Integrating SMART principles in Flood Early Warning System Design in the Himalayas

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Supplementary Information (SI)

A snippet of all the heavy and very heavy events provides a concise summary and underscores the importance of a dense sensor network. This table shows variability in the response of the watershed in terms of water level. "-" represents missing data for that event.

RG1

Time_stamps	RG1(mm)	RG2(mm)	RG3(mm)	RG4(mm)	Category-RG1	Category-RG2	Category-RG3	Category-RG4	Wl1 (cm)	Wl2 (cm)	Wl3 (cm)	Category-wl_1	Category-wl_2	Category-wl_3
9/1/2022	157	46.2	-	11.2	**very heavy**	rather heavy	-	moderate	138	-	165	Advisory	-	Advisory
9/25/2022	73	89	-	92.4	**heavy**	heavy	-	heavy	155	-	199	Advisory	-	Warning
6/25/2023	96.4	50.8	45.8	0.2	**heavy**	rather heavy	rather heavy	very light	56	-	73	Cancellation	-	Cancellation
8/17/2023	70.4	54.6	-	19.6	**heavy**	rather heavy	-	moderate	60	125	124	Cancellation	Advisory	Cancellation
8/21/2023	106.8	167.6	-	242.2	**heavy**	very heavy	-	very heavy	-	113	170	-	Advisory	Advisory

RG2

Time_stamps	RG1(mm)	RG2(mm)	RG3(mm)	RG4(mm)	Category-RG1	Category-RG2	Category-RG3	Category-RG4	Wl1 (cm)	Wl2 (cm)	Wl3 (cm)	Category-wl_1	Category-wl_2	Category-wl_3
9/25/2022	73	89	0	92.4	heavy	**heavy**	-	heavy	155	18	199	Advisory	-	Warning
6/22/2023	14.6	108.6	124.2	3.6	moderate	**heavy**	heavy	light	-	59	136	-	Watch	Watch
7/17/2023	0.4	76.8	124.2	3.2	very light	**heavy**	heavy	light	105	58	150	Watch	Watch	Watch
7/25/2023	-	68	-	49.4	-	**heavy**	-	rather heavy	119	110	133	Watch	Advisory	Watch
7/28/2023	-	90.2	-	11.8	-	**heavy**	-	moderate	102	93	119	Watch	Advisory	Cancellation
8/7/2023	-	107.6	-	25.4	-	**heavy**	-	moderate	-	212	158	-	Warning	Advisory
8/11/2023	-	68.8	-	33	-	**heavy**	-	moderate	-	142	110	-	Advisory	Cancellation
8/14/2023	3.8	170.4	-	165.8	light	**very heavy**	-	very heavy	-	147	172	-	Advisory	Advisory
8/18/2023	53.6	66.2	-	78	rather heavy	**heavy**	-	heavy	-	92	123	-	Advisory	Cancellation
8/21/2023	106.8	167.6	-	242.2	heavy	**very heavy**	-	very heavy	-	113	170	-	Advisory	Advisory

RG3

Time_stamps	RG1(mm)	RG2(mm)	RG3(mm)	RG4(mm)	Category-RG1	Category-RG2	Category-RG3	Category-RG4	Wl1 (cm)	Wl2 (cm)	Wl3 (cm)	Category-wl_1	Category-wl_2	Category-wl_3
6/22/2023	14.6	108.6	124.2	3.6	moderate	heavy	**heavy**	light	-	59	136	-	Watch	Watch
7/4/2023	3	27	66	59.2	light	moderate	**heavy**	rather heavy	68	113	116	Cancellation	Advisory	Cancellation
7/17/2023	0.4	76.8	124.2	3.2	very light	heavy	**heavy**	light	105	58	150	Watch	Watch	Watch

RG4

Time_stamps	RG1(mm)	RG2(mm)	RG3(mm)	RG4(mm)	Category-RG1	Category-RG2	Category-RG3	Category-RG4	Wl1 (cm)	Wl2 (cm)	Wl3 (cm)	Category-wl_1	Category-wl_2	Category-wl_3
9/4/2022	18.4	56.8	-	89.6	moderate	rather heavy	-	**heavy**	132	-	167	Watch	-	Advisory
9/25/2022	73	89	-	92.4	heavy	heavy	-	**heavy**	155	-	199	Advisory	-	Warning
7/9/2023	1.4	57.2	63.6	74.8	very light	rather heavy	rather heavy	**heavy**	83	-	80	Information Statement	-	Cancellation
7/12/2023	1	53.6	55	68.6	very light	rather heavy	rather heavy	**heavy**	77	55	87	Information Statement	Watch	Cancellation
8/13/2023	0	42	-	65.2	no_rainfall	rather heavy	-	**heavy**	-	147	172	-	Advisory	Advisory
8/14/2023	3.8	170.4	-	165.8	light	very heavy	-	**very heavy**	-	147	172	-	Advisory	Advisory
8/18/2023	53.6	66.2	-	78	rather heavy	heavy	-	**heavy**	-	92	123	-	Advisory	Cancellation
8/21/2023	106.8	167.6	-	242.2	heavy	very heavy	-	**very heavy**	-	113	170	-	Advisory	Advisory

Spatial variability of rainfall

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The cumulative plot of monthly observed rainfall across different rain gauges illustrates significant variation in rainfall distribution within the watershed over the course of a year.
Despite the small size of the watershed, noticeable monthly differences highlight the spatial variability in precipitation patterns.

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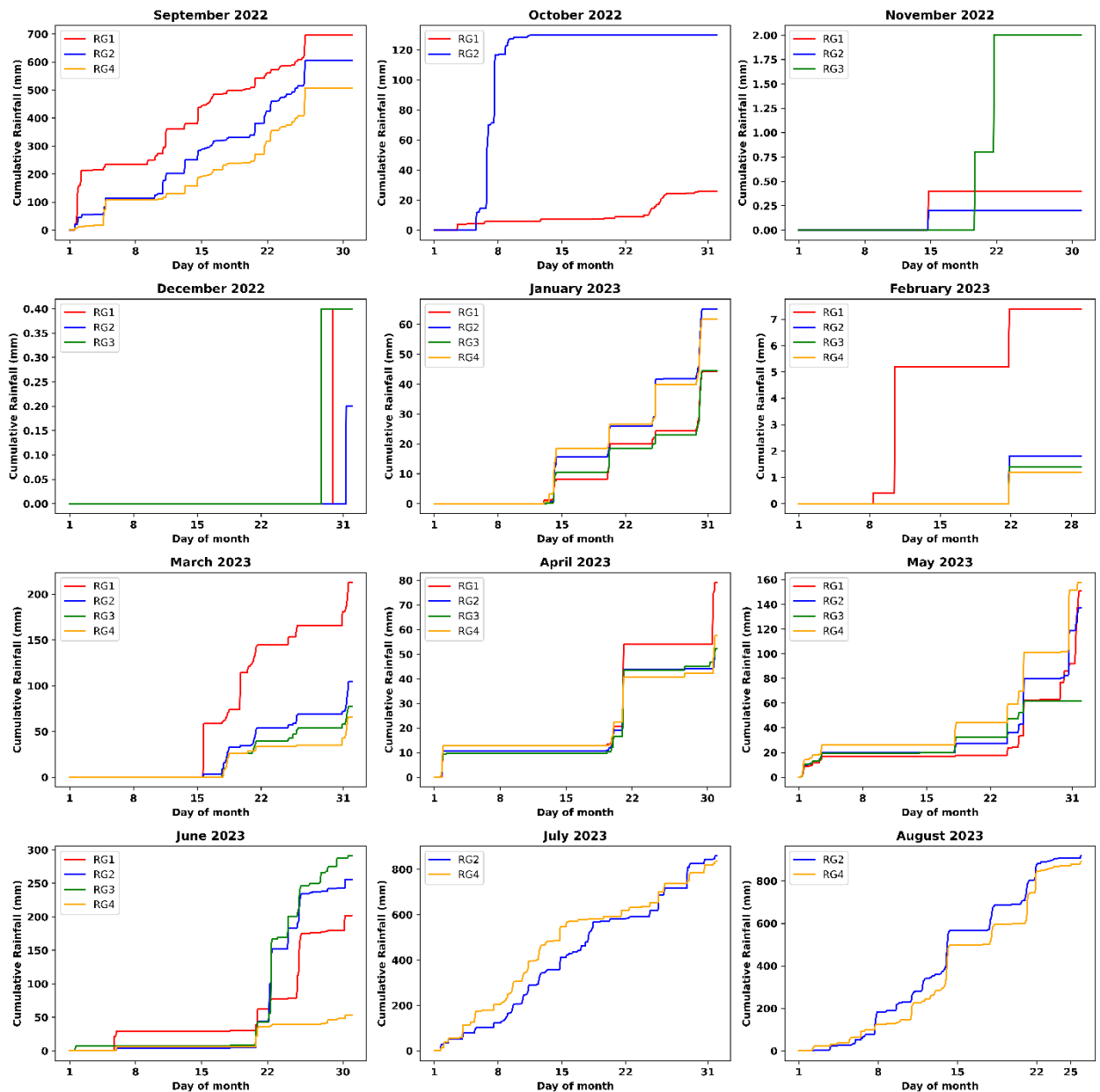
Figure S1: Cumulative plot of monthly observed rainfall in different rain gauges across the watershed.

Community interaction

The following are the key findings from the PRA exercise, which help provide an overall idea of the flood situation.

- ✓ The level of water in the river increases in rainy season (July-Sept) to 10-15 feet else it remains up to 0.5-1 feet only throughout the year.
- ✓ The water quality of Bindal only improves after heavy rainfall for a few days, but it again becomes dirty in the next week.
- ✓ It was found that the waste from all localities was disposed of directly into the river by people and through sewer lines.
- ✓ From the past 3-4 years, the intensity of the flood has increased with every rainfall.
- ✓ The damage caused by the flood was mostly due to bank erosion, and it affected the people living in non/semi-concrete houses compared to those living in concrete houses. No/less damage was recorded in the localities with all concrete houses near the riverbank.

Figure S2: Field team conducting a household survey in the study area

- ✓ In all three stretches, the people who are mostly affected by the flood are from the labor class or low-wage workers. The flood had damaged some parts of their houses, carried away their assets (bicycle, television, documents, etc.), livestock or a family member.
- ✓ Through FGDs, it was observed that people were unable to suggest new ideas about early warning systems since they were less educated and also not able to understand the need to install them in their locality.
- ✓ According to the people, the amount of rainfall today has reduced as compared to 30-40 years ago when there were more trees, forests, and rivers.

Community involvement plays an important role in gaining insights into the varied impacts of floods across different segments of society. By engaging with the community, researchers can discern the specific classes of people most affected by flooding, whether they are marginalized groups, urban residents, or rural communities. Furthermore, community engagement facilitates an understanding of the diverse perspectives held by individuals and communities regarding flood events, including their perceptions, concerns, and experiences.

Summary of Household surveys

Sample Size: 100 Households in 5 critical localities.
Respondents: Male 46%; Female 54%
Origin: From Uttarakhand :31%; Outside Uttarakhand: 69%

Livelihoods of Respondents	Major Problems identified	Major Impacts identified

1) Private/Government Job - 9% 2) Artisanal Activity 11% 3) Small Business – 24% 4) Labour -56%	1) Increase in Settlements – 32% 2) River has narrowed - 14% 3) Polluted river 17% 4) Intensification of floods – 70%	Impacts on Livelihoods: Yes 29%; No 71% Damages of common property: Retaining Wall (6%); Bank/Soil Erosion (6%); Mobile Towers/Electric Pole (6%); Bridges (3%) Loss of Private Property: • Damaged Clothes (52%) • Loss of Utensils (52%) • Loss of ration (29%) • Damaged Houses and Toilets (22%) • Damaged Furniture (10%) • Building Materials (1%) • Refrigerator, Cooler, Cycle (1%) • Not Affected (36%)

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