganga and Mahaweli basins) causes increased sedimentation in rivers. • Loss of vegetative cover reduces the water retention capacity of soils, affecting the river flow and groundwater recharge.
3. Over-Extraction of Water	• Excessive water withdrawal for irrigation, particularly in the Mahaweli and Walawe River basins, has led to reduced down-stream water availability. • Over-extraction has led to saltwater intrusion, particularly in coastal river systems.
4. Sand Mining	• Unregulated sand mining in rivers like the Kelani, Maha Oya, and Deduru Oya leads to erosion of riverbanks, lowering of the riverbed, and habitat destruction for aquatic species.
5. Biodiversity Loss	• Habitat destruction and pollution are major threats to aquatic ecosystems in rivers like the Nilwala Ganga and Gin Ganga. • Overfishing, introduction of invasive species, and changes in water quality further impact native species.
6. Flooding and Altered Hydrology	• Urbanization and improper land use in river basins such as the Kelani and Kalu rivers exacerbate flooding risks. • Deforestation and soil erosion upstream contribute to increased sediment load and altered flow patterns downstream.
7. Climate Change Impacts	• Increased frequency of droughts and intense rainfall events affect water availability and river ecosystems. • Rising temperatures influence river water quality, ecosystems, and agricultural practices.
8. Hydropower Development	• Large-scale hydropower projects, particularly in the Mahaweli basin, alter river flow regimes and disrupt aquatic ecosystems. • Reduced downstream flows affect agriculture and communities dependent on natural water cycles.

Figure 11 shows the schematic diagram of the proposed framework for flood risk assessment and flood frequency analysis, including Hydrologic Engineering Centre's (HEC) Statistical Software Package (HEC-SSP) [20].

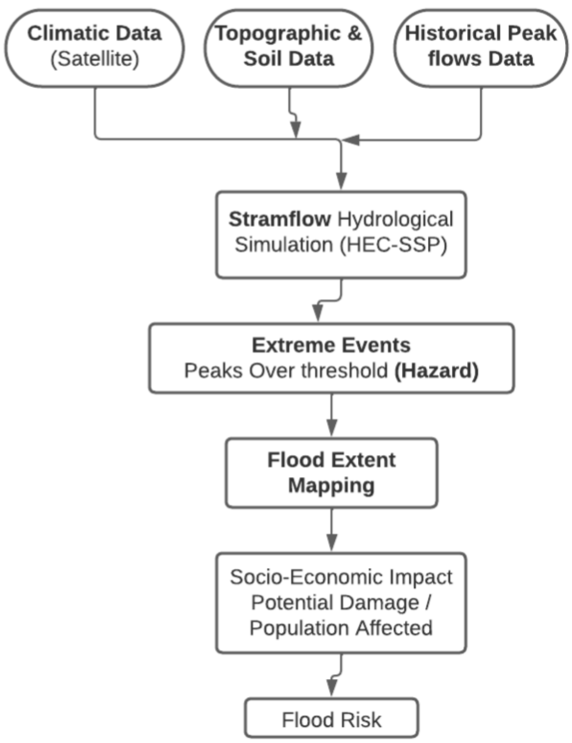


Figure 11. Schematic diagram of the proposed framework for flood risk assessment and flood frequency analysis, including Hydrologic Engineering Centre's (HEC) Statistical Software Package (HEC-SSP) [20].

1.3. Suggested Mitigation Measures

- Strengthening regulations on pollution, sand mining, and deforestation. Promote sand harvesting in sand deposition areas in rivers and link local sand needs to local sand availability.
- Promoting sustainable agricultural practices and waste management systems.
- Enhancing riverbank conservation and reforestation projects in critical areas.
- Conducting public awareness campaigns on the importance of river conservation.
- Developing climate adaptation strategies to address impacts on river systems

1.4. Flood Measurements

Rain gauges and stream flow measuring stations are established by the Irrigation Department for flood forecasting in all rivers (e.g., **Figure 7** for DRB). All flood heights are measured with respect to Mean Sea Level datum, in feet, as read on the principal river gauge established on the left bank, with several other supplementary gauges. Gauge readings are observed every hour round the clock and rainfall measurements are observed at 3-h intervals. Analysis of these data is done by Irrigation Department (DOI). It issues warnings based on the trends observed using trend curves, model results and past experiences. Reservoir floods are monitored based on the water levels of reservoirs and incoming flows.

Currently the water levels of a particular river are categorised into normal-level, alert-level, warning-level and the danger-level. Accordingly, the floods are categorised as Minor, Major, Dangerous and Critical, according to the water level (or stage H) of a particular river gauge, as shown in the **Table 5**. Based on these levels, specific appropriate acts are to be identified. Such information is critical in providing early warning of flood risks for improved flood preparedness. **Table 6** gives the timeline of flood warning and (Colour Coded) Levels of National Warning (Information/Watch/Alert/Evacuation/Stand-down).

Table 5. Critical Water Level at Flood Warning Stations in Kelani & Deduru-oya Rivers.

River-Water Level	Normal	Alert		Warning	Danger	
Flood Category Based on	**-**	**Alert**	**Minor**	**Major**	**Dangerous**	**Critical**
Kelani-Basin Nagalagam River-gauge	5ft > H (1.52 m)		5 ft < H	7 ft (2.13 m) < H more houses inundated; road will be impassable	9 ft (2.74 m) < H Flood Protection Bund (right bank) is not designed against such floods and would therefore tend to be extremely vulnerable.	
Deduru-oya reservoir spill discharge	-	10,000 cf/s	16,000 cf/s	32,000 cf/s	55,000 cf/s	

After 2012, with operating of the Deduru-oya reservoir, its discharge is also used to categorise different flood levels, downstream of the reservoir.

Table 6. Timeline of Flood Warning and (Colour Coded) Levels of National Warning (Information/Watch/Alert/Evacuation/Stand-down).

TIME Sequence	Warning/Advisory Bulletin No.	Flood Message (NFWC, Irrigation Dept.)	Landslide Message (NBRO)	Activity Action Required
T_1 = 5–10 min	Receiving Met Advisory Bulletin	Met Call Heavy Rain Occurred	Estimation of the threat	Estimation of the threat
T_2 = 10–20 min	Information Bulletin-I [Colour-Code: Yellow]	Watch: Flood Heavy Rainfall received.	Since the rainfall within the past 24 h has exceeded 75 mm, if the rain continues, *be watchful about the possibility of landslides, slope failures, rock falls, cutting failures and ground subsidence.*	Stay vigilant wait for more information
T_3 = 15–30 min	Bulletin-II [Colour-Code: Amber]	Alert: Flood Flood may be generated	Since the rainfall within the past 24 h has exceeded 100 mm, if the rains continue, *be on alert on the possibility of landslides, slope failures, rock falls, cut failures and ground subsidence*, and be ready to evacuate to a safe location.	Be vigilant and get ready for possible evacuation.

Table 6. *Cont.*

TIME Sequence	Warning/Advisory Bulletin No.	Flood Message (NFWC, Irrigation Dept.)	Landslide Message (NBRO)	Activity Action Required
T_4 = 5–10 min	Bulletin-III [Colour-Code: Red]	Evacuation Order: Flood	Since the rainfall within the past 24 h has exceeded 150 mm, *if the rains continue, evacuate to a safe location, to avoid the risk of landslides, slope failures, rock falls, cutting failures and ground subsidence.*	Evacuate to the safe areas
	Bulletin-IV [Colour-Code: Green]	Clear all/Stand Down/Withdrawal/ Cancellation Order (Flood Warning)		END of Flood Threat. Act as instructed by the local level authorities.

Note: Landslide Early Warning by National Building Research Organisation (NBRO) and National Flood Warning Centre (NFWC) of the Department of Irrigation.

The US National Weather Service standards used to communicate characteristics of flash flooding include return periods & river flooding severity scale, based on simulation models of worst-case scenarios. Classification of a flood is defined using a Flood Severity Index, in a particular river-basin (**Table 7**). When the water level reached 'Severe-flood' situation, buffer-zones also got inundated. Affected families are categorised based on the score of the exposure shown in **Table 8**. The communities will be categorised based on the geographical zonation of the river; considered as the indicator of the flood severity (**Figure 12**).

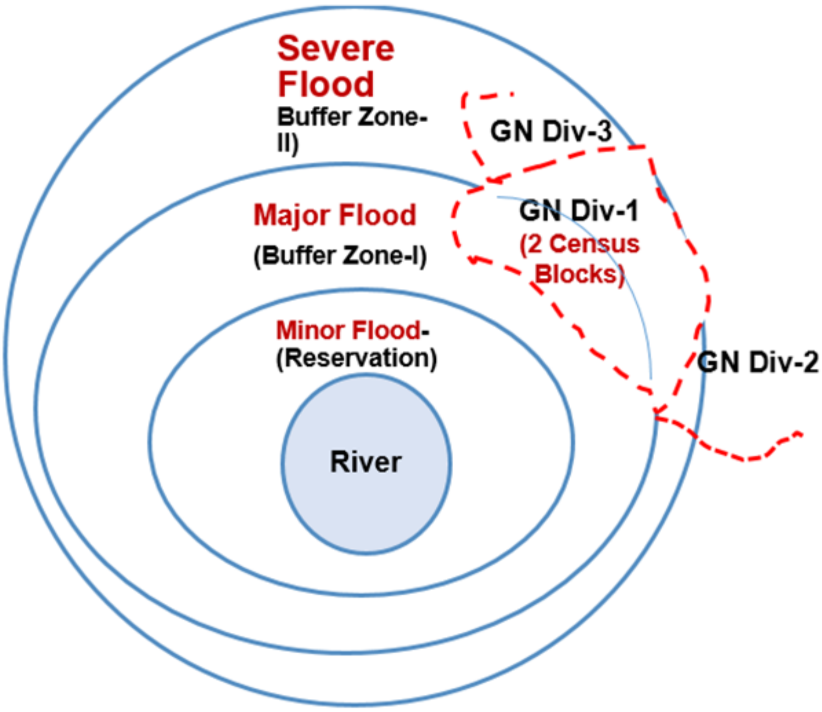


Figure 12. Different flood affected zones, based on conceptual contour-line demarcation of the river-Basin. GN Div is the Village Officer's division, the smallest census block [21].

Table 7. Use of Flood Severity Index for Flood Classification in a River-Basin, Sri Lanka.

Parameter	Level 1 Minor	Level 2 Major	Level 3 Severe	Level 4 Enormous
% Affected Population in River-basin	<1%	5%	<10%	>10%
% Flooded Land Area in River-basin	<1%	1–5%	<10%	>10%
Flood Retention Period	<12 h	12–36 h	36–72 h	>72 h

Note: Enormous Flood is a somewhat hypothetical scenario.

Table 8. Three Categories of the Affected Families [21].

No.	Parameters/Indicators of the Affected Families	Affected/Exposure		
		Category-1	Category-2	Category-3
1	**Indirect Losses**			
	Access Blocked/Isolated	1	1	1
	Diseases	1	1	1
	Environmental Damage	1	1	1
2	**Economic**			
	Livelihood (Crop/Livestock)	0	1	1
	Business damage	0	1	1
3	**Physical Damage**			
	Non-structural/damage to contents	0	1	1
	Structural/House Damaged (Fully/Partially)	0	0	1
4	**Human-Social**			
	Injuries	0	0	1
	Fatalities	0	0	1
	Total Score	3	6	9

Note: Indicator based on total score given.

An impact-based Flash Flood Severity Index (FFSI) was proposed as a damage-based, post-incident assessment tool, to address the misunderstood "return periods" and the limited (USA National Weather Service) NWS scale to flooding on gauged streams and rivers [22]. Accordingly, the thresholds should be set, which are high enough to qualify as truly disastrous situations and become the domain (target) of the National governmental response (mainly making funding and other resources available). Documentation of staff training can be used to standardize your practice versus adapting to all stakeholder requests. **Table 8** shows three categories of the affected families.

According to the land ordinance, river and stream reservations are declared as crown/state land and related authorities must be responsible for acquiring and maintaining them. Census block [21] as shown in **Figure 12**, is the smallest desegregated unit.

For example, in **Figure 12**, during the Severe-Flood status, in GN Div-1, in Buffer Zone-I, the families are in Affected Category 3; and in Buffer Zone-II, the families are in Affected Categories 1 and 2. Buffer-Zone-I is not recommended for permanent buildings, and some illegal constructions are observed (in this zone) in both KRB and DRB river basins.

Physical demarcations of the affected area will be used towards the effective utilization of land and water resources associated with the vulnerable river. Accordingly, the residents and visitors are to assess their risk and take necessary precautions; based on the vulnerability of their houses and properties for future flooding. The possibility of disseminating timely Early-Warning text messages at grass-roots level is to be explored. As most of the river-basins (boundaries) are inter-District or inter-Provincial; the river-basin base is a more sensible way to demarcate the exact flood-affected areas, in future [21,23].

1.5. Effective Flood Response and Environmental Management

Effective flood response and environmental management are critical to mitigating the impacts of floods on communities, ecosystems, and infrastructure. A well-organized flood management strategy involves both proactive measures and reactive response efforts. By combining these strategies, communities can effectively reduce the risks associated with floods, respond more efficiently during emergencies, and recover faster afterwards. Environmental management also ensures that flood response efforts do not harm the natural resources that are essential for long-term resilience.

Supplementary Materials Table S2 gives different response steps of river basin SOP. (End to end warning and response steps). These include actions, and responsible stakeholder agencies, after issuing of early warning or on occurrence of a disaster (exhaustive list to be prepared), working with the important key sectors (safety and security, health, water and sanitation, power, transport, communications, roads, food supply, etc.) ensuring multi-disciplinary and multi-sectoral response.

2. Materials and Methods

This study adopted an integrated qualitative research approach including research papers, reports, codes, guidance documents and databases. The existing secondary data available at government agencies (Irrigation Department, Meteorological Department, Divisional Secretariats and Land Use Planning Department, etc.) that operate in the river basin were utilized for identifying physical features of the basin. Field visits helped confirm the specific issues/features of flood management.

This case study was conducted in August 2020 in Deduru-oya River basin, Sri Lanka. Data were collected via questionnaires from 405 households across 10 village Vulnerable Census Blocks (VCB), supplemented by interviews with 10 Community-Based Organizations and 20 officials (professionals). Field visits and stakeholder consultation were carried out through participatory rural appraisal sessions (PRAs) with different water users in the basin, to understand different water user sectors and their locations. Semi-structured interviews were conducted with the (flood responsible) emergency officers to clarify the strategies set up to respond to emergencies.

At the Ridi-Bendi-Ela diversion point of the river, Deduru-oya basin is divided into an upper and lower basin which are almost equal in size [24]. The hydrometric network in DRB comprises several meteorological stations and two-stream gauging stations (see **Figure 7**). Most of the stations have satisfactory long-term records with the least number of missing data. Consistency and validity of meteorological and hydrological data were tested using standard statistical methods. Analyses, including exploratory factor analysis and reliability testing, were performed with SPSS-V26.

DesInventar database was used to map the most affected DS Divisions in Deduru-oya river basin in the two Districts, Kurunegala and Puttalam (which include most of the river basin). DesInventar is a conceptual and methodological tool for the generation of National Disaster Inventories and the construction of databases of the effects of disasters [18]. Flood inundated areas were mapped using ARC-GIS tool, assessing the water resources. ARC-GIS was further used to store, retrieve and analyse different types of hydrological data and to display them for easy retrieval and understanding.

3. Results and Discussion

3.1. SOPs and Early Warning Systems

Suggested format of DRB SOP will be an improved version of the existing KRB SOP, as given in **Supplementary Materials Table S1**.

The results show that while attractive emergency responses are available, many mismatches could have been avoided when past experience is reviewed carefully (India, SOP). During monsoon season, SAR (Search and rescue) teams can be deployed in the different parts of flood vulnerable areas in the country as a pro-active measure, enabling the local/district authorities to act within the 'Golden Hour' after a disaster event. Multi-sectoral Technical Advisory Committee (TAC) experts, who provide technical and tactical guidance, can be identified and provided resources.

Some response disruptions caused by extreme weather events and system failures emphasize the need to review current resilience strategies. Making in-depth and independent investigations using modelling and simulation could provide evidence for decision-makers to improve current strategies and the National Emergency Operation Plan (NEOP). The complexity of response facilities lies with the number of systems that the DMC host and the interconnectivity of these systems with each other and with external systems and with the new care models [25–28].

Early warning systems trigger the activation of SOPs, and response mechanism, like ICS Incident Command System. This strategy is often based on interconnections between visual observations, past experience and cooperation to mitigate losses from upcoming hazards, informing communities in a timely manner on imminent threats. For an effective early warning system, the inclusion and interaction between risk knowledge, monitoring and warning services, dissemination and communication and response capability, are vital up to the ground level [29,30]. Rainfall threshold levels triggering flood and landslide in each river-basin are to be properly comprehended to issue accurate Warning Bulletins on Floods and Landslides.

The early flood warning system uses different data inputs (satellite imagery, rain radar, precipitation monitoring for flood model calculations) to elaborate forecasts and flood hazards maps. These maps are used to classify imminent flood threats into four danger levels. Inhabitants are then made aware of the impending threat through media and a dedicated website or an App [29,30].

Standard Operating Procedures (SOPs) are highly relevant in both emergency management and environmental management. Both contexts rely on SOPs to standardize actions, reduce errors, and promote safety and sustainability. Well-designed SOPs also facilitate training, accountability, and audits, ensuring that organizations meet legal, ethical, and operational standards. In the context of environmental management, SOPs are supposed to be designed to minimize environmental impact, ensure regulatory compliance, and promote sustainability across various industries and organizations.

SOP has been prepared with the objective that all the required and approved procedures are followed in response operations, and all the processes and activities continue simultaneously and uninterrupted, so that whole tasks are completed in the prescribed schedule. SOP establishes the procedure for the emergency response of the designated SAR team(s) during disasters and prescribes guidance and assigns responsibility for adapting various executive actions to ensure prompt response [31]. Flood warnings are typically categorized into levels based on the severity of the flood event and the expected impact. Flood warning Standard Operating Procedures (SOPs) typically differentiate between upstream and downstream activities based on their geographic locations along a watercourse and the nature of actions required. These levels correspond to various stages of flood risk and preparedness. **Figure 13** shows how upstream and downstream warning levels are structured between the interface in flood warning SOPs. **Figure 14** shows different levels of the flood response proposed.

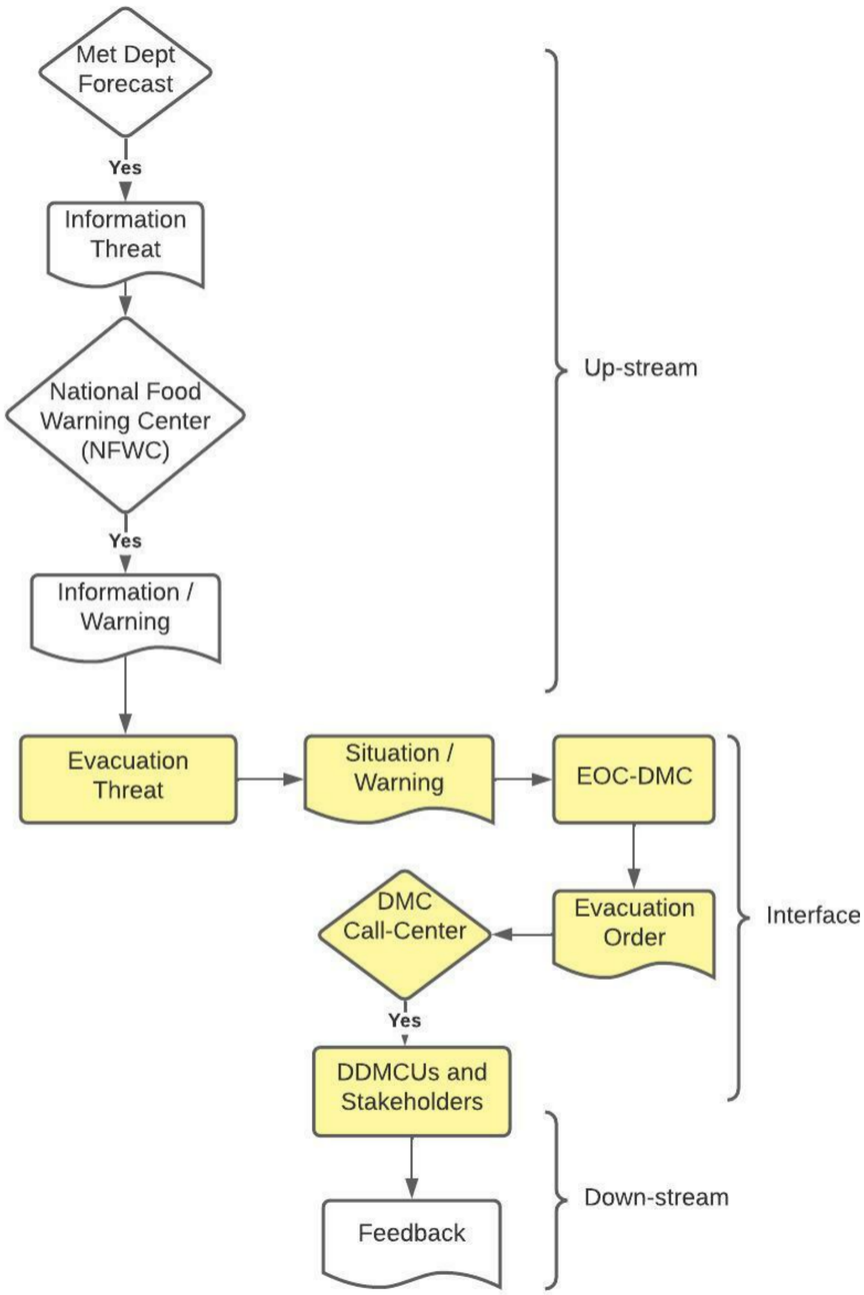


Figure 13. Different levels of the flood warning proposed Up-stream and Down-stream, from disaster interface.

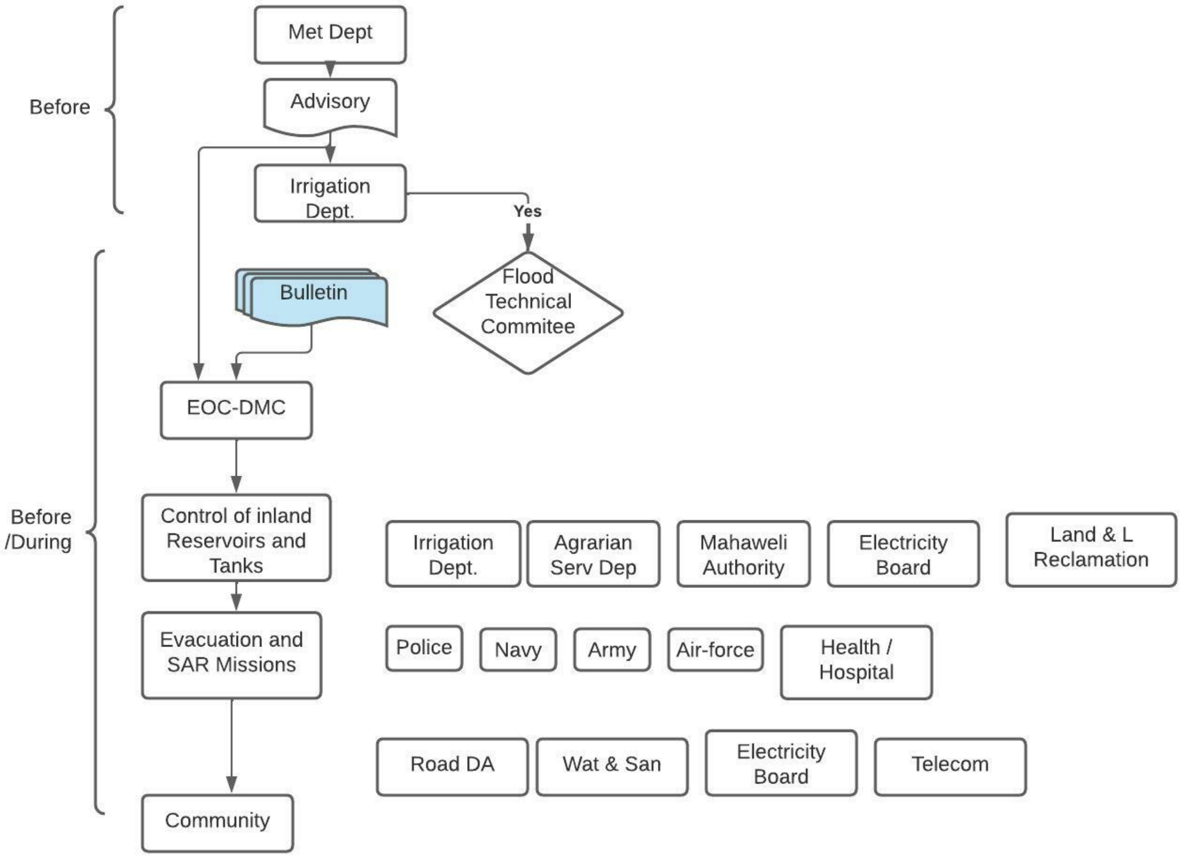
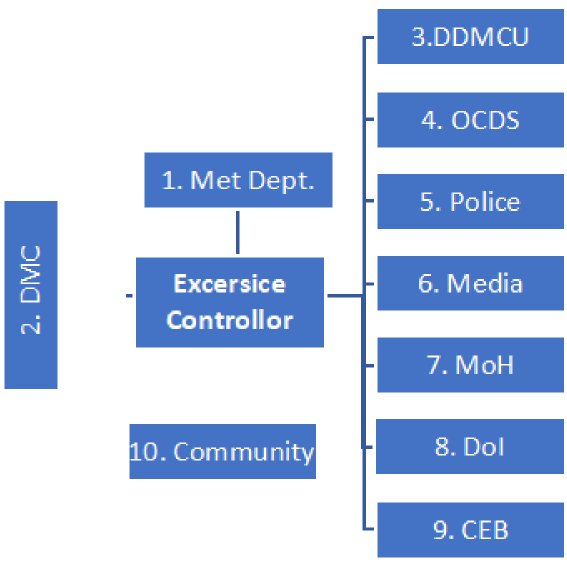


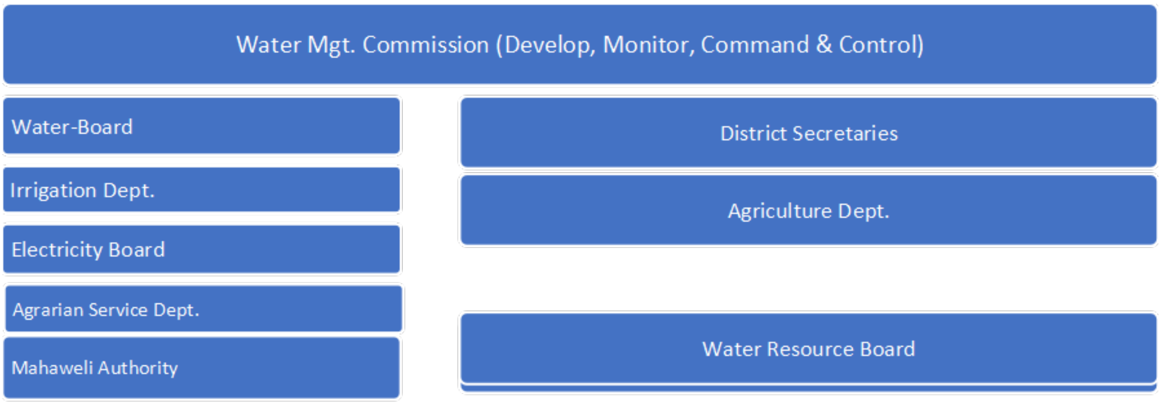
Figure 14. Proposed different levels of the flood response.

Figure 15 shows how the centralized Water Management System was tested in a "Tabletop Exercise" (TTEX) to further strengthen the Public Notification, Public Decision and Public Action.



(a)

Figure 15. *Cont.*



(**b**)

Figure 15. (**a**) Table-Top-Exercise (TTEx) arrangement; (**b**) Centralised Water Management System is tested in a Tabletop Exercise (TTEX) to further strengthen the Public Notification, Public Decision and Public Action.

Major Functional Areas in the Incident Command System (ICS) are enabled for managing an incident. It is designed so that each functional area is led by a team leader, and the entire ICS is led by an Incident Commander [32,33].

3.2. Post Disaster Recovery and Relief

The government is mandated to assist disaster affected communities by providing immediate relief and facilitate them up to early recovery. Cooked meals are provided to all families and persons affected by the disaster, irrespective of their income level. Moreover, timely assistance from the First Responders is vital depending on the magnitude of the disaster [34–38].

In the Sri Lankan scenario where capability for rapid data sharing exists, it is proposed to measure Flood Severity based on "Flood Severity Index" as given in **Table 7**, employing a few parameters, like the number of affected-persons, affected areas and the Flood Retention-Period, etc. Using the updated hazard risk maps and Scenario-Models for the river-basins, some prior demarcation of the frequent flood areas is recommended.

3.3. Emergency Response

It is believed that emergencies will happen regardless of the level of preparedness, and individuals involved with the crisis must deal with the situation. Community resilience is not only for the business continuity, but it is also a "social, moral and ethical necessity"; particularly in terms of public confidence [39–41].

There are 103 rivers-basins in Sri Lanka. The uses of the rivers are mainly designated as drinking, washing and agricultural purposes. Administrative Boundaries are cutting through the waterways and river basins. They create difficulty on proper management of river behaviours. Therefore, a wide discussion must be made in Sri Lanka considering the water management issues and if possible, all the future administrative matters should be organized under a river basin framework, e.g., as given in **Figure 16.** Considering the available legal powers for disaster management, Department of Irrigation can host such a water management Commission (In charge of developing, monitoring, command and control of disaster management response, coordinating with District Secretaries, Disaster Management Centre, NBRO, CEB (Ceylon Electricity Board), Department of Irrigation, Water Resources Board, National Water Board, Department of Agriculture, Department of Agrarian Services and other stakeholders).

Figure 17 shows the risk transfer-model, with response levels (national, provincial, district) and the risk levels, Low (L), Moderate (M) and High (H), denoted by traffic light colours green, amber and red, respectively.

Nearly 21 Acts, Ordinances and other enactments have been passed for development, allocation, regulation, usage and management of water resources, to resolve water issues, to effect soil and forest conservation, and specially to protect water resources and the environment from getting polluted, in several water-use sectors. Considering the river basin as one unit, is advocated as a viable operational concept for the development and management of water resources in future Sri Lanka. The Water Management Act can be revised to address the disasters caused by the rivers, especially the floods, and identify the water-related hazards. Demarcation of administrative boundaries using natural catchments, will solve future water conflicts and help develop a unified disaster response policy and planning process (SOPs).

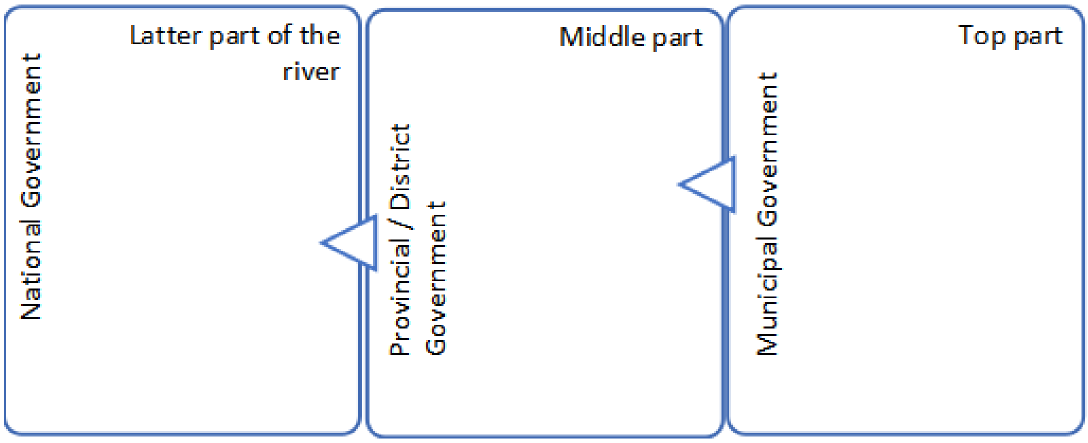


Figure 16. Proposed responsibility areas of water management considering flow in a River Basin [42].

Response Level Risk Level	National	Provincial /District	Divisional	GN (Village Level)
High *(Red)*	1	1	1	1
Moderate *(Amber)*	1	1	1	1
Low *(Green)*	1	1	1	1

Figure 17. Risk Transfer-Model.

Note: When the response to the incident exceeds area capacity (e.g., Divisional Level), it will be escalated to the next area response level, until the colour comes back to green. Accordingly, the risk level will be communicated through a risk value legend, marking in a risk profile map. E.g., at Divisional Level. **Low** *(Green)* L ≤ 4. **Moderate** *(Amber)* 4 < M ≤ 5. **High** *(Red)* 5 < H ≤ 6. Threshold for the Response Level should be identified for each disaster accordingly [43].

Response framework comprises all levels of response, starting with spontaneous community actions immediately following the disaster, supplemented initially by the local emergency services and then by national rescue teams. To ensure interoperability between the different levels of response, it is vital that working practices, technical language and information are common and shared through all levels of the response framework. **Figure 18** shows the hierarchy of emergency management documents. Different levels are shown from top to bottom, down to the generation of operational guidelines. Regulations must be set identifying Incident Command System (ICS) as standard response/operational tool [44].

SOP aims at assigning accountability at all the stages, with exhaustive efforts. To clarify any ambiguity and instructions on any issue, relevant authority shall issue separate (further) orders and instructions. The river basin SOP shall be revised regularly, as more experience is gained, and as and when the procedures mentioned are reviewed or become obsolete with time. In **Figure 19**, during the response sphere, responsible and related tasks are to be clearly defined. Experience proves that the SOP helps to smooth functioning of algorithmic patterns of the physical environment with previously unknown individuals and such a written procedure is useful in emergencies, panicked and confused working environments.

Figure 18. Hierarchy of Emergency Management Documents. Different levels top to bottom, down to the generation of operational guidelines. Regulations to be set identifying Incident Command System (ICS) as standard response/operational tool [44].

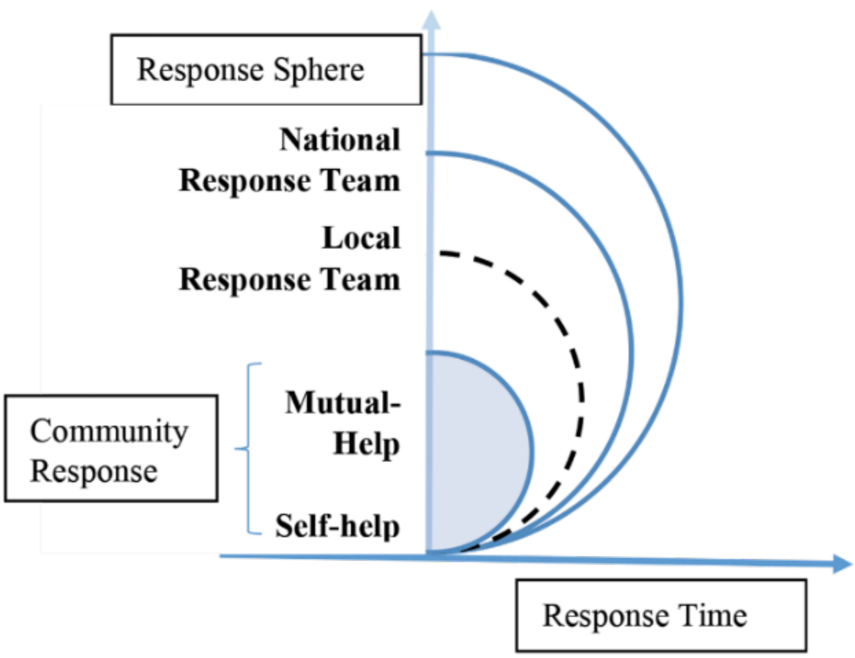


Figure 19. Chronological Response Framework. Change of the Incident Response sphere with temporal dimension. The missing link with the community must be incorporated into the SOP [22,23,45].

4. Conclusions

This study affirms that effective flood management requires more than strategic planning. It demands clearly understood, continually updated, and coordinated operational systems. River basin SOPs (Standard Operating Procedures) must be thoroughly interpreted by stakeholders, with roles, responsibilities, and accountability formally assigned to identified individuals across all levels of governance. The findings verify that interagency coordination mechanisms, inclusive of Community Based Organisations (CBOs) and voluntary response groups, are indispensable, particularly as evidenced during the May 2016 and May 2018 floods in the Kelani river basin. Historical experience underscores the substantial contribution of voluntary actors, justifying their formal integration into structured SOP communication, rehearsal, auditing, and pre-event operational audits.

The study proposes the Census-Block (village, as in **Figure 12**) as the smallest desegregated Incident Response Area, enabling precise accountability and coordinated incident command. It further establishes that iterative SOP rehearsal and auditing cycles strengthen the ability of agencies to deliver rapid, synchronized responses, minimizing both immediate and cascading flood impacts. Results also demonstrate that soft adaptation strategies, such as adaptive SOPs, are often more effective than hard "infrastructure only" responses in managing uncertainty, particularly under increasing climate change scenarios. Given persistent uncertainties, including climate change and reservoir discharge volatility, soft adaptation must be prioritized alongside further research and post-event data integration. The study confirms that actual reservoir discharge records can be used to refine SOP embedded flood forecasting, and improve predictive reliability for future events, supporting a dynamic operational learning loop.

The findings further emphasize the need to revisit existing legislation, including the Water Management Act and related regulatory instruments, to explicitly recognize river induced disasters and formally classify water related hazards using standardized metrics such as the Flood Severity Index. The study advocates for the adoption of the river basin as the core geographic unit for "flood hotspot" classification under a declared State of Climate Emergency. Aligning administrative demarcations with natural flow paths and river basin boundaries is recommended as a strategic policy mechanism to reduce future water conflicts while strengthening disaster governance, planning, and policy coherence.

Collectively, the study concludes that adaptive, inclusive, and regularly revised SOPs enhance institutional readiness, reduce procedural ambiguity, and improve decision making in high stress, panic driven, and multi-actor emergency environments. Importantly, the value of SOPs extends beyond flood response, offering a transferable operational model applicable to other natural disasters, contributing to integrated disaster governance, environmental resilience, and long-term recovery. The future of disaster preparedness must therefore evolve from static procedural compliance toward continuous operational learning, ensuring emergency response systems remain adaptive, collaborative, ecologically aligned, and locally empowered, to act using sub-national resources.

The results of this study will not be limited to floods but also to other natural disasters, to draw a comprehensive picture of SOPs for emergency response.

Supplementary Materials

The supporting information can be downloaded at https://ojs.ukscip.com/files/JHEWS-1649-Supplementary-Materials.docx.

Author Contributions

Conceptualization, H.I.T., D.R.I.B.W., C.M.M.-B. and T.W.M.T.W.B.; data curation, C.S. and S.P.C.S.; formal analysis, H.I.T.; investigation, H.I.T. and A.Y.K.; methodology, H.I.T.; project administration, D.R.I.B.W. and H.I.T.; resources, D.R.I.B.W., A.Y.K., S.P.C.S., S.B.W., C.M.M.-B. and T.W.M.T.W.B.; supervision, H.I.T., D.R.I.B.W., C.M.M.-B. and T.W.M.T.W.B.; validation, H.I.T.; writing—original draft, H.I.T.; review and editing, D.R.I.B.W. All authors have read and agreed to the published version of the manuscript.

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Data can be requested for research purposes from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest.

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