

ASSESSING THE EFFECTS OF CONSECUTIVE EXTREME RAINFALL EVENTS UNDER FUTURE CLIMATE SCENARIOS ON RESERVOIR STORAGE AND SPILLWAY REQUIREMENTS: A CASE STUDY OF MANANKATTIYA RESERVOIR, SRI LANKA

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Abstract

Irrigation reservoirs in the dry zone of Sri Lanka are designed for a single design flood, so the damaging condition arises when a second heavy storm arrives while the reservoir is still full. This study examines how consecutive extreme rainfall events change under future climate scenarios and affect the storage and spillway of Manankattiya Reservoir. Daily observed rainfall from 1994 to 2024 generated 12 projection series from three global climate models, under two shared socioeconomic pathways and two future periods, giving 60 model-years per scenario; as record lengths differ, counts are compared as events per year. An extreme event was defined by a 200 mm event depth and a compound event by two extremes less than seven days apart. Of 50 compound events identified, 22 were routed through a HEC-HMS rainfall-runoff model. By 2081-2100, compound events become over four times more frequent under the high-emission pathway, rising from 0.06 to 0.30 events per year, and the share of storms qualifying as extreme rises from 3.2% to 8.3%. Each event delivers 25 to 47 million cubic metres (MCM) to a reservoir holding 6 MCM at full supply, and a crest length near 24 m is indicated to keep the peak level below the bund top. As the routing uses daily rainfall for a catchment with a 185-minute lag and a derived elevation-storage relationship, this is a screening value requiring confirmation against the probable maximum flood. Reservoir safety and spillway design must therefore account for consecutive extremes rather than a single design flood.

Keywords: CMIP6 projections, Compound hydrological events, Flood risk management, Reservoir capacity, Spillway crest length

1. Introduction

In seasonally dry regions, the water stored or released during a storm depends mainly on reservoir capacity. Analysis of 178 Indian reservoirs found that flood mitigation depends mainly on antecedent storage, and compound events combining high inflow with a nearly full reservoir may roughly double under warming [1]. Extreme precipitation on consecutive days is also increasing worldwide in observations and model simulations [2]. As storage and spillways are sized from a single design flood, successive extremes are treated as independent and compound events are rarely considered.

This concern is critical in the Sri Lankan dry zone, where a cascade of tanks meets the regional water demand and a reservoir may serve a whole command area. Manankattiya Reservoir, a major tank in the Malwathu Oya basin, drains 61.9 km², holds 6 MCM at a full supply level of 136.30 m, and has a bund top level of 138.71 m. This study assesses how compound rainfall events may change under future climate and their implications for reservoir storage and spillway capacity, conventionally verified against the probable maximum flood.

2. Methodology

Daily observed rainfall from the Huruluwewa gauge from 1994 to 2024 (31 years), with no missing records, drove 12 projection series from the LARS-WG stochastic weather generator [3] using the CNRM-CM6-1, HadGEM3-GC1-LL and MRI-ESM2-0 models under SSP2-4.5 and SSP5-8.5 pathways for 2041 to 2060 and 2081 to 2100, giving 60 model-years per pathway and period, so that records of unequal length are compared as events per year. LARS-WG preserves the inter-event gaps and extreme depths that compound-event identification depends on, scaled by each model and emission scenario [3].

A day with 1.0 mm or more of rainfall was treated as wet, a single dry day ended a storm, and an event was an unbroken run of wet days [2]. A fixed threshold of 200 mm in event depth defined extreme events, preferred over a per-dataset percentile to keep models comparable [4]. It sits above the observed 95th percentile (158.4 mm) and below the model values, so no dataset is dominated. A compound event is two extreme events separated by fewer than 7 days. Each was extracted into a fixed 28-day window starting one dry day before the first storm, with unrelated later storms zeroed. The two largest combined rainfall events per series were carried forward, giving 22 runs. Losses used the SCS curve number method (CN 81) and the SCS unit hydrograph transform (lag 185 minutes). The reservoir was routed as a level pool with an ungated broad-crested spillway at full supply level, using an elevation-storage relationship derived from contour data rather than a bathymetric survey, which affects the computed peak level. The minimum crest length, the shortest length keeping the peak level below the bund top, is a screening value, since the 185-minute lag is short relative to the daily rainfall input.

3. Results and Discussion

The screening found 50 compound events, 48 across the 60 model-years of the ensembles and 2 in the 31-year observed record (0.06 per year). Two series, CNRM-CM6-1 under both pathways for 2041–2060, contained no compound events. The largest observed compound event, in December 2010 to January 2011, caused the most damaging flood, supporting the screening rule.

Table 1 compares projections with the observed baseline: compound events rise from 0.06 per year observed (2 in 31 years) to 0.15 and 0.13 at mid-century and to 0.22 and 0.30 by 2081–2100 under the moderate and high pathways, from counts of 9, 8, 13 and 18 in 60 model-years: a twofold rise at mid-century and up to 4.6-fold by the end of the century. The share of storms qualifying as extreme rises from 3.2% to 8.3%.

Table 1: Summary of extreme and compound events for different scenarios. Observed record 31 years, each scenario 60 model-years; bracketed values are events per year.

Pathway and Period	No. of Extreme Events (per year)	No. of Compound Events (per year)	Inflow Volume (MCM)	Minimum Spillway Length (m)
Observed 1994–2024	30 (0.97)	2 (0.06)	25.7–35.5	13–19
SSP2-4.5 2041–2060	106 (1.77)	9 (0.15)	25.9–46.1	14–24
SSP2-4.5 2081–2100	121 (2.02)	13 (0.22)	25.5–46.0	15–24
SSP5-8.5 2041–2060	102 (1.70)	8 (0.13)	32.1–44.5	16–17
SSP5-8.5 2081–2100	144 (2.40)	18 (0.30)	31.1–46.7	16–20

Figure 1 shows the modelled inflow hydrographs. Inflow volume ranges from 25.5 to 46.7 MCM against 6.02 MCM at full supply, 4.2 to 7.8 times the storage. Daily rainfall was used throughout to compare scenarios against a common baseline. This limits spillway sizing: with

a lag of only 185 minutes, daily rainfall cannot resolve the within-day distribution that governs peak discharge, so the crest lengths in Table 1 show relative differences between scenarios rather than design values. The storage-area relationship was likewise derived rather than surveyed. A design assessment would need sub-daily rainfall, a surveyed elevation-storage relationship and comparison against the capacity required by the probable maximum flood, which normally governs major tank sizing and would exceed the floods reported here.

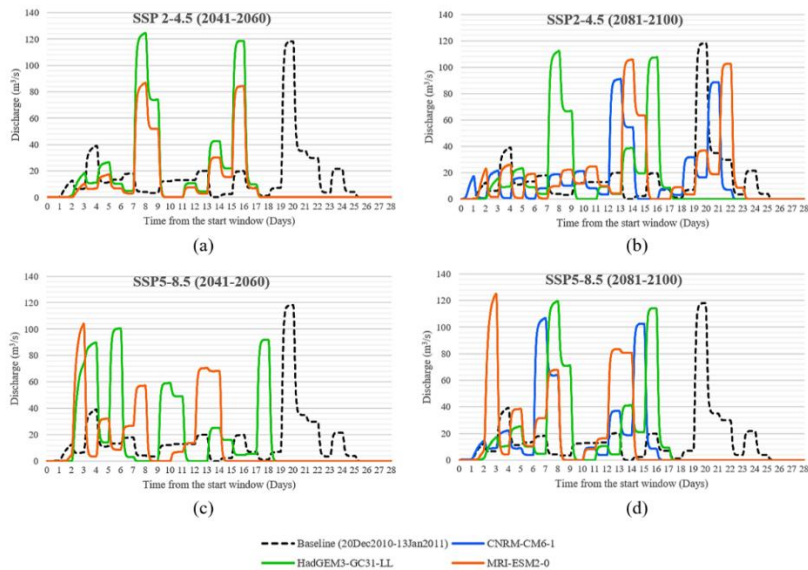


Figure 1: Reservoir inflow hydrographs for (a) SSP2-4.5 2041–2060, (b) SSP2-4.5 2081–2100, (c) SSP5-8.5 2041–2060 and (d) SSP5-8.5 2081–2100.

4. Conclusion

Consecutive extreme rainfall events at Manankattiya become more frequent and moderately more severe under both pathways and most markedly under the high-emission pathway late in the century, where compound events reach 0.30 per year (18 in 60 model-years) against 0.06 per year observed (2 in 31 years), a 4.6-fold rise. Because a single event delivers 25 to 47 MCM, 4 to 8 times the 6 MCM storage, added capacity alone cannot absorb it and a larger spillway crest, of the order of 24 m, is indicated at screening level. This value must be checked against the probable maximum flood, with sub-daily rainfall and a surveyed elevation-storage relationship, before design. Adaptation should also address refill frequency within a season and freeboard when the second storm arrives.

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