

Review

Role of Spatial Analysis in Avoiding Climate Change Maladaptation: A Systematic Review

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Abstract: With the rapid development of climate change adaptation over recent decades, a considerable amount of evidence has been collected on maladaptation associated with climate change adaptation initiatives, particularly in terms of risk transfer and risk substitution. Increasing our understanding of maladaptation is important for avoiding negative outcomes of adaptation project implementation. However, maladaptation has received limited research attention. Previous research has focused on frameworks that can assist in defining and avoiding maladaptive risk and be applied to adaptation initiative planning processes. Adaptation may cause more significant influences on spatial land change than the direct effect of climate change does. Identifying the adaptation consequences that are likely to result in maladaptation is crucial. A combination of spatial land analysis and climate change analysis can be used for the aforementioned identification. However, empirical case studies on methods that can assess and evaluate the risk of maladaptation by integrating spatial and temporal aspects in a land spatial modeling tool have not been conducted. The present study aimed to fill this research gap by exploring the existing knowledge on maladaptation to climate change. We examined the interaction among spatial analysis, evaluated maladaptation frameworks, and project design to extend our conceptual understanding on maladaptation to climate change. We adopted a systematic review method that involved considering several questions including the following: (a) What are the definitions and categories of maladaptation? (b) What methods and theoretical frameworks exist for the assessment and evaluation of maladaptive risk? (c) How have climate-related research communities considered issues of maladaptation? (d) What are the experimental studies on land use change that can be referred to for minimizing maladaptive risks in future adaptation planning? In conclusion, further research on maladaptation should integrate spatial land analysis methods to facilitate the identification and avoidance of maladaptive risk in the initial stage of adaptation planning.

Keywords: climate change adaptation; maladaptation; spatial and temporal; land spatial analysis; systematic literature review



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1. Maladaptation to Climate Change

Human life will be seriously affected by aspects of climate change, such as sea level rise and changes in rainfall patterns and hurricanes, in the next 100 years (Intergovernmental Panel on Climate Change [IPCC] [1]). Even if greenhouse gas levels are reduced to the levels proposed in the Kyoto Protocol, the degree of global warming would still not be reduced effectively [2]; thus, increasing research attention has begun to be focused on the role of adaptation in climate change. An increasing number of studies are being

conducted to determine appropriate methods of adapting to current and future climate impacts. However, adapting to climate change is not an easy task, and adaptation may cause additional vulnerabilities, which are referred to as maladaptation [3].

Barnett and O'Neill [3] proposed definitions and assessment aspects for maladaptation. The Fifth Assessment Report [4] states, "the adaptation literature is replete with advice to avoid maladaptation, but it is less clear precisely what is included as maladaptation." Moreover, "the wide range of actions and circumstances that have been described as maladaptive demonstrates the complexity of the concept and terminology." The aforementioned statements indicate that the scientific community realizes that avoiding maladaptation is crucial. Moreover, these statements indicate that room still exists for research on the definition of maladaptation and its causal relationship with decision-making or action.

To stabilize the state of the environment to make it suitable for human existence, adapting to climate change is essential, and land spatial planning is an indispensable part of adaptation [5]. In addition, subjectively prioritizing social adaptation demands is likely to increase the negative risk to human assets and society [6]. Therefore, in the stage of adaptation planning, if the land spatial changes caused by human intervention and their effect on socioecological systems can be evaluated in advance, suitable plans and adaptations can be developed to increase adaptation efficacy and reduce maladaptive risk.

Research on maladaptation is still in its infancy. The United Nations Environment Programme [7] has provided a warning that maladaptation is an emerging issue of environmental concern. Numerous studies have investigated the risk of maladaptation resulting from adaptive initiatives [8–16]. However, few studies have performed land spatial evaluation to predict the consequences and effectiveness of adaptation interventions [17–19]. Moreover, limited research has been conducted on the extent to which the actors involved in an adaptation system might experience the positive or negative effects of adaptation [15] as well as the spatiotemporal aspects of changes in critical thresholds that can lead to maladaptation [11,13]. A method that integrates spatial and temporal scales for maladaptive risk evaluation is currently unavailable. In land spatial modeling, different climatic and adaptation scenarios can be integrated, which enables the prediction of the efficacy of planned adaptation initiatives and the flexible assessment of the risk of maladaptation at a particular spatiotemporal scale.

This study aimed to fill the research gap on maladaptation by exploring the existing knowledge on maladaptation to climate change and the interaction between land spatial changes and adaptation. This research compiled a database of English papers published in academic journals and used a systematic review methodology to assess the current research developments related to maladaptation to climate change. Specifically, this paper examines four research questions: (a) What are the main current definitions and categories of maladaptation? (b) What methodologies and theories exist for maladaptive risk assessment and evaluation? (c) What discussions relevant to maladaptation have been conducted in climate-related research communities? (d) What experimental studies on land use change can be referred to for evaluating the risks of maladaptation?

2. Methodology—Systematic Literature Review

A few key studies used the review methodology to explore maladaptation definitions and theoretical frameworks (e.g., [3,11,13]). No previous study has conducted a systematic literature review on maladaptation to climate change. The present study mainly explores the maladaptive risk of adaptation initiatives and investigates whether land modeling is suitable for maladaptive risk assessment. This paper presents a comprehensive discussion on maladaptation. A systematic review method was adopted to assess comprehensively the knowledge on maladaptation to climate change.

The studies to be reviewed were selected using five main criteria: (a) only studies published in English, (b) studies that have been published in peer-reviewed academic journals and can be openly accessed online, (c) studies that analyzed and explored maladaptive risks, (d) studies on adaptation and maladaptation to climate change, and (e) studies incor-

porating land analysis tools for adaptation planning or reducing maladaptive risks. Scopus and Web of Science were the two scientific databases selected for searching and collecting data. In 2010, Barnett and O'Neill proposed the definitions and assessment aspects of maladaptation, and the present research began in September 2017; therefore, the time range of the search was from January 2010 to September 2017.

The literature database was constructed using several filtering processes and selection stages (Figure 1). In the first stage, the keywords used for the searches were classified into three categories: (a) "climate change" combined with "maladaptation" or "maladaptive"; (b) "maladaptation" combined with "spatial," "GIS," or "land use"; and (c) "adaptation" combined with terms such as "spatial," "GIS," and "land use." These searches yielded 1204 papers. When overlapping papers were deleted, a dataset comprising 882 papers was obtained in the second stage. In the third stage, 405 articles with the term "climate change" in the title, abstract, and keywords were retained. In this stage, papers not related to the topic of climate change were deleted. Theories of adaptation and maladaptation primarily originate from natural biology and ecological science; however, the focus of this research was to determine how to assess the interaction between society and the environment, how to assess the maladaptation after implementing climate adaptation initiatives, and how to reduce the maladaptive risk in the planning stage by using a dynamic land simulation tool. Therefore, in the fourth stage, articles related to genetic evolution and variation were deleted, which resulted in 177 papers being retained. Finally, 80 papers that met the selected criteria and were directly or indirectly related to maladaptation were reviewed and analyzed in detail by the authors of the present paper.

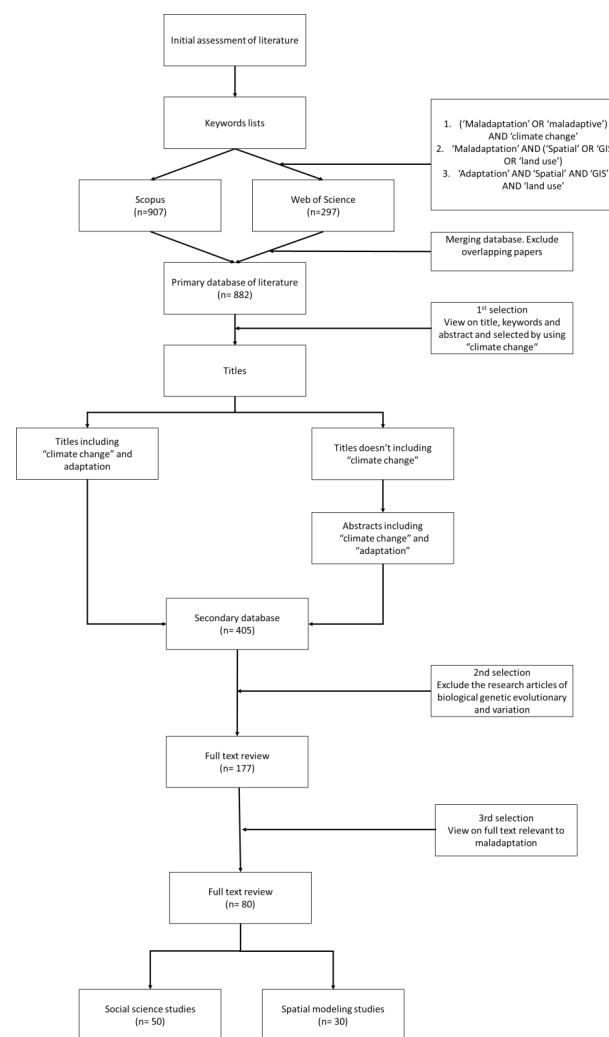


Figure 1. Systematic review process.

3. Evidence Synthesis: Recent Progress in Research on Maladaptation

3.1. Social Science Studies

Barnett and O'Neill [3] were among the first researchers to propose the definitions and assessment aspects of maladaptation. Subsequently, the IPCC [4] proposed the importance of avoiding maladaptation in the Fifth Assessment Report (Figure 2). A total of 50 studies on maladaptation were social science studies. These studies were conducted in various developed and developing countries (Figure 3). In addition, most of the aforementioned studies (58%) used a single data collection method, such as literature review, interview or questionnaire, and document analysis. The remaining studies (42%) used multiple methods, including literature reviews, interviews/questionnaires, document analysis, workshops, and focus groups, to collect data (Figure 4). Most of the aforementioned studies were inductive qualitative studies, and 56% of the aforementioned studies were directly relevant to maladaptation (Figure 5). Most of the studies on maladaptation investigated maladaptation related to water sources, flooding, drought, heat, or multiple issues (Figure 6). Moreover, some of the reviewed studies assessed maladaptation from the perspective of policy planning, agriculture, water management, coastal zone management, or multiple sectors (Figure 7). Most of the aforementioned 50 reviewed studies implicitly refer to maladaptation to climate change as an adaptation process. Approximately 56% of the 50 studies analyzed maladaptation directly, and 50% of the 50 studies were mainly focused on the local scale.

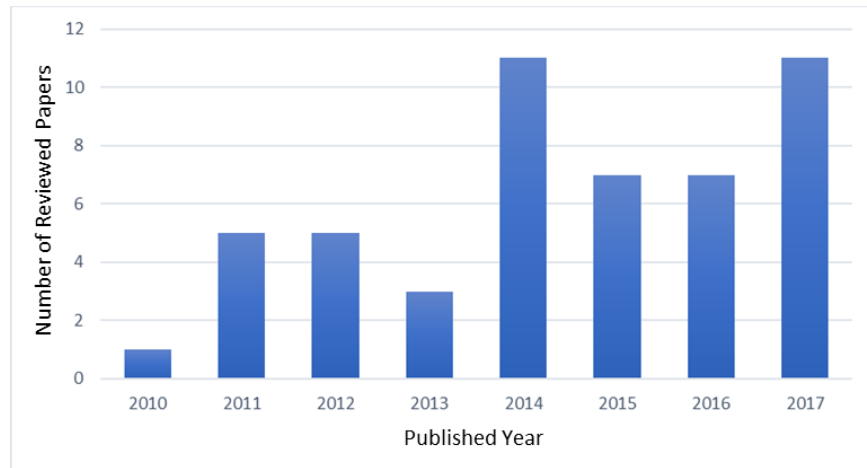


Figure 2. Publication years of the reviewed social science papers.

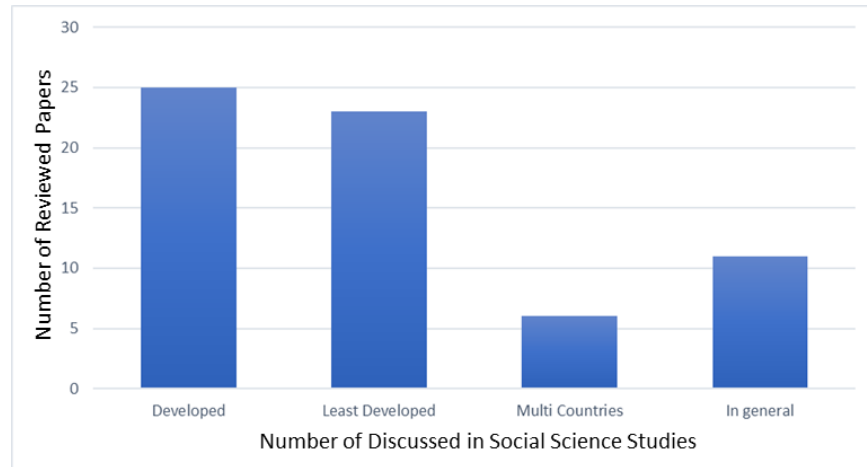


Figure 3. Number of reviewed social science studies conducted in developed and least developed countries.

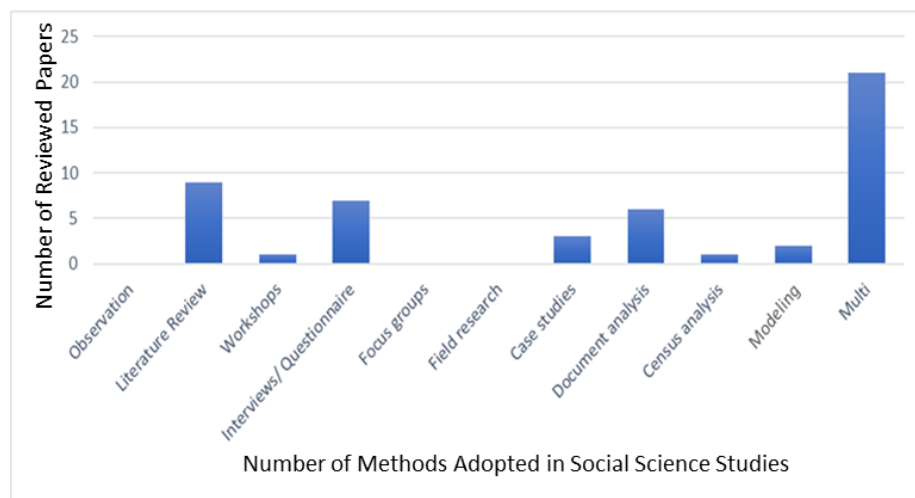


Figure 4. Research methodologies in the reviewed social science studies.

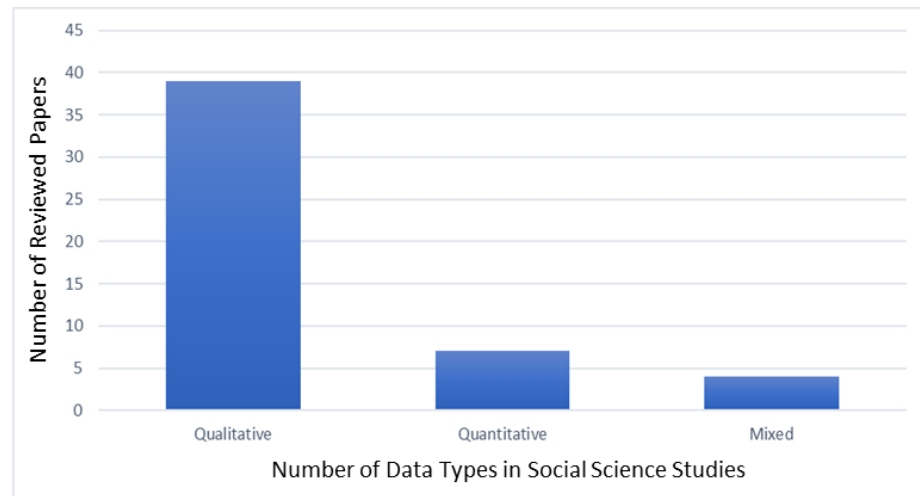


Figure 5. Types of data in the reviewed social science studies.

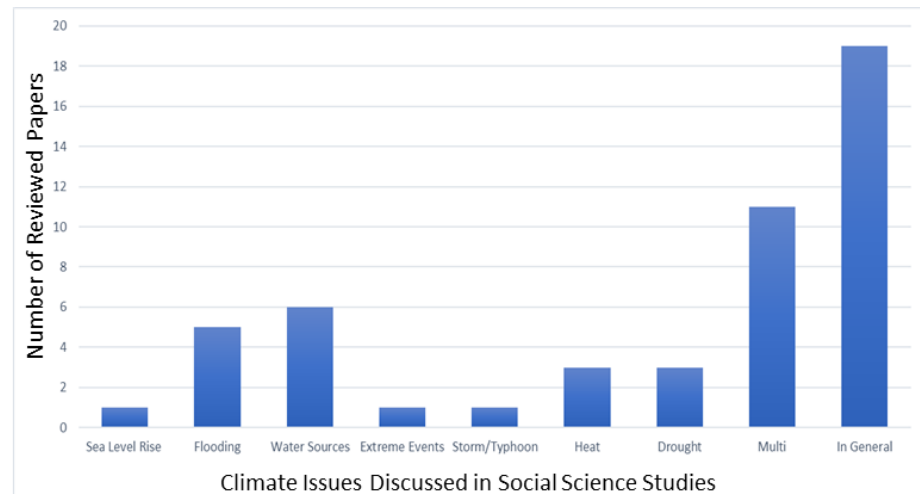


Figure 6. Climate issues in the reviewed social science studies.

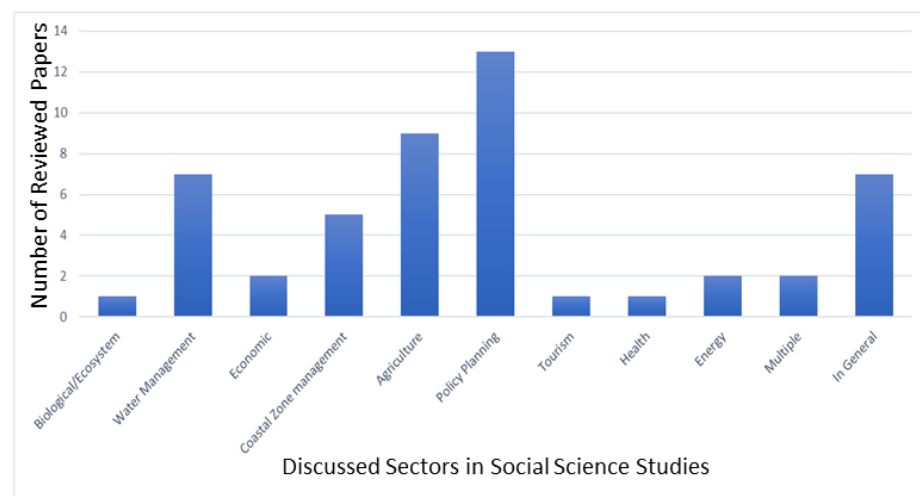


Figure 7. Relevant sectors discussed in the reviewed social science studies.

3.2. Spatial Modeling Studies

In total, 30 studies examined the spatial maladaptation or adaptation to climate change. These studies focused more on developed countries than on developing countries (Figure 8). In addition, approximately 43% and 20% of the aforementioned studies used geographic modeling and mixed-methods modeling, respectively (Figure 9). Most of the 30 studies (63%) adopted quantitative analysis methods (Figure 10). A total of 40% of the studies were directly or indirectly relevant to maladaptation (Figure 11), and only 23% of the papers related to the aforementioned 30 studies used the term “maladaptation.” Most of the 30 studies (23%) examined multiple issues or specific issues related to flooding, sea level rise, and water sources (Figure 12). One-third of the 30 studies analyzed comprehensive climatic issues of different categories. In total, 40% of the studies examined the issues of adaptation in multiple sectors. Some studies focused on the specific sectors of land use (17%), agriculture (17%), ecosystems (6%), coastal zone management (6%), policy planning (6%), economy (3%), and forestry (3%; Figure 13). Most of the 30 studies were focused on the effects of adaptation to climate change on specific spatiotemporal scenarios. Only 40% of the studies analyzed maladaptation, and 63% of the studies were mainly focused on the local scale.

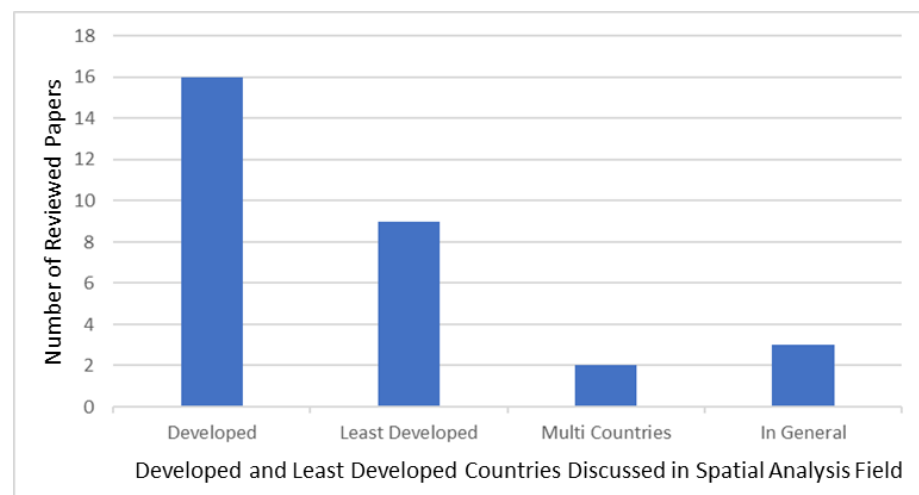


Figure 8. Number of reviewed spatial modeling studies conducted in developed and least developed countries.

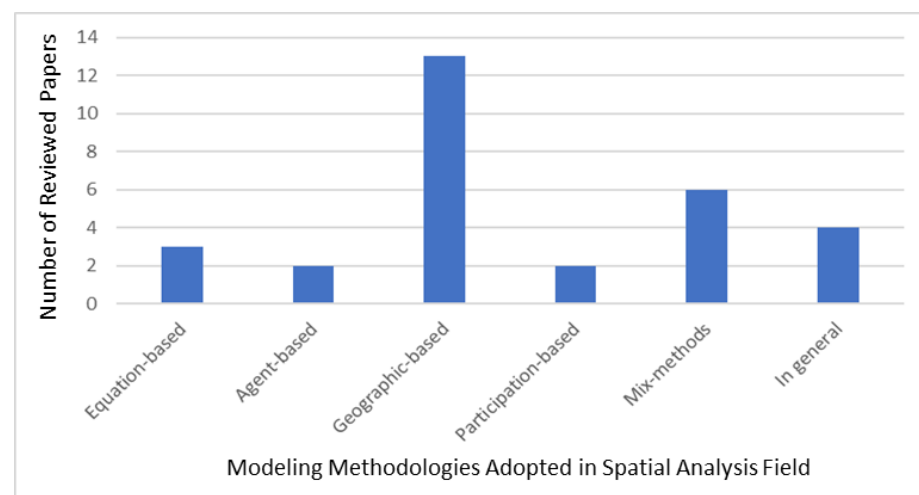


Figure 9. Modeling methodologies used in the reviewed spatial modeling studies.

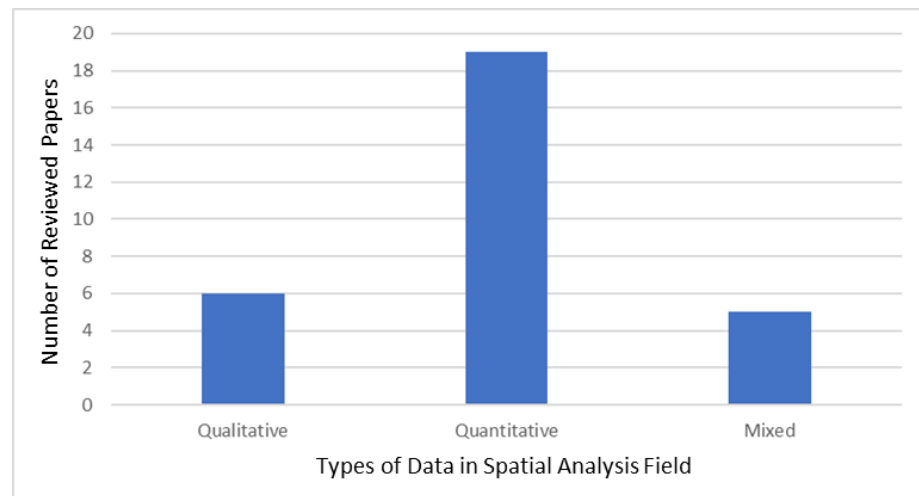


Figure 10. Types of data in the reviewed spatial modeling studies.

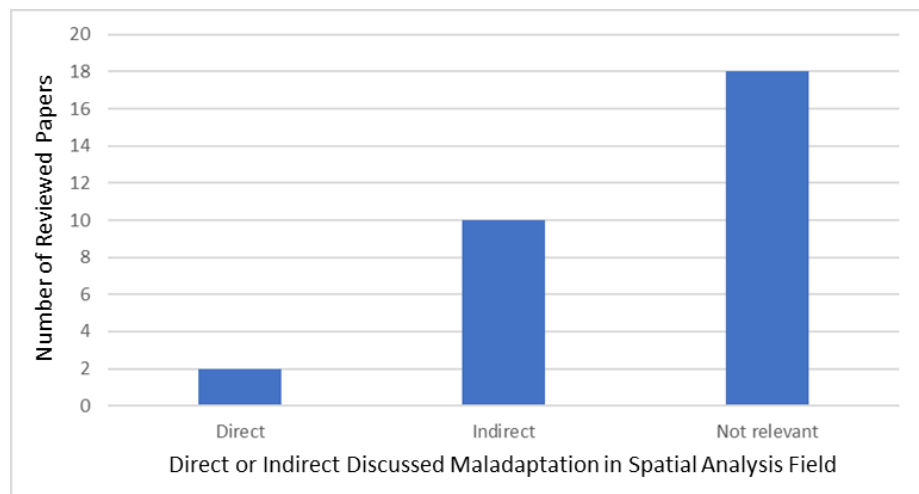


Figure 11. Number of reviewed spatial modeling papers with direct or indirect discussions on maladaptation.

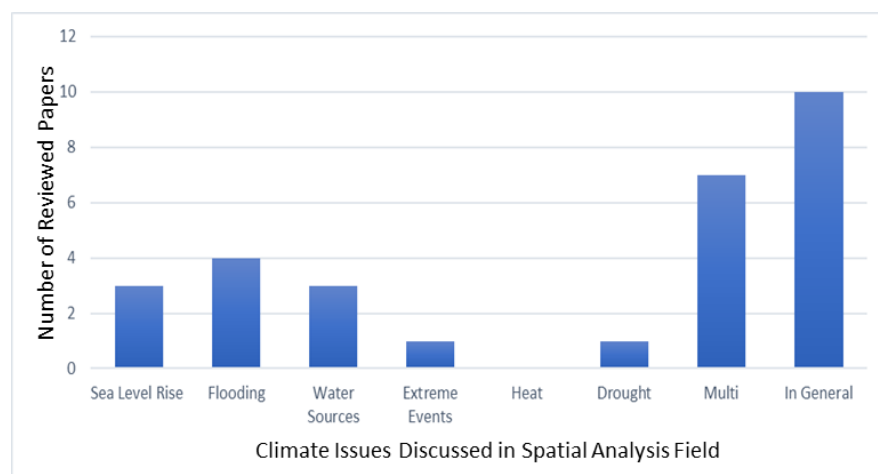


Figure 12. Climate issues in the reviewed spatial modeling studies.

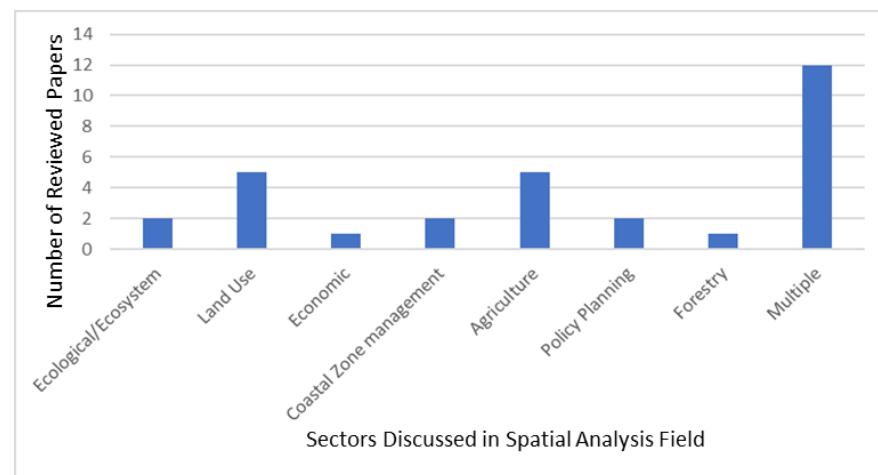


Figure 13. Sectors investigated in the reviewed spatial modeling studies.

4. Definitions of Maladaptation

The terms “adaptation” and “maladaptation” are widely used to describe responses to climate change [20]. Adaptations are adjustments to natural or human systems aimed at exploiting the beneficial opportunities or mitigating the possible negative effects caused by new or changing environments [21]. Adaptations can be also defined as the actions implemented to reduce the vulnerabilities caused by climate change [22]. Vulnerability can be simply described as susceptibility to harm [23]. According to the IPCC [24], “vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.” According to the IPCC [1,22], vulnerability is a function of three factors: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which a system, such as people, locations, objects, or assets, is physically subjected to potential threats or existing hazards. Sensitivity is the degree to which a system, such as a transportation, water, or agricultural system, is adversely or beneficially affected by the stress of climate change. Finally, adaptive capacity refers to a system’s ability to cope with and adapt to the impact of climate change and to take advantage of the opportunities created by climate change. Thus, adaptive capacity can affect vulnerability through structural, institutional, and social actions and influence the impact of, exposure to, and sensitivity to climate change [23]. In general, adaptive capacities generated by adaptations can reduce the socioeconomic vulnerability caused by climate change [25]. Thus, the components of vulnerability can be a basis for classifying the functions of adaptation measures. According to the definition of vulnerability, adaptation measures can be classified into three categories [8]: (1) measures intended to increase adaptive capacity; (2) measures intended to reduce sensitivity by decreasing the susceptibility of a sector, system, or social group to damage; and (3) measures intended to reduce the exposure of a sector, system, or social group to climate change.

Maladaptation is a concept relevant to adaptation and vulnerability but has not been investigated in detail [26]. Table 1 presents the definitions of maladaptation in the context of climate change. The results of our review indicate that only 27 papers presented a clear definition of maladaptation to climate change. Of them, 14 cited the definition proposed in [3]. An intended adaptation is considered a maladaptation when it increases the long- or short-term vulnerability of social groups and sectors [3]. Most of the definitions presented in Table 1 are based on the definition of Barnett and O’Neill [3]. Certain studies have defined maladaptation by referencing intrinsic features. All the definitions presented in Table 1 indicate that maladaptation is caused by adaptation that fails to reduce vulnerability or inadvertently increases it. For instance, Jones et al. [27] defined maladaptation as follows: “Maladaptation occurs when short-term strategies increase vulnerability in the long term.” Barnett and O’Neill [3] defined maladaptation as

the “action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups.” One of main reasons for maladaptation is the uncertainty of climate change. Gersonius et al. [28] stated that uncertainties make it difficult to design adaptive measures and decide which measures are suitable for reducing climate risks. Adaptive measures may lead to decreased flexibility in response to uncertain changes in climate conditions. However, climate uncertainty is not the only factor that increases maladaptive risks. Adaptation involves many systems, fields, time frames, development processes, and actors. Moreover, adaptation effectiveness is affected by human behavior and institutional adjustment. In certain cases, the overall adaptive capacity decreases [29] and vulnerability increases.

Table 1. Definitions of maladaptation in the reviewed literature (updated from Chi et al. [30]).

Sources of Definitions	Maladaptation Defined in Literatures	Cited by Authors
Burton [31]	“a practice is maladaptive if it increases vulnerability”	[32]
Synthesized from Scheraga and Grambsch [33]; Barnett and O’Neill [3] and IPCC [34]	“maladaptation embraces those adaptation responses that increase vulnerability to climatic impacts to the feature to which they are being applied, to other features, and worsen impacts in some other way, including increasing GHG emissions”	[10]
IPCC [1]	“the potential for adaptation measures to (inadvertently) increase vulnerability is referred to as maladaptation”	[14]
Walker et al. [35,36]	“maladaptation in terms of specified or general resilience: too much emphasis on successfully creating resilience to one (specified) driver (e.g., air conditioning to stay cool on a hot day) can undermine resilience to other (general) drivers (e.g., heat tolerance that has been lost if a power failure interrupts the air conditioner)”	[37]
UNFCCC [38]	“maladaptation refers to adaptation measures that fail to reduce vulnerability and rather increase it”	[39]
OECD [40]	“maladaptation is defined as business-as-usual development which, by overlooking climate change impacts, inadvertently increases exposure and/or vulnerability to climate change. Maladaptation could also include actions undertaken to adapt to climate impacts that do not succeed in reducing vulnerability but increase it instead”	[41]
Jones et al. [42]	“maladaptation happens when short-term strategies increase vulnerability in the long term”	[43]
Barnett and O’Neill [3,8,44]	“action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups”	[7,15,16,26,45–60]

Table 1. Cont.

Sources of Definitions	Maladaptation Defined in Literatures	Cited by Authors
Rickards and Howden [61]	“adaptation efforts that fail in this way, or involve excessive costs in the process”	-
IPCC [62]	“maladaptation arises not only from inadvertent badly planned adaptation actions, but also from deliberate decisions where wider considerations place greater emphasis on short-term outcomes ahead of longer-term threats, or that discount, or fail to consider, the full range of interactions arising from the planned actions”	[63]
Magnan [12]	“maladaptation is a process that results in increased vulnerability to climate variability and change, directly or indirectly, and/or significantly undermines capacities or opportunities for present and future adaptation”	[57]
Mycoo [63]	“intervention in one location or sector may increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change”	-
Yaro et al. [64]	“maladaptation refers to the negative changes and practices resorted to by households and individuals in reaction to climate stressors that are inimical to their welfare or that of the community as a whole”	-
Juhola et al. [11]	“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”	[13]

Vulnerability to climate change increases due to adaptation initiatives and causes short- and long-term effects on society. Vulnerability is not an invariant state but a dynamic state [13]. Adaptation has a time-delayed characteristic and various temporal and spatial effects [3]. Maladaptive risks change with time; thus, developing consistent thresholds of maladaptation as evaluation criteria is not possible. However, one can comprehensively examine whether the implementation of adaptation has achieved social goals can be examined. The exploration of maladaptive thresholds is crucial for examining a system’s spatiotemporal scale [11]. According to the reviewed definitions, the spatiotemporal scale should be considered when analyzing the risks of maladaptation.

The remainder of this section discusses four significant topics that characterize the current knowledge on maladaptation: uncertainty, spatiotemporal scales, risk thresholds of maladaptation, and existing analytical frameworks for maladaptation. This study attempts to explain how to solve these problems and analyze maladaptive risks.

5. Methods for Overcoming Climate Uncertainty

Uncertainty in climate change may lead to maladaptation and influence the success of adaptation policy implementation. Such uncertainty makes it difficult for decision makers to determine the appropriate adaptation and the effects of this adaptation. For example, farmers in Victoria, Australia, have not received any guidance from governmental policymakers on how to adapt to climate uncertainties and this means that previous structural measures have been locked in. Therefore, the adaptation initiatives adopted by the farmers have no long-term effectiveness and they reduce the farmers’ capacity to plan to avoid the maladaptation of agricultural systems [65]. Gersonius et al. [28] stated that uncertainty in climate change can make it difficult for people to plan adaptation measures and determine what initiatives are effective. Adaptation planners must develop suitable strategies to address maladaptive risks related to coastal flooding, erosion, and storm events [6]. Identifying whether a short-term adaptation measure would be adequate for managing medium- to long-term risk is difficult [12].

Uncertainty in climate change also influences adaptation planning. Many complexities, such as the difficulty in determining the scale, timing, and distribution of future disasters as well as the positive and negative consequences of adaptation, must be considered when

implementing adaptation initiatives. Ignoring these complexities may cause adaptation initiatives to be ineffective and even maladaptive [66]. Despite uncertainty in and the unknown effects of the local environment, people can adapt to climate change on the basis of past experiences and by predicting such changes. Few studies have assessed adaptation initiatives by considering the uncertainty in climate scenarios [28,67]. Abunnasr et al. [51] constructed a model for incorporating adaptation into the planning process to reduce climate uncertainty and avoid adverse adaptation risks. Radhakrishnan et al. [68] developed an adaptation planning process to examine whether the adaptation measures implemented in Can Tho, Vietnam, were based on multiple perspectives and involved flexible adjustments to reduce maladaptive risk. Fu et al. [69] designed multiple scenarios for sea level rise to assess losses in the Tampa Bay region, Florida. Warnatzsch and Reay [70] determined the effect of climate on high-yield maize planted in Central Malawi by predicting multiple scenarios of climate variations. Klein et al. [71] examined the effect of climate uncertainty on adaptation measures by conducting simulations on two contrasting future climate scenarios.

Although climate uncertainties cause maladaptation, planning appropriate adaptation measures through the spatial modeling of different climate scenarios can minimize the maladaptive risk. Such modeling can enable decision makers to identify and select acceptable risk levels in advance.

6. Ambiguity of the Spatiotemporal Scales of Maladaptation

In addition to causing maladaptation, some adaptation initiatives designed for certain systems can induce different vulnerabilities in other systems because these initiatives do not consider interdependent systems [14]. For example, an adaptation initiative that increases the resilience to climate change at a certain spatial scale may increase the vulnerability at other spatial scales [11]. Moreover, an adaptation initiative useful for one social group may be harmful to other social groups [14]. On the temporal scale, climate change has long-term and uncertain effects. Some adaptations may only be appropriate for coping with the short- and medium-term effects of climate change and may transform into maladaptation in the long term.

Considering the spatiotemporal scale is crucial when analyzing maladaptive risks. Researchers have unintentionally neglected the temporal and spatial dynamics of maladaptive risk [71]. In total, 42% and 22% of the reviewed social science studies (n = 50) considered the temporal and spatial scales, respectively. Moreover, 53% and 73% of the reviewed spatial modeling studies (n = 30) considered the temporal and spatial scales, respectively (Figure 14). More than 50% of the reviewed social science studies proposed maladaptation definitions; however, fewer reviewed social science studies investigated the spatial and temporal scales than did the reviewed spatial modeling studies.

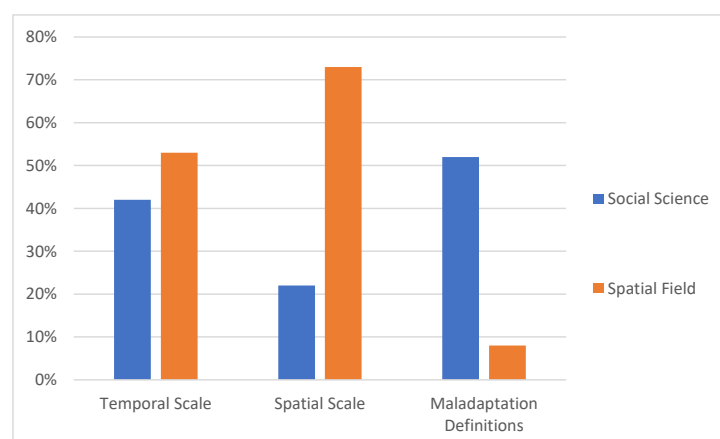


Figure 14. Investigation of the spatiotemporal scale in the reviewed studies.

At the spatial scale, an adaptation designed to adjust to the climate pressures acting on a certain system may cause maladaptation and risk in other linked systems. For example, risk may be transferred from one sector to adjacent sectors, including spaces, ecosystems, and socioeconomic systems. Therefore, in terms of spatial scales, maladaptation should be assessed using a cross-spatial perspective and flexible approach to determine the interdependencies and relationships among actors, sectors, and adaptation goals [11]. The issue of how to avoid the spatial transfer of maladaptive risk remains unresolved [13]. At the temporal scale, adaptation is considered a process that may have short-term positive benefits but may exacerbate the current vulnerability or create a new vulnerability in the long term. Therefore, the short- and long-term negative and positive effects of an adaptation must be evaluated. Identification of the temporal scale is an essential step in analyzing the maladaptive risk.

7. Risk Thresholds for Maladaptation

Risk threshold exploration is one of the most crucial steps in maladaptation analysis. Evaluation criteria suitable for analyzing the adverse impact of maladaptation and the spatiotemporal scales at which maladaptation may occur are currently unavailable. One reason for the aforementioned phenomenon is that the threshold value changes over time. Moreover, maladaptive risk ranges from minor to serious [11]. Formulating a unified threshold as the evaluation standard for temporal and spatial scales is difficult.

Adaptation is a vulnerability reduction process and not a stable result; thus, useful adaptations may have different risks of maladaptation. Vulnerability is an invariant state [13], which also indicates that the degree of maladaptive risk changes with time. The IPCC [24] defined vulnerability as “the propensity or predisposition to be adversely affected,” which comprises three key elements: exposure, sensitivity, and adaptive capacity. The concept of vulnerability may be useful for reflecting diverse drivers, processes, and stress interactions to detect and prevent unsuitable adaptation [72]. Magnan et al. [13] used factors of vulnerability to propose the concept of maladaptive risk and recognized that maladaptation occurs due to increases in the vulnerability of a system and the sensitivity of ecosystems and society. Although adaptation interventions can reduce vulnerability in certain sectors, these interventions may result in the generation of new maladaptive risks and exacerbate the risk over a long period (Magnan et al. [13]: page 655, Figure 1). Vulnerabilities can be exacerbated and cause maladaptation in different systems in the long term. Therefore, accurate thresholds of maladaptation cannot be estimated; however, the interaction between adaptation and the environment can be estimated as comprehensively as possible in the initial adaptation planning. Several alternative adaptation scenarios are compared with a reference scenario to evaluate the effects of different initiatives on the achievement of climate change mitigation and adaptation objectives [73]. Furthermore, the maladaptive risk at different spatiotemporal scales can be predicted and compared.

8. Existing Conceptual Frameworks for Maladaptation Evaluation

Maladaptation is a major issue; however, no framework is available for identifying and evaluating the risks of maladaptation [12] because maladaptation development is affected by natural and human-induced changes at any time. According to Granberg and Glover ([10]: page 150), identifying maladaptation is difficult for several reasons. The authors stated, “there are no widely accepted criteria, no suitable yardsticks against which to judge the adaptation measures, local circumstances vary considerably, the passage of time can alter the extent of success or failure and there are the usual problems of subjective judgements.”

In the reviewed studies, at least four useful frameworks were proposed that can help governmental agencies and decision makers identify suitable adaptation initiatives by considering maladaptive risks in the planning stage. These four frameworks are the Precautionary Framework (proposed by [74] and reviewed by [12,13]), Assessment Framework [13], Feedback Framework [11], and Pathways Framework [3]. The Pathways Framework and

Feedback Framework can be used to assess the plausible risks of maladaptation. Moreover, unlike the Pathways Framework and Feedback Framework, the Precautionary Framework and Assessment Framework can be used to prevent maladaptation in the initial planning stage of adaptation.

The Precautionary Framework and Assessment Framework provide concrete guidelines and checklists to avoid exacerbating the risks of maladaptation through ex ante measurement. However, these frameworks are unsuitable for screening the maladaptation caused by implemented adaptation measures. This phenomenon was demonstrated by Magnan et al. [13], who stated that “maladaptation, however, is difficult to quantify because of the qualitative nature of maladaptation indicators, making it difficult to determine a precise way to measure it.”

The Feedback Framework [11] is a novel and valuable assessment structure based on the definition of maladaptation proposed by Barnett and O’Neill [3]. It considers spatiotemporal effects for classifying the feedback mechanisms of maladaptation. This framework is useful for identifying the progress of adaptation initiatives and the entities negatively affected by an adaptation through three mechanisms of maladaptation: (1) shifting vulnerability, (2) rebounding vulnerability, and (3) eroding sustainable development. The first mechanism is related to adaptation measures that increase vulnerability for one or more external actors in the short or long term. The second mechanism is related to adaptation measures that increase climate vulnerability for implementing actors in the short or long term. Finally, the third mechanism is related to the effects of increased greenhouse gas emissions on environmental, social, and economic factors. Using the Feedback Framework to capture the vulnerability caused by ineffective adaptation or maladaptation is difficult. However, this framework can be used to investigate the maladaptation generated from specific adaptation measures, the interactions of risks among stakeholders, and who or what is affected by maladaptation effects in what manner.

Barnett and O’Neill [3] were among the first researchers to propose a framework for evaluating maladaptation. At least five pathways exist for categorizing maladaptive outcomes. These pathways can be considered initial criteria for screening potential maladaptation [3]. The aforementioned five pathways are mentioned as follows: (1) If adaptation leads to increased emissions, increased climate change would occur. (2) If adaptation actions meet the needs of one sector, system, or group but increase the vulnerability of those most at risk, disproportionate burdening of the most vulnerable would occur. (3) If economic, social, or environmental costs are higher than alternatives, the opportunity costs would be high. (4) If adaptation actions encourage unnecessary dependence on others, stimulate rent-seeking behavior, or penalize early actors, the incentives to adapt would decline. (5) If adaptation actions commit institutions and significant amounts of capital to trajectories that are difficult to change in the future, path dependency would occur. According to the literature reviewed in this study, the Pathways Framework is typically used to describe the outcomes of maladaptation. This framework recognizes the need to consider the effects of adaptations on spatiotemporal scales; however, the reviewed studies conducted ex post assessments and obtained feedback experience on a case-by-case basis.

Among the reviewed social science studies (n = 50), 28% used the Pathways Framework, probably because the Pathways Framework is advocated in AR5 and other frameworks. The most important property of the Pathways Framework is that it provides concrete scenarios of negative adaptation outcomes, which are widely used to assess and explain the circumstances of maladaptation. Other frameworks are relatively new and do not examine the risks of maladaptation but focus on minimizing the risks of maladaptation in advance. These frameworks had fewer citations than the Pathways Framework did in the reviewed social science studies. None of the reviewed spatial modeling studies adopted any framework. A main reason for this phenomenon is that research on maladaptation remains in its infancy. Disciplines of spatial modeling science have not yet been incorporated into the field of climate change adaptation [2].

Maladaptation must be analyzed in terms of the response process on spatiotemporal scales [13]. However, high uncertainty exists within the adaptation process. Societies may be affected by various risks of maladaptation over different timeframes [3,75]. The vulnerability also varies in different periods due to the changing climate and maladaptation. Current discussions on maladaptation mostly focus on ex post evaluation. However, Magnan et al. [13] argued that climate change is a type of continuous variance and that maladaptive risk should be avoided before adaptation measures are implemented. Maladaptation exacerbates vulnerability; thus, identifying maladaptive risks is difficult in the initial stage of adaptation planning. Juhola et al. [11] suggested that the risk of maladaptation can be investigated by predicting the ex post results of adaptation initiatives.

The assessment frameworks adopted in the reviewed studies are suitable for analyzing specific climate risks. However, maladaptation must be considered within a comprehensive risk framework [50]. Maladaptive risks arise from initial climatic risks and increase vulnerability due to risk dynamics and substitution. This study preliminarily proposes the following dynamic characteristics of maladaptive risk to capture risk exhibition:

(a) Risk substitution: Risk substitution refers to actions that decrease the exposure of groups to one risk but increase their vulnerability to other risks. Thus, the original risk may decrease but new risks are generated.

(b) Risk transfer: Risk transfer refers to actions that do not decrease the overall risk but transfer it across different spaces. An adaptation initiative is considered maladaptation if it shifts risks existing in one space to other spaces. Risk transfer results in a vulnerability being relocated rather than reduced [12].

A lack of integrated studies to analyze the circumstance since that adapted specific climate risk but increasing original or inducing other risks. The aforementioned two dynamic characteristics of maladaptive risk are a convergence of spatiotemporal scales and should be basic elements of maladaptive risk assessment.

Various difficulties exist in quantifying maladaptive risks, such as the ambiguity of spatiotemporal scales, lack of risk thresholds, and spatial exhibition of various maladaptive risks. Existing spatial assessment techniques are unable to link the basic maladaptation theory with the four evaluation frameworks used in the reviewed studies. Information from multiple disciplines must be integrated for designing suitable adaptation initiatives; otherwise, the likelihood of implementing maladaptive initiatives and decisions would increase [76]. The present study emphasizes that integrating relevant spatial modeling techniques and existing evaluation frameworks for maladaptation is crucial for accurate maladaptive risk assessment.

9. Maladaptive Evaluation Pathways

Climate change causes pressures on land [77] because adaptation to climate change could be a potential driver force of spatial land change. For instance, if people decide to out-migrate to adapt to climate variability and change, increased land changes are likely to occur. Such changes may result in the loss of ecosystem goods and services in the medium-to-long term [78]. Adaptation and environmental change are likely to influence each other and developing policies for minimizing the unintended outcomes caused by implemented adaptation initiatives is crucial [78]. In addition, the effects of adaptation initiatives vary with space [79]. The spatial modeling of land changes is a fundamental step in adaptation planning because such modeling can indicate how to reduce the effects of climate change and avoid maladaptation [63]. Spatial land management can play a crucial role in mitigating emissions and be used to store carbon at a relatively low cost [77].

The development of an adaptation initiative is an iterative continuous learning process. This study constructed maladaptation evaluation pathways (Figure 15) that combine spatial modeling and theoretical maladaptation frameworks to investigate maladaptive risk. These pathways include climate scenarios, adaptation initiative scenarios, spatial land modeling scenarios, the dynamic characteristics of maladaptive risk, functions for increasing vulnerability, the affected entity, and pathways of maladaptation.

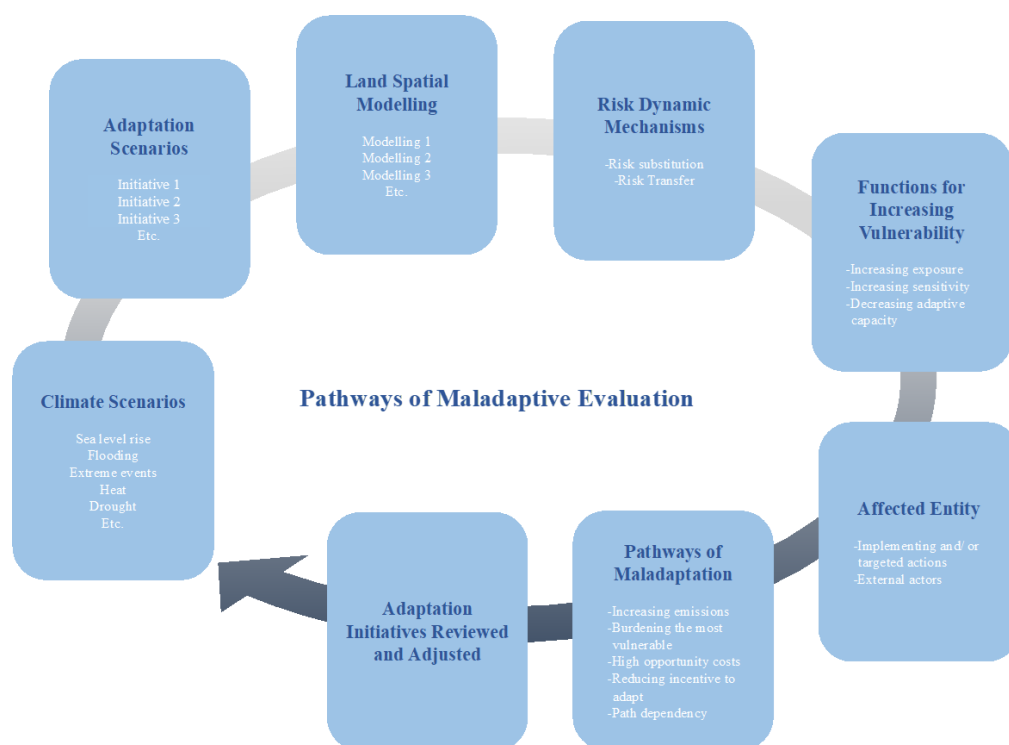


Figure 15. Developed maladaptive evaluation pathways.

An adaptation initiative can increase risk and vulnerability in the long term [41]. The effectiveness of adaptation is dependent on how the future unfolds and can be assessed through scenario modeling. The modeling of different climate and adaptation scenarios can reduce uncertainty and provide proactive mechanisms for managing changing circumstances. For instance, Poussin et al. [80] examined the effectiveness of selected adaptation initiatives for flood risk reduction at the river Meuse by comparing different adaptation and flood risk scenarios. Gersonius et al. [28] conducted a case study that indicated that maladaptive decisions may result if uncertainty and flood risk flexibility are not considered in economic analysis and coastal management strategies. Planning long-term strategies according to the knowledge and experiences of recent climatic events is unreasonable [81]. Therefore, the most important aspects of adaptation planning involve systematically linking present challenges with future climate risks and examining the various timeframes of maladaptive risk [12]. In addition, to prevent adaptation initiatives from becoming maladaptation, adaptation planners may select multiple adaptation initiatives and consider several possible future climate scenarios to predict plausible medium-to-long-term situations. They may also examine the maladaptive and climate risks of implemented adaptation initiatives.

Stakeholders may have varying and conflicting considerations in adaptation initiatives. Spatial modeling can be used to predict future situations and to coordinate the activities of multiple stakeholders for producing long-term benefits [63]. Thus, the effect of climatic events on stakeholders can be determined. Climatic events may become disasters due to inadequate or inappropriate human intervention. Spatial land change is driven by a complex combination of natural, social, and economic factors [77], and adaptation to climate change is a vital driving force of spatial land change. Most adaptation studies focus on conceptual approaches for investigating vulnerability, climate risk, and adaptive capacity but do not consider stakeholders' adaptation preferences [2]. The present study advocates that capturing the preferences of stakeholders is essential for identifying plausible future maladaptive risks. Thus, for identifying maladaptive risks, real perspectives on the selected adaptation initiatives and climate awareness must be collected from adaptation decision

makers and spatial land change prediction must be performed. According to Magnan [12], if an adaptation initiative increases a system's vulnerability to climate impacts in both the present and future, it may be considered maladaptation.

Numerous studies have focused on adaptation issues, and future studies on these issues should consider the use of spatial analysis and planning [63]. Spatial analysis is a key tool in adaptation planning. It can be used to predict the effects of climate change and indicate the effects of adaptation at local scales. Through appropriate modeling, the effects of various adaptation initiatives can be quantified and compared by calculating the area of land change. Spatial land changes can be considered actually or potentially beneficial in adapting to climate change or may be considered maladaptation if they cause environmental degradation [82]. For quantification with spatial analysis tools, the maladaptive risks can be divided as risk transfer and risk substitution. This study suggests that a spectrum of climate and adaptation scenarios for future timeframes should be considered for identifying adaptation initiatives with the highest robustness (Mitter et al. [83] defined robust strategies as low-regret strategies, that is, strategies that are beneficial even without significant changes in climatic conditions and can be reversed due to their low cost of maladaptation) for various plausible future scenarios.

Spatial analysis involves integrating important factors across various spatiotemporal and governance scales. It can be used to simulate and predict plausible scenarios for implemented adaptation measures [84]. Spatial analysis provides opportunities to consider, assess, and select alternative future scenarios. It also facilitates the management and consideration of competing interests. The objective of using spatial modeling is to provide feedback regarding a predicted effect of a future state to the local environment and different stakeholders. The feedback mechanism and affected entity in the Feedback Framework are helpful for identifying conflicting interests among sectors or stakeholders from the spatial land change and risk distribution for the initial adaptation preferences and climate scenarios. After the identification of the conflicting interests, one can examine whether adaptation initiatives for a particular sector (or stakeholder) may drive maladaptation in other sectors (stakeholders) [85].

Proposed adaptation initiatives can be tested for maladaptation by examining the long-term effects of an implementation path [51]. Spatiotemporal scales cannot be identified using the original Pathway Framework, which enables outcome-oriented evaluation. However, the framework with concrete categories of maladaptive risks and suited for illustrating the specific states of risk when combined with spatiotemporal predicted modeling. This study compared the evaluation thresholds for different climate scenarios, socioeconomic conditions, and spatiotemporal scales. Maladaptation includes potential social and behavioral influences. For example, in Bihar, India, embankments were constructed to constrain rivers to their watercourses; however, when these embankments are breached, large areas of land are inundated with water that does not quickly return to river channels [16]. The maladaptive risks that may arise in different adaptation initiative scenarios at different timeframes and scopes should be explored.

The constructed maladaptation evaluation pathways are suitable for evaluating planned adaptation initiatives. A main reason for this phenomenon is that not all adaptation initiatives involve spatial allocation; thus, spatial analysis need not be conducted for some adaptation initiatives [79]. For example, in Australia, adopting refrigerant air conditioners may be a valid adaptation response to climate-related increases in temperature; however, this measure is a poor response from an electricity network perspective because it increases peak demand, network costs, carbon dioxide emissions, and finally, electricity prices, which disproportionately affects low-income residents [86]. According to Juhola et al. [11], when analyzing maladaptive risk, autonomous adaptation initiatives should not be considered. However, adaptation is affected by changes in the behaviors or coping initiatives of stakeholders due to risk perception or past experiences of climate change. Not all autonomous adaptations have positive consequences [87]; some autonomous adaptations may cause negative outcomes and maladaptive states. This study advocates that

one should focus on not only planned adaptation initiatives but also maladaptive risks of autonomous adaptation initiatives in the evaluation of maladaptive risks because autonomous and planned initiatives can affect each other. Maladaptive risk depends on the nature of the implemented adaptive initiatives, if any. The mechanisms and pathways of maladaptation that may undermine the adaptive capacity of sectors or stakeholders must be determined by investigating the cause-and-effect relationships between adaptation initiatives and implementing (or targeted) or external actors.

Finally, this study recommends that spatial modeling, dynamic mechanisms of maladaptive risk, the Feedback Framework [11] and the Pathways Framework [3] must be integrated as analytical bases for determining the mechanisms and pathways of maladaptation. By combining the Feedback Framework and Pathway Framework and using social science investigation methods, one can explore the interactions among the risks for stakeholders (winners and losers) and determine who or what was affected by maladaptation effects in what manner.

10. Conclusions and Further Suggestions

This study found that research on maladaptation to climate change is still in its infancy; however, the amount of research on this topic is increasing quickly. The concept of maladaptation encapsulates the relationship between coping and adaptation and conveys the potential tradeoffs between short- and long-term considerations when addressing climate risks. Short-term gains may lead to increased vulnerability in the medium and long terms. Understanding how climate change and climate initiatives may increase vulnerability is crucial. This study advocates the integration of spatial modeling, dynamic mechanisms of maladaptive risk, the Feedback Framework, and the Pathways Framework as analytical bases for determining the risk mechanisms and pathways of maladaptation.

The results of the reviewed studies indicate that maladaptive risk exists in both developed and developing countries. Many of the reviewed studies used multiple methods to collect and analyze data. The reviewed social science studies mainly performed qualitative analysis, whereas the reviewed spatial modeling studies mainly performed quantitative analysis. Many studies considered multiple climate issues. The results of the reviewed studies indicate that an interdisciplinary perspective must be adopted to reduce the possibility of adopting maladaptive initiatives and decisions.

Climate uncertainties can cause maladaptation. The appropriate spatial modeling of flexible climate and adaptation scenarios can minimize the risk of maladaptation. To analyze the maladaptive risk, this study proposes two dynamic characteristics of maladaptive risk for capturing risk exhibition: risk substitution and risk transfer. This study also recommends that maladaptive risk assessment should be conducted on the basis of the Feedback Framework and Pathway Framework and social science investigation methods should be used to examine the interactions among the risks for stakeholders (winners and losers) and determine who or what was affected by maladaptation effects in what manner. Thus, the maladaptive risks for different adaptation scenarios on different spatial–temporal scales can be predicted and compared.

Adaptation planning is a decision-making process that involves considering current and future climate information [88]; however, planned adaptation initiatives may meet past and present conditions of development but may be unable to cope with future needs. Adaptation directly affects vulnerability, and environmental change reflects the impact of human activities. Therefore, spatial land change simulation can be used not only as an adaptation tool for planning to reduce the negative impact of climate change, but also to predict the negative impact of planned future adaptation initiatives on society and the environment. The incorporation of land spatial modeling into climate change adaptation is a recent phenomenon, and different disciplines should be integrated in climate change adaptation research. This study mainly advocates considering the predicted spatial land changes for future climate change scenarios and different adaptation initiatives to explore how maladaptive risks can be avoided or reduced and thus determine which adaptation

initiatives are ideal at different spatiotemporal scales. Pathways for maladaptive evaluation were developed in this study. The results of land spatial modeling can be incorporated with social data to alter or adjust adaptation strategies and compare the benefits and risks of different adaptation initiatives.

Adaptation initiatives enable vulnerability to be minimized but may have unintended maladaptive effects in the long term. Inappropriately framed adaptation initiatives have high maladaptive risks. Quantifying and comparing the benefits of adaptation initiatives and the environmental and socioeconomic effects of maladaptation are difficult tasks. If the spatiotemporal changes caused by adaptation and their effects on socioecological systems can be evaluated in advance at the adaptation planning stage, appropriate decisions can be taken to increase the adaptation efficacy and reduce maladaptive risk [30]. Finally, an increased number of experimental studies should be conducted on land spatial modeling to better incorporate such modeling into decision-making related to adaptation initiatives, identify maladaptive risks, and reduce uncertainties.

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