American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

Visual Information Design for Communicating Complex Public Risks

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Abstract

Public risks associated with disease outbreaks, extreme weather, environmental contamination, technological failures, infrastructure disruption, and other emergencies are frequently communicated through numerical indicators, maps, probability estimates, dashboards, warning labels, and statistical graphics. The growing availability of risk data has not necessarily produced equivalent improvements in public understanding because complex evidence can overwhelm audiences when it is presented without attention to information hierarchy, visual literacy, uncertainty, accessibility, and decision relevance. This study examines how visual information design can improve the communication of complex public risks by transforming technically accurate information into formats that support comprehension, uncertainty recognition, recall, and protective decision-making. The investigation adopts a simulation-based methodological design because no primary participant dataset was available. Four communication conditions were modeled: a text-heavy risk brief, a conventional infographic, a layered risk visualization, and an accessibility-enhanced layered visualization. A synthetic analytical sample of 480 observations, with 120 observations assigned to each condition, was generated to demonstrate an evaluation framework rather than to represent real human-subject findings.

The simulated results indicate a progressive increase in risk-comprehension performance from the text-heavy condition to the accessibility-enhanced layered design. Mean comprehension scores were 63.9, 72.2, 82.3, and 85.3 respectively, while similar patterns were observed for protective-action recall and uncertainty recognition. The analysis suggests that visual effectiveness depends less on graphic density than on disciplined selection, perceptual hierarchy, consistent quantitative encoding, explicit uncertainty representation, actionable guidance, and accessibility. The paper proposes that public-risk graphics should be treated as decision interfaces rather than decorative summaries. It concludes that visual design can strengthen risk communication when it preserves scientific accuracy while reducing unnecessary cognitive burden and clearly distinguishing what is known, what remains uncertain, who is affected, and what audiences can reasonably do next.

Keywords: visual information design, public risk communication, data visualization, risk perception, uncertainty communication, information hierarchy, public communication, visual literacy

1. Introduction

Public institutions increasingly depend on visual communication when explaining risks that are difficult to represent through ordinary prose. Disease transmission, flood probability, wildfire exposure, air pollution, heat stress, chemical hazards, infrastructure vulnerability, and technological emergencies often involve multiple interacting variables, uncertain forecasts, changing spatial patterns, and differences in vulnerability across population groups. Consequently, public communication may involve maps, statistical graphics, dashboards, pictograms, probability displays, warning systems, and infographics. The World Health Organization treats risk communication as a critical component of emergency preparedness and response because people need timely information that enables them to make informed protective decisions. WHO communication guidance also recognizes that visual presentation can improve understandability across audiences with different levels of literacy and educational experience.

The central challenge is not simply the availability of information but the translation of technical evidence into representations that preserve meaning under conditions of limited attention. Numerical probabilities can be difficult to interpret when audiences encounter unfamiliar denominators, inconsistent scales, relative rather than absolute changes, or competing indicators. Visual representations can reduce some of this burden by making magnitudes, comparisons, and patterns perceptually accessible. However, Ancker and colleagues demonstrated in their systematic review that graphical design features influence quantitative reasoning and that graphical characteristics associated with comprehension do not always produce the same effects on attitudes or behavior. García-Retamero and colleagues similarly found that visual aids can improve risk understanding, particularly in contexts where numerical information would otherwise be difficult to process.

A further complication is that visualizations are not neutral containers. The choice of axis, scale, aggregation period, icon structure, comparison frame, map classification, uncertainty encoding, and visual emphasis can alter what audiences notice and infer. Padilla and colleagues showed experimentally that different visualizations of the same COVID-19 forecasting information produced different risk perceptions, demonstrating that technically equivalent underlying evidence can acquire different psychological meaning through design. Bannister and colleagues likewise found substantial differences in the accuracy, confidence, ease, and preference associated with alternative representations of environmental-model uncertainty. Their findings caution against assuming that visually elaborate or intuitively attractive graphics necessarily maximize interpretability.

The issue has become more important as public communication moves through mobile interfaces and rapidly circulating digital media. Risk graphics may now be viewed for only a few seconds, cropped from their original context, shared without explanatory text, or interpreted on small screens. Under such conditions, designs that depend on extensive legends, subtle visual distinctions, specialized graphical conventions, or unstated statistical assumptions may fail even when their underlying analysis is accurate. Recent evidence on risk-probability communication also indicates that no single graphical format can be assumed to outperform alternatives in every decision task. Scalia and colleagues found context-dependent differences between icon arrays and bar graphs, while more recent systematic evidence emphasizes matching probability formats to the specific cognitive task being supported.

2. Objectives of the Study

2.1 To Examine the Relationship Between Visual Structure and Risk Comprehension

The first objective is to determine how different forms of information organization may influence the comprehensibility of complex public-risk messages. Particular attention is given to visual hierarchy, quantitative comparison, risk magnitude, population context, and the separation of essential information from secondary technical detail.

2.2 To Evaluate Action Recall and Uncertainty Recognition

The second objective is to assess whether communication designs that clearly distinguish hazard magnitude, recommended protective behavior, and uncertainty can theoretically improve audiences' ability to remember appropriate actions while accurately recognizing the limits of available evidence.

2.3 To Develop a Practical Evaluation Framework for Public-Risk Visuals

The final objective is to construct a methodological framework that public agencies and researchers can use to compare alternative risk-communication designs before deployment. The framework emphasizes comprehension, accessibility, uncertainty interpretation, and decision usefulness rather than relying exclusively on visual attractiveness or audience preference.

3. Review of Literature

3.1 Visual Representation, Numeracy, and Risk Understanding

Research on graphical risk communication has consistently demonstrated that audiences do not process numerical risk information uniformly. Differences in numeracy, graph literacy, prior knowledge, attention, and familiarity with probability terminology influence interpretation. Ancker, Senathirajah, Kukafka, and Starren reviewed graphical approaches to health-risk communication and concluded that design decisions affect quantitative reasoning in meaningful ways. Their work also established an important distinction between graphics designed to improve accurate reasoning and graphics designed primarily to influence attitudes or behavioral intentions.

García-Retamero, Okan, and Cokely reviewed evidence demonstrating that visual aids can help audiences understand risk information that would otherwise place substantial demands on numerical reasoning. Icon arrays are particularly useful when part-to-whole relationships are central to the message because they represent outcomes as countable units rather than abstract proportions. Yet later research has shown that graphical effectiveness is conditional rather than universal. Scalia and colleagues compared icon arrays with bar graphs and reported that understanding and preference were influenced by numeracy and graph literacy, reinforcing the need to consider who will use the visualization and what judgment they need to make.

More recent evidence strengthens this task-specific interpretation. Zikmund-Fisher, Benda, and Ancker's 2021 synthesis found that communication recommendations should be tied to defined probability tasks rather than derived from a broad assumption that any visualization is better than numbers alone. Contemporary work by Kandel and colleagues also suggests that icon arrays and bar charts can produce different perceptual and decision effects, and that estimation accuracy may not perfectly correspond with subsequent decision quality. These developments move the literature away from identifying a universally superior graph and toward designing representations around audience characteristics, specific comparisons, and intended decisions.

3.2 Communicating Uncertainty Without Creating Confusion

Public risks are frequently uncertain because forecasts depend on incomplete observations, model assumptions, evolving conditions, or competing scenarios. Removing uncertainty may make a visual appear simpler, but it can also create unjustified confidence. Conversely, displaying every available uncertainty layer can overwhelm viewers. Effective communication therefore requires a balance between transparency and cognitive manageability.

Bannister, Blackwell, Hyder, and Webb compared several ways of presenting environmental-model projections and found that audiences differed substantially in their ability to interpret specific values, trends, and uncertainty depending on graphical form. Dot and box plots performed strongly for some tasks, whereas visually attractive alternatives did not consistently produce the best interpretation. Their results illustrate that uncertainty graphics should be tested according to the questions users need to answer rather than selected only for familiarity or appearance.

Padilla and colleagues reached a complementary conclusion in pandemic forecasting. Their experiments demonstrated that variations in time scale and uncertainty presentation changed participants' perceptions of COVID-19 risk even when the underlying data source remained comparable. Such findings are particularly significant for public communication because perceived risk influences preparedness, attention, and response. A visualization that unintentionally amplifies or suppresses perceived danger may therefore affect behavior without altering any underlying scientific estimate.

Uncertainty is also influenced by language accompanying graphics. Juanchich and colleagues reported in 2020 that logically comparable low-probability descriptions could generate different impressions of scientific consensus depending on whether the probability was framed negatively or affirmatively. Across eight preregistered experiments involving 4,150 participants, positively framed low-probability expressions were generally interpreted as indicating stronger evidential and scientific support than negative formulations. The implication for visual information design is that graphical and verbal uncertainty should be developed together; a carefully designed uncertainty band can still be undermined by misleading accompanying language.

3.3 Accessibility, Actionability, and Public Communication

Visual risk communication is useful only when audiences can identify the central message and connect it with an appropriate response. WHO guidance emphasizes understandable and actionable communication rather than information transmission alone. The CDC's Crisis and Emergency Risk Communication framework likewise focuses on helping communicators deliver information capable of supporting protective behavior during emergencies. Visual cues, including hierarchy, spacing, emphasis, shape, and other perceptual signals, can direct attention toward the most important message, provided they are used consistently and accessibly.

Accessibility introduces requirements that extend beyond simplification. Color should not be the sole carrier of meaning. Critical distinctions require textual labels, shape differences, or other redundant encodings. Small-screen readability, alternative text, plain-language explanations, sufficient contrast, legible typography, and understandable legends are equally relevant. A communication that works only for highly graph-literate users may systematically disadvantage the people who most need immediate guidance.

The literature therefore supports a transition from visualization as presentation toward visualization as an interaction between evidence, cognition, and action. The strongest public-risk design does not merely display what analysts know. It identifies what an audience needs to notice, compare, remember, and do while simultaneously preserving scientific qualifications. This synthesis establishes the basis for the simulation framework used in the present investigation.

4. Research Methodology

4.1 Research Design and Analytical Logic

The study adopts a simulation-based comparative research design. It does not report an administered experiment or observations obtained from real participants. Instead, a synthetic dataset is used to demonstrate how four risk-communication strategies could be evaluated in a future controlled study.

The hypothetical communication scenario concerns a complex public environmental-health warning containing information about hazard severity, probability of exposure, geographical variation, uncertainty, vulnerable populations, and recommended protective actions. The substantive risk values are assumed to remain constant across conditions. Only the presentation architecture is varied.

A synthetic analytical sample of 480 observations was created, with 120 observations allocated to each design condition. Three outcome measures were represented on 0–100 scales: risk comprehension, protective-action recall, and uncertainty recognition.

Table 1: Experimental Design Framework for Comparing Risk-Information Formats

Condition	Simulated n	Information Design Characteristics	Intended Cognitive Effect
Text-heavy risk brief	120	Long prose, embedded percentages, limited hierarchy, no visual probability display	Baseline technical communication
Standard infographic	120	Headings, icons, selected statistics, basic visual hierarchy	Reduced reading burden and faster orientation
Layered risk visual	120	Risk magnitude, affected groups, uncertainty, comparison, and actions organized into distinct visual layers	Improved comprehension and decision relevance
Accessible layered visual	120	Layered design plus redundant encoding, clearer labels, simplified legend, accessibility-sensitive structure	Broader comprehension across heterogeneous audiences

Note: All conditions and observations in Table 1 are methodological simulations. They are not records of real participants.

4.2 Variables and Evaluation Criteria

Risk comprehension represents the ability to correctly interpret hazard magnitude, comparison values, affected population groups, and the meaning of the stated probability. Protective-action recall represents the ability to identify the principal recommended response after exposure to the communication. Uncertainty recognition represents the ability to distinguish established evidence from forecast ranges, assumptions, and information that remains unresolved.

The synthetic observations were generated around prespecified condition means with realistic dispersion to demonstrate comparative statistical procedures. A one-way analysis of variance was used separately for each of the three outcome variables. Effect magnitude was summarized through eta-squared. Because the observations are synthetic, significance values describe the properties of the simulated dataset only and must not be interpreted as evidence about an actual population.

4.3 Transparency, Reproducibility, and Ethical Position

No human participants were recruited, contacted, observed, or experimentally assigned in this study. Accordingly, the manuscript does not claim participant consent, field recruitment, or completed human-subject experimentation. The synthetic analysis is intended as a methodological demonstration that can subsequently be preregistered and tested using real participants.

A future empirical validation should recruit participants representing differences in age, education, language background, numeracy, graph literacy, disability status, and previous exposure to the relevant risk. Random assignment should be used where feasible, and researchers should record exposure duration, device type, response latency, comprehension, behavioral intention, and delayed recall.

Researchers conducting such a study should obtain ethics approval where required by their institution, document exclusion criteria before analysis, preserve de-identified data, preregister primary outcomes, and report unsuccessful or null comparisons as transparently as statistically significant findings.

5. Analysis

5.1 Comparative Performance Across Communication Conditions

9. The standard infographic increased this value to 72.2, while the layered risk visualization reached 82.

3. The accessibility-enhanced layered design generated the highest simulated mean of 85.3.

A similar progression occurred for protective-action recall. The text-heavy condition produced a mean of 58.4 compared with 70.1 for the conventional infographic, 77.9 for the layered design, and 82.3 for the accessibility-enhanced design.

Uncertainty recognition showed an especially important difference. Its simulated mean increased from 55.9 under the text-heavy design to 65.9 under the standard infographic, 77.3 under the layered visual, and 80.9 under the accessible layered visual. This pattern illustrates the possibility that simplified communication does not have to conceal uncertainty when uncertainty itself is designed as a visible information layer.

Table 2: Simulated Outcome Scores Across Visual Information Design Conditions

Communication Condition	Risk Comprehension Mean ± SD	Protective-Action Recall Mean ± SD	Uncertainty Recognition Mean ± SD
Text-heavy brief	63.9 ± 11.3	58.4 ± 12.6	55.9 ± 12.5
Standard infographic	72.2 ± 9.0	70.1 ± 10.3	65.9 ± 12.0
Layered risk visual	82.3 ± 8.6	77.9 ± 7.4	77.3 ± 9.9
Accessible layered visual	85.3 ± 8.3	82.3 ± 7.7	80.9 ± 9.0

Source: Authors' synthetic simulation. Values are illustrative methodological data and are not empirical observations.

5.2 Statistical Interpretation

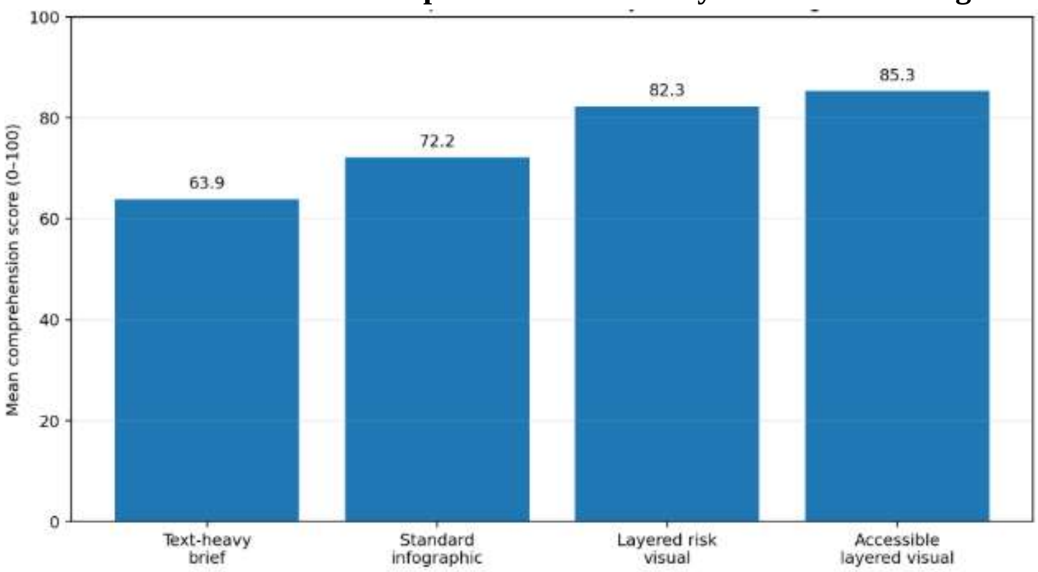
The simulated one-way ANOVA for risk comprehension generated $F(3,476) = 130.18$, $p < .001$, with an eta-squared value of approximately 0.451.

Protective-action recall produced $F(3,476) = 138.89$, $p < .001$, with $\eta^2 \approx 0.467$, while uncertainty recognition produced $F(3,476) = 129.47$, $p < .001$, with $\eta^2 \approx 0.449$.

These large simulated effects should not be interpreted as estimates of real-world effect sizes. Their analytical purpose is to show how future empirical studies can move beyond satisfaction ratings and compare communication formats through measurable cognitive and decision-oriented outcomes.

5.3 Graphical Comparison of Risk Comprehension

Graph 1: Simulated Mean Risk-Comprehension Scores by Information Design Condition



Interpretation: The graph demonstrates a clear simulated increase in comprehension as information architecture becomes more structured. Moving from the text-heavy brief to the conventional infographic corresponds to an 8.3-point increase. The layered risk visualization produces a further improvement of approximately 10.1 points, while the accessible layered format adds another 3.0 points.

The progressively smaller gain between the layered and accessibility-enhanced conditions is also conceptually important. Accessibility should not be viewed merely as a mechanism for raising an average score. Its more important function may be reducing exclusion and increasing the probability that understandable information reaches users with differing perceptual, linguistic, and graphical abilities.

Key Finding: Within the simulation, the strongest overall condition was not the design containing the largest amount of visual material, but the design in which risk magnitude, uncertainty, vulnerable groups, and protective actions were intentionally separated and made perceptually accessible.

6. Discussion

6.1 From Information Density to Information Hierarchy

The principal implication of this study is that public-risk visualization should not be evaluated according to the amount of information it contains. Complexity in the underlying hazard does not require equivalent visual complexity in the public-facing message. Instead, designers should preserve analytical complexity behind the communication while presenting the most decision-relevant elements through a hierarchy that guides attention.

This interpretation is consistent with WHO's emphasis on understandable and actionable risk communication and with evidence showing that visual formats differ according to the cognitive task they support.

A layered risk design can organize communication around a sequence of questions that naturally arise when people confront a threat: What is happening? How serious is it? How likely is exposure? Who is most affected? What remains uncertain? What should be done? The answers need not appear as literal questions in every communication, but the visual structure should make these dimensions identifiable without requiring extensive interpretive effort.

Hierarchy is also important because audiences do not necessarily read risk graphics linearly. A viewer may first notice a warning category, then a map, then an action statement, and only afterward examine technical details. The communication should remain coherent under this non-linear viewing pattern.

6.2 Accuracy, Uncertainty, and Protective Action

An ethically sound risk visualization must avoid two opposing failures: alarmist exaggeration and false reassurance. Exaggeration can damage credibility and create unnecessary fear, whereas understatement may prevent appropriate preparation. Scientific uncertainty therefore needs to be communicated as meaningful information rather than treated as a flaw in the evidence.

Padilla and colleagues' work demonstrates that even apparently technical visualization choices can affect perceived risk. Bannister and colleagues similarly show that some visualizations support different uncertainty tasks more successfully than others. More recent work by Juanchich and colleagues indicates that verbal probability framing can alter impressions of evidence and consensus even when numerical meanings are similar. Together, these studies indicate that uncertainty should be designed at both visual and linguistic levels.

For operational risk communication, an uncertainty statement should answer why the estimate may change and whether the uncertainty affects the recommended action. A forecast may contain considerable uncertainty while still supporting a clear protective recommendation. Separating confidence in the prediction from confidence in the action can therefore improve communication.

Action guidance should also be visually distinguishable from descriptive statistics. A reader who understands that flood probability is 25% but cannot determine whether evacuation, preparation, monitoring, or no immediate action is recommended has not received complete decision support.

6.3 Limitations and Directions for Empirical Validation

The most important limitation is that the numerical analysis is synthetic. It demonstrates a methodological framework rather than establishing causal effects in an actual population. The simulated differences should therefore not be cited as empirical evidence that an accessibility-enhanced layered visualization will produce an exact 85.3 comprehension score or a particular improvement over conventional infographics.

A second limitation is that the model simplifies public-risk communication into four broad design conditions. Actual communications vary simultaneously in color, typography, spatial organization, source credibility, message framing, interaction, animation, device size, language, and cultural interpretation.

A third limitation concerns behavioral outcomes. Comprehension and recall are important, but correct understanding does not automatically produce protective behavior. Trust in institutions, perceived personal relevance, resource constraints, social norms, prior beliefs, and the feasibility of recommended actions may intervene between understanding and response.

Future empirical studies should therefore conduct preregistered experiments comparing individual design components rather than only complete infographic packages. Studies should include participants with diverse numeracy and graph-literacy levels and should evaluate not only immediate comprehension but delayed recall, confidence calibration, behavioral intention, and actual decision performance where ethically and practically possible.

Recent research provides a strong foundation for such task-specific evaluation. The 2025 Making Numbers Meaningful evidence program and 2026 work comparing icon arrays with bar charts reinforce the proposition that visualization effectiveness depends on the decision task, audience, and perceptual encoding rather than on a universal graphical hierarchy.

7. Conclusion

Visual information design has become a fundamental component of public-risk communication because contemporary threats are increasingly represented through complex datasets, probabilistic models, forecasts, maps, and rapidly updated indicators. Yet the availability of sophisticated data does not guarantee public understanding. Communication succeeds only when evidence can be interpreted accurately enough to support proportionate and informed action.

The present study proposes that effective public-risk visualization depends on five closely connected principles: disciplined information hierarchy, appropriate quantitative encoding, visible treatment of uncertainty, explicit connection between risk and protective action, and accessibility across heterogeneous audiences. These principles shift the role of visual design from aesthetic packaging to functional decision support.

The simulation illustrates how alternative communication strategies can be evaluated through measurable outcomes. Within the synthetic dataset, the accessibility-enhanced layered visualization produced the highest comprehension, protective-action recall, and uncertainty-recognition scores, while the text-heavy condition consistently produced the lowest scores. These results are methodological demonstrations and should not be mistaken for findings obtained from real participants.

The broader contribution of the paper is therefore its evaluation logic. Public agencies should not assume that an infographic is effective merely because it is concise, attractive, or widely shared. Risk graphics should be tested for whether people understand the magnitude of danger, identify who is affected, interpret uncertainty appropriately, remember the recommended action, and avoid predictable misinterpretations.

Ultimately, complex risks do not require visually complicated messages. They require carefully designed representations that preserve the integrity of evidence while making its practical meaning accessible. When visual information design is integrated with scientific analysis, accessibility, uncertainty communication, and behavioral decision requirements, it can strengthen the ability of communities to understand public threats and respond to them responsibly.

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E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

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