



# Gamified Disaster Education. A Systematic Review of Serious Games on Dealing with Natural Hazards and of their Impacts and Outcomes for Users

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10 **Abstract.** Natural hazards pose a threat to human life and health. As a tool of risk communication and disaster education serious games are being used with increasing frequency. Even though an increase in research in the field is observable, little is known about serious games' actual effectiveness. This systematic review gives an overview of existing publications on serious games dealing with natural hazards and evaluations of reported effects on users. We analyse 132 scientific articles and conference papers published between 2007 and 2025. Most publications describe digital serious games; analogue or hybrid  
15 formats were rarely explored. Flooding is the hazard addressed most frequently. 17 publications introduce and describe the serious games, while about half of the publications (n=73) report a usability evaluation of the games. This review focuses on the 42 publications that also include an evaluation of the serious games' impact on the player. Most of these effectiveness evaluation studies do not apply any theoretical frameworks for the game development and/or evaluation processes. A noticeable concentration of findings concerns positive impacts on knowledge and self-efficacy. Behaviour, motivation,  
20 intention, further psychological impacts as well as specific competencies are explored in comparably few publications. Our findings show that theoretical frameworks play a subordinate role in the current research landscape examined. The quality of applied evaluation methods varied considerably. Most commonly reported impacts and outcomes for players were increased knowledge and self-efficacy.

*Keywords:* educational games, gamification, climate change adaptation, risk communication, disaster risk research

## 25 **1 Introduction**

Consequences of climate change such as natural hazards pose a threat to human life and wellbeing, and cause severe damages every year (IPCC, 2023). The Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015) provides guidelines for action to mitigate and adapt to climate risks. Within Disaster Risk Reduction (DRR), adaptation and protection measures are necessary both on the individual and institutional level (UNDRR, 2015). Effective adaptation requires societal acceptance  
30 and action-oriented knowledge which can be strengthened through risk communication and disaster education (Moser, 2014; Wirth et al., 2014).



In this context, serious games are often discussed as a promising tool (Flood et al., 2018; Solinska-Nowak et al., 2018) offering opportunities to engage with natural hazards in a playful yet meaningful way. However, the scientific literature on serious games in disaster context lacks evidence regarding their effectiveness, particularly their impacts or outcomes for players. With this systematic review, we aim at gathering empirical evidence on *whether, how, and with which theoretical frameworks* the effectiveness of serious games addressing natural hazards has been explored in scientific publications.

### 1.1 Definitions and Categorizations of Serious Games and Related Concepts

Serious Gaming is an emerging field of research across different disciplines. The concept of *Serious Games* was first articulated by Abt (1970), who emphasized their deliberate educational intent beyond mere entertainment. Serious games can be defined as fully developed games (Deterding et al., 2011) that prioritise objectives other than entertainment, regardless of medium (Michael and Chen, 2011). They often seek to influence players' behaviour, attitudes, or knowledge (Becker, 2021), and may also serve purposes beyond education, such as in artistic or therapeutic contexts (Breuer and Bente, 2010). However, definitions of serious games remain inconsistent and highly dependent on disciplinary perspectives (Sawyer and Smith, 2008). Terms such as *educational games*, *training games*, and *learning games* are sometimes used interchangeably in the literature, although their meanings may vary depending on context (Landers, 2014). The underlying process of learning through games is referred to as *game-based learning* (Becker, 2021). The implementation of isolated game design elements—such as scoring systems, leaderboards, or rewards—into non-game contexts is referred to as *gamification* (Breuer and Bente, 2010; Deterding et al., 2011).

Various taxonomies support the classification of serious games (see review by De Lope & Medina-Medina, 2017). The widely used GPS-model (Alvarez and Djaouti, 2011; Djaouti et al., 2011) categorizes serious games by *gameplay type*, *pedagogical purpose*, and *application scope*. Additionally, the Comprehensive Serious Games Taxonomy (De Lope and Medina-Medina, 2017) employs 16 distinct criteria—such as target audience, genre, and development methodology—to generate a detailed hierarchical classification.

Recent educational discourses, reinforced by the COVID-19 pandemic underscores a shift toward personalized, active, student-centred learning environments, with flexible learning structures (González-Pérez and Ramírez-Montoya, 2022; Zhao and Watterston, 2021). In parallel, future skills frameworks (e.g., reviews by Chen, 2019; González-Pérez & Ramírez-Montoya, 2022; Kotsiou et al., 2022) highlight the promotion of individual-object-related digital competences (e.g., González-Pérez & Ramírez-Montoya, 2022). In light of these developments, (digital) serious games represent innovative learning environments with differentiable levels of difficulty (Gampell et al., 2020), promoting autonomous and inclusive learning (Zhonggen, 2019), and a long examination of the topic in a motivating way (Schuller et al., 2013; Zhonggen, 2019).

### 1.2 Serious Games: Tools for education and risk communication in DRR?

Serious games in the context of DRR can be located within the framework Education for Disaster Risk Reduction (Aghaei et al., 2018; Cabello et al., 2021). More broadly, teaching about DRR aligns with the core tenets of Education for Sustainable



65 Development, as outlined in Sustainable Development Goal 4 (Quality Education). As customizable game worlds enable targeted engagement with core geographic dimensions (temporal, spatial, and systemic; Fögele, 2018), serious games can represent a promising tool for education and risk communication: they can visualize climate dynamics and DRR strategies through immersive simulations and animations (Sheppard, 2015; Wirth et al., 2014), while offering indirect, experiential access to complex phenomena (Bösche, 2014; Caserman et al., 2020; Wachinger et al., 2013). Temporal aspects of hazards thus become more tangible (Fernández Galeote, 2024; Sheppard, 2015).

70 Serious games are not new in the field of DRR and natural hazards research as existing reviews show. For example, Solinska-Nowak et al. (2018) reviewed 45 games related to DRR by researching games and matching publications. They provide an overview of serious games and simulations in the field and identify a lack of evaluation studies on the pertinent games or applications. Flood et al. (2018) conducted a systematic review on serious games in climate change adaptation. Some of the reviewed 43 papers covered natural hazards, but the article's main focus is on other aspects of climate change adaptation. More recently, Forrest et al. (2022) published a review specifically on serious games concerning Flood Risk Management (FRM). To our knowledge no more recent review exists in this field. Since a lot of research has been conducted on serious games in the context of natural hazards, our aim is to provide an updated, structured overview of the current research landscape. In contrast to existing reviews, we place particular emphasis on the effectiveness of serious games addressing natural hazards.

### 1.3 Evaluating Serious Games

80 To gather evidence of serious games' effectiveness, thorough evaluation is required. The criteria for high-quality evaluations often relate to dimensions such as utility, feasibility, fairness, and accuracy (DeGEval, 2016; Yarbrough et al., 2011). Evaluative approaches can be differentiated according to their temporal orientation: distinguishing formative (ongoing, project-accompanying) and summative (final product-focused) evaluations (Scheffler, 2018). Another differentiator is the focus of the evaluation, which may either be set on evaluating the serious game's usability or its effectiveness. Usability evaluations aim at testing the game's functionality and the appeal for users. Effectiveness evaluations examine the potential impacts and outcomes a serious game may have on its players. In most studies, a pre-post design (Shek and Zhu, 2018) is used to capture changes over time and to compare groups. A pre-test survey is carried out before the intervention and a post-test survey is carried out afterwards. To check for stability of effects over time, a follow-up questionnaire can be carried out after a certain period of time. In this process different quantitative or qualitative methods can be employed such as surveys, interviews, observations, workshops or focus group discussions etc. To identify differences between the intervention (playing a serious game) and other intervention groups and/or a control group ('null-intervention') survey are commonly used. Connolly et al. (2012) found that most effectiveness evaluations of computer games and serious games in various thematic fields focused on aspects of knowledge, understanding, and emotional or motivational outcomes. The authors point out that none of the 38 papers they reviewed addressed the long-term effects of serious games. As knowledge acquisition is often stated as a learning objective, we look into different possible learning objectives relating to knowledge in more detail. The Competence Model for Environmental Education (Roczen et al., 2014) differentiates between three forms of factual

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environmental knowledge: environmental systems knowledge (e.g., the emergence of a hurricane), action-related knowledge (e.g., individual protective action during an earthquake), and effectiveness knowledge (e.g., efficacy of different flood protection measures). We further distinguish action-related aspects on the individual and on the collective and/or administrative level. When measuring knowledge, we distinguish between *self-perceived knowledge* (sometimes also described as *subjective knowledge*), which is measured through self-stated feedback (e.g., via a questionnaire or an interview) and *factual knowledge* (Raju et al., 1995, in other sources sometimes called *objective knowledge*), which refers to the application of a fact-based test with possible right and wrong answers. Both approaches are used in the literature. When comparing evaluations of competencies, the ‘fuzzy nature’ of the concept may pose a challenge (Le Deist and Winterton, 2005; Westera, 2001; Wong, 2020). The concept encompasses all resources underlying human action that are available to the individual, including skills, knowledge, attitudes, and values (McGuinness, 2018; Roczen et al., 2014). However, in practice it is frequently used interchangeably with the notion of skills (Chen 2019; Kotsiou et al. 2022), describing the capacity to perform a defined activity with proficiency (McGuinness, 2018).

In addition to answering the question of *whether* serious games are effective, theoretical frameworks help to explain *how* they work (Krath et al., 2021). Although the aforementioned reviews (Forrest et al., 2022; Solinska-Nowak et al., 2018) did not focus specifically on theoretical approaches, a meta-review by Krath et al. (2021) did and found a broad spectrum of theories applied in research on serious games in general. The question remains if this accounts for serious games with a focus on natural hazards as well.

#### 1.4 Objective and Research Questions

Taken together, the aim of our paper is to provide a broader overview of current research and to gather empirical evidence regarding the effectiveness of serious games, as reported in scientific publications.

The following three research questions are to be answered:

(RQ1) Are behavioural theories or models applied in the development or evaluation of serious games on natural hazards?

We assume that most serious games are developed and evaluated without a clear theoretical framework. However, theories that are currently in use shall be reported and compared here.

(RQ2) Which evaluation methods are applied in the existing research on serious games on natural hazards?

We want to give an overview of the various evaluation formats applied in the literature. Based on these results, we will make recommendations for (standardised) evaluations of serious games.

(RQ3) Which impacts and outcomes do serious games about dealing with natural hazards have for players?

We explore the actual benefits of serious games for players, including their (subjective or objective) knowledge, behavioural changes, self-efficacy, and any other effects that were explored in the research. We specifically set the focus on findings that go beyond mere usability analyses.



130 Furthermore, we will characterise the investigated serious games and report on the explored natural hazards, countries of study, targeted audiences, as well as targeted outcomes.

## 2 Methods

The format of a systematic review was chosen in order to give a structured overview on the current state of research concerning our research questions following the PRISMA 2020 statement (Page et al., 2021).

### 2.1 Eligibility Criteria

135 We formulated three inclusion criteria that had to be fulfilled in order to be part of the review. We included publications that:

1. focus on one or multiple natural hazards and its potential negative consequences,
2. report on one or multiple serious games of which (1) is a relevant element, and
3. are original research articles or conference papers.

140 Accordingly, papers that addressed no natural hazards, covered no serious game, and/or were published in other formats (e.g., review, meta-analysis, comment, editorial, book, chapter, reports) were excluded. Concerning natural hazards, we included flooding, volcanic eruptions, earthquakes, extreme heat or cold, drought, various severe storms, wildfires, landslides, severe weather, and fog. Studies which focused only on general health risks/public health (e.g., pandemics, viruses, COVID-19), general climate change adaptation, police work including cybercrime, or industrial and other man-made disasters (nuclear safety, fire unrelated to natural hazards) did not fulfil the inclusion criteria.

145 By including publications that report on at least one serious game on natural hazards, we did not require the publications to use the term *serious game*, as they were sometimes called *educational games*, *disaster games*, or just *games*. We did, however, make sure that the included studies covered complete games: meaning that e.g., educational programmes or mobile applications with single gamification elements were excluded. Publications on gaming ideas that were still in the early stages of development were also excluded. Publications that used serious games to address research questions unrelated to the topic  
150 were not included. Further formal exclusion criteria were publications written in a language other than English. No restrictions were set regarding the year of publication.

### 2.2 Search and Selection

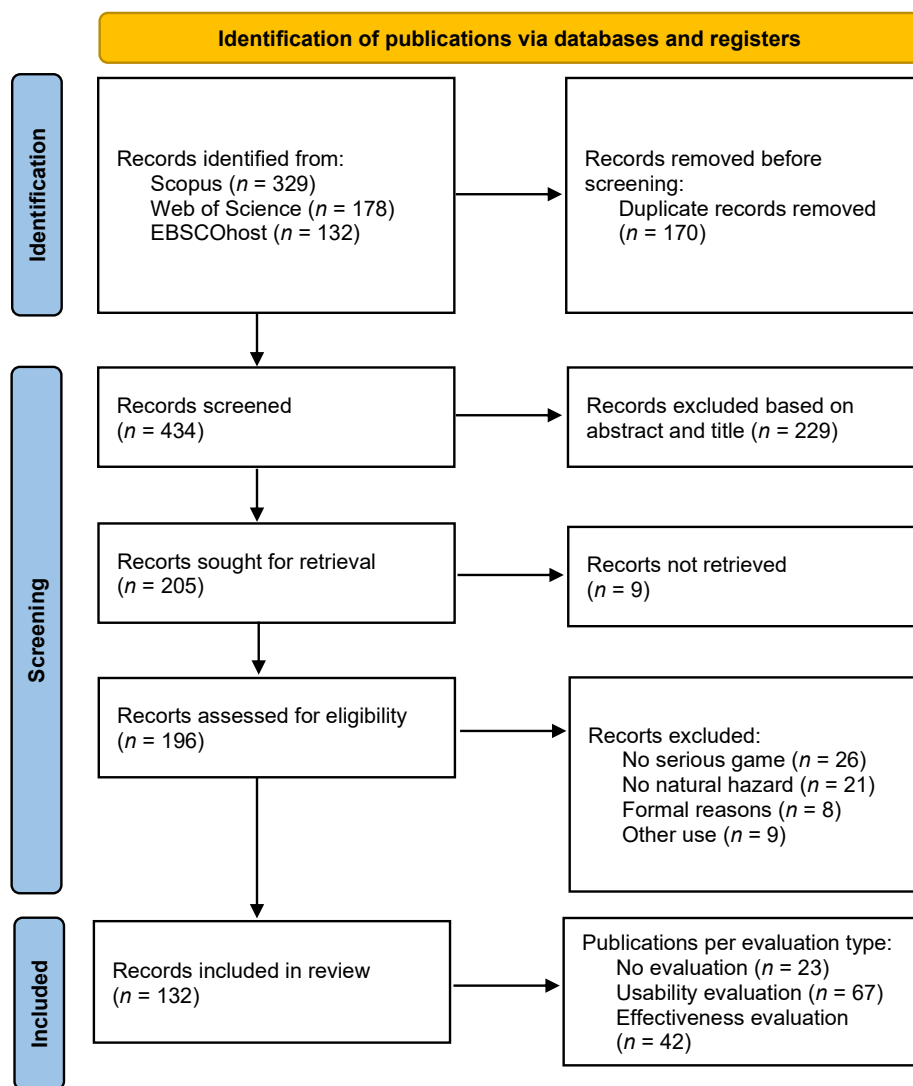
We used three scientific databases, namely Scopus, Web of Science, and EBSCOhost for literature research.

The search string was formulated as follows:

155 ("Natur\* hazard\*" OR flood\* OR volcan\* OR earthquake\* OR heat OR drought\* OR tsunami\* OR storm\* OR thunderstorm\* OR hurricane\* OR tornado\* OR "Severe weather" OR geohazard\* OR "Natur\* Disaster\*" OR "Geo\* Disaster\*" OR lightning OR "Extreme cold" OR fog\* OR wildfire\* OR bushfire\* OR "forest fire" OR landslide\*) AND ("serious gam\*" OR "game-based learning" OR gamification OR "Education\* gam\*")



160 Figure 1 depicts the process of identifying eligible publications. The search was carried out on January 16<sup>th</sup>, 2025 and resulted in a total of 639 records, which were reduced to 434 records after duplicates were removed. A screening of abstracts and titles resulted in a further exclusion of 229 records. Nine records could not be retrieved; hence 196 full-text records were assessed for eligibility. After reading, 64 records were excluded for various reasons, i.e. no serious game, no natural hazard, other formal reasons, or the serious game being used in other contexts (fig. 1).



**Figure 1. Prisma flow chart of the publication identification process.**

A total of 132 original research articles and conference papers were included in the review (Appendix, Table A1). Descriptive results are given for these publications, while further analyses following the research questions were carried out for 42 out of the 132 publications, as these were categorised as impact evaluations (see below). For brevity's sake, the total body of 132

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records will henceforth be referred to as *publications*, while the subsample of 42 publications which included impact  
170 evaluations will be referred to as *effectiveness evaluation studies* (short: EE studies).

### 2.3 Data Analysis

At least one of the authors read and documented each of the publications following an analysis protocol based on the three  
research questions. The analysis protocol covered the following items: the name of the serious game, the natural hazards  
175 addressed, the format of the serious game, and the country of study. It also covered the methods and outcomes of the study.  
The records were collected using a survey software (SoSciSurvey) and the data was analysed using SPSS and Microsoft Excel.

### 3 Results

In this section we first provide an overview of the publications, starting with quantitative descriptions of the research landscape.  
In the second part we will report findings on the effectiveness evaluation studies (EE studies) regarding theory-based research,  
180 evaluation methods, and analysed impacts and outcomes.

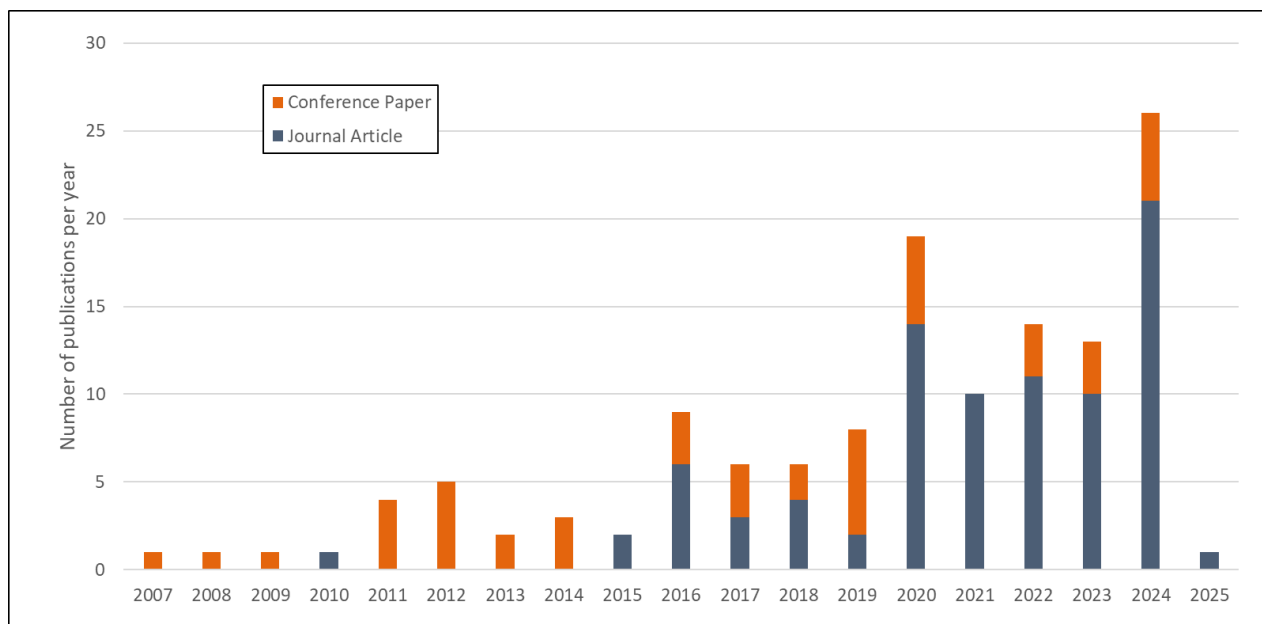


Figure 2. Number of publications per year, distinguished by publication type.

#### 3.1 Research on Serious Games in the Field of Natural Hazards

The review includes 132 publications of which 85 are journal articles and 47 are conference papers. In general, there has been  
185 an increase in publications on the topic in recent years, in particular between 2020-2024 (fig. 2). This indicates that serious



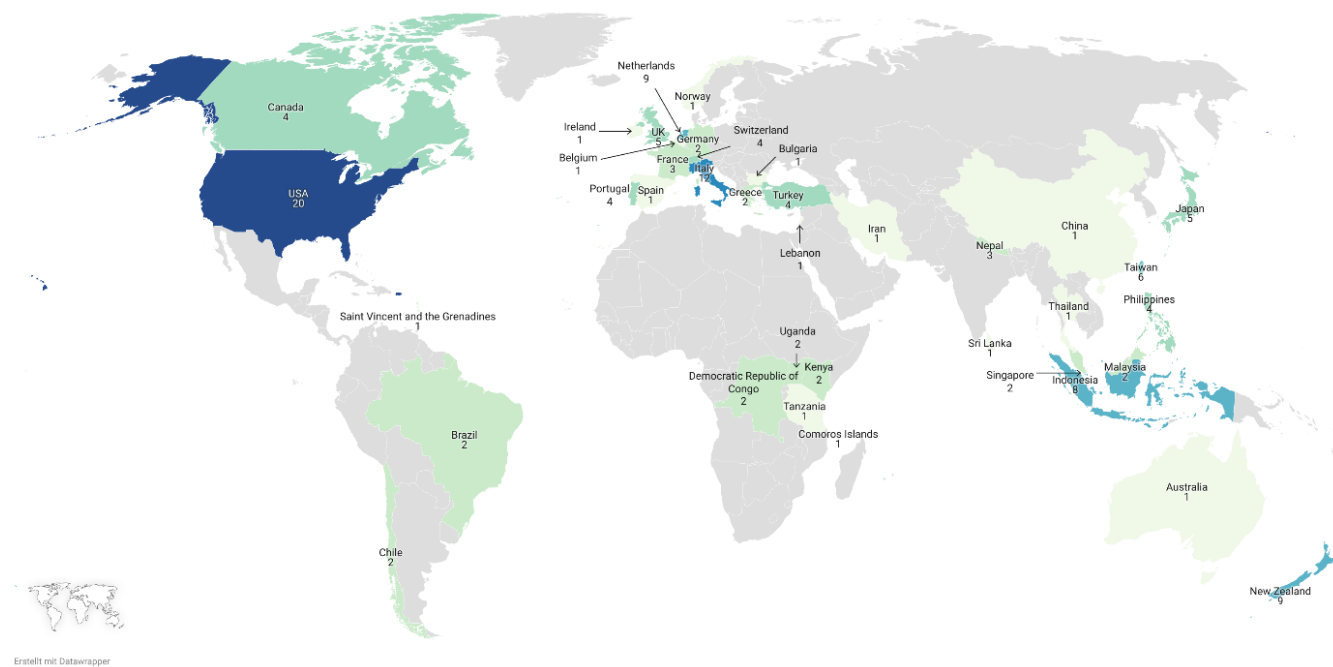
games gained increasing popularity in natural hazards research during the last years. Even though no constraints were set regarding publication year, the topic was absent in the literature before 2007.

With 14 publications, the *International Journal of Disaster Risk Reduction* stands out among the journals. Six of the publications were published in the journal *Sustainability*. No other journal published more than two articles. Concerning conference papers, we see a wide range of different conferences with between one and three conference papers each.

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Figure 3 shows the countries where the studies referenced in the publications were carried out. The texts were screened for specific mentions regarding locations of the development and/or evaluation of the serious games (note that the authors' affiliations were not taken into account here). Studies were carried out across the world, but some countries stand out. These are the USA with  $n = 20$  (14.4%) publications, Italy with  $n = 12$  (8.6%), the Netherlands and New Zealand with  $n = 9$  (6.5%) each, Indonesia with  $n = 8$  (5.8%), Taiwan with  $n = 6$  (4.3%), and Japan and the UK with  $n = 5$  (3.6%) each. Please note that many of the articles reported conducting their studies in multiple countries. Eight papers (5.8%) reported neither on the conduct of an empirical study nor on the country of their study. Overall, it is evident that serious games on natural hazards are implemented and explored globally, particularly in North America, Southern and Western Europe, Central Africa, and the Pacific region.

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**Figure 3. Countries where the studies were carried out.**

As mentioned above, we also included publications that did not explicitly use the term *serious game*, but which clearly described a serious-game-like application. When comparing the terms and definitions that appear in the text, we find that three-quarters of the publications (75.8%) use the term *serious game*. The alternative or additional terms that were mentioned most frequently were *Game-Based Learning/GBL* (25.8%), *gamification* (21.2%), *(immersive) virtual reality* (18.2%), and

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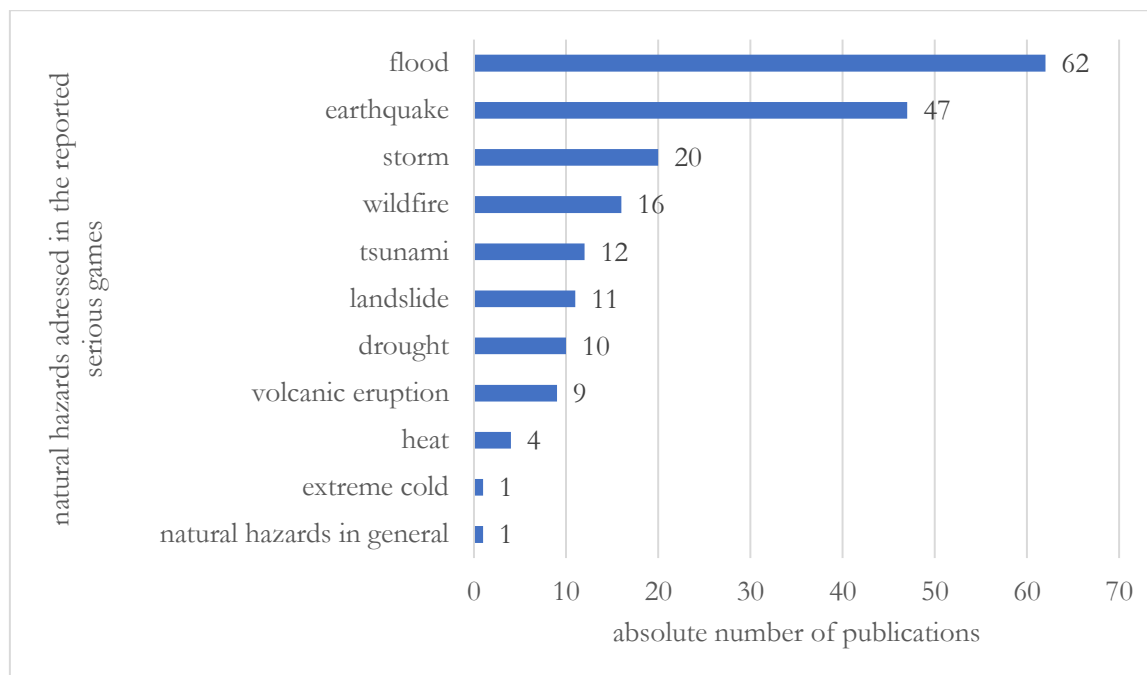
*educational game* (17.4%). However, the majority of the publications (52.3%) did not define the terms in detail, regardless of which one is mentioned. Regarding the concept of serious games, many authors refer to the definitions by Abt (1970), or Michael and Chen (2011); others propose their own definitions without referring to specific authors.

To determine the focus of the publications, we looked into the reported keywords. The number of keywords varied strongly, and some publications did not provide any. The terms *serious game*, *serious games*, *serious gaming* were mentioned 62 times in total, accounting for almost half of the publications. Many publications set a clear focus on the game/gamification aspect of their research, as indicated by the other keywords provided, which is visible in the frequent mentions of *game-based learning* and *gamification*, as well as in many singular game-related terms. The pedagogical focus is evident in various different combinations with the words *learning* and *training*. A focus on disaster-related aspects is apparent in many different mentions of specific natural hazards and related terms, such as *disaster*, *emergency*, *evacuation*, and *management*.

The majority of publications ( $n = 98$ , 74.2%) describe digital serious games, including smartphone/tablet games, computer games, and games for virtual reality (VR) glasses. Purely analogue games are reported less frequently ( $n = 28$ , 21.2%); this includes board games, card games, escape rooms, and role-playing games. Only six publications (4.5%) report on games which either combine digital and analogue elements, or on different versions of the same game. More than half of the publications address single-player games, which are predominantly digital. The multi-player games presented, which involve either multiple teams or multiple individual players, are often analogue or hybrid, but some also have digital formats.

Most of the publications present serious games that were designed by the corresponding researcher group, but some publications also explore existing games. With four mentions the serious game *Stop Disasters!* developed by the United Nations Office for Disaster Risk Reduction (UNDRR; Blasko-Drabik et al., 2013; Felicio et al., 2014; Kankanamge et al., 2022; Pereira et al., 2014) is analysed most frequently, followed by three mentions of the serious game *Levee Patroller* (Bosschaart et al., 2016; Hartevelde et al., 2010; Houtkamp et al., 2008). Some serious games were addressed in two publications each: *DisCoord* (Delima et al., 2021; Mertens et al., 2023), *Earth Girl* (Kerlow, 2011; Kerlow et al., 2012), *FEWS game/Water Coach* (De Kleermaeker et al., 2011; De Kleermaeker and Arentz, 2012), *Hazagora* (Mafuko-Nyandwi et al., 2024; Mossoux et al., 2016), *MANTRA* (Mueller et al., 2020b, a), *RAMSTETE* (Booth et al., 2020; Schueller et al., 2020), *SeCom2.0* (Breuer et al., 2017; Sewilam et al., 2017), and *SPRITE* (Adam et al., 2016; Taillandier and Adam, 2018). The other publications either report on other singular game or do not mention the name of the game at all; an overview of all serious game titles is given in Table A1.

Most publications only report on serious games that address one natural hazard (70.5%), less frequently two (13.6%), occasionally three (9.8%), and rarely four or more (6.1%). Flooding (including different flood types and sea level rise) is the most frequently addressed topic per publication ( $n = 62$ , 47.0%, see fig. 4), followed by earthquake ( $n = 47$ , 35.6%). All other natural hazards are mentioned far less frequently. Storms, including hurricane, tornado, cyclone, and typhoon, are mentioned 20 times (15.2%), wildfire (bushfire, forest fire) 16 times (12.1%), tsunami 12 times (9.1%), landslide 11 times (8.3%), drought 10 times (7.6%), volcanic eruption 9 times (6.8%), heat four times (3.0%), and extreme cold once (0.8%). One game addressed natural hazards in general.



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**Figure 4. Natural hazards that were addressed in the respective serious games, counted per publication.**

Following the Disaster Risk Management (DRM) cycle we can attribute most serious game implementations to one or more of the four phases: prevention/mitigation, preparedness, response, and recovery. 43.9% of the publications implemented serious games regarding one specific phase, 49.2% addressed multiple or all phases, while 6.8% covered no phase in particular.

245 Like Solinska-Nowak et al. (2018), who found in their review of DRM games that most focused on the pre-disaster phases (prevention/mitigation: 36.4%; preparedness: 60.6%) we also see these phases addressed frequently. Regarding the post-disaster phases, half of the publications (50.0%) mention response, but the recovery phase is mostly neglected (15.9%).

The serious games address diverse audiences. Analysing the games' target groups, we found one central difference in focus: private individuals vs. professional audiences. The majority of the serious games were used to communicate information about natural hazards to private individuals. While many publications addressed the general public, others specified particular audiences for their serious game. Children and students were frequently addressed; many studies were set in schools and other educational contexts. Some publications report implementing games with specific groups, such as blind people (Maharani et al., 2019), tsunami survivors (Cubelos et al., 2021), and indigenous peoples (Blackett et al., 2022). Publications focused on professional audiences address different groups, particularly relevant stakeholders in disaster risk management and decision making concerning natural hazards, as well as medical professionals, teachers, and scientists.

250 The publications discussed various learning objectives; often, more than one was addressed. Most learning objectives focus on different forms of knowledge. Based on Roczen et al. (2014) we differentiate between the following categories of knowledge: (1) environmental systems, (2a) action-related aspects on the individual level, (2b) action-related aspects on the collective and/or administrative level, and (3) effectiveness. For clarification, we give examples of each category in the



260 following. Environmental systems knowledge includes an understanding of the hazards processes, such as debris flow and its  
possible impacts on a nearby village, as shown in the *MurGame* (Berger et al., 2023). An example of action-related knowledge  
on the individual level is learning how to pack an emergency bag in *BYEK: Build Your Emergency Kit* (Mirza et al., 2024).  
Action-related knowledge on a collective or administrative level is conveyed in *FloodSim* (Rebolledo-Mendez et al., 2009), in  
265 which the player assumes the role of a flood policy strategist, and in *Drought in Play* (Cid et al., 2024), a tabletop game in  
which all players learn about drought processes and collectively develop a drought plan. In *SPRITE* (Taillandier and Adam,  
2018), the player assumes the role of a mayor, deciding on flood protection activities and learning about their effectiveness  
and the possible outcomes of their decisions.

The approaches towards evaluation differ strongly between the publications. In some of the publications (12.9%,  $n = 17$ ) the  
serious games and often also the development processes are described, but these publications do not report on any evaluation  
270 or testing specifically. There is, however, in many cases a clear mention of planned evaluation studies in upcoming  
publications, which were not reported in detail in the publications in question. More than half of the publications (55.3%,  
 $n = 73$ ) report evaluating the games' usability or carrying out game tests. These usability evaluations aim at verifying the  
serious games' functionalities and the playability for the users. Another 31.8% ( $n = 42$ ) of the papers report an effectiveness  
evaluation (often also including a usability evaluation), meaning that any kind of impacts or outcomes of the serious games on  
275 the players are examined.

There has been a call for preregistration of studies across disciplines (Nosek et al., 2018). This encourages publishing results  
of a study, whose methods were reported during the preregistration process, making the research and publication process more  
transparent and credible (Nosek et al., 2018). Some scientific journals require submissions to refer to preregistrations.  
However, none of the 132 publications had been pre-registered, possibly because this concept is not yet widely known across  
280 disciplines. Furthermore, many researchers may have focused primarily on developing the game rather than evaluating it.

### 3.2 Exploring serious games' effectiveness

We analysed the 42 publications which reported effectiveness evaluations (see above: *EE studies*) in more detail according to  
our research questions concerning: (1) underlying theoretical approaches, (2) evaluation methods, and (3) impacts on players.

#### 3.2.1 Theoretical frameworks applied

285 Of the EE studies, most do not explicitly name a theory ( $n = 25$ ; 59.5%). The majority of the theoretical approaches mentioned  
can be attributed to the broader fields of psychology and educational research. As shown in table 1, a broad variety of theories  
is applied, with no single theory emerging as dominant. The author mentioned most frequently is Albert Bandura with three  
different but related theories that are often applied in sociopsychological research: Social Cognitive Theory (Bandura, 2001,  
 $n = 4$ ), Social Learning Theory (Bandura, 1977b,  $n = 3$ ), and Self-Efficacy Theory (Bandura, 1977a,  $n = 1$ ). We also find three  
290 references to Mihaly Csikszentmihalyi's Flow Theory (1990), which rather describes the process of playing.



**Table 1. Theories and research approaches applied in publications with effectiveness evaluation studies (n = 42).**

Theoretical Framework or Research Approach	Publications
Social Learning Theory (Bandura, 1977b)	Arakawa et al. (2024), Çoban & Gökteş (2022, 2023)
Social Cognitive Theory (Bandura, 2001)	Nilsen et al. (2020), Perkins et al. (2016), Safran et al. (2024), Tanes (2017)
Self-Efficacy Theory (Bandura, 1977a)	Blasko-Drabik et al. (2013)
Flow Theory (Csikszentmihalyi, 1990)	Bachen et al. (2016), Crisman et al. (2023), Wang et al. (2019)
Protection Motivation Theory (PMT; Rogers, 1983)	Ong & Araral (2022)
Person-relative-to-Event (PrE) theory (Duval and Mulilis, 1999)	Safran et al. (2024)
Protective Action Decision Model (PADM; (Lindell and Perry, 2012)	Molan et al. (2023)
Expectancy-Value Theory (Atkinson, 1957)	Coban & Goktas (2023)
Stage model of Selfregulated Behavioural Change (SSBC, Bamberg, 2013)	Nguyen et al. (2024)
Extended Parallel Process Model (EPPM, Witte, 1992)	Ong & Araral (2022)
Affect Heuristics (AH; Slovic et al., 2007)	Ong & Araral (2022)
Cognition and Environment (Kaplan and Kaplan, 1982)	Crisman et al. (2023)
Instructional Systems Development (ISD; Dick et al., 2001)	Coban & Goktas (2022), Perkins et al. (2016)
ARCS model (Keller, 1987)	Coban & Goktas (2023), Lu et al. (2022)
Design-Based Research (Philippakos et al., 2021)	Crisman et al. (2023)
Design principles of climate change education (Anderson, 2012)	Nussbaum et al. (2015)
Kolb's experiential learning cycle (ELC, Kolb, 1984)	Çoban & Gökteş (2022), Tsai et al. (2020)
Problem-Based Gaming (PBG; Kiili, 2007)	Feng et al. (2021)

### 3.2.2 Evaluation methods

It stands out that most EE studies use quantitative methods, especially quantitative surveys ( $n = 39, 92.9\%$ ). More than a fifth of these publications ( $n = 9, 21.4\%$ ) report on (quasi) experimental studies. Other methods were behavioural observations, qualitative interviews and focus-group discussions (each:  $n = 4, 9.5\%$ ), as well as workshops ( $n = 2, 4.8\%$ ). Half of the EE studies use more than one method.

Regarding the study design, we see that nearly three-quarters of the EE studies ( $n = 34, 81.0\%$ ) describe a pre-post design, though follow-up questionnaires are rarely used ( $n = 5, 11.9\%$ ). Only 19.0% of the EE studies ( $n = 8$ ) reported a control group comparison. Some studies ( $n = 3, 7.1\%$ ) included comparing different versions of the game.

Ethics approvals are required especially in clinical research in order to ensure participants' safety. 12.9% ( $n = 17$ ) of all publications mentioned an ethics approval and a further 3.0% ( $n = 4$ ) mention an ethics statement (that does not cover an ethics approval), while 84.1% mention neither. Among the EE studies the share of ethics approvals (23.8%,  $n = 10$ ) and ethics statements (4.8%,  $n = 2$ ) is higher than in the whole sample, but still the majority of EE studies (71.4%,  $n = 30$ ) do not have ethics approvals.



### 3.2.3 Impacts and outcomes on players

The EE studies have a rather heterogeneous scope concerning serious games' impacts and focus on various different aspects in their evaluations. A previous systematic review on the impacts of computer/serious games regarding learning and engagement (Connolly et al., 2012) concludes that knowledge acquisition, content understanding, as well as affective and motivational outcomes were reported most frequently. Reported impacts and outcomes within the EE studies were grouped into (A) knowledge, (B) competencies, (C) motivation, intention, and behaviour, as well as (D) psychological impacts, a structure that partly follows the findings by Connolly et al. (2012) and is extended by further aspects that were found multiple times. In the following, we present the reported impacts and refer to the corresponding publications that analysed them.

#### (A) Knowledge

Knowledge gains are explored in the majority of EE studies ( $N = 24$ , 57.1%). Two publications (Crisman et al., 2023; Gargiulo et al., 2024a) reported an increase in self-perceived knowledge measured through quantitative questionnaires. Factual knowledge was measured most frequently in the EE studies ( $N = 22$ , 52.4%). The quantitative survey method is the most frequently implemented approach. Most findings suggest that playing a serious game can indeed improve the players' knowledge on the presented natural hazard. In 12 EE studies, an increase in factual knowledge was reported using a pre-post design (Ahmadi et al., 2024; Blasko-Drabik et al., 2013; D'Amico et al., 2023; Feng et al., 2020a; Kankanamge et al., 2022; Khoury et al., 2018; Maharani et al., 2019; Mueller et al., 2020b; Nguyen et al., 2024; Perkins et al., 2016; Taillandier and Adam, 2018; Yannier et al., 2013), and in three, a pre-post control group design revealed a positive impact (Feng et al., 2021; Lu et al., 2022; Nussbaum et al., 2015). However, Feng et al. (2023) found no difference concerning factual knowledge gain between the intervention and the control group. Wang et al. (2019) found that only participants who were not regular computer game players gained knowledge from a serious game about heat risk. Mossoux et al. (2016) report mixed results concerning knowledge acquisition: for most participants, knowledge stays constant, while some show an increase and others a decrease. In a pre-post design study of volcanic risk education, Mafuko-Nyandwi et al. (2024) found an increase in knowledge in two intervention groups (one group playing the serious game *Hazagora* and the other group visiting a museum) compared to a control group.

The possibility of memory effects occurring if participants answer the same (pre-post) questionnaire twice was not discussed in the above publications. Although few used different versions of the same factual knowledge test, none split the test groups in half to control for undesirable test effects. One exploratory study involving ten students found that coded open answers indicated a positive outcome in terms of factual knowledge gain (Caroca et al., 2019). Here, as in many of the aforementioned studies, the lack of a control group remains a critical issue. Finally, Çoban & Gökteş (2022) compared two different serious games with a drill and with traditional learning methods (the control group). They found that the playing a serious game resulted in greater knowledge gains compared to the control group, but the drill group achieved the greatest improvement.



### **(B) Competencies and skills**

Compared to knowledge acquisition the research approaches on specific competencies and skills that players should learn are fewer with six EE studies explicitly focusing on this. Maulida et al (2023), for example, show that playing a tsunami game can foster children's response skills, and Tomaszewski et al. (2020) found that their serious game *project lily pad* increased the players spatial orientation and disaster response skills. A study by Tsai et al. (2020), showed that disaster prevention skills increased, as did civic responsibility. Feng et al. (2020, 2021) framed their serious game experiments specifically as a training for concrete preparedness measures. Arakawa et al. (2024) report finding no significant impact of a serious game on earthquake disaster concerning cooperation skills and intentions to help others.

### **(C) Motivation, intention and behaviour**

Motivational, intentional, and behavioural aspects were explored in 13 EE studies. Four publications reported on behavioural intentions (i.e. increasing one's own hazard preparedness) following serious game interventions (Mafuko-Nyandwi et al., 2024; Nilsen et al., 2020; Safran et al., 2024; Tanes, 2017). Further four EE studies (Bachen et al., 2016; Gargiulo et al., 2024b; Tsai et al., 2015, 2020) reported that their serious games evoked an *interest in learning* more about the specific hazard, which Lu et al. (2022) phrased as a *motivation to learn*. Other study participants indicated that they were considering implementing protection measures that they had not previously considered (Maragkou et al., 2023). Compared to a control group, Nussbaum et al. (2015) found that there was an increased interest in further engagement with the topic of climate change as a trigger of natural hazards. Dulic et al. (2011) report mixed findings on participants perceptions and behavioural intentions: while some perceptions on climate change and society changed, no change in behavioural intention was observed. Çoban & Göktaş (2023) compared different education modes and found that the serious game evoked a lower motivation to engage with earthquake preparedness than traditional education methods. Among the EE studies, only Khoury et al. (2018) report on actual behaviour. Study participants playing a serious game about local flooding later formed a community flood partnership.

### **(D) Psychological impacts**

*Self-efficacy* was the psychological impact focussed on most frequently in the studies. Five EE studies (Ahmadi et al., 2024; D'Amico et al., 2023; Feng et al., 2020a; Nilsen et al., 2020; Safran et al., 2024) reported an increase in self-efficacy using pre-post designs. Tanes (2017) showed that people playing the earthquake-themed game *A Quake Story* showed an increase in self-efficacy compared to a control group who did not play the game. A group of researchers in New Zealand (Feng et al., 2021, 2023) found an increase in self-efficacy, but a comparison of game intervention groups with a control group (reading an informative leaflet) revealed no difference.

A pre-post questionnaire-based evaluation by Gargiulo et al. (2024) resulted in inconsistent findings regarding *risk perception*. Mafuko-Nyandwi et al. (2024) found no substantial impact of a serious game intervention on risk perception, possibly due to moderately high manifestations in the pre-test. Other studies refer to (*risk awareness* and/or *risk understanding*). For example,



370 Tzioutzios et al. (2024) reported an increase in risk awareness. A pre-post study using open questions on awareness and understanding revealed an increase in both through the gameplay (Spyropoulos et al., 2022). Overall, when comparing the survey items used, we see that some of the reported studies treat awareness, perception, or understanding of risk as knowledge, and vice versa.

Further psychological impacts were explored in individual publications. For example, Safran et al. (2024) showed a pre-post tested increase in *sense of control*, and Bachen et al. (2016) found an increase in *empathy* as a possible impact of serious gaming. Comparing different versions of the serious game *Levee Patroller*, Houtkamp et al. (2008) found a variability of 375 *emotional outcomes* and an increase in the players' arousal (by measuring facial muscle tension). Ong & Araral (2022) explored *pro-environmental orientation* and found no effects of the game intervention. Taken together, we cannot make a generalisable statement on serious games' impacts on psychological aspects since there are not enough EE studies focussing on this.

#### 4 Discussion

This systematic review shows the highly diverse research landscape surrounding serious games on natural hazards. Among the 380 132 publications included in the review (fig. 1, tab. A1), we found a wide variety in research approaches and methodologies. In communicating natural hazards and educating people about disasters, flooding is the most frequently addressed topic per publication. Such a dominance of flooding as the main focus of serious games on natural hazards was also found by Solinska-Nowak et al. (2018). In their systematic review, they found that the gap between flooding and all other hazards was even bigger. A meta-analysis on factors motivating adaptation to climate change adaptation (Van Valkengoed and Steg, 2019) also 385 revealed that, when comparing different hazards, the majority of research was conducted in the field of flooding. This highlights that, not only in the field of serious gaming (see also Forrest et al., 2022), but also in other fields flooding is often the most prominent research topic among peer-reviewed literature on natural hazards. Solinska-Nowak et al.'s study (2018) was over five years old by the time this review was conducted. While we did find that the topic of flooding was dominant, we also found that the topic of earthquake is not far behind. It can tentatively be proclaimed that the research focus is broadening, 390 as six hazards (storm, wildfire, tsunami, landslide, drought, volcanic eruption) have each been explored in between nine and 20 publications. However, an additional finding is the underrepresentation of extreme heat and extreme cold, as well as the lack of studies on fog in the publications. Within this review we cannot explain whether this is due to a lack of ideas for suitable gamified representations, lower respective risk perceptions among decision makers and project administrators or other possible reasons.

395 There has been a clear increase in publications concerning on the topic of serious games with two notable peaks in 2016 and 2020. The 2016 rise might be connected to the publication of the Sendai Framework for DRR (UNDRR, 2015), while the development since 2020 presumably shows an effect of the COVID-19 pandemic that required new methods of distanced learning, or is an echo of the projects completed since 2015.



400 More than half of the studies address single-player games, which are predominantly digital. The multi-player games, which  
involve either multiple teams combatting or multiple individual players, are often analogue or hybrid, but some also have  
digital formats. Different game types can presumably have different social and psychological impacts, but no comparative  
analysis of combat or collaboration in a learning context has been carried out in the reviewed studies.

The aim of this work was to provide an overview of existing publications on serious games on natural hazards and to explore  
the findings on *how* and *why* they work. Therefore, we looked at 42 of the publications reporting impact evaluations, and  
405 compared their theoretical approaches (RQ1), evaluation methods (RQ2), and impacts on players (RQ3).

Theories allow easier comparability of research and offer a starting point for research questions and hypotheses. While Krath  
et al. (2021) report on 118 theories found and conclude that there has been an increase in theory-based research on serious  
games across different thematic fields, in the field of natural hazard, theories have only been used in some cases to design  
and/or evaluate serious games (RQ1). This may be for different reasons. For instance, the high diversity of the researchers'  
410 disciplinary backgrounds is an important factor, as behavioural theories do not necessarily play a significant role in the research  
frameworks of some disciplines. Some central psychological theories in hazard research are the aforementioned PMT (Rogers,  
1983) and PADM (Lindell and Perry, 2012). These theories are employed in some of the studies, but they play a subordinate  
role. However, the concept of self-efficacy as a central element of PMT has been explored extensively. Additionally, we see  
more applications of learning/education theories and research frameworks that focus on the learning process itself rather than  
415 specific hazard knowledge, competencies, or behaviour.

Regarding the evaluation methods (RQ2), quantitative pre-post designs were prioritised. While this practical approach allows  
reproducibility, in some cases it comes close to a pseudo-evaluation. Exploring the processes of learning and understanding  
during a serious game requires the use of a broader range of methodologies, which are more complex and expensive in practice.  
Some studies have applied observations, thinking-aloud, or discussion formats, but the comparability of findings is often  
420 problematic if method protocols are not reported.

The impacts or outcomes that playing a serious game actually has on the players was a central question of this work (RQ3).  
Using a systematic review, we were unable to assess this impact ourselves; however, we analysed the focus of the publications  
and compared their methodologies. The strongest common finding among the studies was evidence of knowledge gain,  
demonstrated by multiple studies employing different methodologies. As increasing knowledge is a key aim of risk  
425 communication and education approaches, this finding is clearly positive. However, as mentioned above, some methods appear  
to be borderline pseudo-evaluations, so conclusions should be drawn with caution. Unfortunately, specific competencies or  
skills are rarely explored, and the findings are mixed, as they are for motivational, intentional, and behavioural outcomes. Self-  
efficacy is explored in most detail regarding psychological impacts. In a several theoretical approaches (e.g. PMT, Rogers,  
1983), self-efficacy plays a central role in fostering behavioural changes, and meta-analysis show that self-efficacy motivates  
430 climate change adaptation behaviour, for example (Van Valkengoed and Steg, 2019). Hence, the growth of topic-related self-  
efficacy through gameplay observed in multiple studies is a promising finding.



435 A central problem in research is the inconsistent use of terms; for example, the terms risk awareness, perception, understanding are often framed in similar terms to knowledge items. Future research would clearly benefit from standardised research protocols and questionnaires. Many serious game interventions have been carried out on the premise of allowing participants to engage with the topic and share their experiences and perceptions of the relevant natural hazard(s) with others. While this ‘engaging with the topic of natural hazards’ is a legitimate learning objective, it is quite difficult to evaluate directly.

#### 4.1 Implications for practitioners and future research

440 Based on our findings, we conclude that there is a clear need for a more structured approach to serious game research in the future. We recommend standardising evaluation protocols, as this would facilitate comparisons between different works. While some validated instruments exist for usability evaluations, such as the Game Experience Questionnaire (IJsselsteijn et al., 2013), to the best of our knowledge, there is no standardised instrument for impact evaluations of serious games.

445 Negative or null findings are rarely reported in the reviewed publications. Consequently, publication bias can be assumed, which could be overcome by preregistering future studies. Our findings could encourage researchers to pursue preregistered studies, which were absent from this sample, but also to focus more strongly on ethical aspects. Although ethics approvals required for publication by many scientific journals, they were mentioned in only some of the publications. Due to this shift in publication policies, an increase in ethics approvals is to be expected.

450 One open question remains regarding the comparability of the reviewed publications. We found a great heterogeneity in the serious games presented, their learning objectives, and the associated studies, as well as in the evaluation methodologies that were applied. Therefore, we assume that, given the current state of research, a thorough meta-analysis of the impact of serious games in the field of natural hazards is not to be expected too soon. However, a metanalytical study, would be desirable in order to make recommendations about the application of serious games based on their validated impact.

455 Based on our findings, we cannot recommend whether to use a serious game instead of other methods for disaster education or risk communication. Clearly, serious games are not a universal solution for conveying information on specific natural hazards to different groups in any learning or risk communication context, but they may serve as one element in the toolbox. The communication or education context needs to be taken into account when implementing serious games in practice and this must be heeded in the corresponding research.

460 Game developers and scientists must collaborate on improving serious games’ usability and the relevance of the presented facts and learning units. Some studies suggest that users may be less likely to engage with serious games if they do not enjoy them, which can prevent knowledge transfer (Blasko-Drabik et al., 2013; Çoban and Gökteş, 2023). Granic et al. (2014) describe this problem as the ‘chocolate-covered broccoli’: “the games look great, they are good for you, but they ultimately fail to work because the creative game dynamics that induce transportation and immersion are missing, making them simply not fun” (p. 74). To achieve better outcomes for education and communication an interdisciplinary approach on improving serious games is needed.



## 4.2 Limitations

465 A number of limitations of this work need to be pointed out. As we excluded grey literature from our work, a number of reports and other publications on project findings concerning serious games on natural hazards may have been overlooked. Possibly another future review can explore this gap.

A number of established hazard games stand out, as many studies have been carried out using the same serious game. This may have caused our findings to be distorted. While the overrepresentation of some serious games may foster the comparability  
470 of findings, it may also limit their validity. To gain a conclusive overview of this research field, researchers should be encouraged to report relevant background information on the games that were implemented in the pertinent studies. So far, serious games have often been described superficially, and sometimes not even a name has been given. Researchers should be encouraged to build on existing findings to increase expertise and enable meaningful transfer into society.

The heterogeneous usage of terms highlights a lack of consensus on what constitutes a serious game. However, we only  
475 included publications that explored serious games as we understand them, i.e. complete games and not mere gamification elements, emergency training, simulation tools, or gamified educational concepts. This narrows the range of definitions of serious games discussed in our sample. Other researchers may have decided differently on specific publications.

In terms of identifying theories, the authors of this review may have been biased by their individual disciplinary backgrounds, and other researchers may have identified different theories. Furthermore, we should point out that we did not look into in-  
480 game behaviour, which is sometimes framed as an impact of the game. Instead, we looked at the impact of games on events happening outside of the games themselves, while some papers thoroughly explored in-game behaviour (Ong and Araral, 2022).

## 4.3 Conclusion

This research aimed to provide an overview of the current state of research on serious games on natural hazards, particularly with regard to their impacts on players. Future research should apply theory-driven, structured, comparable and standardised  
485 approaches to further explore the effectiveness of serious games on natural hazards for users. In the current research landscape theoretical frameworks play a subordinate role and the quality of evaluation methods is diverse. At an individual level, it can be concluded that serious games have the potential to increase people's knowledge and self-efficacy regarding personal action in relation to natural hazards. It would be desirable to learn about the impact of those serious games on society as a whole, e.g. in terms of improving societal adaptation towards natural hazards.



490 **Appendix**

**Table A1. Conclusive list of all 132 publications included in this systematic review.**

*Note:* “N/a” regarding Type of Evaluation indicates that no evaluation method and results were reported, but it is possible that the publication referred to other evaluation studies. If the publication did not report the location of a possible development and/or evaluation study, the table does not list a country of study.

<b>Authors (Year)</b>	<b>Name of the Serious Games</b>	<b>Type of Evaluation</b>	<b>Country of study</b>
Brown et al. (2007)	(unnamed serious game)	usability evaluation	UK
Houtkamp et al. (2008)	Levee Patroller	effectiveness evaluation	Netherlands
Rebolledo-Mendez et al. (2009)	FloodSim	usability evaluation	UK
Harteveld et al. (2010)	Levee Patroller	n/a	Netherlands
De Kleermaeker et al. (2011)	FEWS game, Procedure game, SVSD game	n/a	-
Dulic et al. (2011)	Future Delta	effectiveness evaluation	Canada
Kerlow (2011)	Earth Girl	n/a	-
Kolen et al. (2011)	SPOEL	usability evaluation	Netherlands
Chou et al. (2012)	Running Tommy	usability evaluation	Taiwan
De Kleermaeker & Arentz (2012)	Water Coach (formerly known as FEWS game)	usability evaluation	Netherlands
Kerlow et al. (2012)	Earth Girl: The Natural Disaster Fighter	usability evaluation	Singapore
Noda et al. (2012)	(unnamed serious game)	usability evaluation	Japan
Oliveira et al. (2012)	(unnamed serious game)	usability evaluation	Portugal
Blasko-Drabik et al. (2013)	Stop Disasters!	effectiveness evaluation	USA
Yannier et al. (2013)	EarthShake	effectiveness evaluation	USA
Felicio et al. (2014)	Stop Disasters!	usability evaluation	Brazil
Pereira et al. (2014)	Stop Disasters!	effectiveness evaluation	Portugal
Nussbaum et al. (2015)	Losing the Lake	effectiveness evaluation	USA
Tsai et al. (2015)	NTU WATER GAME	effectiveness evaluation	Taiwan
Adam et al. (2016)	SPRITE	usability evaluation	France
Bachen et al. (2016)	Inside the Haiti Earthquake	effectiveness evaluation	USA
Bosschaart et al. (2016)	Levee Patroller	usability evaluation	Netherlands
den Haan et al. (2016)	Virtual River	n/a	Netherlands
Herrera et al. (2014)	(unnamed serious game)	usability evaluation	Chile
Mani et al. (2016)	St. Vincent' Volcano	usability evaluation	Saint Vincent and the Grenadines
Mossoux et al. (2016)	Hazagora	effectiveness evaluation	Belgium, Comoros Islands, Democratic Republic of Congo, Tanzania
Onencan, Kortmann, et al. (2016)	MAFURIKO FLOODED	n/a	Kenya
Onencan, Van De Walle, et al. (2016).	WeShareIt	usability evaluation	Kenya



Perkins et al. (2016)	Earthquake	effectiveness evaluation	USA
R. Breuer et al. (2017)	SeCom2.0	usability evaluation	Germany
Chu et al. (2017)	EDSS (Earthquake Drill Scripts generation and rendering System)	n/a	Taiwan
Rosli et al. (2017)	Hurricane Safety: The Game	usability evaluation	Malaysia
Sewilam et al. (2017)	SeCom2.0	n/a	Germany
Tanes (2017)	Quake Story	effectiveness evaluation	USA
Vega et al. (2017)	VR Wildfire Prevention	n/a	USA
Caballero & Niguidula (2018)	(unnamed serious game)	usability evaluation	Philippines
Khoury et al. (2018)	(unnamed serious game)	effectiveness evaluation	UK, Netherlands
Kimura & Kawamoto (2018)	Anzen no Tebiki	usability evaluation	Japan
Lovreglio et al. (2018)	(unnamed serious game)	usability evaluation	New Zealand
Taillandier & Adam (2018)	SPRITE	effectiveness evaluation	France
Winarni et al. (2018)	SIAGA	usability evaluation	Indonesia
Caroca et al. (2019)	(unnamed serious game)	effectiveness evaluation	Chile
Jacoby et al. (2019)	VR Tsunami	n/a	Canada
Karunanayake et al. (2019)	Flood Run	usability evaluation	Sri Lanka
Krishnan et al. (2019)	(unnamed serious game)	n/a	-
Maharani et al. (2019)	Monopoli Bencana (Monca)	effectiveness evaluation	Indonesia
Sermet & Demir (2019)	Flood Action VR	n/a	USA
Wang et al. (2019)	Counter-attack of urban heat island	effectiveness evaluation	Taiwan
Yamamoto et al. (2019)	(unnamed serious game)	usability evaluation	Japan
Alifia et al. (2020)	Tsunami Fighters	usability evaluation	Indonesia
Arinta et al. (2020)	(unnamed serious game)	usability evaluation	Indonesia
Belinda et al. (2020)	Earthquake Mitigation Educational Game	usability evaluation	Indonesia
Booth et al. (2020)	RAMSETE II	usability evaluation	Switzerland
Catal et al. (2020)	(unnamed serious game)	usability evaluation	Turkey
Feng, González, Amor, et al. (2020)	(unnamed serious game)	effectiveness evaluation	New Zealand
Feng, González, Mutch, et al. (2020)	(unnamed serious game)	usability evaluation	New Zealand
Gordon & Yiannakoulis (2020)	Decision Game	usability evaluation	Canada
Irshad & Perkis (2020)	(unnamed serious game)	usability evaluation	Norway
Manalang et al. (2020)	Kidzaster	n/a	Philippines
Mueller et al. (2020a)	MANTRA	usability evaluation	Nepal
Mueller et al. (2020b)	MANTRA	effectiveness evaluation	Nepal
Nilsen et al. (2020)	(unnamed serious game)	effectiveness evaluation	USA



Poděbradská et al. (2020)	Ready for Drought?	usability evaluation	USA
Schueller et al. (2020)	RAMSETE III	usability evaluation	Italy
Solarino et al. (2021)	TremeTreme, Find the difference: be safer!, Do it right: be safer!	usability evaluation	Italy, Portugal
Tomaszewski et al. (2020)	Project Lily Pad	effectiveness evaluation	USA
Tsai et al. (2020)	Battle of Flooding Protection	effectiveness evaluation	Taiwan
Undorf et al. (2020)	Cascade: A Decade of Weather	usability evaluation	UK
Xu et al. (2020)	Iowa Watershed Decision Support System (IoWaDSS)	n/a	USA
Bareford et al. (2021)	Watershed Game	n/a	USA
Catedrilla et al. (2021)	(unnamed serious game)	usability evaluation	Philippines
Cubelos et al. (2021)	Evacuation Game	usability evaluation	Japan
de Ruyter et al. (2021)	Breaking the Silos	usability evaluation	Switzerland
Delima et al. (2021)	DisCoord	usability evaluation	Uganda
Feng et al. (2021)	IVR SG training system	effectiveness evaluation	New Zealand
Gamberini et al. (2021)	Safer Water	usability evaluation	Italy
Teague et al. (2021)	Multi-Hazard Tournament	usability evaluation	USA
Weyrich et al. (2021)	ANYCaRE	usability evaluation	Switzerland
Avendano-Uribe et al. (2022)	Playing With Uncertainty	usability evaluation	New Zealand
Blackett et al. (2022)	Marae-opoly	usability evaluation	New Zealand
Bontchev et al. (2022)	Let us save Venice	usability evaluation	Italy, Turkey, Bulgaria
Çoban & Göktaş (2022)	3D Earthquake, Earthquake Game, Earthquake Master	effectiveness evaluation	Turkey
Fisaini et al. (2022)	SG EvaNami - Promoting Tsunami Evacuation Route	usability evaluation	Indonesia
Hoermann et al. (2022)	Magma Pop	usability evaluation	New Zealand
Hügel & Davies (2022)	iAdapt	usability evaluation	Ireland
Kankanamge et al. (2022)	Stop Disasters!	effectiveness evaluation	Australia
Lu et al. (2022)	disaster-proof warrior	effectiveness evaluation	Taiwan
Ong & Araral (2022)	(unnamed serious game)	effectiveness evaluation	Singapore
Rismayani et al. (2022)	(unnamed serious game)	usability evaluation	Indonesia
Piangiamore & Maramai (2022)	Salvina's Adventures - 5 educational games	usability evaluation	Italy
Salomão et al. (2022)	Bus Driver Game, Earthquake Game	usability evaluation	-
Spyropoulos et al. (2022)	(unnamed serious game)	effectiveness evaluation	Greece
Al Rahman et al. (2023)	Earthquake Damage Inspector	usability evaluation	Lebanon
Berger et al. (2023)	MurGame	n/a	Switzerland
Çoban & Göktaş (2023)	Earthquake Escape	effectiveness evaluation	Turkey



Crisman et al. (2023)	Chill City	effectiveness evaluation	USA
D'Amico et al. (2023)	(unnamed serious game)	effectiveness evaluation	Italy
De Fino et al. (2023)	(unnamed serious game)	n/a	-
den Heijer et al. (2023)	Dike Dilemmas Under Pressure	usability evaluation	Netherlands
Feizizadeh et al. (2023)	(unnamed serious game)	usability evaluation	Iran
Feng et al. (2023)	IVR SG training system	effectiveness evaluation	New Zealand
Maragkou et al. (2023)	VRQuake	effectiveness evaluation	Greece
Maulida et al. (2023)	Roblox	effectiveness evaluation	Indonesia
Mertens et al. (2023)	DisCoord	usability evaluation	Uganda
Toyoda & Tanwattana (2023)	Local Disaster Knowledge Extracting Game: Flood management in Thailand	usability evaluation	Thailand
Ahmadi et al. (2024)	(unnamed serious game)	effectiveness evaluation	-
Arakawa et al. (2024)	(unnamed serious game)	effectiveness evaluation	-
Araujo-Junior et al. (2024)	Flood Adventures	usability evaluation	USA
Asgary et al. (2024)	Road to Resettlement	usability evaluation	Canada
Cid et al. (2024)	Drought in Play	usability evaluation	Brazil
Forrest et al. (2024)	The Flood Recovery Game	usability evaluation	UK
Gargiulo, Woo, et al. (2024)	E se ... ("What if ... ")	effectiveness evaluation	Italy
Gargiulo, Napolitano, et al. (2024)	ALARM (eArthquAke heLp mAgnitudo epicenteR seisMologist)	effectiveness evaluation	Italy
Gordan et al. (2024)	PRECINCT SG	usability evaluation	-
Goretti & Musacchio (2024)	Catch the Plate - Digital, Make Your Room Safer, The Emergency Bag	usability evaluation	Italy
Hawthorn et al. (2024)	(unnamed serious game)	usability evaluation	Portugal
Ji et al. (2024)	(unnamed serious game)	usability evaluation	China
Johns et al. (2024)	8 mini games: Happy House/Happy Home, Info Overload Gameplay, Alert the City, Shelter in Place, Save Your Neighbor, Early Warning, Find Your Things, Smoke Detective	usability evaluation	USA
Latham et al. (2024)	(unnamed serious game)	usability evaluation	Philippines
Mafuko-Nyandwi et al. (2024)	Hazagora	effectiveness evaluation	Democratic Republic of Congo
Marahatta et al. (2024)	Snake and Ladder Game for Landslides Awareness Building, Picture Story Game for Fire Safety, Relay	usability evaluation	Nepal



	Game for Earthquake Awareness		
Mirza et al. (2024)	BYEK: Build Your Emergency Kit	usability evaluation	New Zealand
Nguyen et al. (2024)	SuDSbury	effectiveness evaluation	Netherlands
Pitchay et al. (2024)	(unnamed serious game)	usability evaluation	Malaysia
Safran et al. (2024)	Cascadia 9 Game	effectiveness evaluation	USA
Solarino & Eva (2024)	Science journalist for one day	usability evaluation	Italy
Solarino et al. (2024)	Inundation	usability evaluation	Spain, Italy
Thompson (2024)	Plan for It!	n/a	USA
Tzioutzios et al. (2024)	EGNARIA	effectiveness evaluation	Japan
Vigna et al. (2024)	A Picit Jeu	usability evaluation	Italy
Webber & Ozis (2024)	Decsion for a Decade	effectiveness evaluation	USA
Taillandier et al. (2025)	Draw and Flood	usability evaluation	France

#### 495 **Data availability**

No data sets were used in this article.

#### **Author contributions**

AH, TK, and FW contributed to conceptualization and investigation of the systematic review. The literature search and formal analysis was carried out by AH. The first draft of the manuscript was written by AH and all authors commented and critically revised previous versions of the manuscript. All authors read and approved the final manuscript.

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#### **Competing interests**

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## Ethical statement

510 This paper presents a systematic review of existing literature and does not involve the collection of new primary data or direct interaction with human or animal subjects. As such, no ethical approval from an institutional review board was required. All included studies were screened for reported ethics statements or ethics approvals, as documented in section 3.1. The review process itself was conducted in accordance with the PRISMA guidelines for systematic reviews, ensuring transparency, reproducibility, and integrity in the synthesis of existing research.

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