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Redefining maladaptation to climate change: a conceptual examination of the unintended consequences of adaptation strategies on ecological-human systems

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This study presents a redefinition of maladaptation to climate change, offering a comprehensive analysis through qualitative content analysis with an inductive approach, supported by focus group discussions. The main goal was to uncover the conceptual dimensions of the unintended and negative impacts of adaptation strategies on socio-ecological systems, particularly forests and natural resources. The findings indicate that some adaptation measures, though initially aimed at mitigating climate change effects, can paradoxically exacerbate long-term vulnerability, leading to environmental degradation and a diminished adaptive capacity of these systems. In response to these outcomes, the study offers strategic recommendations for managing maladaptation risks. These include adopting integrated adaptation management practices, fostering participatory policymaking, and leveraging local knowledge to enhance both social and ecological resilience. By highlighting the critical need to recognize maladaptation's potential, this research equips policymakers and natural resource managers with insights into the unintended consequences of adaptation efforts, enabling them to craft more effective strategies for climate resilience.

KEYWORDS

maladaptation, climate resilience, vulnerability, socio-ecological systems, content analysis

1 Introduction

Climate change has been unequivocally recognized as a global crisis by international authorities, including the Intergovernmental Panel on Climate Change (2017) and IPCC (2019), underscoring the urgent need for societies and governments to prepare for its far-reaching effects (Atteridge and Remling, 2018). The imperative for incorporating climate change considerations into decision-making processes is clear (Noble et al., 2015; Savari et al., 2024c), as failure to do so presents substantial risks to ecosystems, human well-being, and societal stability (Bustos and Vicuña, 2016; IPCC, 2019; Savari and Khaleghi, 2023; Savari et al., 2023). The IPCC's Sixth Assessment Report reveals that the impacts of climate change are more severe and widespread than previously projected, with escalating threats anticipated, particularly for vulnerable populations (IPCC, 2022). This growing climate risk is especially concerning for developing regions, including low-lying coastal areas, arid and semi-arid regions, and small island developing states (IPCC, 2014; Lemi and Hailu, 2019).

The effects of climate change extend across various sectors, impacting agriculture, natural ecosystems, and the environment at large (Isse, 2024; Savari and Khaleghi, 2024; Savari et al., 2024a). Extreme weather events and shifts in climatic patterns can disrupt the structure and functionality of ecosystems that sustain local communities, such as forests, agricultural lands, and grasslands, severely diminishing their capacity to provide critical ecosystem services, particularly for rural populations closely connected to these resources (Arenas-Wong et al., 2023). This disruption jeopardizes the reciprocal relationship between ecosystems and human communities, threatening livelihoods and overall well-being (IPCC, 2014; Arora, 2019; Savari et al., 2024b). As a result, the long-term sustainability of these environments is at risk, highlighting the need for proactive and adaptive strategies to mitigate climate change impacts and enhance the resilience of both natural ecosystems and the communities they support (Arenas-Wong et al., 2023; Savari et al., 2024d).

Despite the adverse impacts of climate change, adaptation serves as a critical mechanism for mitigating these effects (Zobeidi et al., 2021). Historically, human societies have demonstrated resilience by adjusting to evolving social, economic, and climatic conditions (Noble et al., 2015). Adaptation equips communities to reduce vulnerability and better prepare for future challenges (Fankhauser, 2017), encompassing actions aimed at enhancing adaptive capacity and minimizing exposure to risks (IPCC, 2012; Neset et al., 2019; Savari et al., 2024b). As mitigation of GHGs efforts alone are insufficient to fully address the complexities of climate change, adaptation has become increasingly recognized as an essential strategy (Westoby et al., 2020; Piggott-McKellar et al., 2020).

The necessity for adaptation strategies was identified as early as the 1990s when the IPCC first began evaluating the causes and responses to climate change (El Chami et al., 2022). While many nations have acknowledged the importance of adaptation, regional climate variations have resulted in differing priorities and approaches (Nwedu, 2020; Grasso, 2011). In developing countries, adaptation initiatives encompass a diverse range of activities, from localized interventions to national policies and regional programs (Magnan, 2014). These initiatives are crucial due to the heavy reliance of these populations on climate-sensitive sectors, including agriculture, animal husbandry, and fisheries. Additionally, their dependence on natural resources, combined with limited adaptive capacities, makes these nations particularly vulnerable to climate change (Müller et al., 2017). Research by Pouliotte et al. (2009) demonstrates that climate change directly affects climate-dependent activities while indirectly hindering social and economic development plans. Effective adaptation measures can safeguard ecosystems, promote environmental sustainability, and bolster the resilience of local communities (Sintayehu, 2018; Malhi et al., 2020). In response to climate change impacts on ecosystems and local livelihoods, communities near forests and reserves have implemented a range of adaptation strategies. These efforts include improving forestry and agricultural practices, conserving biodiversity, and employing water management techniques such as rainwater harvesting and sustainable irrigation. These initiatives aim to strengthen resilience to climate change while simultaneously enhancing human well-being and ecological integrity (Boon and Ahenkan, 2013).

Despite the recognized importance of adaptation in mitigating the effects of climate change, a critical challenge that has received less attention is the issue of "maladaptation." Maladaptation refers to adaptation actions that may appear beneficial in the short term but ultimately intensify climate vulnerabilities, degrade ecosystems, or exacerbate social inequalities over time (Chi et al., 2021; Schipper, 2020). Such actions undermine the core objectives of adaptation and can create new crises for communities and ecosystems (Magnan et al., 2016). Therefore, the accurate identification and assessment of maladaptation are crucial for developing sustainable climate strategies and should be prioritized in policymaking and planning.

Neglecting to recognize, evaluate, and mitigate maladaptation can result in various adverse consequences, including heightened vulnerability to climate impacts, resource misallocation, reduced resilience, and increased susceptibility of communities and ecosystems to harm (Schipper, 2020). To address this, it is imperative for policymakers to develop a nuanced understanding of maladaptation risks and for adaptation planners to integrate considerations of these risks into their programs to minimize negative outcomes (Magnan et al., 2016). However, Jones et al. (2015) highlight that the concept of maladaptation remains underexplored in both theoretical and practical contexts, suffering from a lack of consensus regarding its definition and application. Moreover, while awareness of the negative impacts of certain adaptation measures has grown in recent years, ambiguity surrounding the precise nature of maladaptation persists (Magnan, 2014). A review of the literature reveals that although maladaptation has been discussed in various ways, its conceptual dimensions remain insufficiently defined (Noble et al., 2014; Jones et al., 2015; Juhola et al., 2016). Juhola et al. (2016) further argue that despite increasing recognition of maladaptation, its use remains conceptually vague. Similarly, the IPCC's Fifth Assessment Report points to a lack of consensus on a precise definition (Noble et al., 2014).

In this study, we redefine the concept of maladaptation through a systematic review of the scientific literature and feedback from researchers, providing a deeper understanding of its dimensions, consequences, and strategies for prevention. The objective is to identify recurring themes and key components in existing definitions of maladaptation to develop a more comprehensive framework and clarify researchers' interpretations of the concept. The findings will contribute to establishing a theoretical foundation for evaluating and addressing maladaptation risks in climate adaptation programs.

2 Theoretical foundations

While the need for climate change adaptation is widely acknowledged, whether vulnerable communities can successfully manage its impacts through adaptation remains an unresolved issue (Rickards and Howden, 2012; Malik and Ford, 2024). Addressing this challenge requires a thorough analysis of several key theoretical concepts from the climate adaptation literature. This section delves into the theoretical underpinnings of climate change adaptation, with a focus on three critical concepts: successful adaptation, sustainable adaptation, and maladaptation. By examining these ideas, this framework seeks to offer a clear and cohesive explanation of the central principles, providing a robust foundation for understanding and evaluating climate change adaptation efforts.

2.1 Successful adaptation

Adaptation to climate change has the potential to reduce vulnerability and generate significant socio-economic benefits (Tubi

and Williams, 2021). However, the success or failure of adaptation efforts is influenced by the varied and widespread impacts of climate change, as well as a society's ability to recognize and manage these effects (Smit and Pilifosova, 2003; UNFCCC, 2007; Torabi et al., 2018; Piggott-McKellar et al., 2020). As Dapilah and Nielsen (2020) highlights, adaptation strategies, irrespective of their intent or type, may fail to meet their objectives if they do not account for broader contextual issues and long-term implications.

Research on climate change adaptation distinguishes between adaptation in general and "successful" adaptation (Magnan et al., 2016). Some scholars, including Adger et al. (2005), define successful adaptation as the balance of effectiveness, efficiency, and equity achieved through decision-making structures that incorporate learning. On the other hand, Magnan et al. (2016), referencing Barnett and O'Neill (2010), adopt a more cautious perspective, suggesting that while unsuccessful adaptation may fail to meet its goals, it does not necessarily lead to significant harm.

Piggott-McKellar et al. (2020) describe successful adaptation as any adjustment that reduces climate-related risks or vulnerabilities to an acceptable level, without compromising economic, social, or environmental sustainability. Jones et al. (2015) further argue that successful adaptation should yield measurable benefits in reducing climate risks, without negatively impacting community well-being, while unsuccessful adaptation has little or no impact on mitigating these risks. However, there remains little consensus on how to define successful adaptation (Dilling et al., 2019; Westoby et al., 2020). Much of the debate stems from the fact that determining success is often tied to the specific goals of adaptation programs, which themselves are subject to critique and revision by the scientific community (Neset et al., 2019).

The success of an adaptation effort is typically assessed by its ability to reduce or avoid damage that would otherwise have occurred. However, this method of evaluation presents temporal and spatial challenges (Barnett and O'Neill, 2013). Some researchers argue that defining success solely based on goal achievement is problematic for two main reasons. First, an action may fulfill its immediate objectives but have unintended consequences at other scales, both in time and space. Second, adaptation actions that benefit one group may inadvertently create negative externalities, such as spillover effects, which increase risks for others or limit their adaptive capacities (Adger et al., 2005; Dapilah and Nielsen, 2020).

2.2 Sustainable adaptation

The international community is committed to achieving 169 Sustainable Development Goals (SDGs) by 2030 and, in alignment with the Paris Agreement, advancing adaptation to climate change. However, researchers have pointed out that while there is potential for synergy between these objectives, the alignment remains challenged due a limited understanding of the complex interactions between SDGs and climate change adaptation efforts (Fuldauer et al., 2022). A review of documented adaptation experiences in developing countries suggests that many responses to climate impacts have, in fact, contradicted sustainable development principles (Eriksen and Brown, 2011; Sakapaji and Puthenkalam, 2023). Additionally, several studies indicate that inefficient or unsustainable adaptation measures can worsen the effects of climate change and heighten community

vulnerabilities (Adger et al., 2005). Such maladaptive approaches not only increase vulnerability but also risk undermining progress toward sustainable development (Guodaar et al., 2020).

Sustainable adaptation has emerged as a crucial component of efforts to raise awareness of climate change impacts on vulnerable communities and the broader implications for sustainable development (Yang et al., 2020). This approach advocates for targeted interventions that support climate adaptation, risk reduction, and poverty alleviation (Brown, 2011). The concept of sustainable adaptation recognizes the growing necessity of adaptation in the coming decades but acknowledges that there is still limited understanding of the broader, long-term impacts of these actions, and uncertainty remains about whether current responses are truly socially and environmentally sustainable (Eriksen and Brown, 2011). From the perspective of Shoko Kori and Kori (2022), sustainable adaptation involves strategies aimed at reducing vulnerability, enhancing resilience, and addressing underlying factors such as poverty that exacerbate vulnerability in the face of climate change. Meanwhile, Eriksen et al. (2011) define sustainable adaptation as "adaptation that contributes to socially and environmentally sustainable development pathways, including social justice and environmental integrity," two fundamental pillars of sustainable development (Brown, 2011).

While the concepts of successful adaptation and sustainable adaptation share some commonalities, they are distinct in several key respects, particularly in terms of their focus and temporal frameworks (Santos et al., 2021). This distinction complicates the conceptual exchange between the two. To ensure a comprehensive evaluation of adaptation strategies that properly address the concerns underlying the above concepts, there is a complementary concept that largely reflects the uncertainty of achieving the ideals of successful and sustainable adaptation: maladaptation.

2.3 Maladaptation

The effectiveness of adaptation strategies has increasingly been called into question by researchers from multiple perspectives (Antoci et al., 2020). Despite the importance of reducing community vulnerability through adaptation, significant challenges remain in implementing these strategies (Guodaar et al., 2020; UNEP, 2019). In fact, many interventions not only fail to help communities cope with climate change but may also exacerbate existing vulnerabilities, limit future adaptive capacities, or undermine sustainable development efforts (Guodaar et al., 2020). These adverse outcomes are referred to as maladaptation (Fazey et al., 2011).

Maladaptation, a deviation from successful climate adaptation, manifests across various sectors and scales, influencing both individual behaviors and public policies (O'Hare et al., 2016; Reckien et al., 2023). Recognizing its profound implications, the United Nations Environment Program (UNEP) has identified maladaptation as one of the emerging environmental challenges (UNEP, 2019). Broadly, maladaptation refers to actions intended to reduce vulnerability to climate change but that ultimately have detrimental effects on other systems or sectors, increasing their vulnerability (Barnett and O'Neill, 2013). Borrowed from evolutionary biology, the term was first applied to climate adaptation literature by Scheraga and Grambsch (1998), who noted that adaptive responses can sometimes

have negative consequences for human health, the environment, and social welfare. The concept was later formalized in the Third Assessment Report of the IPCC, where maladaptation is defined as "any change in natural or human systems that inadvertently increases vulnerability to climatic stimuli, or adaptation that fails to reduce vulnerability but instead increases it" (IPCC, 2001, p. 990).

Another prominent definition is provided by Barnett and O'Neill (2010), p. 211, who describe maladaptation as actions that, while ostensibly designed to reduce vulnerability to climate change, inadvertently increase vulnerability in other systems, sectors, or social groups. They identify five pathways through which maladaptation can occur, serving as a framework for evaluating adaptation decisions to prevent potential negative outcomes (Brown, 2011). The United Nations Framework Convention on Climate Change (UNFCCC) defines maladaptation as the reduction of a community's adaptive capacity resulting from ineffective adaptation measures (UNFCCC, 2007). At its core, maladaptation refers to adaptation strategies that ultimately heighten the vulnerability of critical social groups and ecosystems essential for health and livelihoods (Christian-Smith et al., 2015). Juhola et al. (2016) extend the discussion by explaining that maladaptation arises when adaptation policies or measures directly increase the vulnerability of the targeted or external actors and erode the preconditions for sustainable development, thereby increasing societal vulnerability indirectly (Juhola et al., 2016, p. 139). They identify three potential maladaptive outcomes: rebound vulnerability, vulnerability displacement, and undermining sustainable development (Antwi-Agyei et al., 2018). Schipper (2020) frames maladaptation as part of a continuum, with successful adaptation at the opposite end, emphasizing its evolving nature over time. This view aligns with Jones et al. (2015), who suggest that successful adaptation minimizes the risk of maladaptation. Consequently, the conceptual framework for this study is presented in Figure 1.

Local adaptation measures aimed at mitigating climate change can sometimes produce unintended negative consequences for natural resources, agriculture, and forests. Research has demonstrated that while community-level adaptation strategies are intended to address climate impacts, they may inadvertently lead to maladaptation and ecosystem degradation. For example, in Zimbabwe, adaptation efforts have, paradoxically, increased the long-term vulnerability of socio-ecological systems and reduced their adaptive capacity (Tanyanyiwa and Madobi, 2017). Similarly, in British Columbia, Canada, genomics-based assisted migration, a forest adaptation initiative, has been associated with technical failures, increased opportunity costs, and path dependency, potentially undermining its intended benefits (Findlater et al., 2021). Moreover, maladaptive responses can create self-reinforcing cycles, exacerbating the very climate challenges they aim to alleviate. A study of Indonesia's Sadang watershed revealed that upstream deforestation as a drought response not only damaged local ecosystems but also increased downstream vulnerability by diverting water and creating new hazards (Naufal et al., 2023). In Ghana, agricultural and irrigation expansion (implemented as an adaptation measure) has contributed to deforestation, thereby disrupting the carbon cycle, increasing greenhouse gas emissions, and intensifying climate change vulnerability (Antwi-Agyei et al., 2018). Similarly, in California, drought adaptation efforts have unintentionally heightened vulnerabilities in other sectors, notably aquatic ecosystems and

marginalized social groups (Christian-Smith et al., 2015). Masson-Delmotte et al. (2021) states that maladaptive practices in forest management and natural resource use often result from short-term solutions that overlook long-term ecological impacts. For instance, some afforestation projects or land use changes aimed at increasing carbon sequestration can unintentionally disrupt biodiversity, alter water cycles, or heighten fire risks.

These examples highlight that local adaptation strategies, if not carefully designed and implemented, can have far-reaching and detrimental effects on ecosystems. Such interventions may disturb the delicate balance between ecosystems and human societies, compromising essential resources like forests and groundwater, and diminishing ecosystem resilience. Ultimately, these disruptions jeopardize the fundamental well-being of human communities (Allen et al., 2010; Flannigan et al., 2009; Millennium Ecosystem Assessment, 2005).

While researchers have expressed concerns that a lack of understanding about maladaptation could significantly weaken the broader field of climate adaptation studies (Tubi and Williams, 2021), Magnan (2014) highlights that maladaptation remains underexplored within academic discourse, with limited attempts to investigate its diverse dimensions thoroughly. Despite its growing importance, maladaptation has attracted insufficient research attention (Chi et al., 2021). Some scholars, emphasizing the context-specific nature of adaptation, are reluctant to propose a universal definition of maladaptation (Westoby et al., 2020; Dilling et al., 2019). In contrast, others argue that establishing a shared terminology and definition is essential to effectively address challenges like maladaptation. Such clarity is not only vital for recognizing the extent of its effects but also provides a structured basis for advancing scholarly discussion (Noble et al., 2014).

This study aligns with the latter perspective, seeking to redefine the concept of maladaptation from a more comprehensive standpoint. By examining existing definitions in the literature and soliciting expert opinions, the aim is to develop a more robust and inclusive understanding of maladaptation.

3 Research methodology

This study employed a qualitative content analysis with an inductive approach to establish a comprehensive definition of maladaptation. The first phase involved an in-depth examination of existing definitions, identifying implicit aspects and key dimensions. Through a synthesis and interpretation of the literature, a preliminary definition was formulated. In the second phase, feedback was gathered from domain experts—academics and researchers with substantial experience in maladaptation—using the focus group method. This process refined the preliminary insights, ultimately producing a robust, inclusive definition of maladaptation.

3.1 Content analysis

Content analysis encompasses a family of systematic review techniques used to examine the informational content of written, verbal, or visual communications (Forman and Damschroder, 2007;

FIGURE 1
The conceptual framework of research.
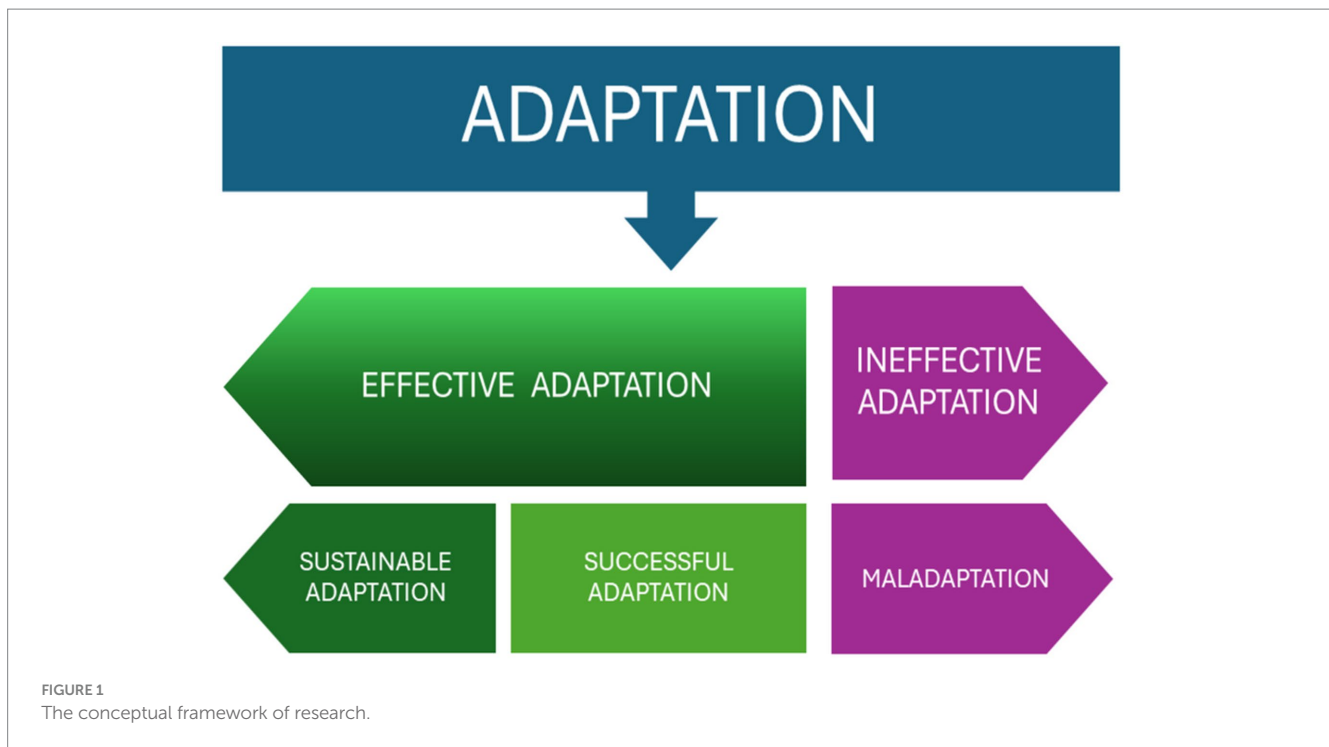
Kyngäs et al., 2019). Initially applied in the 19th century to analyze newspaper and magazine articles (Elo and Kyngäs, 2008), it has since gained prominence in fields such as health, psychology, and sociology (Forman and Damschroder, 2007; Rimmel and Cordazzo, 2021).

As both a research method and a data analysis tool, content analysis offers a structured and objective means of describing and interpreting concepts, enhancing the analysis of theoretical issues (Sandelowski, 1995). It involves grouping words into related categories under the assumption that terms classified together share similar meanings (Elo and Kyngäs, 2008; Kyngäs et al., 2019). This process supports a deeper understanding of texts and facilitates the discovery of underlying messages (Shrivastava and Ansari, 2010).

Originally grounded in a quantitative, positivist framework, content analysis has evolved over time, transitioning into a more interpretive approach within the hermeneutic paradigm (Lindgren et al., 2020). Although various types of content analysis now exist within both quantitative and qualitative research, they all share the fundamental goal of systematically classifying textual data to improve understanding. The primary distinctions lie in how categories are generated and applied, as well as the techniques used to analyze the findings (Forman and Damschroder, 2007; Sheydayi and Dadashpoor, 2023).

3.1.1 Qualitative content analysis

Qualitative content analysis (QCA) is a method used to systematically interpret the subjective content of textual data through a structured coding process, identifying patterns and themes (Mayring, 2000; Kibiswa, 2019). Unlike quantitative research, which aims to generalize findings to a larger population, the focus of qualitative research is on understanding and describing phenomena in depth (Forman and Damschroder, 2007; Rimmel and Cordazzo,

2021). The goal of QCA is to provide a concise, yet accurate, description of the phenomenon under study, with categories or concepts emerging from the data serving as tools for deeper comprehension (Kibiswa, 2019). QCA typically relies on data gathered through open-ended collection techniques, aiming to capture detailed insights rather than to measure variables (Elo and Kyngäs, 2008).

QCA can follow both inductive and deductive approaches. The inductive approach, often guided by research questions, is particularly useful when the existing literature on a topic is sparse or fragmented (Safitri et al., 2022). This method allows researchers to immerse themselves in the data, enabling categories and themes to emerge organically without the use of predefined codes (Rimmel and Cordazzo, 2021). The process begins with careful reading, followed by coding and identifying themes from the data, which are then used to create initial categories that inform the analysis of the remaining data (Kibiswa, 2019).

In this study, an inductive QCA approach is employed to achieve a more comprehensive understanding of maladaptation. This method is particularly recommended for studies aiming to explore and describe complex phenomena (Elo and Kyngäs, 2008; Vaismoradi and Snelgrove, 2019). To systematically analyze the research literature and extract key definitions, this study adopts a three-phase inductive content analysis model, integrating the processes outlined by Mayring (2000), Elo and Kyngäs (2008), and Vears and Gillam (2022). This model comprises seven key steps (Figure 1), providing a structured framework for coding and analyzing the data, leading to the identification of essential themes and semantic patterns that elucidate the dimensions of maladaptation. The combination of these methods is designed to capitalize on their complementary strengths. Mayring's (2000) process offers a systematic approach to coding, enabling detailed qualitative analysis. Elo and Kyngäs (2008) contribute to the

consistency of theme and concept extraction across different stages of the analysis, while Weirs and Gilliam emphasize transparency and methodological rigor, ensuring the validity of the research findings.

The initial phase of this research, comprised of two key steps, focuses on defining the research question in line with the study's objective, selecting a suitable sampling method, and gathering relevant data. This is followed by a thorough immersion in the chosen texts to explore the concept of maladaptation from multiple perspectives. As outlined in the introduction, this study aims to construct a comprehensive definition of maladaptation by employing a purposive sampling approach (Assarroudi et al., 2018). A systematic review of relevant literature—including journal articles, books, and official reports—was conducted using a text-based data collection method (Forman and Damschroder, 2007). Initially, 87 articles, 1 book, and 3 official reports were identified, which, after screening for duplicates and irrelevant sources, were narrowed down to 16 articles and 3 official reports (a total of 18 sources) for detailed analysis (see Figure 2). Table 1 lists the selected sources examined in this study (see Figure 3).
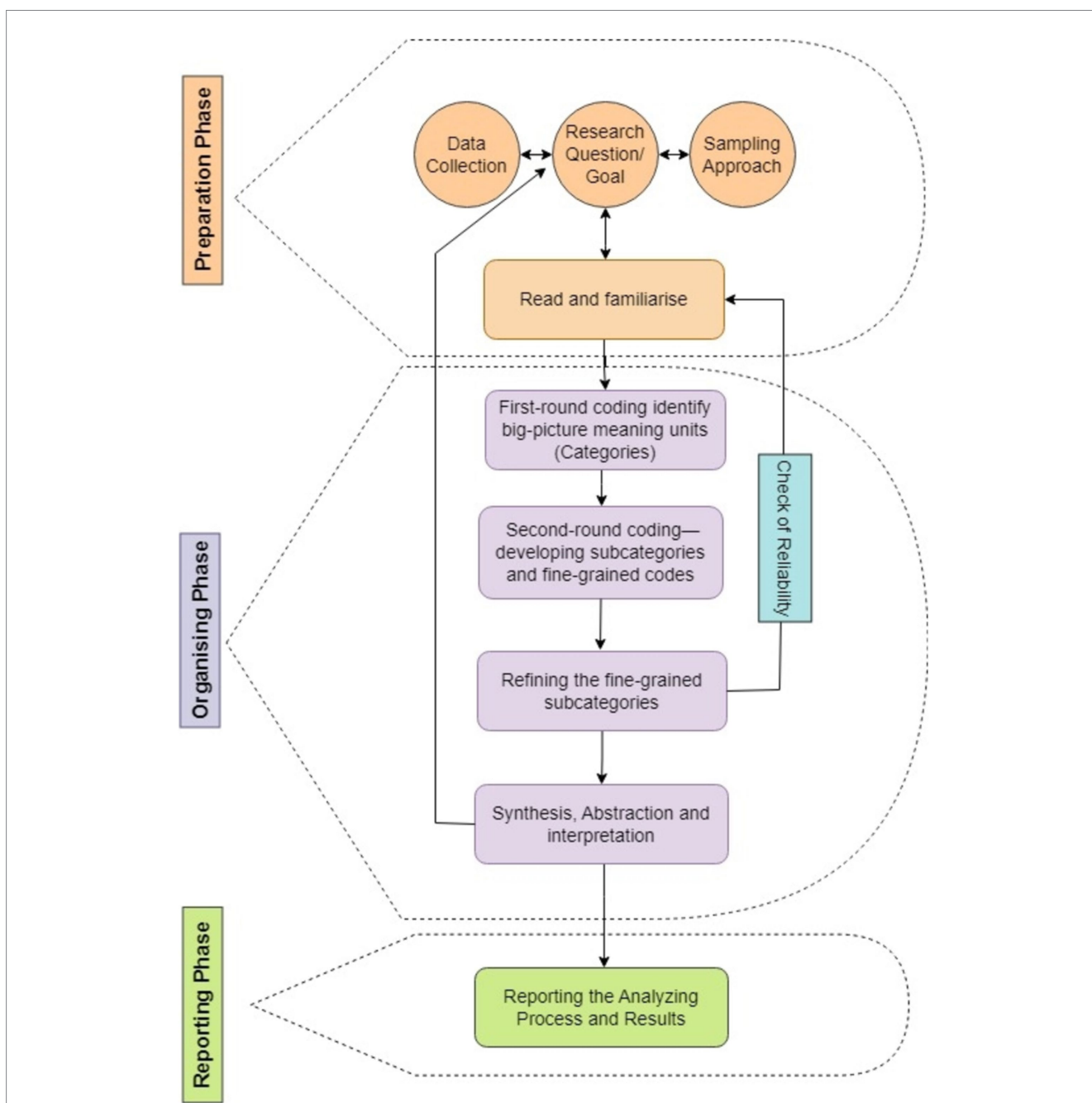

FIGURE 2
Inductive qualitative content analysis model (based on Mayring, 2000, Elo and Kyngäs, 2008, Vears and Gillam, 2022).

TABLE 1 Sources of content analysis related to maladaptation.

Publisher	Journals	References	Research type (Citation)	Study area/type
Elsevier	Global Environmental Change	Smithers and Smit (1997)	Research article (810)	Analytical review
Inter-Research	Climate Research	Scheraga and Grambsch (1998)	Research article (305)	USA
Springer	Adapting to Climate Change	Burton (1996)	Research article (296)	Analytical review
Cambridge University Press	Cambridge University Press	IPCC (2001)	Book (10,708)	Analytical review
Cambridge University Press	Cambridge University Press	UNDP (2005)	Book (357)	Analytical review
Cambridge University Press	Cambridge University Press	Heyd and Brooks (2009)	Book (97)	Analytical review
Taylor & Francis	Climate and Development	Schipper (2009)	Research article (283)	Analytical review
Elsevier	Global Environmental Change	Barnett and O'Neill (2010)	Research article (1,503)	Melbourne Australia
Taylor & Francis	Global Environmental Change	Fazey et al. (2011)	Research article (168)	Solomon Islands
S.A.P.I.EN.S	S.A.P.I.EN.S Surveys and Perspectives Integrating Environment and Society	Magnan (2014)	Research article	Analytical review
S.A.P.I.EN.S	S.A.P.I.EN.S Surveys and Perspectives Integrating Environment and Society	Magnan (2014)	Research article (120)	Analytical review
Cambridge University Press	Cambridge University Press	IPCC (2014)	Book	Review
John Wiley & Sons	WIREs Climate Change	Magnan et al. (2016)	Research article (464)	Analytical review
Elsevier	Environmental Science & Policy	Juhola et al. (2016)	Research article (359)	Analytical review
PLoS One	PLoS One	Zavaleta et al. (2018)	Research article (60)	Peru
John Wiley & Sons	WIREs Climate Change	Atteridge and Remling (2018)	Research article (193)	Analytical review
Elsevier	World Development	Eriksen et al. (2021)	Research article (482)	Analytical review
Elsevier	Journal of Cleaner Production	Ma et al. (2021)	Research article (19)	Hong Kong
Keywords to search	Maladaptation, maladaptive measures, maladaptive outcome			
Total	17 articles + 1 book			

4 Results

The results of the inductive qualitative content analysis, conducted in four stages according to the research model (Figure 2), are outlined below:

4.1 First step

4.1.1 Identifying the big picture or unit of meaning

By carefully examining the definition texts, the big picture was identified as two main meaning units of Interventions and Consequences inductively from the texts. At this stage, the selected definitions were categorized based on the core categories derived from the text. The coding process involved highlighting specific segments, with yellow used to denote Interventions and turquoise representing Consequences (as shown in Table 2). This systematic approach helped clarify the distinction between these key categories.

4.1.2 Coding tree of the first stage (coding schema)

The coding tree is actually the clear expression of the main categories that were distinguished and identified in the above table as yellow and turquoise color symbols (see Table 3).

4.2 Second step

4.2.1 Second round coding

After identifying the meaning units and main categories, the next step involves outlining subcategories that correspond to specific elements within the definitions. These subcategories represent a more detailed breakdown of the main categories derived from the selected definitions. Using an inductive approach, the subcategories are labeled based on terms and phrases directly extracted from the text. At this stage, distinct colors are applied for coding (see Table 4). Continuing the coding scheme from the previous step, yellow represents Interventions, turquoise signifies Consequences, and additional subcategories are distinguished using further color variations, as shown in Figure 4.

4.2.2 Summary chart of categories and subcategories

At this stage, the extracted categories and subcategories from the texts were organized by color, facilitating the process of refinement, synthesis, and interpretation. This color-coded organization helps in systematically analyzing and cross-referencing the findings based on the researcher's methodology.

4.2.3 Second stage coding tree (coding schema)

The coding tree at this stage actually represents the specific sub-categories that were distinguished and identified in the above table as different colored symbols (see Table 5).

FIGURE 3
Steps of selecting literature sources for systematic review.
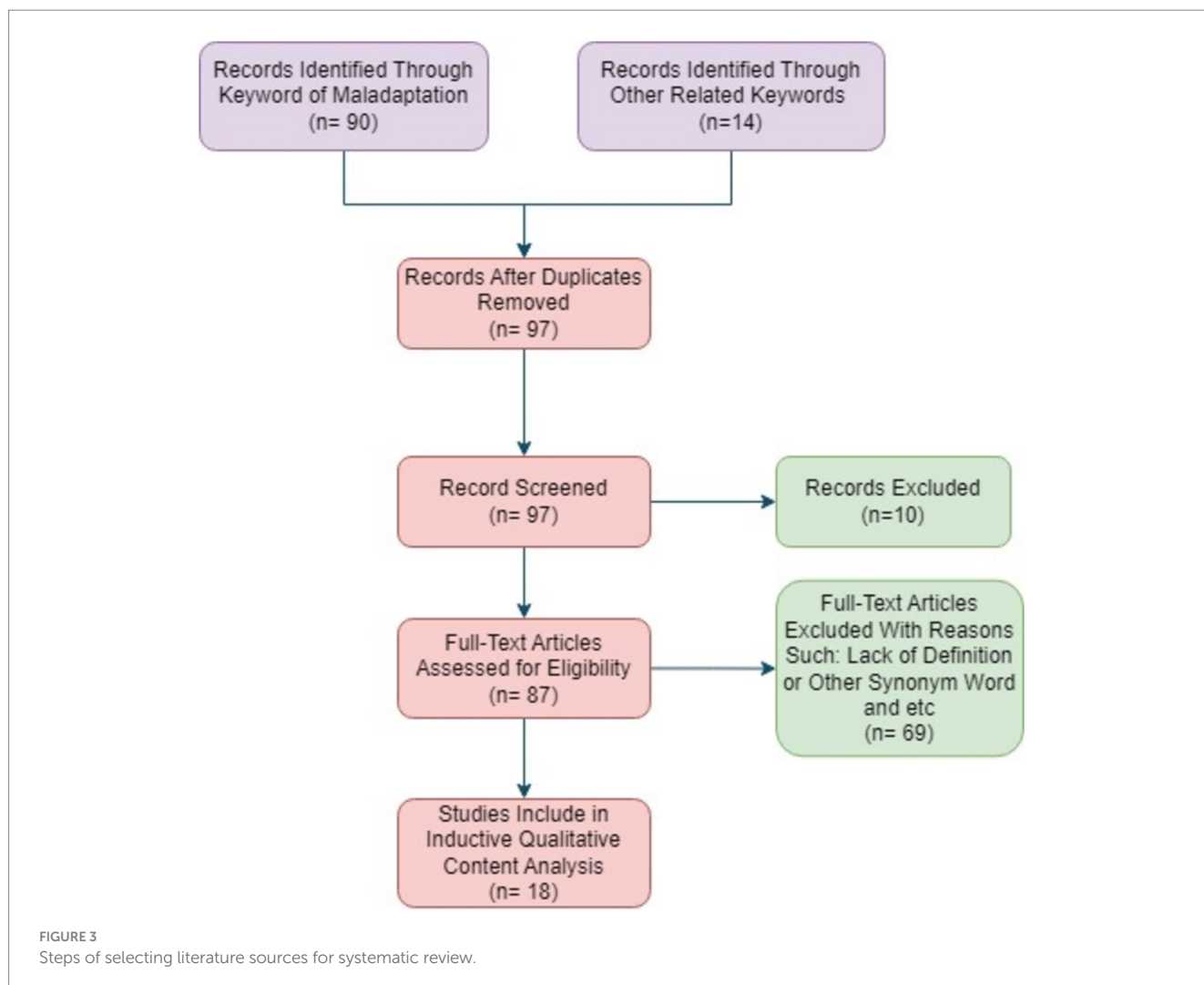
4.3 The third step: refining the sub-categories in detail

In this phase, the identified categories and subcategories from the previous stage are refined through a third round of coding. This step ensures the accuracy of the relationships between subcategories and their corresponding higher-level categories, as well as clarifies any ambiguous subcategories or overly broad categories. The coding process is revisited at the level of subcategory components, allowing for a more comprehensive and precise understanding of the extracted definitions. The refined coding tree is presented in Table 6, offering clearer insights into the structure and interrelations of the data.

4.4 The fourth step: integration and interpretation of results

In this stage, the categories and subcategories identified in previous phases are consolidated into a cohesive framework. This framework lays the foundation for a comprehensive definition, synthesizing insights from the diverse definitions encountered in the research literature. Using an inductive qualitative content analysis

approach, we systematically reviewed, compared, and categorized the data, which led to the development of a well-rounded definition of maladaptation. Furthermore, after gathering feedback and comments from 6 researchers involved in the study of maladaptation worldwide through a focus group and incorporating their suggestions and critiques, the study proposes the following refined definition:

Maladaptation refers to any adaptation intervention, whether individual, organizational, or infrastructural, that unintentionally results in negative consequences at any point within interconnected social-ecological systems over time.

These outcomes preeminently emerge through dynamic processes (such as activating change trajectories or dynamic mechanisms) or constraining processes (lock-in effects, traps, and path dependency). Identifying maladaptation is mainly possible by focusing on critical concerns and clearly defining system boundaries, as well as temporal and spatial scopes.

This definition was developed by analyzing various dimensions of maladaptive behaviors and their impacts from multiple perspectives of researchers and experts in this field over the past three decades. It

TABLE 2 Identification of categories (meaning unit).

	Author/year	Definition	Categories
1	Burton, 1996	"Many policies and practices in place increase vulnerability to atmospheric events." (p. 60)	Interventions Consequences
2	Smithers & Smit, 1997	"Mal(adaptation) is driven largely by non-climatic forces and serve short-term human goals, but often with attendant costs on individuals, communities, and society." (p. 131)	Interventions Consequences
3	Scheraga & Grambsch,1998	• "Maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided." (p. 87) • "potential adverse side effects of adaptive strategies… to avoid solutions that are worse than the problem." (p. 85)	Interventions Consequences
4	IPCC, 2001	• "Any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead". (p. 990) • "Measures that increase exposure rather than decrease vulnerability." (p. 846)	Interventions Consequences
5	UNDP, 2004	"when adaptations contradict and/or create obstacles for each other or with other developmental objectives (maladaptation) " (p. 214)	Interventions Consequences
6	(S) Chipper, 2009	"The responses that do not typically contribute to enhancing the adaptive capacity may actually reinforce the path towards inappropriate or reversed development, resulting instead in higher disaster risk over the long term." (p. 20)	Interventions Consequences
7	Heyd and Brooks, 2009(Adger et al, 2009)	"The pursuit of policies and practices [that] make people more vulnerable to changes in the natural environment in which human systems are embedded. " (p. 275)	Interventions Consequences
8	Barnett and O'Neill, 2010	"Actions are taken ostensibly to avoid or reduce vulnerability to climate change that adversely impacts or increases the vulnerability of other systems, sectors, or social groups." (p. 211)	Interventions Consequences
9	Fazey et al 2011	"Overall trajectories of change are not reducing underlying drivers [of vulnerability], and that capacities for collective adaptive response are being eroded, the trajectory of change in [the island studied] can be described as maladaptive" (p. 1288)	Interventions Consequences

(Continued)

TABLE 2 (Continued)

10	Rockefeller Foundation Center, 2012	"Maladaptation is a process that directly or indirectly increases vulnerability to climate variability and change and significantly undermines capacities or opportunities for present and future adaptation."	Interventions Consequences
11	Magnan, 2014	"The foster adaptation in the short term but insidiously affect the system's long-term vulnerability and/ or adaptive capacity to climate change." (p. 1)	Interventions Consequences
12	IPCC, 2014(IR5)	"Actions or inaction that may lead to an increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future." (Glossary/ p. 857)	Interventions Consequences
13	Magnan et al., 2016	• "Efforts can potentially foster adaptation in the short term, but there is a risk that they will affect territories, sectors, and people's long-term capacity and opportunities to cope with and manage the impacts of climate change. This possibility generally describes 'maladaptation.'" (p. 646) • "Maladaptation is also a process(*pathway*) that, evidenced by the emergence of the adverse effects of adaptation initiatives, occurs when there is increased short and/or long-term vulnerability" (p. 653) • "In practice, maladaptation refers to initiatives—for example, policy, plan, project, decisions, etc.—that are designed initially for adaptation but are actually at high risk of inducing adverse effects either on the system in which it is developed or on another connected system or both." (p. 655)	Interventions Consequences
14	Juhola et al. 2016	"Maladaptation could be defined as a result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s) and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability." (p. 139)	Interventions Consequences
15	Zavaleta et al., 2018	"Maladaptive pathways refer to processes or conditions that exacerbate the sensitivity of human populations (e.g., social exclusion) or reduce options (e.g., erosion of knowledge about environmental risks) to respond to future climatic events." (p 3)	Interventions Consequences

(Continued)

TABLE 2 (Continued)

		"Maladaptive pathways' represent changes or trajectories that are neither social nor environmentally sustainable." (p 4)	Interventions Consequences
16	Atteridge & Remling, 2018	'Maladaptation' includes all negative side effects of an activity, so is broader in scope than the risk we are interested in here" (p. 5)	Interventions Consequences
17	Ma et al., 2021	• "Undesirable adaptation that neglected considerations of long-term and systematic effects and, due to the lack of beneficial transformation, causes more damage in the future and other systems." (p 2) • "Wrong" adaptation that would worsen climate change impacts caused by avoidant reactions (i.e. emotional responses, e.g. denial of threats, fatalism, wishful thinking)" (p 4) • "Maladaptation refers to actions that may alleviate short-term and individual impacts but deter the building of long-term sustainability and go against public adaptation." (p 4)	Interventions Consequences
18	Siri Eriksen et al., 2021	Unintended negative consequences of adaptation measures, to suggest that adaptation interventions risk becoming tools for marginalization and instruments of abuse" (p 11)	Interventions Consequences

TABLE 3 The coding scheme of the first step.

A. Interventions B. Consequences

is derived from key conceptual elements present in prominent definitions of maladaptation found in the literature and reflects critical insights emphasized by leading scholars in this domain.

5 Discussion

As noted by Magnan et al. (2016), a deeper understanding of the roots and forms of maladaptation is urgently needed. This study, through its analysis of various definitions and research on maladaptation, offers several insights to further the discussion. First, while the definition presented here emphasizes the theoretical framework of maladaptation, it is essential, as Magnan (2014) highlights, to transition from a theoretical approach to a practical and

objective approach. Theoretical models provide a foundation for identifying and conceptualizing maladaptation, but their practical application is crucial for assessing and mitigating its negative consequences. The objective aspect of maladaptation is particularly noteworthy, as it enables the evaluation of adaptation efforts in real-world contexts. By acknowledging the interplay between theoretical and practical aspects, researchers and practitioners can develop more effective strategies for addressing maladaptation.

Moreover, in assessing maladaptation, objectivity should be prioritized. While subjective judgments inevitably play a role, especially in interpreting complex socio-environmental data, relying on objective indicators wherever possible enhances the accuracy and relevance of findings. Objective assessments, grounded in measurable data, offer a practical basis for comparison across different contexts. However, as Jones et al. (2015) caution, even objective assessments are not entirely free from subjective interpretation. The challenge lies in carefully managing subjectivity to ensure that biases do not compromise the analysis of adaptation efforts.

Additionally, this research underscores the importance of adopting both ex-ante and ex-post perspectives when defining and assessing maladaptation. Maladaptive outcomes may emerge at various stages of the adaptation process, and both perspectives are critical to understanding and addressing these outcomes. Ex-ante evaluations, by anticipating potential maladaptive consequences before strategies are implemented, provide opportunities for

TABLE 4 Identification of subcategories.

	Author/year	Definition	Sub-Categories
1	Burton 1996	Many policies and practices in place…	Action Type
		..increase vulnerability to atmospheric events.	Vulnerability
2	Smithers & Smit, 1997	Mal(adaptation) is primarily driven by non-climatic forces and serves short-term human goals,	Action Type / Time scale / Primary Goals / Intentionality
		…but often with attendant costs on individuals, communities, and society.	Impact dimension
3	Scheraga & Grambsch,1998	Adaptive strategies... / maladaptation can result in … / ..that are as serious as the climate-induced effects being avoided. / to avoid solutions that are worse than the problem	Action Type
		serious negative effects..	Effects
		potential adverse side effects …	Impact dimension
4	IPCC, 2001	Any changes in natural or human systems that, / an adaptation that.. / measures that.. / inadvertently… / rather than decrease vulnerability. / does not succeed in reducing vulnerability but	Action Type / Intentionality / Primary Goals
		..increase vulnerability to climatic stimuli; / ..increases it(vulnerability) instead. / ..increase exposure ..	Vulnerability / exposure
5	UNDP, 2004	When adaptations ...	Action Type
		…contradict and/or create obstacles for each other or with other developmental objectives (maladaptation)	Challenging for Development
6	(S)Chipper, 2009	The responses that do not typically contribute to enhancing the adaptive capacity	Action Type / Primary Goals
		and may actually reinforce the path towards inappropriate or reversed development, resulting instead in higher disaster risk over the long-term.	Challenging for Development / Time scale
7	Heyd and Brooks, 2009(Adger et al, 2009)	the pursuit of policies and practices ..	Action Type
		[that] makes people more vulnerable to changes in the natural environment in which human systems are embedded	Vulnerability / Impact dimension

(Continued)

TABLE 4 (Continued)

8	Barnett and O'Neill, 2010	action taken ostensibly to avoid or reduce vulnerability to climate change	**Action Type**
			Intentionality
			Primary Goals
		that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups.	Vulnerability
			Impact dimension
9	Fazey et al 2011	given that the overall trajectories of change are not reducing underlying drivers of vulnerability	**Action Type**
			Primary Goals
		and that capacities for collective adaptive response are being eroded, the trajectory of change can be described as maladaptive'	Impact dimension
10	Rockefeller Foundation Center, 2012	Maladaptation is a process . . . . . for present and future adaptation	**Action Type**
			Time scale
		. . that results in increased vulnerability to climate variability and change, directly or indirectly, . . and/or significantly undermines capacities or opportunities.	Vulnerability
			Impact dimension
11	Magnan, 2014	the foster adaptation in the short term but	**Action Type**
			Time scale
		insidiously affect system long term vulnerability and/ or adaptive capacity to climate change.	Vulnerability
			Effects
12	IPCC, 2014	actions, or inaction that may now or in the future	**Action Type**
			Time scale
		lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare.	Effects
			Vulnerability
			Impact dimension
13	Magnan et al., 2016	efforts can potentially foster adaptation in the short term..	**Action Type**
			Primary Goals
			Time scale
		There is a risk that they will affect territories, sectors, and people's long-term capacity and opportunities to cope with and manage the impacts of climate change. This possibility generally describes 'maladaptation	Effects
			Impact dimension
14	Juhola et al. 2016	maladaptation could be defined as a result of an intentional adaptation policy or measure	**Action Type**
		Directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability.	Vulnerability
			Challenging for Development
			Impact dimension

(Continued)

TABLE 4 (Continued)

15	Zavaleta et al., 2018	Maladaptive pathways refer to processes or conditions that 'maladaptive pathways' represent changes or trajectories	Action Type
		that are neither socially nor environmentally sustainable. exacerbate the sensitivity of human populations (e.g., social exclusion) or reduce options to respond to future climatic events.	Effects Impact dimension
16	Atteridge & Remling, 2018	an activity,	Action Type
		includes all adverse side effects of	Effects
		so is broader in scope than the risk we are interested in here	Impact dimension
17	Ma et al., 2021	undesirable adaptation,.. "wrong" adaptation,.. maladaptation refers to Actions,, neglected considerations of long-term,.. Due to the lack of beneficial transformation, more damage will be caused in the future. other system,.. by avoidant reactions (i.e. emotional responses, e.g, denial of threats, fatalism, wishful thinking) that may alleviate short-term and individual,.. impacts,..	Action Type Time scale Intentionality Primary Goals
		Neglected systematic effects would worsen climate change impacts caused but would deter the building of long-term sustainability and go against public adaptation,	Impact dimension Effects Time scale
		adaptation measures unintended to suggest that adaptation interventions	Action Type Intentionality
18	Siri Eriksen et al., 2021	negative consequences of risk becoming tools for marginalization and instruments of abuse	Effects Impact dimension

prevention and course correction. This preemptive approach can prevent costly socio-ecological impacts. As Magnan et al. (2016) stress, in the face of accelerating climate change, societies cannot afford to invest resources in misguided adaptation efforts. On the other hand, ex-post assessments are essential for understanding the long-term impacts of adaptation actions and optimizing future strategies to prevent maladaptation. Adopting a comprehensive approach to maladaptation enables researchers and policymakers to understand the complexities of maladaptation better and develop more effective methods to enhance the sustainability of socio-ecological systems and avoid costly mistakes. The definition provided by this research has attempted to cover both aspects as much as possible.

The new definition of climate change maladaptation offers a conceptual framework for future research in this area. Based on an analysis of 18 key publications, this definition builds upon previous perspectives and highlights the need to consider the unintended impacts of adaptation measures on social-ecological systems. This approach can help to better identify factors that contribute to long-term vulnerability and improve adaptation strategies.

6 Conclusion

Maladaptation poses a significant threat to climate stability, acting as a hidden risk similar to a Trojan horse. Mitigating this risk
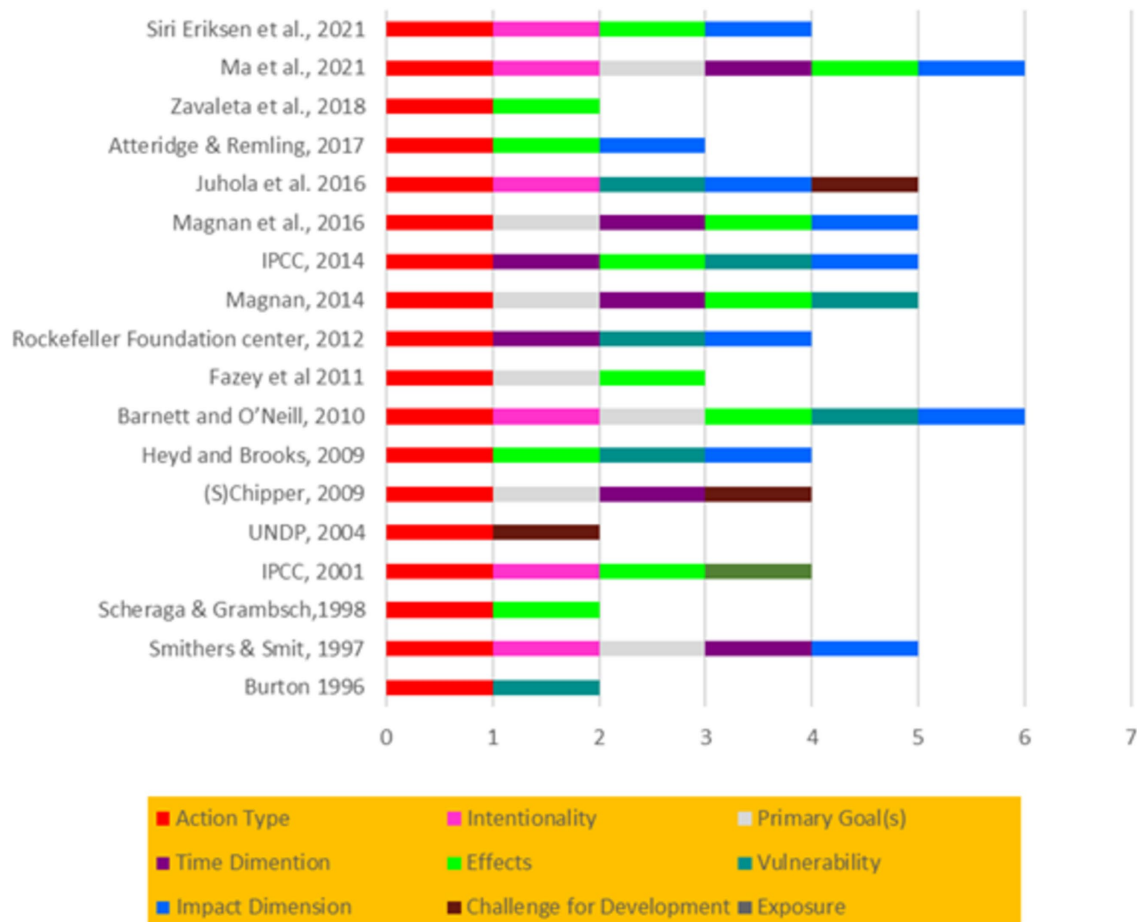
FIGURE 4
Summary of categories and subcategories.

TABLE 5 The coding schema of the second step.

A. Interventions
I. Action Type
II. Intentionality
III. Primary Goals
IV. Time Scale
B. Consequences
I. Effects
II. Vulnerability
III. Impact Dimension
IV. Challenging for Development
V. Exposure

TABLE 6 The coding scheme of the third step.

A. Interventions:

   I.   Action Type:

        a) Actions

        b) Inaction

        c) Interventions

        d) Process

        e) policies

        f) practices

  II.   Intentionality:

        a) Intended

        b) Unintended

 III.   Primary Goals

        a) Decrease vulnerability

        b) Enhance Adaptive Capacity

 IV.   Time Scale

        a) Short term/ Long term

        b) Now/ Future

B. Consequences:

   I.   Effects

        a) Adverse/ Side Effects

        b) Actually/ Potentially

        c) Effect on Human Systems

        d) Effect on Environmental Systems

  II.   Vulnerability

        a) Increase to any climate event

        b) Increase to any climate stimuli

        c) Directly

        d) Indirectly

 III.   Impact Dimensions

        a) Temporal / Spatial

        b) Human System

        c) Environmental System

 IV.   Challenging for Development

  V.   Exposure

        a) Increase Exposure

requires the adoption of comprehensive, participatory, and continuous monitoring approaches that engage all relevant stakeholders in an inclusive process. The findings of this study, consistent with the work of Schipper (2020), underscore the importance of detailed planning, active stakeholder engagement, and a thorough understanding of local vulnerabilities and contexts. Prioritizing adaptation strategies that are regionally focused, collaboratively designed, and sustainable can reduce the likelihood of maladaptation while enhancing community resilience to climate change. As noted by Adhikari et al. (2018), this necessitates integrating adaptation efforts at both individual and community levels, with a broader outlook that considers far-reaching impacts and demonstrates heightened sensitivity to local needs.

Additionally, the findings of this research align with recent IPCC reports, which emphasize the importance of adopting a holistic approach and strengthening environmental monitoring, education, and inclusion in the design and implementation of future adaptation strategies (Mimura et al., 2014). Comprehensive and long-term frameworks for monitoring and evaluating adaptation efforts, as highlighted by Atteridge and Remling (2018), not only instill greater confidence among financiers but also assist policymakers in making informed decisions about effective adaptation measures. One of the most impactful ways to prevent maladaptation, as suggested by this research, is to establish platforms that enable local community participation in the sustainable management of natural resources such as farmland, forests, and watersheds. This participatory approach, by leveraging local knowledge and fostering a sense of ownership, can significantly improve adaptive capacities, sustainability, and resilience. Integrating local knowledge into vulnerability assessments also encourages active stakeholder involvement, contributing to a stronger capacity to avert maladaptation.

Redefining maladaptation to climate change in natural resources and forests is crucial for effective management. A comprehensive definition helps managers and policymakers understand the long-term effects of adaptation decisions, enabling them to design more sustainable and effective strategies that preserve forest ecosystems and strengthen social-ecological resilience against climate change.

In this regard, future research should focus on developing context-specific frameworks for assessing the impacts of maladaptation. These frameworks should be designed in collaboration with field experts, local stakeholders, and specialists, and should employ an iterative process of pre-action and post-action assessments to ensure continuous refinement and effectiveness.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

DR: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

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