Estimation of Probabilistic Precipitation at an NPP Site Considering the SSP3-7.0 Climate Change Scenario

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1. Introduction

Climate change is expected to increase the frequency and intensity of short-duration extreme rainfall in Korea, which raises the question of whether the rainfall conditions adopted at the design stage of infrastructure will remain valid in the future. A nuclear power plant (NPP) is vulnerable to such changes, since an increase in extreme rainfall may lead to insufficient capacity of the site drainage system and to site flooding.

The purpose of this study is to quantitatively estimate the future probabilistic precipitation at the site of NPP A under the SSP3-7.0 climate change scenario of the IPCC Sixth Assessment Report (AR6), and to provide the basic data required for reviewing the adequacy of the site drainage capacity. The SSP3-7.0 scenario assumes passive mitigation policies and a society vulnerable to climate change, and therefore represents a conservative but realistic future for a safety assessment in which the risk of underestimation must be excluded. The target future year was set to 2093, the end of the design life of the plant, and probabilistic precipitation was estimated for durations from 1 h to 24 h.

2. Methods

2.1. Analysis procedure

The overall analysis procedure is shown in Fig. 1. Frequency analysis was applied to the bias-corrected data to obtain the daily probabilistic precipitation for the future projection period, and the results were converted into the probabilistic precipitation of 1-24 h durations by quantile-based temporal scaling.

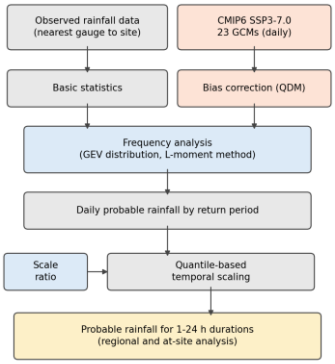


Fig. 1. Flow of the analysis procedure.

2.2. Observed rainfall data

The Standard Guidelines for Flood Estimation (Ministry of Environment, 2019) classify 615 rainfall gauges in Korea into 26 hydrologically homogeneous cluster regions, and recommend regional frequency analysis (RFA) with the generalized extreme value (GEV) distribution as the optimal probability distribution. NPP A belongs to a cluster region that contains 27 rainfall gauges. Among them, the gauge nearest to the site, located approximately 9.87 km away and holding 53 years of record (1972-2024), was selected as the target station. The distribution parameters were estimated by the L-moment method.

2.3. GCM data and bias correction

Daily precipitation (pr) outputs of 23 CMIP6 GCMs providing the SSP3-7.0 scenario were collected from the Earth System Grid Federation (ESGF) and combined into a multi-model ensemble, so that the uncertainty due to the choice of an individual model could be reduced. Quantile delta mapping (QDM) was applied for bias correction. Unlike the standard quantile mapping technique, QDM preserves the relative change of each quantile projected by the climate model, and therefore removes the systematic bias while maintaining the climate change signal in the extreme range.

2.4. Quantile-based temporal scaling

Because the scenario data are provided on a daily basis, the daily probabilistic precipitation was converted

into the probabilistic precipitation of duration d by quantile-based temporal scaling. The scale ratio is defined in the quantile domain from the observed data as Rd(p) = Qd,obs(p) / Qday,obs(p), and the future value is estimated as Qd,futr(p) = Rd(p) x Qday,futr(p). Since this approach does not rely on the moments of rainfall, it directly reflects the nonlinear change of the scaling behavior in the upper quantile range and provides more stable results for extreme rainfall, in which the tail behavior of the distribution is important.

2.5. Parallel application of at-site analysis

The disaster impact assessment carried out by the local government in which NPP A is located adopted at-site frequency analysis. Accordingly, RFA was applied as the primary method, while at-site frequency analysis combined with the SSP3-7.0 scenario was carried out in parallel, so that a direct comparison with the local disaster prevention performance target could be made on the same methodological basis. All the other procedures were identical.

3. Results

3.1. Probabilistic precipitation based on observed data

For the target station, the observation-based probabilistic precipitation of 1 h duration was estimated as 53.0 mm and 56.6 mm for the 50-year and 80-year return periods, respectively. The ratio between the probabilistic precipitation of each duration and the daily value was used as the scale ratio in the subsequent temporal scaling.

3.2. Probabilistic precipitation under the SSP3-7.0 scenario

The probabilistic precipitation projected for 2093 under the SSP3-7.0 scenario, estimated by regional frequency analysis, was 57.7 mm for the 50-year return period and 63.5 mm for the 80-year return period at a duration of 1 h. These values correspond to increases of approximately 8.9% and 12.2% with respect to the observation-based results, which indicates a significant future increase in the intensity of extreme rainfall at the site. As shown in Fig. 2, the probabilistic precipitation increases with both the return period and the duration.

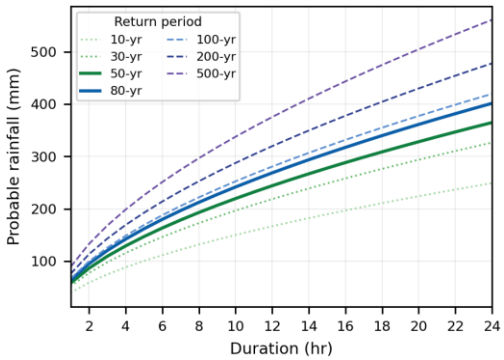


Fig. 2. Probabilistic precipitation by duration and return period under SSP3-7.0 (RFA, GEV, 2093).

The probabilistic precipitation estimated by at-site frequency analysis was 61.8 mm and 66.9 mm for the 50-year and 80-year return periods, respectively, and was thus slightly larger than the results of the regional frequency analysis.

3.3. Comparison with the local disaster prevention target

The local government presented 65 mm as the 1 h disaster prevention performance target through the revision of its public notice in 2023. As shown in Fig. 3, the 1 h probabilistic precipitation of the 80-year return period obtained by at-site frequency analysis with the SSP3-7.0 scenario, that is 66.9 mm, slightly exceeds this target. This result quantitatively demonstrates that extreme rainfall under climate change may exceed the current level of the local disaster prevention performance target.

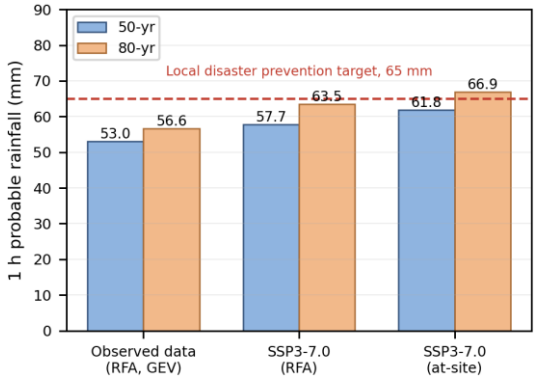


Fig. 3. Comparison of the 1 h probabilistic precipitation by method.

4. Conclusions

In this study, the future probabilistic precipitation at the site of NPP A was estimated considering the SSP3-7.0 climate change scenario, using 23 bias-corrected CMIP6 GCMs, regional frequency analysis with the GEV distribution and the L-moment method, and quantile-based temporal scaling for durations of 1-24 h.

The 1hr probabilistic precipitation increased from 53.0 mm (50-year) and 56.6 mm (80-year) for the observed data to 57.7 mm and 63.5 mm under the SSP3-7.0 scenario, and the at-site analysis gave 61.8 mm and 66.9 mm. The 80-year value of 66.9 mm exceeds the local 1 h disaster prevention performance target of 65 mm, which suggests that the existing design criteria may not sufficiently reflect the influence of the future climate crisis.

The results can be used as input data for evaluating the adequacy of the site drainage capacity and as a technical basis for reviewing whether the design return period should be raised. Considering the uncertainty inherent in climate projections, periodic re-evaluation using the latest scenarios and observation data is also required.

Acknowledgments

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