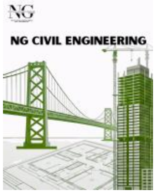

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A Review on Nonstationary Flood Frequency Analysis under Climate and Catchment Change

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HIGHLIGHTS

- Nonstationary flood frequency analysis better reflects changing flood risk under climate and catchment change.
- Physically meaningful covariates improve flood estimation more than simple time-trend models.
- Design-life risk and reliability metrics are more suitable than fixed return periods under nonstationarity.

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ABSTRACT

Flood frequency analysis has traditionally relied on the assumption that hydrological extremes fluctuate within a stationary probabilistic regime, allowing past observations to serve as a basis for estimating future flood risk. That assumption has become increasingly questionable in many river basins affected by climate change, land-use transformation, urbanization, river regulation, and evolving hydroclimatic variability. In response, nonstationary flood frequency analysis has emerged as a major research area in modern hydrology. This review critically examines the conceptual basis, statistical frameworks, covariate strategies, uncertainty sources, and practical implications of nonstationary flood frequency analysis. It discusses the hydrological mechanisms that generate nonstationarity, evaluates methodological developments including time-varying extreme value models, generalized additive models for location, scale and shape, Bayesian approaches, and regional methods, and assesses the opportunities and limitations of machine learning and hybrid frameworks. The review argues that nonstationary analysis should not be treated as a universal replacement for stationary frequency methods, but as a context-dependent approach that must be justified by hydrological evidence, physically meaningful covariates, and decision relevance. Particular attention is given to uncertainty, because flexible nonstationary models often improve in-sample fit while weakening extrapolative reliability. The review concludes that future progress depends on stronger process-statistics integration, more disciplined covariate selection, clearer reporting standards, and a shift from fixed return periods toward design-life risk and reliability-based planning. These directions are essential if nonstationary flood frequency analysis is to become a robust tool for hydrologic design and flood risk management.

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1. INTRODUCTION

Floods remain among the most damaging and societally disruptive natural hazards worldwide. Their consequences extend far beyond direct economic losses, affecting infrastructure, agriculture, water supply systems, ecosystem function, human health, and regional development planning. Hydrologists and engineers have therefore long depended on flood frequency analysis to estimate the likelihood and magnitude of rare flood events and to guide the design of levees, culverts, bridges, dams, spillways, urban drainage systems, and floodplain regulations. At the core of conventional flood frequency analysis lies a simple but consequential assumption: the probability distribution governing flood extremes does not change over time. Under this stationary framework, the historical record is treated as a statistically representative sample of future conditions.

That assumption has become increasingly difficult to defend in many catchments. Over the last several decades, hydrological systems have been altered by a combination of climatic and anthropogenic pressures. Intensifying rainfall, changing seasonality, snowpack decline, warmer winters, shifting antecedent moisture regimes, reservoir construction, urban expansion, wetland loss, agricultural drainage, and channel modification have all affected runoff generation and flood response in different ways. These changes do not always produce a simple monotonic increase in flood magnitude, but they do undermine the idea that flood extremes arise from an invariant process. The debate sharpened considerably when Milly et al. (2008) argued that stationarity was no longer a defensible foundation for water management under anthropogenic climate change. That statement had substantial impact because it forced hydrologists to reconsider a design philosophy that had shaped practice for decades.

However, the issue is more nuanced than the slogan suggests. Not every flood record exhibits statistically significant change, and not every apparent trend reflects a genuine shift in the flood-generating process. Some records are too short to distinguish trend from low-frequency climate variability. Others are affected by measurement inconsistencies, rating curve changes, reservoir operations, or mixed flood populations driven by different meteorological mechanisms. As a result, the central challenge is not simply whether stationarity is “dead,” but when and how the stationary approximation becomes inadequate for a given basin, time horizon, and design decision. That distinction matters because nonstationary models are not automatically superior. They often increase complexity, expand uncertainty, and create new opportunities for overfitting and false confidence.

Nonstationary flood frequency analysis has therefore emerged as both a scientific necessity and a methodological minefield. The field has advanced rapidly, producing a wide range of approaches that allow flood distributions to vary through time or in response to external covariates. These include time-varying generalized extreme value models, generalized additive models for location, scale and shape, Bayesian hierarchical formulations, and regional climate-informed methods. At the same time, unresolved issues remain around covariate selection, model identifiability, extrapolation, uncertainty quantification, and translation of changing hazard into design criteria.

This review critically synthesizes the current state of knowledge on nonstationary flood frequency analysis. Rather than advocating uncritical adoption of flexible models, it evaluates the hydrological rationale, statistical structure, limitations, and practical implications of different approaches. The review has four main objectives. First, it examines the hydrological and anthropogenic processes that generate nonstationarity in flood extremes. Second, it evaluates the principal statistical frameworks used to model nonstationary flood behavior. Third, it discusses the major uncertainty sources and conceptual pitfalls that limit confidence in nonstationary design estimates. Fourth, it identifies methodological and reporting priorities needed to improve the reliability and engineering usefulness of future studies. By bringing these dimensions together, the review aims to provide a more disciplined basis for interpreting nonstationary flood risk in modern hydrology.

2. HYDROLOGICAL BASIS OF NONSTATIONARITY IN FLOOD EXTREMES

The shift from stationary to nonstationary flood frequency analysis is not merely a statistical innovation; it is rooted in changing hydrological systems. Flood nonstationarity arises when the mechanisms controlling extreme runoff evolve through time, altering the distribution of flood peaks, their timing, their frequency, or their variance. These changes may be gradual, abrupt, periodic, or nonlinear, and their manifestation depends on both climate dynamics and catchment characteristics.

Climate variability and climate change are among the most widely discussed drivers. Changes in atmospheric moisture capacity, storm persistence, convective intensity, cyclone behavior, snow accumulation, and snowmelt timing can alter flood magnitude and seasonality. In snow-dominated basins, warmer temperatures may reduce snow storage and advance melt-driven floods, while increasing the likelihood of rain-on-snow events in some regions. In rainfall-dominated basins, the relevant mechanism may instead be an increase in sub-daily rainfall intensity, a shift in storm sequencing, or a change in antecedent wetness conditions. The effect is rarely uniform across regions, which explains why some basins show stronger evidence of nonstationarity than others. Importantly, flood change cannot be inferred solely from changes in mean precipitation, because runoff extremes depend on storm structure, soil moisture, catchment memory, and channel routing as much as on rainfall totals (Figure 1).

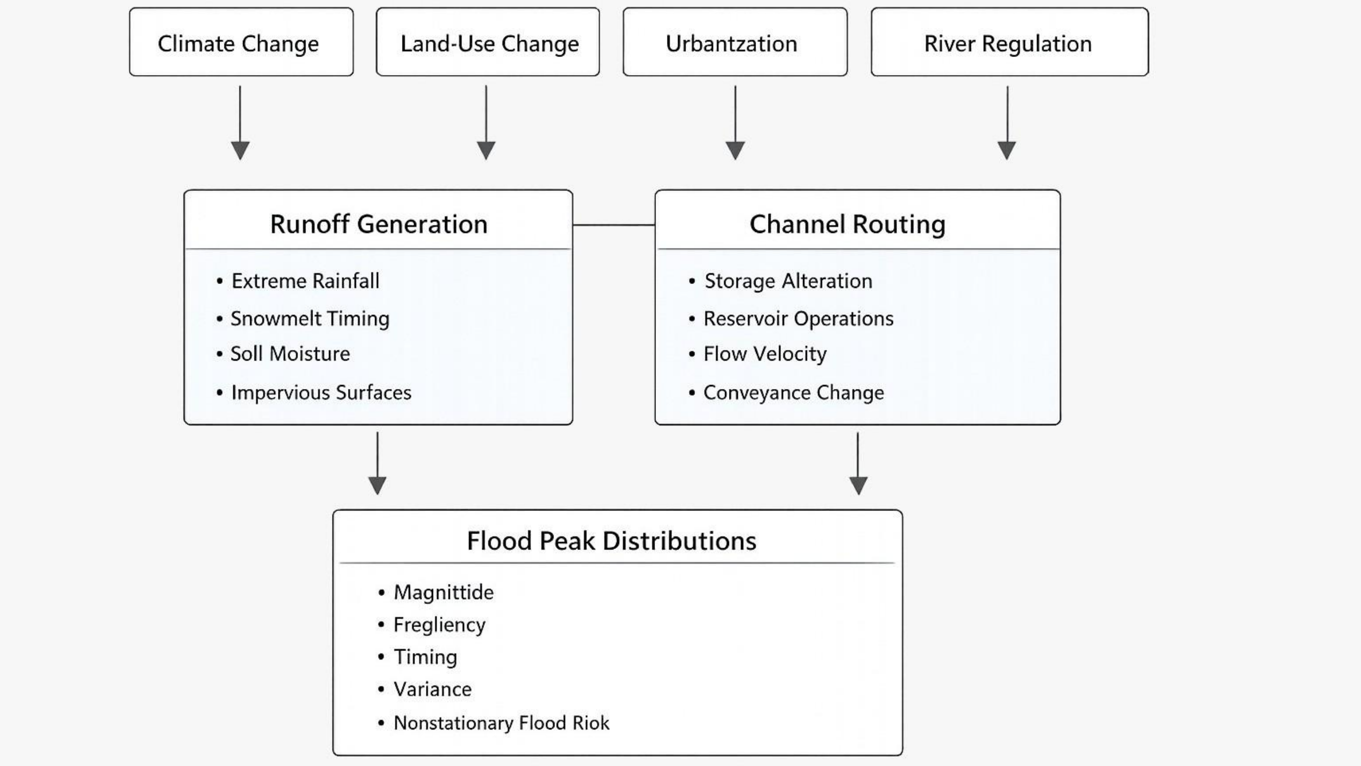

Figure 1. Conceptual framework of flood nonstationarity

Catchment modification is equally important. Urbanization is one of the clearest anthropogenic causes of nonstationary flood response. Expansion of impervious surfaces reduces infiltration, accelerates runoff concentration, and amplifies peak discharges, especially for small and medium events. Stormwater networks and channelized drainage further speed runoff delivery. In agricultural landscapes, subsurface drainage, compaction, vegetation removal, and changes in tillage or land cover can modify runoff generation and storage. Deforestation and wetland loss reduce landscape buffering capacity, while reforestation or restoration can alter response in the opposite direction. These processes complicate attribution because flood trends may reflect combined climate and land-use effects rather than either factor alone. River regulation introduces another layer of complexity. Reservoirs, diversion structures, detention basins, levees, and flood-control operations can suppress some types of flood peaks while altering the seasonal pattern and routing of others. In regulated basins, observed flood records are often composite products of both meteorological forcing and operational management. Changes in reservoir rule curves, storage capacity, or release policy can create abrupt shifts in flood series that may be misinterpreted as hydroclimatic trends if basin infrastructure history is ignored. Similarly, channel modification, sedimentation, bank stabilization, and floodplain encroachment can alter conveyance, stage-discharge relations, and effective storage, introducing apparent nonstationarity even where runoff inputs are not changing dramatically. A further complication is that flood records frequently represent mixed populations of events. A single annual maximum series may include floods generated by frontal systems, convective storms, snowmelt, rain-on-snow processes, tropical cyclones, or reservoir releases. These mechanisms differ in seasonality, spatial scale, runoff efficiency, and sensitivity to climate drivers. If their relative frequency changes through time, the aggregate record may appear nonstationary even when each process type is stationary within its own regime. This is one reason why many trend-based studies remain difficult to interpret physically. Statistical change in the pooled series does not necessarily reveal whether flood magnitudes are increasing, whether flood types are changing, or whether the basin is shifting between flood-generating mechanisms (Figure 2).

The hydrological basis of nonstationarity therefore demands more than detecting a temporal trend. It requires reconstructing why the flood-generating system is changing and which processes matter most. This is where many papers remain weak. They report nonstationary model improvement without establishing whether the selected covariates are physically meaningful or whether the observed signal could be produced by short records, multi-decadal variability, or data inhomogeneity. A defensible nonstationary study must begin with basin history, flood process understanding, and data quality assessment rather than with automated model fitting (Table 1).

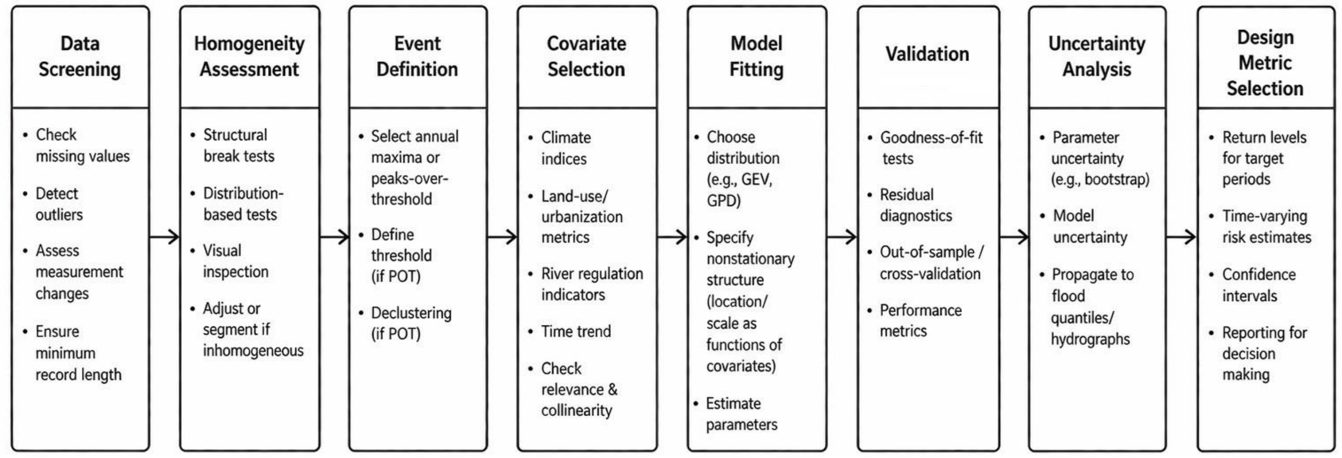

Figure 2. Workflow for nonstationary flood frequency analysis

Table 1. Major drivers of flood nonstationarity and their hydrological implications

Driver	Main hydrological effect	Typical manifestation in flood series	Example covariates
Climate change or variability	Alters precipitation extremes, snowmelt timing, antecedent moisture	Trend, regime shift, seasonality change, changing variance	rainfall indices, temperature, snowpack, ENSO, NAO
Urbanization	Increases imperviousness and drainage efficiency	Rising flood peaks, faster hydrograph response	impervious area, built-up fraction, population
Land-use change	Modifies infiltration, evapotranspiration, and runoff storage	Nonlinear or gradual trend	forest cover, cropland, wetland area
Reservoir regulation	Changes attenuation and routing of floods	Abrupt shifts, reduced variance, altered seasonality	storage ratio, dam period, release index
Channel and floodplain modification	Alters conveyance and stage-discharge relation	Apparent trend or discontinuity	channel geometry, levee construction
Mixed flood mechanisms	Changes composition of event types	unstable tails, inconsistent trend behavior	event classification, season, storm type

3. STATISTICAL FRAMEWORKS FOR NONSTATIONARY FLOOD FREQUENCY ANALYSIS

Conventional flood frequency analysis relies on the assumption that a single probability distribution with fixed parameters can adequately describe flood extremes. In a nonstationary context, this assumption is relaxed by allowing one or more parameters of the distribution to vary in time or in response to covariates. The most common starting point is the generalized extreme value distribution for annual maxima or the generalized Pareto distribution for peaks over threshold. The key difference is no longer the choice of family alone, but the way in which location, scale, and occasionally shape are permitted to evolve.

A common nonstationary strategy is to model the location parameter as a function of time or external drivers, while holding the scale and shape parameters constant. This reflects the idea that central tendency may shift more clearly than tail form. In some cases, the scale parameter is also allowed to vary when evidence suggests changing variability. Allowing the shape parameter to vary is much harder to justify because it is already difficult to estimate under stationarity; making it time-dependent often produces unstable and poorly interpretable tails. For practical applications, parsimonious parameter variation is generally more defensible than fully dynamic formulations.

Time itself is the simplest nonstationary covariate and is often used as a benchmark. A linear or nonlinear time trend can reveal whether a stationary model is being systematically violated, but time has weak explanatory power from a hydrological perspective. A significant time trend does not identify the mechanism of change. It is therefore best treated as a diagnostic tool or null alternative rather than a final explanatory model. More informative approaches condition the flood distribution on physically meaningful covariates such as precipitation extremes, temperature, climate indices, antecedent moisture proxies, reservoir storage, or measures of urban growth (Figure 3).

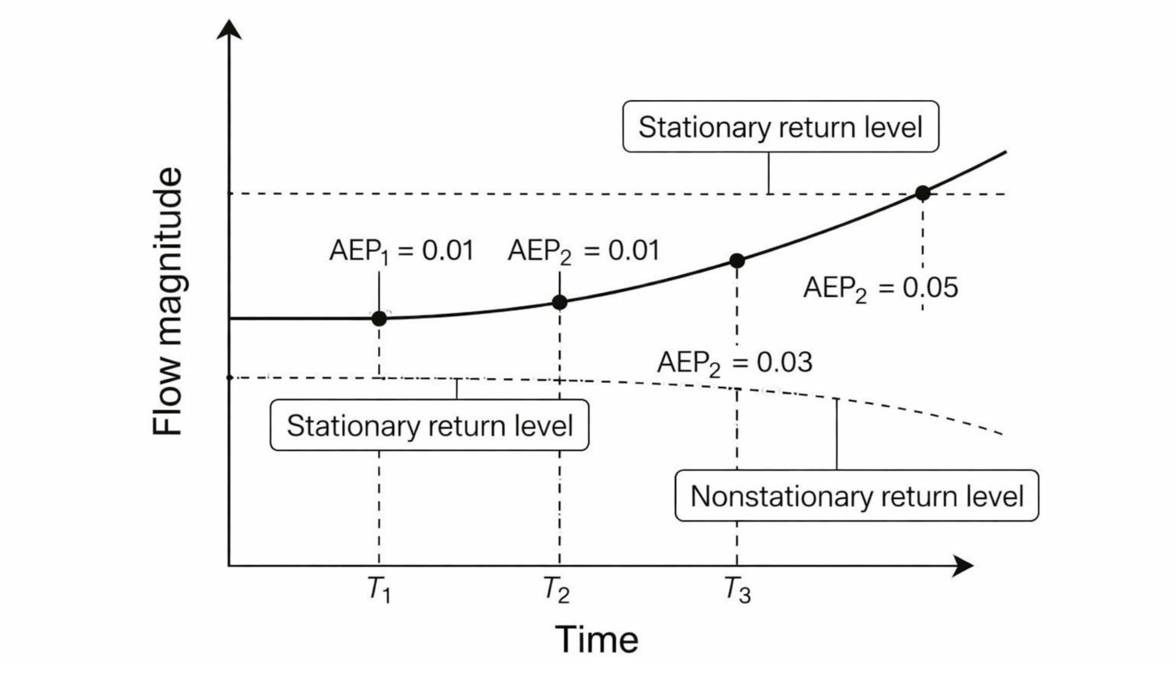

Figure 3. Stationary versus nonstationary design interpretation

The development of generalized additive models for location, scale and shape, commonly known as GAMLSS, was particularly important because it enabled flexible relationships between distribution parameters and covariates (Rigby & Stasinopoulos, 2005). Instead of assuming strictly linear effects, GAMLSS allows smooth nonlinear functions, making it useful for systems where hydrological response evolves in complex ways. This flexibility has encouraged widespread application in nonstationary hydrology. Chen et al. (2021), for example, used such approaches to evaluate flood nonstationarity across UK gauging stations and found that nonstationary models improved representation in some catchments, though not universally. The attraction of GAMLSS is clear: it can handle nonlinearity and multiple covariates without abandoning a probabilistic design framework. Its danger is equally clear: too much flexibility can produce an excellent in-sample fit at the cost of poor extrapolation and weak physical interpretation.

Bayesian methods have also gained importance, especially for data-sparse regions, regional analyses, and applications where uncertainty propagation matters as much as point estimation. A Bayesian framework allows prior information, hierarchical pooling across sites, and direct estimation of posterior uncertainty in time-varying return levels. This is particularly valuable when at-site records are short or when covariate effects need partial pooling to avoid unstable estimates. However, the benefits come with higher computational and conceptual cost. Poor prior choices, weak identifiability, and overly elaborate hierarchical structures can easily create models that look sophisticated but are hard to validate and even harder to communicate to engineering users.

Regional nonstationary flood frequency analysis addresses one of the central limitations of at-site studies: record length. Since extreme flood estimation is inherently data-hungry, regionalization helps by borrowing information from multiple hydrologically similar basins. Classical regional frequency analysis has a long history in hydrology, but under nonstationarity the concept of similarity must be reconsidered. Static descriptors such as basin area or slope may not be sufficient if the basins are undergoing different climatic or anthropogenic changes. Renard and Lall (2014) showed that regional frequency analysis conditioned on large-scale atmospheric or oceanic fields can capture evolving flood hazard more effectively than traditional homogeneous-region assumptions. This shift is important because it aligns regionalization with dynamic drivers rather than fixed physiographic groupings alone.

Table 2. Comparison of major nonstationary flood frequency approaches

Approach	Main strength	Main limitation	Most suitable application
Time-varying GEV	Interpretable and directly linked to design quantiles	Can be unstable if too many parameters vary	At-site annual maxima with moderate data length
GAMLSS	Flexible nonlinear covariate effects	High risk of overfitting and unstable extrapolation	Basins with strong covariate information
Bayesian hierarchical models	Full uncertainty propagation and regional pooling	Computationally intensive and sensitive to specification	Sparse data and multi-site studies
Regional nonstationary analysis	Reduces at-site uncertainty by pooling sites	Requires defensible dynamic similarity	Large basin networks and climate-informed studies
POT with nonstationary rate	Uses more event information	Threshold selection and dependence issues	Event-rich records and changing flood frequency
ML or hybrid methods	Captures nonlinear predictor interactions	Weak tail theory and poor interpretability	Screening, emulation, and support modeling

Another major modeling decision concerns event sampling. Most nonstationary studies use annual maximum series because they are straightforward and compatible with classical extreme value theory. However, annual maxima discard potentially useful information about event frequency. Peaks-over-threshold methods can exploit multiple events per year and are attractive where both the occurrence rate and the magnitude of floods may be changing. Yet peaks-over-threshold modeling under nonstationarity is technically more demanding because threshold stability, declustering, and time-varying exceedance rates all need careful treatment. Many studies choose annual maxima not because it is always superior, but because it is operationally easier and less vulnerable to threshold subjectivity.

Machine learning has begun to appear in this field, but its role needs to be stated honestly. It is useful for detecting nonlinear relations, screening high-dimensional predictors, and emulating more computationally demanding modeling chains. It is not, on its own, a replacement for extreme value theory in design flood estimation. Purely data-driven models often perform well within the observed sample range but become untrustworthy in rare-event extrapolation. Their predictive surfaces are shaped by the available data, not by asymptotic tail behavior. This makes them much better suited to covariate discovery or hybrid frameworks than to direct estimation of 100-year or 500-year design floods.

The methodological literature has produced a rich toolkit, but no universal best method exists. The right framework depends on record length, flood regime, covariate availability, decision purpose, and tolerance for complexity. The strongest studies are not those with the most elaborate model architecture, but those that combine statistical adequacy with hydrological credibility and transparent uncertainty treatment (Table 2).

4. UNCERTAINTY COVARIATE SELECTION AND THE PROBLEM OF DESIGN UNDER CHANGE

The central promise of nonstationary flood frequency analysis is that it offers a more realistic representation of changing hazard. The central danger is that it can produce highly unstable design estimates under the appearance of sophistication. This tension is why uncertainty lies at the heart of the field.

The first major uncertainty source is sampling. Flood records are often short relative to the timescales of climate variability and much shorter than the return periods of interest. A 30- or 40-year record may detect some forms of change, but it remains a fragile basis for estimating a 100-year or 500-year event under a time-varying process. The second uncertainty source is model structure. Different choices of distribution family, parameterization, link functions, smoothing terms, event sampling definitions, and covariate sets can produce materially different return level estimates. In nonstationary contexts, these structural choices often matter more than under stationarity because the design quantiles depend on both the estimated distribution and the assumed trajectory of change.

Covariate selection is especially problematic. Many studies add predictors simply because they improve fit statistics, not because they represent the dominant hydrological controls on flood generation. This is bad practice. Time trends alone are easy to fit but hydrologically weak. Climate indices may be statistically significant but physically indirect. Land-use variables may be relevant but poorly measured. Reservoir operation proxies may capture abrupt changes but remain unavailable or inconsistent. The real task is not to maximize statistical significance but to identify a parsimonious set of predictors that has defensible physical meaning. If a covariate cannot be explained hydrologically, its use in extrapolative design is hard to justify.

Another serious issue is confounding between trend and variability. Apparent nonstationarity in a short record may reflect low-frequency climate oscillations rather than a long-term change in hazard. Likewise, abrupt shifts caused by dam construction or data inhomogeneity can be mistaken for gradual climatic trends. This is why nonstationary studies should begin with homogeneity checks, metadata review, process understanding, and exploratory diagnostics rather than proceeding directly to flexible modeling. Otherwise, there is a real risk of fitting a change signal that does not correspond to the actual hydrological mechanism.

The interpretation of return period becomes particularly difficult under nonstationarity. Under stationarity, the return period is simply the inverse of the annual exceedance probability. Under nonstationarity, annual exceedance probability changes over time, so the traditional notion of a single fixed “100-year flood” loses coherence. Salas and Obeysekera (2014) and Read and Vogel (2015) showed that under changing conditions, design should be framed in terms of evolving annual risk, expected exceedances over infrastructure life, or reliability-based metrics rather than conventional stationary recurrence language. This is not an abstract statistical detail. It directly affects infrastructure design. A flood magnitude associated with a 1 percent annual exceedance probability today may have a substantially different risk interpretation over a 50-year project life if hazard is increasing.

This is where many papers still fail. They adopt a nonstationary model but continue to report results as if the meaning of return period has not changed. That is conceptually inconsistent. If the hazard is changing, the decision metrics must also change. Design-life level, reliability, or time-dependent exceedance probability are more coherent measures for planning under nonstationarity. Rootzén and Katz (2013) advanced this discussion by proposing the design-life level concept, which explicitly reframes extreme event risk for changing climates. Uncertainty should therefore be communicated at multiple levels. Parameter uncertainty alone is insufficient. Studies should also address model-selection uncertainty, covariate uncertainty, data quality issues, and extrapolation sensitivity. A practical way forward is ensemble thinking: compare multiple plausible models, examine the stability of conclusions across them, and present intervals or scenario ranges rather than a single deterministic design value. Hydrologic design has always involved uncertainty; nonstationary design simply makes the hidden uncertainty harder to ignore (Table 3).

Table 3. Key uncertainty sources in nonstationary flood frequency analysis

Uncertainty source	Why it matters	Consequence of ignoring
Short record length	weak tail estimation and trend identification	misleading return levels
Distribution choice	different tails and parameter behaviour	unstable design quantiles
Covariate uncertainty	predictors may be weak, noisy, or non-causal	false attribution and poor extrapolation
Structural model uncertainty	competing formulations can fit similarly	overconfidence in one model
Data inhomogeneity	rating changes or regulation shifts mimic trend	incorrect nonstationarity diagnosis
Future scenario uncertainty	land use and climate may evolve unpredictably	unreliable long-horizon design

5. RESEARCH GAPS METHODOLOGICAL PRIORITIES AND IMPLICATIONS FOR HYDROLOGIC PRACTICE

The rapid expansion of nonstationary flood frequency analysis has generated a large methodological literature, but several gaps continue to limit its usefulness for hydrologic design and risk management. The first is the incomplete integration of process understanding with statistical modeling. Too many studies remain method-driven rather than hydrology-driven. They compare model families, optimize information criteria, and report time-varying return levels without establishing whether the selected covariates actually represent the basin's flood-generating mechanisms. Future work needs to treat nonstationarity as a hydrological problem first and a statistical problem second.

A second gap is the limited use of rigorous validation. Nonstationary models often show improved in-sample fit, but this is not the same as better predictive credibility. Temporal cross-validation, hindcasting, split-period evaluation, and sensitivity to record truncation should become standard practice. A model that is only superior on the same data used for calibration is not convincing, especially when nonlinear smoothers or multiple covariates are involved. For design applications, stability under extrapolation matters at least as much as in-sample likelihood.

Third, the field needs better reporting standards. Many published studies still omit crucial details such as homogeneity checks, rating history, event selection criteria, threshold justification, covariate preprocessing, parameter constraints, and uncertainty treatment. This makes comparison across studies difficult and weakens reproducibility. A stronger reporting culture would make it easier to distinguish robust findings from fragile model artifacts.

Fourth, more attention is needed on mixed populations and process-conditioned analysis. Floods do not arise from one universal mechanism. Regional and basin-scale studies increasingly need to distinguish between event types, seasons, and flood-generating pathways. Nonstationarity in a mixed annual maximum series can be much harder to interpret than nonstationarity within a more homogeneous event class. Process-informed decomposition is likely to become more important as compound events and seasonal shifts become more prominent under climate change.

Fifth, regionalization remains underdeveloped in the nonstationary context. The classical idea of homogeneous regions based on fixed physiographic similarity is often inadequate when basins are evolving in different ways. Dynamic regional approaches that incorporate climate teleconnections, anthropogenic disturbance gradients, or shared process regimes appear more promising. This is particularly important for data-scarce regions, where at-site inference alone is weak.

From a practical standpoint, the most important implication is that hydrologic design can no longer rely unquestioningly on fixed recurrence terminology where change is evident. Engineers and planners increasingly need metrics that reflect evolving annual risk over a project life. This does not mean abandoning probability-based design. It means making the probability framework consistent with changing conditions. In many basins, stationary analysis may still remain a reasonable approximation, especially where records are short and evidence for change is weak. But where there is credible process-based evidence of evolving flood hazard, nonstationary methods provide a more honest basis for decision-making.

The way forward is not to declare stationary analysis obsolete in all contexts, nor to assume that more flexible nonstationary models are automatically better. The real advance lies in disciplined model choice, physically meaningful covariates, explicit uncertainty treatment, and alignment between statistical outputs and engineering decisions. That is the standard the field now needs to meet.

Table 4. Recommended checklist for applied nonstationary flood frequency studies

Component	Recommended reporting item
Data	record length, missing data, rating changes, regulation history
Flood series	AMS or POT choice, declustering, event type definition
Covariates	source, rationale, preprocessing, temporal coverage
Model structure	distribution family, varying parameters, link functions
Validation	split-sample, temporal validation, sensitivity tests
Uncertainty	parameter, structural, covariate, and scenario uncertainty
Design outputs	time-varying return levels, reliability, design-life risk

6. CONCLUSION

Nonstationary flood frequency analysis has emerged because the assumption of a fixed flood-generating regime is no longer tenable in many hydrological systems. Climate change, urbanisation, land-use conversion, regulation, and channel modification are altering the magnitude, timing, and variability of flood extremes in ways that challenge conventional frequency analysis. The field has responded with a diverse set of methods, including time-varying extreme value models, GAMLSS, Bayesian hierarchical approaches, and regional nonstationary frameworks. These methods have expanded the ability of hydrologists to describe evolving hazard, but they have also exposed major conceptual and practical difficulties. The most important lesson from the literature is that nonstationarity should not be assumed merely because it is fashionable, and stationary analysis should not be retained merely because it is familiar. The choice between them must be evidence-based and hydrologically justified. A nonstationary model is only useful when it reflects credible process change, uses covariates with physical meaning, remains parsimonious enough to avoid unstable tails, and improves decision relevance rather than just statistical fit. Studies that rely on weak covariates, short records, and over-flexible structures often produce results that look modern but are not reliable for design. A second central conclusion is that uncertainty is even more fundamental under nonstationarity than under stationarity. Flexible models can reduce residual error while increasing extrapolation risk. This makes validation, sensitivity analysis, and model comparison essential. Point estimates of time-varying return levels are not enough. Decision-makers need uncertainty bounds, alternative model perspectives, and metrics that reflect risk over the life of an infrastructure system. A third major conclusion concerns design philosophy. The traditional return period framework becomes conceptually unstable when exceedance probabilities change through time. In such settings, hydrologic practice should move toward reliability-based and design-life risk metrics rather than continuing to use fixed, stationary recurrence language without qualification. This shift is necessary if flood frequency analysis is to remain relevant for modern infrastructure planning. Future progress in the field will depend on closer integration of hydrological process understanding and statistical modelling, better treatment of mixed flood populations, stronger regional and data-scarce approaches, and more transparent reporting standards. Nonstationary flood frequency analysis has already changed the way hydrologists think about extremes. The next challenge is to ensure that the methods are not only statistically flexible, but also physically defensible, reproducible, and useful for real-world flood risk management.

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