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Delayed Evacuation after a Disaster Because of Irrational Prediction of the Future Cumulative Precipitation Time Series under Asymmetry of Information

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Abstract: This study investigated biased prediction of cumulative precipitation, using a variety of patterns of histories of cumulative precipitation, to explore how such biased prediction could delay evacuation or evacuation orders. The irrationality in predicting the future of cumulative precipitation was examined to obtain insights into the causes of delayed evacuation or evacuation orders using a simulated prediction of future cumulative precipitation based on the cumulative precipitation history. Anchoring and adjustment, or availability bias stemming from asymmetry of information, was observed in the prediction of cumulative precipitation, and found to delay evacuation or evacuation orders.

Keywords: flooding of riverbanks; delayed evacuation; cumulative precipitation; asymmetry of information; prediction failure; anchoring and adjustment; availability bias

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1. Introduction

A root cause of many disasters is mistakes in risk estimation because of a system's high complexity [1–3] or natural phenomena. Estimating or predicting a variety of risks caused by natural disasters, and making decisions rationally without cognitive biases, such as the optimism bias, are important in terms of enabling people to protect their safety with certainty. Accurate recognition of risks and corresponding rational behavior can minimize the damage caused by natural disasters.

Torrential rain fell on western Japan from 6 to 7 July 2018 and induced extensive damage around this area, particularly in the Hiroshima, Okayama, and Ehime prefectures [4–8]. Many people were victims of this disaster, and 51 people were affected by the flooding in Mabi town, Kurashiki city. The hazard map of Kurashiki city indicated a risk that cumulative precipitation above 225 mm over 2 days would lead to the collapse of the riverbank along the Odagawa river and a subsequent flooding disaster. However, Kurashiki city officially issued evacuation orders 4 min before the collapse of the riverbank along the Odagawa river, thus resulting in delayed evacuation for many residents. Members of the self-defense force and police rescued approximately 2350 people [9,10]. Unfortunately, appropriate and rational evacuation orders were not issued.

The necessity of immediate evacuation was underestimated even though flooding was likely, and the evacuation was ultimately delayed. This mindset arises from a belief that the cost of evacuation would be greater than that of the flooding damage, thus enhancing the tendency toward loss aversion [11] with evacuation and optimistically underestimating the threat of flooding.

Decision-makers are not sufficiently skilled to predict the future [12], thus making appropriate decision-making regarding the future impossible. Akerlof [13] proposed the concept of asymmetry of information [9], in which one group has more information than another. A group with less information cannot make decisions accurately and rationally, owing to the lack of information necessary for predicting the future. This situation corresponds to an asymmetry of information between the information available to predict the future and the information necessary for predicting the future accurately and rationally (Figure 1). Decisions or behaviors under uncertainty, such as evacuation due to flooding, are likely to be vulnerable to cognitive biases (irrational behavior decisions) [11,14,15] because of the increases in the asymmetry of information caused by uncertainty. Under uncertainty, during outbreaks of natural disasters, asymmetry of information hinders accurate prediction of the future and rational decision-making. The worst case would result in many disaster victims.

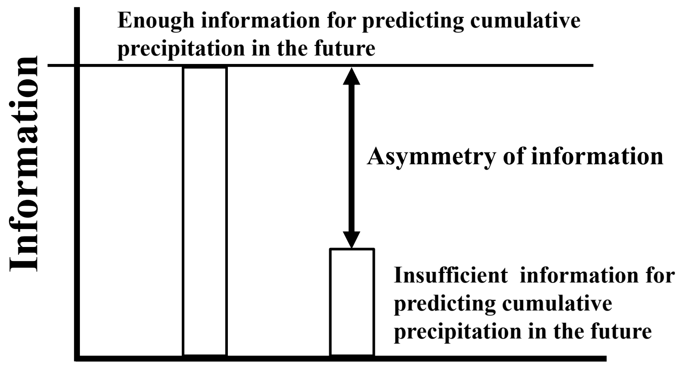

Figure 1. Schematic summary of asymmetry of information.

Several cases of crashes or disasters have been found to stem from irrational behavior under uncertainty or asymmetry of information [16–18]. Studies have identified irrational behaviors on the basis of analyses after crashes or disasters. Irrational behaviors, particularly failures of prediction, have been empirically identified in the fields of finance, business, economics, and psychology [19–21]. A variety of cognitive biases lead to prediction errors in investment, finance, or business, and investors tend to predict increases in stock prices by mistake, hold losing shares for a long time, and incur losses [19]. However, the irrational behaviors caused by prediction failures have not been sufficiently examined to prevent people from becoming victims of delayed evacuation, as described above. To date, failures of prediction due to human behaviors or attitudes under uncertainty have not been empirically investigated in the field of safety management, particularly emergency management, and few studies have investigated how irrationality or cognitive biases lead to prediction failures that could potentially delay evacuation in disasters. Therefore, the characteristics of prediction failure must be empirically explored to gain insights into how these failures delay evacuation in disasters such as torrential rain (flooding), hurricanes, or earthquakes.

We hypothesized that one cause of delayed evacuation is the failure to predict the cumulative precipitation because of cognitive biases (participant's psychology), such as anchoring and adjustment, or availability bias [22–25]. In anchoring and adjustment [25], individuals use a starting point called an anchor and make minor adjustments until they reach an acceptable solution. Anchoring and adjustment is a psychological state that leads to errors in judgment or decisions when the initial solution deviates from a rational state. We assumed that this bias would lead to a failure in the accurate prediction of cumulative precipitation and delay evacuation. Individuals trapped in availability bias are in a psychological state that relies on immediate or recent and familiar information (available information) that is readily recollected [25]. Individuals tend to mistakenly believe that readily recollected (immediate or recent and familiar) information is more important than information that is not readily recollected. The availability bias might also lead to misunderstanding or misrecognition of the state, thus resulting in delayed evacuation or a failure to predict cumulative precipitation.

This study explored humans' irrational prediction of cumulative precipitation using a variety of histories of cumulative precipitation, then assessed how this irrationality caused delayed evacuation. That is, using an experiment (questionnaire survey) to assess the prediction of future cumulative precipitation according to a time series history of cumulative precipitation, we investigated irrationality in predicting the future of cumulative precipitation to obtain insights into the cause of delayed evacuation. This study was conducted to answer the research question that cognitive biases (human psychology), caused by an asymmetry of the information necessary for accurately predicting the future, led to delayed evacuation or evacuation orders. A variety of time series of cumulative precipitation with divergence tendencies, convergence tendencies, and linear increasing tendencies were used to examine how these patterns affected the prediction of future cumulative precipitation and psychological feelings regarding the necessity of immediate and specific evaluation orders. Moreover, the data for Mabi town in Kurashiki city together with the experimental data were applied to assess irrational decision-making in an actual evacuation. We further investigated the relationship between the predicted cumulative precipitation X in the next 12 h and the subjective possibility for each participant that cumulative precipitation would not lead to X. On the basis of our survey, we discuss implications for safe evacuation without irrationality (cognitive biases).

2. Methods

Using different patterns of time series history of cumulative precipitation such as convergence, divergence, or linear increasing tendencies, we investigated how participants predicted the future change in cumulative precipitation over time, and perceived the necessity of immediate and specific evacuation orders for each pattern of the time series history of cumulative precipitation. On the basis of our findings, we discuss triggers of optimism regarding flooding risk and delayed evacuation.

2.1. Participants

Fifty-eight (53 male and 5 female) undergraduate or graduate students in engineering at Okayama University, Japan, agreed to take part in the survey. This study was approved by the Ethical Committee of the Department of Intelligent Mechanical Systems, Okayama University.

This study required the participants to predict future cumulative precipitation over 12 h on the basis of the history of 12-h cumulative precipitation. Therefore, we decided to study undergraduate or graduate students in engineering who were deemed to have mastered the basic knowledge or concepts of the prediction model in their educational curriculum. Although only five women were included among the participants, we concluded that gender differences would not affect the prediction of the cumulative precipitation over 12 h.

2.2. Task and Procedure

Participants were first instructed to imagine that a risk of riverbank collapse would exist when the cumulative precipitation during 2 days reached 200 mm. The investigation consisted of three tasks.

The first task was to predict the cumulative precipitation over the next 12 h for each of the five patterns of the time series history of cumulative precipitation shown in Figure 2. Participants were also required to predict the cumulative precipitation over the next 12 h for the actual time series of cumulative precipitation that occurred at Mabi town, Kurashiki city, on 6 and 7 July 2018 (Figure 3). The order of prediction for the six patterns of time series was randomized across participants. Notably, the cumulative precipitation in Mabi town at the start of the prediction was not exactly 100 mm.

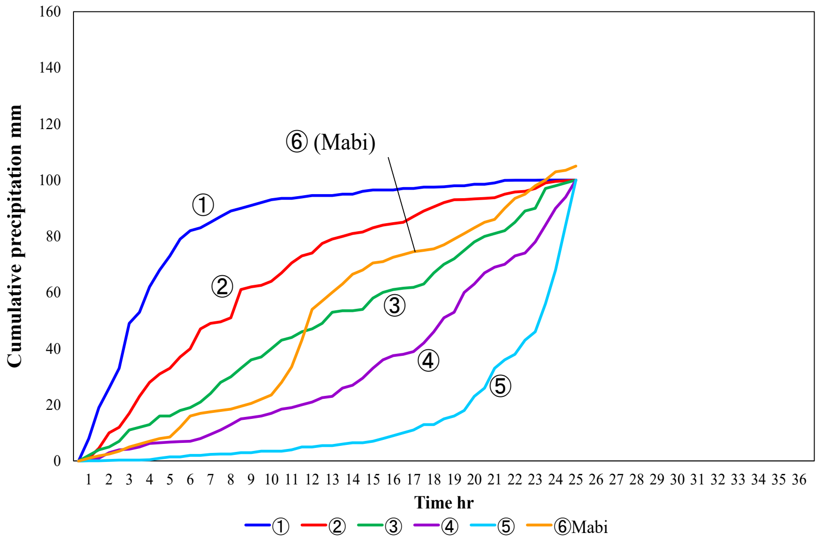

Figure 2. Assumed patterns and actual data (Mabi town in Kurashiki city) for cumulative precipitation in the past 24 h.

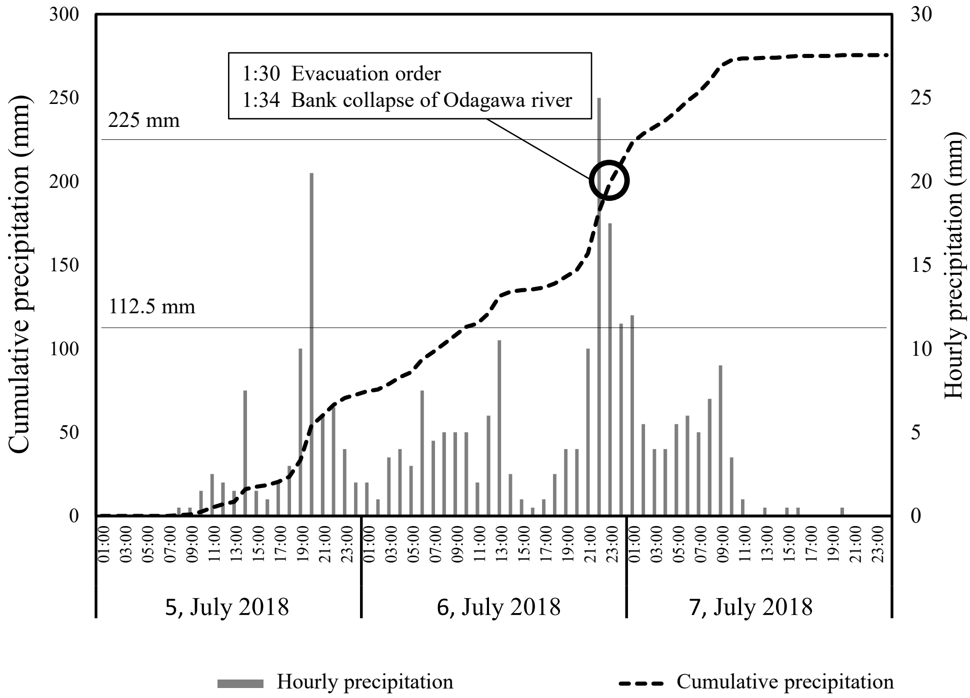

Figure 3. Cumulative precipitation and hourly precipitation from 5 July 2018 to 7 July 2018 along the Odagawa river in Mabi town, Kurashiki city.

The second task was evaluation of the subjective possibility that the cumulative precipitation would not lead to X from $X = 110$ mm to 200 mm every 10 mm for each pattern of past cumulative precipitation in Figure 3 (actual data for Mabi town) and Figure 2 (pattern assumed by the authors). Here, the subjective possibility that the cumulative precipitation would not lead to X was denoted by Y. The evaluation was conducted using an integer from 0 (very low possibility) to 100 (very high possibility). The order of evaluation of the subjective possibilities for the six past patterns of cumulative precipitation was randomized across participants.

The third task required participants to evaluate the necessity of immediate and specific evacuation orders according to the first and second task. Participants were required to evaluate the necessity scores of immediate and specific orders on a seven-point scale (1: no need for immediate and specific evacuation orders; 7: absolute need for immediate and specific evacuation orders). This evaluation was conducted for the six patterns of past change in cumulative precipitation over time. The order of evaluation for the six patterns of past time series was randomized across participants.

2.3. Data Analysis

The first data set, containing the predicted cumulative precipitation over 12 h for each of the six patterns, was analyzed by fitting a linear regression function to the predicted cumulative precipitation over 12 h. The second data set, Y (that is, the subjective probability of the cumulative precipitation not leading to X), was analyzed with a two-way (predicted cumulative precipitation X (ten levels) for each pattern of time series history of cumulative precipitation (six levels)) analysis of variance (ANOVA). The third data set, which comprised evaluation scores of the necessity of immediate and specific evacuation orders among the six patterns of time series history of cumulative precipitation, was statistically analyzed with a non-parametric Kruskal–Wallis test.

3. Results

Figure 4 shows the geometric mean of the predicted cumulative precipitation across all participants for the five assumed patterns in Figure 2. In Figure 4, the results of the prediction of cumulative precipitation over the next 12 h, using mathematical models, are also depicted. As shown in this figure, the prediction by participants corresponded well with that by mathematical models. Figure 5 shows a similar result to the data in Figure 3. Linear regression analysis was conducted on the predicted cumulative precipitation across all participants for the five assumed patterns in Figure 2 and one actual pattern in Mabi town in Figure 3. Figure 5 also shows a result for the prediction of cumulative precipitation over the next 12 h using a mathematical model. It must be noted that the mathematical model was applied to the data after 12 h. Even for the actual data of Mabi town, Kurashiki city, the prediction by participants corresponded well with that by a mathematical model. The prediction using past time series could not predict the future cumulative precipitation accurately after 37 h, as shown in Figure 5. The slopes of a simple linear regression for patterns ①–⑥ were 0.27, 1.29, 3.25, 9.67, 11.75, and 4.01, respectively. For the convergence pattern (①) and pattern ②, the slopes tended to be smaller. As the pattern changed from ① (convergence) to ⑤ (divergence), the slopes increased. The slopes of data based on the actual pattern for Mabi town (⑥) were slightly greater than those of pattern ③. In summary, the prediction results provided by participants were not far from those of mathematical models.

Figure 6 shows the relationship between the predicted cumulative precipitation X in the next 12 h and Y (the subjective possibility for each participant that cumulative precipitation would not lead to X). A two-way analysis of variance conducted on the possibility Y (subjective possibility that the cumulative precipitation would not lead to X) revealed a significant main effect of X ($F(9,2560) = 149.559$, $p < 0.01$) and pattern of time series history of precipitation ($F(5,2560) = 712.654$, $p < 0.01$). The interaction between X and the pattern of time series history was also significant ($F(45,2560) = 8.305$, $p < 0.01$). This interaction indicated that the relationship between X and Y differed in terms of the (i) convergence patterns (① and ②), (ii) divergence patterns (④ and ⑤), and (iii) patterns ③ and ⑥.

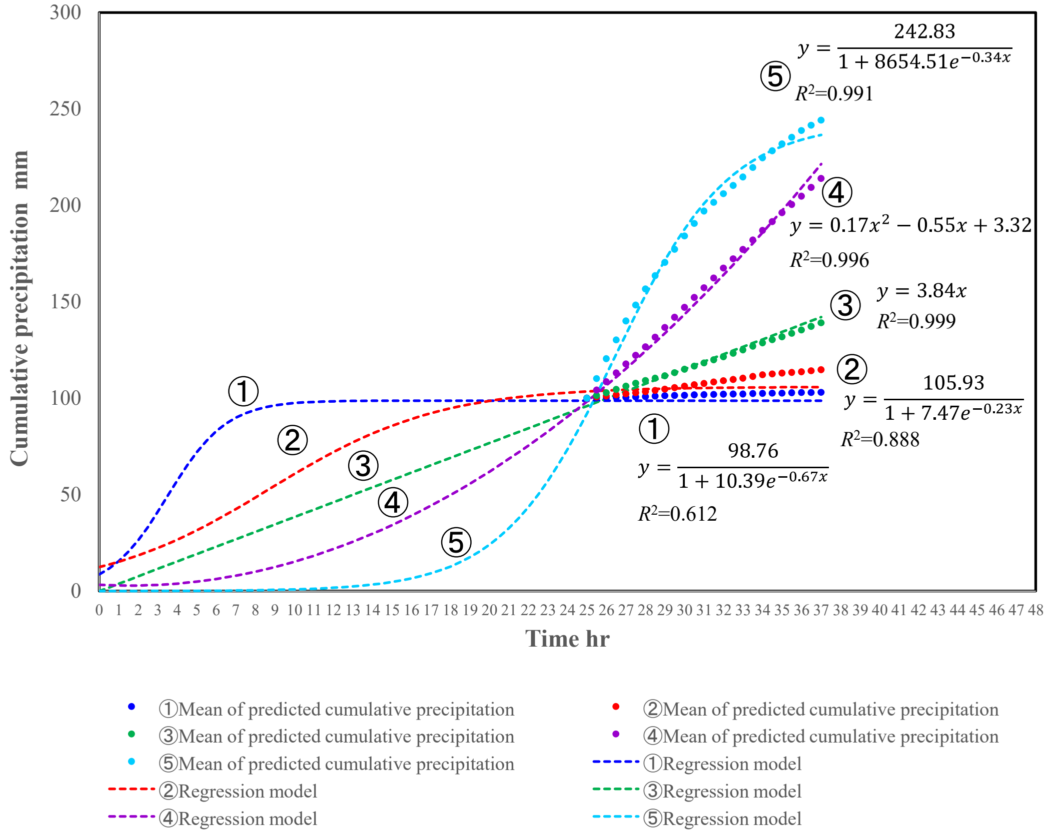

Figure 4. Geometric mean of predicted cumulative precipitation over 12 h for each pattern and results of prediction by mathematical models.

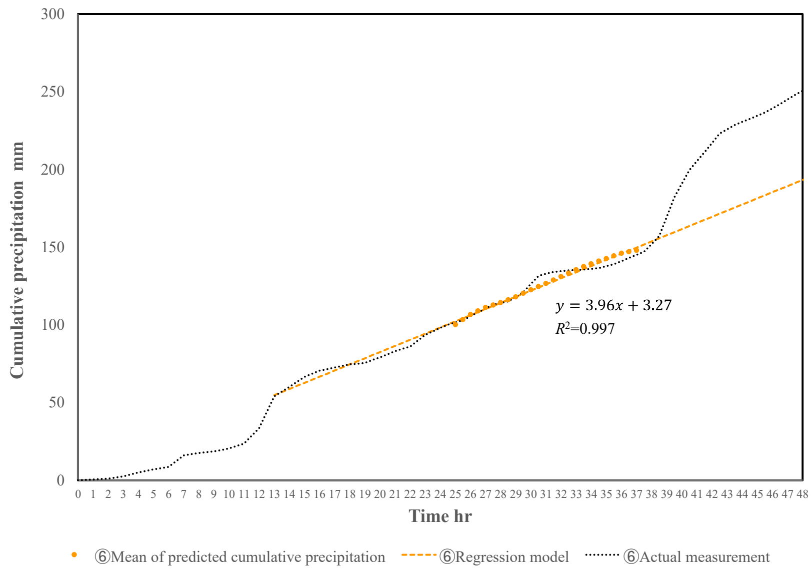

Figure 5. Geometric mean of predicted cumulative precipitation over 12 h for the data of Mabi town, Kurashiki city (from 5 to 7 July 2018), and results of prediction by a mathematical model.

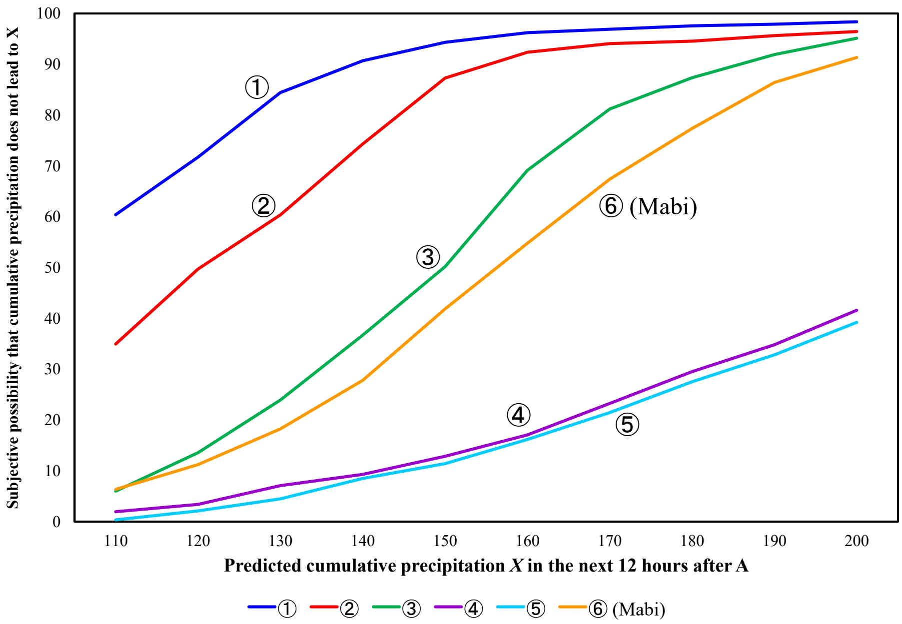

Figure 6. Subjective possibility of cumulative precipitation not exceeding *X*, compared among *X*s for the five assumed patterns and the data for Mabi town, Kurashiki city, 5–7 July 2018.

Figure 7 compares the psychological evaluation of the necessity of immediate and specific evacuation orders for the five patterns in Figure 2 and the actual cumulative precipitation in the Kurashiki flooding disaster in Figure 3. A non-parametric Kruskal–Wallis test revealed significant differences in patterns ($\chi^2(5) = 172.50$, $p < 0.01$). Table 1 shows the results of Scheffe's multiple comparison. The perceived need for immediate and specific evacuation orders was stronger for patterns ④ and ⑤, but was not as strong for pattern ⑥ (actual data for Mabi town). The perceived need was smallest for convergence pattern ①.

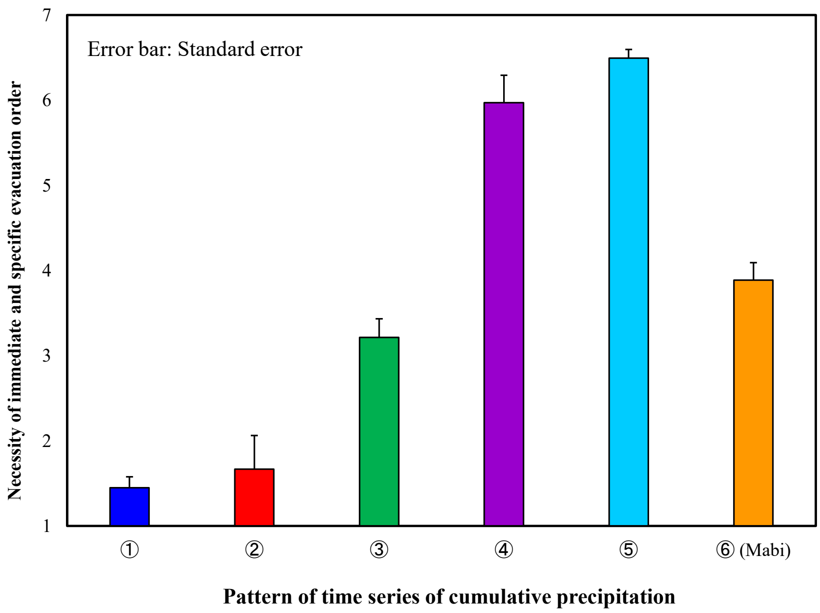

Figure 7. Evaluation of the necessity of immediate and specific evacuation orders, compared among five assumed patterns and data for Mabi town, July 2018.

Table 1. Results of Scheffe's multiple comparison.

	①	②	③	④	⑤	⑥
①						
②	n.s.					
③	**	n.s.				
④	**	**	**			
⑤	**	**	**	n.s.		
⑥	**	*	n.s.	n.s.	**	

n.s.: not significant, *: $p < 0.05$, **: $p < 0.01$.

As clearly shown in Figure 5, the predicted cumulative precipitation corresponded well with the actual cumulative precipitation. As shown in Figure 6, Y (the subjective possibility for each participant that cumulative precipitation would not lead to X) compared among conditions of X in the convergence pattern (①) and pattern ② was overestimated. The similar subjective possibility for each participant indicated that the cumulative precipitation in the divergence pattern (⑤) and pattern ④ had relatively lower values. Participants tended to overestimate the subjective possibility with respect to the actual data for the Kurashiki flooding disaster (Mabi town). The value of Y (the subjective possibility that cumulative precipitation would not lead to X) was 91.54, thus suggesting that the participants underestimated the risk of riverbank flooding and optimistically felt that the cumulative precipitation would not reach a hazardous level (X = 200 mm). This finding was further supported by the data shown in Figure 7, because the necessity of immediate and specific evacuation orders for the actual time series of cumulative precipitation (Figure 3) was 3.88, a value lower than those of patterns ⑤ and ④.

4. Discussion

All patterns were based on the assumption that the cumulative precipitation reached approximately 100 mm in 24 h. Notably, the data for Mabi town slightly exceeded 100 mm, as described above (Figure 3). The patterns of the past time series differed, as shown in Figures 2 and 3. The prediction of the time series of cumulative precipitation and the decision regarding evacuation orders differed among the patterns of past time series of cumulative precipitation (Figures 4, 5 and 7). When the time series tended to converge, as in patterns ① and ②, participants predicted that similar convergence tendencies would continue according to the past pattern of the time series. Participants predicted that divergence patterns ④ and ⑤ would continue for the next 12 h. As shown in Figures 4 and 5, the predictions given by participants were not so far from the predictions given by mathematical models. This must mean that both the participants and mathematical models predicted the future such that the predictions reflected the past time series of cumulative precipitation.

The subjective possibility Y (subjective possibility that cumulative precipitation would not reach X), compared among conditions of X, is discussed (Figure 6). Notably, the higher the value in Figure 6, the more participants felt that the cumulative precipitation would not lead to X, and thus, that risk of flooding of the riverbank would not actually occur. In accordance with the results in Figure 4, the subjective possibility value was higher in convergence patterns ① and ② than in divergence patterns ④ and ⑤ for all values of X. Moreover, the necessity of immediate and specific evacuation orders was perceived to be stronger for patterns ④ and ⑤ than patterns ① and ② (Figure 7).

The results of the actual data for Mabi town in Kurashiki city in July 2018 are discussed. The predictions given by the participants were not so far from the predictions reached via mathematical modelling (Figure 5). As shown in Figure 6, the subjective possibility score Y was between the possibility scores of patterns ④ and ⑤ and of patterns ① and ②. These results eventually led to necessity scores (Figure 7) ranging between those of patterns ④ and ⑤ and patterns ① and ②. Although the situation of Mabi town evoked less optimism than patterns ① and ② (data after 38 h in Figure 5), participants did not perceive the necessity of immediate and specific evacuation as strongly as with patterns ④ and ⑤. This psychology of participants reacting to the data for Mabi town (Figure 2) (availability bias or anchoring and adjustment) might have caused the delayed evacuation orders in the Kurashiki disaster involving riverbank flooding. As shown in Figure 5, the cumulative precipitation began to increase abruptly after 38 h (14 h after time point A). The prediction (dashed line) based on the past time series in Figure 5 caused delayed evacuation when the cumulative precipitation increased suddenly after 38 h (14 h after time point A). We propose that the possibility that the cumulative precipitation might increase abruptly after 38 h (14 h after time point A), as shown in Figure 5, was not observed because of asymmetry of information or a lack of the data or information necessary for accurately predicting the future (Figure 1). It seems that asymmetry of information made it impossible for both participants and mathematical models to predict the future accurately. The fact that both predictions were based on only past time series of cumulative precipitation must have led to similar predictions.

According to the results in Figures 4–7, the causes of delayed evacuation are further discussed from the viewpoints of cognitive biases, such as anchoring and adjustment, or availability bias. Individuals or organizations are well recognized to perform poorly in predicting the future, particularly under uncertainty [12,26,27]. Murata and Karwowski [17] suggested that misunderstanding occurs readily under uncertain situations with asymmetry of information [13]. The asymmetry of information during the collapse of the riverbank (flooding) under torrential rain corresponds to the asymmetry of information reflected in the gap between the actual future time series of cumulative precipitation and the irrational human prediction of cumulative precipitation. This situation causes individuals or organizations to fail to predict the future state, such as how the collapse of the riverbank might proceed and result in a disaster [16,17]. The prediction of future events is difficult, particularly under conditions of information asymmetry, as shown in Figure 1. Cognitive biases such as anchoring and adjustment, or availability bias, hinder the accurate prediction of the future. Only available information, such as the history of the time series of cumulative precipitation (anchoring and bias) or the more recent time series of cumulative precipitation (availability bias) led to the prediction shown with the dashed line in Figure 5, and made participants think that immediate evacuation or evacuation orders should not be undertaken, without believing that the cumulative precipitation would increase abruptly after 38 h, as shown in Figure 5. The availability bias or anchoring and adjustment must have caused the delayed evacuation or evacuation orders. This is also supported by the results in Figure 7, where it can be seen that the necessity score of immediate and specific evacuation for the data of Mabi town was lower than that of patterns ④ and ⑤.

The results in Figures 4 and 5 might indicate that the history of cumulative precipitation over time is used as an anchor or is regarded as available information for future prediction. Because the cumulative precipitation at the start of the prediction was approximately 100 mm for all six patterns, all patterns had a potential risk of reaching 200 mm. Thinking the future by taking such a possibility into account as well as the future prediction is rational. Thinking the future based on only the prediction using limited information leads to irrational (optimistic) decision that cumulative precipitation will not lead to a hazardous level (more than 200 mm) and causes delayed evacuation. This will cause the delay of evacuation. Although people must first consider the present cumulative precipitation, they used only the future prediction and did not take the risk of present cumulative precipitation leading to the hazardous level into account. In other words, the future prediction was markedly affected by anchoring and adjustment or availability bias where only the available pattern of the past time series was used for predicting the future. The participants appeared to be affected by the past time series rather than the present cumulative precipitation. Although all patterns could reasonably be considered to have a risk of reaching the limit of 200 mm regardless of the past time series of cumulative precipitation, the participants did not consider the possibility that any pattern might reach the cumulative precipitation of 200 mm and lead to riverbank collapse. The results clearly showed anchoring and adjustment, or availability bias, under which only available data were present in the prediction of the future cumulative precipitation. As described above, participants' psychological mechanisms, such as anchoring and adjustment, or availability bias that forced participants to predict the future using only past time series of cumulative precipitation, must have contributed to the delayed evacuation orders, because participants felt that immediate and specific evacuation orders were not necessary for patterns ① and ② and the Mabi data, as shown in Figure 7 together with their prediction that the cumulative precipitation would not reach the hazardous level of 200 mm.

The deviation of the predicted cumulative precipitation from the actual cumulative precipitation was likely to have been caused by an asymmetry of information, as shown in Figure 1, which must have been vulnerable to anchoring and adjustment or availability bias. The cumulative precipitation over 24 h at the time of prediction of the future cumulative precipitation was 100 mm for all patterns in Figure 2. Nonetheless, the future prediction was irrationally affected by availability bias or anchoring and adjustment, which relied only on the past time series of cumulative precipitation to predict the future precipitation. This effect might have hindered participants from assuming the worst result (X reaches 200 mm), thus inevitably causing delayed evacuation.

5. Conclusions

In exploring humans' irrational characteristics in predicting cumulative precipitation, using a variety of histories of cumulative precipitation, we reached the following answer to the research question regarding the reasons for delayed evacuation In conclusion, anchoring and adjustment, or availability bias stemming from asymmetry of information, resulted in a failure to predict cumulative precipitation, which might have caused the delayed evacuation of residents or delayed evacuation orders from the local government (Kurashiki city). Such cognitive biases should be eliminated when evacuation from a disaster area is necessary.

The limitation of this study is that an effective method for eliminating irrationality or cognitive biases in predicting the future threat of natural disasters has not yet been generalized and established. Future research should generalize the results of this study so that safe evacuation or evacuation orders can be put into practice. An effective method to remove humans' irrational characteristics in predicting the future is essential to avoid failures such as delayed evacuation. To minimize the number of disaster victims, local governments or residents must be sufficiently trained to collect information with less asymmetry and without cognitive biases.

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