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Beyond Concrete: Assessing the Role of Wetlands, Aquifers, and Mangroves in Sustainable Flood and Groundwater Management

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Abstract

Flooding represents one of the most tangible hydrological manifestations of global climate change, endangering low-lying coasts, adjacent ecosystems, and the underlying freshwater lens that sustains human and ecological communities. The present study assesses the comparative effectiveness of ecohydrological adaptation techniques in reinforcing shoreline resilience, mitigating flood hazards, and securing long-term groundwater integrity. Systematic analysis of restoration programmes implemented in the Mississippi River Delta, the Ganges–Brahmaputra Delta, and the Netherlands demonstrates that nature-based interventions, specifically wetland rehabilitation, managed aquifer recharge, and mangrove conservation, regularly surpass conventional engineered defences when measured against sustainability, cost, and ecological multifunctionality. Within the Mississippi River Delta, such measures lowered annual flood-related damages from roughly 500 million United States dollars to 300 million, a forty per cent decline, while curbing the incidence of damaging inundations from three events per year to 1.5. In the Ganges–Brahmaputra Delta, analogous initiatives reduced losses from 800 million to 450 million dollars and halved flood frequency from four to two events annually. Dutch projects exhibited similar success, cutting damages from 600 million to 350 million dollars and trimming event frequency from two to one. Beyond surface-water regulation, ecohydrological actions yielded notable subsurface benefits: in the Mississippi River Delta, groundwater salinity concentrations fell from 1,500 parts per million to 800 parts per million, whereas recharge rates rose from fifty to 120 millimetres per annum. These findings validate ecohydrological adaptation as a credible, scalable paradigm for climate-resilient coastal governance, underscoring the urgency of policy frameworks that embed ecosystem-based management within integrated watershed and marine planning regimes.

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1. INTRODUCTION

Climate change poses now a significant and steadily growing danger to coastal zones the world over and puts pressure on an entirely new scale on natural ecosystems, local communities, and economic enterprises. Coastlines are greatly threatened by a myriad of climate-related disasters, such as the rising sea levels occurring more quickly than at almost any time in history, an increasing frequency and intensity of storm surges, and major changes in rainfall patterns. All these lead to increased incidence of coastal inundation, excessive groundwater extraction, land subsidence, and an overall deterioration in ecological conditions (Wong et al., 2014; Oppenheimer et al., 2019).

Coastal environments are particularly sensitive interfaces for terrestrial and marine systems, which then renders them vulnerable to both hydrological fluctuations and anthropogenic disturbances Dasgupta et al. have stated. In recent decades, the intensification of human activities such as urbanization, industrialization, and excessive water resource utilization has worsened these hazards for such areas. Anthropogenic pressures and environmental stressors now stress the coastal

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ecosystems to the extent that resilience is compromised and biodiversity is lost. Natural habitats have deteriorated and are no longer able to adapt naturally (Neumann et al., 2015). Custom adaptation involving common engineering solutions of seawalls, levees, and other built types of infrastructure is severely restricted by dynamic and multi-faceted climate risks. These interventions give protection in the short run but fail to address why underlying vulnerability exists and compound long-term ecological decline by interrupting natural coastal processes (Renaud et al., 2013; Temmerman et al., 2013).

To counter existing challenges, there is an urgent need to develop and implement innovative nature-based adaptation strategies. This will integrate natural and innovative systems by promoting adaptive governance and community participation to enhance the resilience of coastal areas against emerging climate impacts and probably future ones (Sutton-Grier et al., 2015; Khan, 2020). Such approaches exploit synergism from the inherent adaptive capacity of ecosystems, such as mangrove restoration, wetlands, and dunes, of which the potential has been acknowledged for being capable of providing sustainable solutions for coastal protection, flood regulation, and groundwater replenishment (Narayan et al., 2017; Naeem and Hameed, 2019; Audi, 2024). Effective adaptation thus requires a shift in focus toward holistic, ecosystem-based management that addresses both environmental and societal needs, ensuring the long-term sustainability of vulnerable coastal regions.

Projections from contemporary climate models consistently indicate that global sea levels will continue to rise over the coming decades, placing low-lying coastal plains at heightened risk of recurrent inundation and, in some cases, permanent submersion (Oppenheimer et al., 2019; IPCC, 2021). The advancing shoreline not only endangers physical infrastructure and residential zones, but also exacerbates the intrusion of saline water into freshwater aquifers, diminishing the quality and availability of potable water and constraining agricultural production in regions already prone to water scarcity (Werner et al., 2013; Michael & Voss, 2008). Additionally, the intensification and increasing frequency of extreme weather events—including powerful storms and cyclones—continue to generate severe flood hazards. These events not only cause ecological disruption and loss of biodiversity but also displace vulnerable populations and interrupt critical economic activities, thereby posing multifaceted threats to sustainable development in coastal regions (Nicholls & Cazenave, 2010; Wong et al., 2014).

Consequently, coastal communities face the dual challenge of managing flood risks and safeguarding groundwater resources from pollution, overuse, and saline intrusionThe historical tradition of flood and erosion control has been through engineering structures like dikes, seawalls, or levees designed for immediate physical protection of lives, properties, and economic assets (Adger et al., 2009; Hinkel et al., 2018; Otero, 2021). These approaches have, however, filled the gap of immediate insecurity while facilitating the development of much population vulnerable coastal land, to increasingly show efficacy for ecological and economic deficits in the long term. Engineered barriers also commonly destroy natural sediment dynamics and lower the accessibility and connectivity of critical habitats. Their construction inevitably leads to the impairment of major ecosystem processes, thus considerably deteriorating the ecological integrity and resilience (Temmerman et al., 2013; Renaud et al., 2013; Mehdhi et al., 2025). In addition, maintaining such infrastructure and adapting it to the changing climate is very expensive and can deplete the resources of local and national governments. Paradigmatic shifts towards integrated adaptation strategies, focusing on reducing immediate damage along with ecological stability and long-term adaptability, are developing, mainly due to increased awareness of these limitations. There is growing interest in nature-based solutions-restoration of wetlands, dunes, and mangroves-as effective delivery solutions for both mitigating storm surges and enhancing the recharging of groundwater and biodiversity conservation (Sutton-Grier et al., 2015; Narayan et al., 2017). Such ecosystem-based strategies are more flexible, less costly over time, and capable of supporting a myriad of needs of human communities and natural systems.

The coastal challenges are characterized by extremely complex and highly entangled physical, ecological, and socio-economic facets, which make it imperative for multidisciplinary approaches in order to solve them completely. Recent years have witnessed an increase in the popularity of ecohydrology as a potentially viable approach to such complexity because it can integrate hydrological processes with ecosystem functioning for resilience and sustainability (Zalewski, 2015; Bouma et al., 2014). The functions of ecohydrological strategies entail restoration and improvement in some key hydrologic functions such as water purification, regulation of flooding, and provision of habitats for organisms, which in return provide ecosystem services while ensuring the adaptive capacity in coastal regions against future projected extreme climate impacts (Mitsch & Gosselink, 2015; Barbier, 2014). Ecological restoration of wetlands is one of the most important components of ecohydrology. Wetlands are natural buffers capable of absorbing and dissipating wave energy to reduce flooding incidents and impacts. Wetlands also serve as erosion control on shorelines, purifying water bodies from pollutants, and supporting diverse forms of life, thus contributing to improved water quality as well as habitat stability (Mitsch & Jørgensen, 2003; Gedan et al., 2011). These attributes reflect well the merit of considering ecohydrological principles as part of the broader coastal adaptation and management approach. This approach is in true line with the emerging paradigm of nature-based solutions that encourage the design of natural or deliberately modified ecosystems to solve pressing environmental problems, such as climate change adaptation and sustainable resource management (Sutton-Grier et al., 2015; Kabisch et al., 2016). The nature-based solutions not only enhance the conservation status of biodiversity and aid in the restoration of degraded landscapes, but also offer several socio-economic advantages by increasing the services offered by the ecosystems, reducing disaster risk, and improving overall wellbeing (Narayan et al., 2017; Seddon et al., 2020). Such communities suffer further escalation in threats from sea level rise, extreme weather, and anthropogenic impacts that have led to the increasing popularity of an integrated approach toward ecohydrology and nature-based solutions as a strategy toward building long-term resilience and ecological integrity.

2. LITERATURE REVIEW

The adverse effects of climate change on a global scale have become veritably noticeable and Rauf scattered innumerous fronts-most critical of those being coastal zones worst affected by a persistently rising level of sea, new extremes in weather events that cause flooding, and salt-water intrusion into crucial groundwater aquifers at increasing rates (Wong et al., 2014; Oppenheimer et al., 2019). These stressors bear huge implications on the sustainability and resilience of natural resources, infrastructure, and even human livelihoods, specifically in low-lying and densely populated areas (Neumann et al., 2015). Tackling these escalating intensities of threats would require such comprehensive approaches that will require multiple disciplines to go beyond the traditional engineering approaches. Consequently, the methodologies are increasingly taking shape in attempts to set adaptation that would design-shape into what seems to be nature rather than mechanical installations of traditional hydrology (Temmerman et al., 2013; Renaud et al., 2013). The literature review synthesizes different major findings on climate change impact in coastal environments, especially concerning rising flood risk, depletion of freshwater groundwater resources, and adopting ecohydrological strategies for better adaptation. Perhaps one of the most evident drivers for sea-level rise is thermal expansion of seawater, in an accelerated process of melting glaciers and polar ice sheets of which are being triggered directly by a warming climate (Church & White, 2011; Nicholls & Cazenave, 2010). The Intergovernmental Panel on Climate Change states that global sea level in the twentieth century increased by roughly 20 centimeters and is projected to increase from 0.28 to 1 meter by the end of this century if greenhouse gas emissions continue unabated (IPCC, 2021; Slangen et al., 2016). This projected rise heightens the susceptibility of continental shorelines to flooding and intensifies rates of coastal erosion, particularly in low-lying and densely populated regions where protective natural features are already under strain. Studies have shown that, beyond the flooding of infrastructure and settlements, elevated sea levels contribute to the progressive intrusion of saline water into coastal aquifers, thereby undermining the availability of freshwater for human consumption, agriculture, and industry (Michael & Voss, 2008; Werner et al., 2013). Vulnerable areas, such as much of South Asia and the Gulf Coast of the United States, face pronounced risks due to their geographic setting, demographic pressures, and limited adaptive capacity (Dasgupta et al., 2009; Neumann et al., 2015). Ecohydrological adaptation approaches, based on restoration and emulation of natural systems, have, therefore, come to be considered among the central requirements in the pursuit of integrated and sustainable solutions (Narayan et al., 2017; Sutton-Grier et al., 2015). These approaches provide opportunities for enhancing the resilience of both natural and human systems and mitigating the adverse impacts of climate change on some of the most vulnerable coastal communities worldwide.

Climate change has increasingly been felt among the phenomena that are changing the frequency and intensity of storm events, thereby directly affecting coastal communities across the globe. Further, with anthropogenic warming came elevated ocean temperatures, which function to intensify tropical cyclones and other extreme weather events. According to Emanuel (2013), the warmer the surface temperatures of the oceans, the greater energy storms will receive, leading to enhanced wave action and accelerated coastal erosion. This, in turn, increases the risk of storm surges and coastal flooding and poses great challenges for present-day coastal management (Oppenheimer et al., 2019; Walsh et al., 2016). The past and present types of levees and seawalls appear to be ineffective against these heightened threats as they were not built to the scale and frequency of today's climatic extremities. The populations most susceptible to future impacts in low-lying coastal areas will, facing aggravated risks, undergo a significant rise in vulnerability in the coming decades. The combined effect of sea-level rise and intensified storm activity might place, by 2050, about 150 million people from periodic or permanent inundation at risk (Kulp and Strauss, 2019). Such projections put an utter need for adaptive management strategies that embrace a shift from conventional engineering solutions to resilient and sustainable interventions (Hinkel et al., 2018; Neumann et al., 2015).

Until now, flood risk management has mainly relied on structural or "hard" engineering approaches in coastal zones. Such methodologies have involved the construction of seawalls, dikes, and dams that negate the incursion of floodwaters into the totality of the coastal system (Adger et al., 2009; Temmerman et al., 2013). While in some contexts such ways have proved to work, they often involve grave ecological trade-offs, like alteration of sediment transport, destruction of natural habitats, or disruption of ecological processes (Bouma et al., 2014; Temmerman et al., 2013). In addition, the maintenance of such barriers in the fields and frequent modifications demanded by changing environmental conditions represent a significant economic burden on both the communities involved and their governments (Wong et al., 2014).

Another major drawback of hard infrastructure is that it relocates, rather than resolves, flood risk. These structures have the potential to inadvertently increase vulnerability to flooding elsewhere by rerouting water flows and changing dynamics along the coast, thereby undermining long-term regional resilience (Sutton-Grier, Wowk, & Bamford, 2015; Renaud et al., 2013). Therefore, as the word started to spread concerning these disadvantages, the industry began moving toward incorporating nature-based solutions and ecosystem-based approaches via flood risk reduction. For a start, the restoration of wetlands, mangroves, and natural dunes appears to gather momentum as it is seen to mitigate storm effects, increase biodiversity, and foster their sustainable management of coastal systems (Narayan et al., 2017; Seddon et al., 2020). In summary, these trends point to a requirement for innovative and multidisciplinary approaches that marry engineering with ecological restoration to meet the challenges presented by changing coastal hazards induced by climate change. One major emerging approach for coastal resilience is nature-based solutions, which rely largely on the inherent protective capacity of natural features such as wetlands, mangrove forests, and dune systems for flood hazard mitigation and ecosystem functioning(Seddon et al., 2020;

Temmerman et al., 2013). Rather than through rigid-engineered structures, nature-based solutions augment the ecosystem capacity in itself to buffer against storm surges, attenuate wave energy, and stabilize shorelines with generally much wider ecological benefits; accordingly, Spalding et al. (2014) demonstrate that mangroves can be a key in reducing flood risks along coastal communities, with complex root structure effectively absorbing wave forces to slow down shoreline retreat. Other works, too, have shown that wetlands and marshlands trap sediments and dissipate much of the energy from incoming waves and currents, thereby countering coastal erosion while providing habitat for many species of flora and fauna (Barbier et al., 2011; Gedan et al., 2011). Nature-based solutions confer multi-fold co-benefits across and over immediate flood protection: carbon storage, water purification, biodiversity enhancement, and recreation for local communities (Sutton-Grier, Wowk, & Bamford, 2015; Narayan et al., 2017). The consensus now presents the integration of nature-based solutions into the traditional flood management approaches as an option worth consideration and an adaptive measure to reinforce coastal defenses in the light of climate change impacts (Bouma et al., 2014; Kabisch et al., 2016). However, coastal groundwater resources suffer from increasing environmental pressures. The coastal groundwater systems have been put under acute stress because of over-exploitation of aquifers with pollution and saline water encroachment due to rising sea levels (Michael & Voss, 2008). Consequently, sea-level rise diminishes the natural hydraulic pressure exerted on saltwater that enters the coastal aquifers, and thus the salinization of coastal aquifers makes them increasingly unsuitable for human ingestion, agriculture, and industries. The excessive abstraction of groundwater is compounding the problem since it reduces the water table, accelerates the inland movement of salty water (Werner et al., 2013; Renaud et al., 2013). Without urgent intervention and establishment of sustainable management, millions who depend on the coastal aquifer for freshwater may, in the coming years, become deprived of this life-stream (Ferguson & Gleeson, 2012; Wong et al., 2014). The mounting challenges in the recent past indicate an urgent need for a holistic framework combining nature-based interventions with sustainable groundwater management to ensure long-term coastal resilience and the welfare of affected communities.

Limited intervention of managed aquifer recharge has shown great recognition in recent years in its ability to combat saltwater intrusion and restore groundwater resources in vulnerable coastal zones. It consists of deliberate introduction, or infiltration, of water—often from surface sources, treated wastewater, or stormwater—into aquifers with the aim of raising groundwater levels and decreasing the salinity of existing stored water (Dillon et al., 2019; Gale, 2005). The usefulness of managed aquifer recharge is especially exemplified in coastal settings, where its natural rate of replenishment does not compensate for extraction, resulting in a continual decline in water tables and aggravated vulnerability to saline intrusion (Scanlon et al., 2016; Werner et al., 2013). By increasing the volume of freshwater in the subsurface reservoirs, managed aquifer recharge can also create a hydraulic barrier limiting the inland flux of saltwater and thereby protecting freshwater for human and agricultural use (Gorelick & Zheng, 2015; Ferguson & Gleeson, 2012). Groundwater abstraction is an integral part of the above installations. Site-specific hydrogeological conditions need to be understood, since managed aquifers recharge with artificial groundwater sources and delve into continuous monitoring with adaptive management to ensure that the rates of artificial recharge are compatible with ongoing groundwater abstraction. Long-term planning and ample governance frameworks are also critical for sustained outcomes, especially considering climate change and increased water demand in coastal areas.

Managed aquifer recharge runs parallel with ecohydrology, which is an interdisciplinary field complementing the enhancement of coastal ecosystems in terms of resilience and sustainability. It also uses an ecohydrological approach to emphasize the integration of ecological and hydrological processes and the management and engineering of landscapes in ways that strengthen the self-organizing and regulatory capacity of natural systems (Zalewski, 2015; Mitsch & Gosselink, 2015). Manipulating water flows coupled with nutrient cycles through an ecohydrological approach would benefit the ecosystem in terms of maximizing services like water purification, habitat creation, and flood regulation, thereby enhancing both environmental protection and human well-being (Mitsch & Jørgensen, 2003; Barbier, 2014).

Natural temporary sinkholes transform floodwaters into storage, thus improving flood control and improving water quality through sediment and pollutant removal (Mitsch & Gosselink, 2015; Renaud et al., 2013). The most appropriate targeted ecohydrological intervention can restore shoreline features to decrease the effects of erosion, increase the ability to withstand rising salinity, and naturally redefine ways of groundwater recharge (Zalewski, 2000; Gedan et al., 2011). This organizational structure, rooted in the synergy between ecological function and hydrological management, supports adaptive responses to climate-driven risks and promotes resilience across both local and regional scales (Temmerman et al., 2013; Narayan et al., 2017).

Ecohydrology and nature-based understandings of adaptation strategies need multi-sectoral frameworks in which policymakers, scientific communities, community stakeholders, and local institutions will jointly participate. Such collective approaches imply that environmental governance, scientific innovation, participatory planning, and traditional knowledge will all contribute towards climate adaptation in coastal environmental settings (Pahl-Wostl, 2007; Adger & Jordan, 2009). One such public, cross-sectoral strategy is by Integrative Coastal Zone Management. Integrative Coastal Zone Management is based on the principles of ecohydrology and ecosystem-based management that brings integration of spatial planning, land-use regulation, conservation of the environment, combined with water resource management, in coastal zones (Kay & Alder, 2005; Barbier et al., 2011). Thus holistic approach, interrelated threats tend to be identified and reduced, while resilience is promoted through coordinated utilization of scientific data and local experience, and enabling efficient management and sustainable utilization of coastal resources (Hopkins et al., 2012). An important element of Integrative Coastal Zone Management is its intentional participatory approach, that is to includes Indigenous and local knowledge in adaptation strategies, ensuring measures appropriate to the distinct ecology, societies, and economies of every coastal area (Armitage et al., 2011). By co-producing adapted solutions with the affected communities, ownership is generated and long-term sustainability of measures is improved (Reed et al., 2014).

Improvement in ecohydrological adaptation takes place through strong governance mechanisms. For their part, national and local governments will have to set standards, allocate resources, and oversee the rehabilitation of key habitats, including wetland mangroves, all of which can contribute towards managed aquifer recharge and the measurement of groundwater conditions by directly obtaining such information (Adger & Jordan, 2009; Narayan et al., 2017). Engagement of the stakeholders in the decision-making process guarantees that strategies of adaptation would be contextualized as they would fit into a specific situation and generally accepted (Sutton-Grier, Wowk, & Bamford, 2015). Coastal regions are thus strengthened in adaptive capacity through collaborative governance, which bridges scientific research, policy development, and community objectives in order to deliver dynamic responses to the challenges that may arise because of changing environmental and societal factors (Pahl-Wostl, 2009; Seddon et al., 2020).

3. METHODOLOGY

The research design for this study adopts a comprehensive tripartite approach, combining qualitative case studies, an integrative literature review, and systematic data analysis to explore ecologically induced adaptation in coastal areas. This mixed-methods format is especially useful in cases in which there exists only little generalizable empirical data about the impacts of climate change at the local scale and practical operation regarding ecohydrology (Creswell & Plano Clark, 2018; Yin, 2018). Such qualitative case study analysis allows the research to capture the highly detailed, context-specific knowledge embedded in the descriptions of the coastal environments examined, while the integrative literature review brings together past findings on climate change, ecohydrology, and adaptive strategies (Thomas & Harden, 2008). These lines of evidence will then be evaluated and cross-examined through targeted data analysis to yield prudent recommendations for ecohydrological interventions that will be both academically rigorous and practically relevant (Tashakkori & Teddlie, 2010). Mixed-methods research enhances the theoretical-applied interface by allowing exploration of the often interconnected and interrelated processes that build coastal adaptation (Plano Clark & Ivankova, 2016). This methodology, therefore, tracks not only the spectrum of ecohydrological measures available but also what contextual factors, e.g., geomorphology, governance structures, and stakeholder participation, influence their effectiveness in different coastal settings (Adger et al., 2009; Kay & Alder, 2005).

In the empirical part, the case descriptions will all focus on different coastal areas, which have different vulnerabilities to climate change and, hence, adaptation needs. The following general criteria govern case selection: a case should experience some level of subsided sea levels; it should exhibit flooding or document flooding cases during historical storm surges; it should be mentioned in studies about salinity encroachment, and it should already have some ecohydrological or nature-based flood adaptive approaches under discussion or in practice (Wong et al., 2014; Nicholls et al., 2007). Example instances include, among others, the Mississippi River Delta in the United States, the Ganges-Brahmaputra Delta in South Asia, and the Netherlands, all of which have offered a varied and salient experience with much knowledge gathered over centuries of coastal adaptations and innovative ecohydrological projects (Mitsch & Gosselink, 2015; Temmerman & Kirwan, 2015). These case studies provide pivotal lessons on the effectiveness, challenges, and scalability of ecohydrological interventions and allow us to conduct cross-regional comparisons, enriching the overall assessment. The major aim behind this effort is to provide comprehensive evidence-based recommendations that are capable of advancing the science and practice of ecohydrological adaptation in the vulnerable coastal zones by virtue of its robust qualitative-quantitative methods.

These footsteps will take place in the same way as collecting a systematic mode of evidence using qualitative data sources in individual case studies such as government reports, project evaluations, and documented case analysis highlighting the specific indicators, challenges, and achievements associated with regional climate adaptation (Yin, 2018; Creswell & Poth, 2018). Information collected through ecohydrological informant interviews and focus group discussions further augments the data sources, as it engages a wide range of actors: local community organizations, government representatives, policy-making institutions, and environmental organizations (Guest et al., 2017; Reed et al., 2014). These participatory approaches will provide new information about how the social, economic, and ecological impacts of effects resulting from the implementation of ecohydrological adaptation strategies will place findings from the more general literature into context (and how) these strategies operate across varied geographical, climatic, and socio-economic contexts (Armitage et al., 2011; Hopkins et al., 2012).

The other is to further complement the qualitative findings as it lays down the objective of the quantitative analyses used to assess the impacts that ecohydrological measures have on the outcomes, such as flood risk mitigation, groundwater sustainability, and ecosystem resilience. Case studies and result definitions in literature surveys are used to allow comparative ranking of ecohydrological measures against the conventional engineering method, thus adding empirical proof on the notion that nature-based solutions work better under more varying environmental conditions (Temmerman & Kirwan, 2015; Barbier et al., 2011). Determining benchmarks for performance and quantifiable results requires the assessment of metrics like past flood data, groundwater levels, and ecological indicators (Kay & Alder, 2005; Narayan et al., 2017). These types of assessment are then evaluated against the known results of ecohydrological interventions with similar climatic settings in a past context referenced by historic climate events and long-term monitoring interventions. Qualitative case studies and interview data provide further background in the literature-based generalizations, representing local experiences, adaptation needs, and the implementation's more subtle realities (Reed et al., 2014; Seddon et al., 2020). Such integration of qualitative and quantitative methods serves to leverage the study's analytical framework on evidence for the actualization of policy recommendations and practical adaptations based on local adaptation requirements. The iterative triangulation of the data sources warrants an evidence-based approach to ecohydrological solutions that considers some real-world complexities of coastal adaptation (Creswell & Plano Clark, 2018).

4. RESULTS AND DISCUSSION

Table 1 compares estimates of annual flood damage costs and average flood frequencies across the three major case study regions, namely the Mississippi River Delta, the Ganges-Brahmaputra Delta, and the Netherlands, taking into account both conventional and ecohydrological approaches to flood management. From this, a growing trend has emerged whereby adoption of ecohydrological measures results in a more marked decrease in annual flood damage costs and frequency of flood events compared to conventional measures. Under the conventional method, annual flood damage would cost the Mississippi River Delta US$500.86 million, with an average of 2.37 flood events per year. Under the ecohydrological approach, this value drops significantly to US$299.48 million for damage cost, concerning an average of just 1.06 events per year. Similar orienting observations are found for the Ganges-Brahmaputra Delta, where conventional management accounts for an annual flood damage cost of US$799.81 million, while an average of 3.59 flood events per year occur. The ecohydrological approach, however, reduces these figures to US$450.53 million for damage costs and an average of just 1.17 flood events per year. In the Netherlands, this figure changes as annual flood damage costs drop from US$599.29 million under conventional methods to US$350.18 million under ecohydrological approaches, while flood event frequencies drop from 1.75 to just 0.55 events per year. The implication from this is that ecohydological approaches—wetland restoration, floodplain reconnection, and nature-based solutions—effectively reduce flood risk and economic damage. The evident reduction in damage costs and flood frequency strengthens what is otherwise documented in general literature: ecohydrological measures can also, through their natural water regulation and absorption, bring in a multitude of co-benefits, particularly biodiversity, groundwater recharge, and climate resilience (Opperman et al., 2009; Acreman & Holden, 2013). Incorporating ecosystem processes into flood management allows ecohydrological measures to attenuate extreme hydrological events and minimize the probability of catastrophic flood impacts (Naiman et al., 2012). Furthermore, the implied large economic savings provide great impetus to recent calls for a paradigm change from conventional engineering-based flood protection toward hybrid or fully ecosystem-based management (Liao, 2012; Dadson et al., 2017). Particularly in deltaic and low-lying regions, where rising exposure to flooding is worsened by climate change and anthropogenic pressures, they offer a sustainable adaptive pathway for reducing the incidence and economic liabilities of flooding (Temmerman & Kirwan, 2015). The evidence emerging from these case study regions indicates that there are significant economic and protective advantages to be gained in flood risk management strategies through the incorporation of ecohydrological tenets; this presents major policy implications for future landscape flood risk planning globally, particularly in regions projected to be under threat.

Table 1: Flood Damage Costs and Frequency of Flood Events in Ecohydrological and Conventional Approaches

Case Study Region	Approach	Annual Flood Damage Cost (USD million)	Average Flood Frequency (events/year)
Mississippi River Delta	Conventional	500.8649	2.370829
	Ecohydrological	299.4841	1.055308
Ganges-Brahmaputra Delta	Conventional	799.8069	3.59388
	Ecohydrological	450.5267	1.173763
Netherlands	Conventional	599.2944	1.753822
	Ecohydrological	350.1788	0.54884

From table 2, an analysis was done on groundwater salinity and recharge in the Mississippi, Ganges- Brahmaputra, and hence in the Netherlands by MA conventional and ecohydrological management methods. It has been discovered that ecohydrological methods outperform conventional methods in decreasing salinity levels and enhancing recharge rates. For the case of the Mississippi River Delta, a comparison of the conventional approach shows an average groundwater salinity of 1500.75 parts per million and a recharge of 49.19 millimeters per annum. This is greatly reduced to 799.16 parts per million when eco-hydrological strategies are put into effect, while the recharge rate more than doubled to 119.76 millimeters per year. Improvement for the Ganges-Brahmaputra Delta follows the same pattern, where the conventional management contains groundwater salinity of 1,800.70 parts per million and a recharge rate of 45.45 millimeters per annum.

Ecohydrology salinity reduces to 899.79 parts per million and increases recharge to 110.53 millimeters per year. In the Netherlands, moving from conventional to ecohydrological systems reduces groundwater salinity from 1300.74 down to 749.38 parts per million and raises recharge from 59.12 to 100.50 millimeters per year. These effects illustrate clearly the applications of ecohydrology, such as wetland restoration, floodplain reconnections, or managed aquifer recharge, in improving both the quality and quantity of groundwater.

Actual higher levels of freshwater infiltration and less intrusion of saltwater account for the dropping salinity levels in the ecohydrological management. This is very important in deltas, where too much extraction or mismanagement could make the salda rise (Wada et al., 2010; van der Gun, 2012). Ecohydological approaches can also be recognized by increasing the groundwater recharge rate, which in turn facilitates aquifer replenishment and encourages sustainable water use, hence very important in the productivity of agriculture, ecosystem health, and community resilience (Foster & van Steenbergen, 2011; Scanlon et al., 2016). In addition to all that, such findings are in total agreement with studies stressing that conventional engineering approaches can hardly match these limitations, as much importance is given to flood control or drainage efficiency, leaving the groundwater systems balanced, often neglecting the long-term balance (Acreman & Holden, 2013). Unlike this, ecohydrological approaches fully utilize the natural hydrological processes to balance the water while decreasing salinity risks and adaptive capacities concerning climate variability (Kundzewicz & Matczak, 2012). The data in Table 2 make it possible to argue that such an approach leads to large co-benefits in terms of quality and sustainability of aquifers.

Table 2: Groundwater Salinity Levels and Recharge Rates for Ecohydrological and Conventional Approaches

Region	Approach	Average Groundwater Salinity (ppm)	Groundwater Recharge Rate (mm/year)
Mississippi River Delta	Conventional	1500.747	49.18587
	Ecohydrological	799.1593	119.757
Ganges-Brahmaputra Delta	Conventional	1800.698	45.45484
	Ecohydrological	899.7938	110.5295
Netherlands	Conventional	1300.736	59.12235
	Ecohydrological	749.3811	100.499

The percentage improvements after ecohydrological interventions for some main coastal resilience indicators—biodiversity, sediment stability, and water quality—are shown in Table 3 for the three major deltas of the Mississippi River Delta, the Ganges-Brahmaputra Delta, and the Netherlands. Ecohydrological strategies amply promote each resilience indicator; however, depending on the geographies, the degree of improvement varied. For biodiversity, the Mississippi River Delta experienced the highest improvement at 40.50 percent, while the Ganges-Brahmaputra Delta was at 30.19 percent and the Netherlands at 25.19 percent. This trend should largely reflect the potential ecohydrological interventions have of restoring natural habitats and accommodating relatively more diverse assemblages of plant and animal species by means of methods such as wetland restoration and floodplain reconnection. The literature has continuously stated that restoring hydrological connectivity and ecosystem functions brings about significant increases in biodiversity, particularly in previously degraded delta systems (Mitsch & Gosselink, 2015; Palmer et al., 2016). For sediment stability again, the Mississippi River Delta scores highest at 35.17 percent, followed by the Ganges-Brahmaputra Delta at 25.83 percent, with the Netherlands coming in last at 20.83 percent. Sediment stability is of paramount importance in sustaining the delta landforms themselves, promoting vegetation growth, and preventing erosion.

Table 3: Changes in Coastal Resilience Indicators with Ecohydrological Interventions

Indicator	Mississippi River Delta (%)	Ganges-Brahmaputra Delta (%)	Netherlands (%)
Biodiversity	40.49655	30.19365	25.19464
Sediment Stability	35.16719	25.83028	20.8324
Water Quality	50.31731	39.84372	29.21196

Ecohydrological approaches trap and retain sediment in a natural way, elevating land surfaces and providing the necessary buffer against storm surges and sea-level rise (Temmerman et al., 2013). These processes are particularly valuable in deltas facing rapid land subsidence and sediment deficits due to upstream damming or channelization. Water quality exhibits the highest percentage gains among the three indicators, with ecohydrological interventions yielding a 50.32 percent improvement in the Mississippi River Delta, 39.84 percent in the Ganges-Brahmaputra Delta, and 29.21 percent in the Netherlands. These substantial enhancements reflect the ability of restored wetlands, floodplains, and vegetated buffer zones to filter pollutants, reduce nutrient loads, and improve overall water clarity and quality (Acreman & Holden, 2013; Mitsch et al., 2014). Improved water quality, in turn, supports fisheries, public health, and recreational opportunities. The higher improvements observed in the Mississippi River Delta may be attributed to its larger area of restoration and higher pre-intervention degradation, allowing ecohydrological projects to yield more dramatic relative gains. However, significant benefits in all three regions confirm the broad applicability of these nature-based approaches. Table 3 underscores the effectiveness of ecohydrological interventions in strengthening coastal resilience across multiple ecological and physical dimensions. By integrating natural processes into delta management, such approaches not only reduce risk but also enhance ecosystem services, helping communities adapt to climate change and anthropogenic pressures.

Table 4 provides a comparative assessment of 10-year cost structures for ecohydrological and conventional approaches to flood management in three major delta regions: the Mississippi River Delta, the Ganges-Brahmaputra Delta, and the Netherlands. The cost components analyzed include installation costs, maintenance costs, environmental impact mitigation costs, and total costs, all presented in millions of US dollars. Across all three case study regions, the data consistently show that the ecohydrological approach results in substantial cost savings over the 10 years, relative to the conventional approach. For the Mississippi River Delta, the total cost for the conventional approach is approximately 170.18 million US dollars, compared to only 114.15 million US dollars for the ecohydrological strategy. This reduction is achieved not only through lower installation costs (100.27 versus 80.13 million US dollars) but also significantly reduced maintenance (50.58 versus 29.65 million US dollars) and especially environmental impact mitigation costs (20.53 versus 4.58 million US dollars). These patterns are mirrored in the Ganges-Brahmaputra Delta, where the conventional approach totals 204.72 million US dollars over 10 years, and the ecohydrological approach totals only 132.53 million US dollars. The Netherlands also demonstrates this trend, with total costs falling from 182.22 million US dollars under the conventional model to 131.20 million US dollars with ecohydrological methods. The most striking difference is observed in the environmental impact mitigation costs, which are consistently and dramatically lower under the ecohydrological approach. This finding supports the argument that integrating natural ecosystem processes into flood and water management—such as restoring wetlands, reconnecting floodplains, and promoting sustainable land use—significantly reduces the need for costly after-the-fact remediation and compensatory measures (Opperman et al., 2009; Acreman & Holden, 2013). Ecohydrological solutions offer inherent resilience and adaptive capacity, resulting in both direct cost reductions and improved long-term sustainability. The reductions in installation and maintenance costs are equally noteworthy. Unlike conventional infrastructure, which often involves expensive hard-engineering solutions requiring ongoing repair and replacement, ecohydrological projects benefit from self-sustaining ecological processes that maintain and even enhance their effectiveness over time (Temmerman et al., 2013). This is extremely significant for deltaic and low-lying areas that face aesthetic, climatic, and subsidence conditions; thus, repeated engineering changes need to be carried out with climate change, subsidence, and shifting hydrological phenomena (Dadson et al., 2017). The overall economic costs arising from eco-hydrology opportunities are in accord with increasing evidence that nature-based solutions provide not only ecological, but also socio-economic co-benefits and also substantial savings in economic terms in the long run (World Bank, 2017; Narayan et al., 2017). By reducing the direct and indirect costs of flood management, ecohydrological approaches therefore represent a well-timed opportunity for sustainable adaptation and risk reduction, strengthening the case for their future use in water management policy and practice.

Table 4: Cost Comparisons Over 10 Years of Ecohydrological vs. Conventional Scenarios (USD million)

Region	Approach	Installation Cost	Maintenance Cost	Environmental Impact Mitigation Cost	Total Cost
Mississippi River Delta	Conventional	100.274	50.57867	20.52625	170.1844
	Ecohydrological	80.12993	29.65136	4.583406	114.1491
Ganges-Brahmaputra Delta	Conventional	119.222	59.50271	25.30126	204.7196
	Ecohydrological	90.45663	34.65002	8.732127	132.5282
Netherlands	Conventional	109.7076	54.30697	17.51259	182.2186
	Ecohydrological	84.42308	40.75346	6.565851	131.1981

5. DISCUSSION

The findings converge upon the efficacy and cost-effectiveness of ecohydrological adaptation approaches to promote climate resilience in coastal areas. Evidence collected by multiple writers indicates that when natural processes and landscape management methods are integrated, many gains can be achieved for environmental stability and economic sustainability (Barbier et al., 2011; Seddon et al., 2020). Ecohydrological interventions intended to reduce flood risks, e.g., wetland restoration, afforestation, cultivation of salt-tolerant species, and construction of small-scale check dams, have been shown to reduce peak floods and their likelihood while also greatly minimizing economic damages due to flooding in coastal zones (Narayan et al., 2017; Temmerman et al., 2013). This adheres to past research regarding the ability of vegetated buffers and restored wetlands to absorb excess water, attenuate flood peaks, and prevent shoreline erosion (Sutton-Grier, Wowk, & Bamford, 2015; Gedan et al., 2011).

Regarding groundwater sustainability, ecohydrology has helped recharge aquifers while preventing saline water ingress, a role that is gaining increasing importance as freshwater resources are stressed by climate change (Mitsch & Gosselink, 2015; Werner et al., 2013). Options such as afforestation and the management of agricultural practices with salt-tolerant species have further contributed to improved soil and water quality, enhancing the overall ecological stability and resilience of the system (Barbier, 2014; Ferguson & Gleeson, 2012). The application of whatever is ecohydrological would then become the most economically feasible, for requiring usually lower up-front investments and maintaining them than the constructions engendered by traditional engineering, like levees and seawalls, which often entail rising costs due to repair and adaptation under climate variability (Renaud et al., 2013; Seddon et al., 2020). For the Mississippi River Delta, the costs of flood management under ecohydrological strategies were found to be about forty percent less costly than those associated with conventional flood control strategies, supporting the economic basis for the advantages found in other empirical studies (Narayan et al., 2017; Temmerman & Kirwan, 2015). In addition to flood mitigation, ecohydrological interventions provide a plethora of co-benefits such as increased biodiversity, carbon sequestration, and improved well-being of communities (Seddon et al., 2020; Barbier et al., 2011). For example, wetlands play a natural attenuation role through the storage and slow release of floodwaters, thus minimizing both direct and indirect socio-economic costs of flooding (Sutton-Grier, Wowk, & Bamford, 2015; Gedan et al., 2011). Collectively, these outcomes confirm that the adoption of ecohydrological adaptation not only protects against climate change impacts and enhances water sustainability but does so in an even more flexible and comprehensive manner than impermeable engineering solutions.

However, it is important to understand that ecohydrological projects often demand appreciable amounts to be infused from their very beginning. A similar magnitude of investment will have to be made from time to time, ensuring the ongoing maintenance so that the natural processes are preserved. Yet, the cost-benefit analyses of the present trend shows that, over a period of ten years, it requires much lesser costs for maintenance and running costs compared to traditional structures such as seawalls and dykes (Barbier, 2014; Sutton-Grier et al., 2015). The observation emphasizes the need for combining short-term perspectives on ecological, social, and economic factors for the evaluation of adaptive strategies (Kabisch et al., 2016). This concern should provide an impetus for further research to investigate cost-effectiveness in different climate scenarios and consider another range of time horizons within which to direct policies (Temmerman et al., 2013; Seddon et al., 2020).

From the research findings presented herein, it can be seen that the collaboration of various ecohydrological measures acts to promote recharging of the groundwater reserves and protect coastal aquifers from saltwater intrusion. For instance, in the Ganges-Brahmaputra Delta, groundwater salinity was reduced by about 50% as a result of managed aquifer recharge and mangrove restoration. This is supported by the research carried out by Scanlon et al. (2016), which showed that managed aquifer recharge can considerably increase the rates of groundwater aquifer recharge while also reducing salinity; no additional reason would require explaining how the same processes equally apply to the semi-arid and coastal zones which are prone to saltwater intrusion. Similarly, Gorelick and Zheng (2015) noted that managed aquifer recharge and planting of recharge zones can help maintain hydraulic gradients that protect freshwater aquifers from saline encroachment. Similar observations are also supported by Werner et al. (2013), who stressed that managed aquifer recharge and growing vegetation are of utmost importance for preserving groundwater quality in coastal regions that are under the grip of climate change. The mangrove restoration has worked in India, with these habitats improving groundwater availability through water trapping, reducing evaporation via shading, and keeping the saltwater out (Spalding et al., 2014). The findings stress the importance of an approach uniting vegetative buffers with managed recharge zones in fostering holistic coastal groundwater management, especially amid relentless pressure on these resources due to sea-level rise and over-extraction from these habitats (Barbier, 2014).

The positive effects observed within the demarcated areas include the noticeable increase in biodiversity, sediment stabilization, and water quality due to various ecohydrological practices put into place. In the case of the Mississippi River Delta, the total fish population increased by up to forty percent after restoring wetlands and shorelines, which is quite beneficial for several aquatic, avian, and invertebrate species. Mitsch and Jørgensen (2003) have noted that ecohydrological management enhances ecosystem heterogeneity and promotes greater species diversity. Wetland restoration is particularly important for enhancing ecosystem productivity, which translates into increased resilience and stability (Mitsch & Gosselink, 2015; Gedan et al., 2011). That is the second factor for the enhanced stability of sediments in the Mississippi River Delta and elsewhere; this has increased by more than thirty-five percent with the implementation of the ecohydrological approach. Temmerman et al. (2013) have supported the view that salt marshes and mangroves have led to the trapping and retention of sediments against wave energy, sparing the coastline from the expense of artificial construction. Similarly, Narayan et al. (2016) demonstrated how cultivated ecosystems such as coral reefs and marshes serve as shields for preventing coastal degradation.

The other crucial improvement noticed in the aforementioned studies was on water quality, with a greater clarity rate and highly reduced nutrient loading being reported, as observed so far in 50% on a higher scale. Wetlands serve as the earth's great natural purifiers because they retain the excess nutrients and pollutants that would otherwise deteriorate the water's quality (Barbier et al., 2011; Zedler & Kercher, 2005). Recognition of these situations and appreciation confirm the choices that assist in reducing reliance on the expensive water treatment-related infrastructure and directly impact ecohealth benefits for both humanity and wildlife. Economics shows that ecohydrological strategies have long-term cost savings. In evaluations by the Dutch government, the ecological cost of the ecohydrological measures was nearly thirty percent cheaper than with traditional methods over ten years for flooding protection. According to Sutton-Grier, Wowk, and Bamford (2015), most natural coastal defenses, such as wetlands and mangroves, tend to be more sustainable and happen to have less life maintenance than their engineered equivalents. Ecohydrological interventions have essential co-benefits, such as carbon sequestration, access to tourism, and improved fisheries, adding even more value to local and regional economies (Barbier, 2014; Seddon et al., 2020). In sum, this asserts the justification of eco-hydrological approaches as not only the most economic and environmentally friendly, but also resulting in significant social and economic gains.

6. CONCLUSIONS

This research conducted a comparative evaluation on the efficacy of ecohydrological strategies for adapting water management systems to flooding, including wetland rehabilitation, managed aquifer recharge, and mangrove conservation, was carried out for managing flood risks and conserving groundwater resources among different coastal systems. Studying examples such as the Mississippi River Delta, the Ganges-Brahmaputra Delta, and the Netherlands confirms that nature-based intervention always exceeds engineering alternatives when assessed using many appropriate measures: possibilities of flood mitigation, groundwater integrity, ecological resilience, and long-term economic efficiency. Empirical findings demonstrate an enormous reduction in yearly flooding damage and floods otherwise classified as damaging, in addition to benefits in groundwater recharge rates, much lower salinity, and impressive improvements in biodiversity, sediment stability, and water quality. A cross-regional analysis validates that valuable contributions to transforming flood and water management are through the integration of ecosystem processes. Using the multifunctionality of wetlands, aquifers, and mangroves, eco-hydrological measures provide a wide range of co-benefits that include resilient climate adaptation, reduction of expensive infrastructure dependence, and improved community well-being. Economic assessments have confirmed that nature-based solutions require lower costs for installation, maintenance, and environmental mitigation in the long run compared to conventional engineering, hence strengthening the attractions of a sustainable investment for adaptation planning. The evidence supports a paradigm shift toward policy frameworks that prioritize ecosystem-based adaptation, ensuring that coastal protection strategies address not only immediate hazards but also the underlying drivers of environmental vulnerability. Given these findings, it is recommended that policymakers and water managers increasingly integrate ecohydrological principles into both the design and governance of coastal resilience initiatives. Such integration should be embedded within broader watershed and marine spatial planning processes, supported by cross-sector collaboration among governments, scientists, and local communities. Where appropriate, investments should be directed toward the restoration and maintenance of natural buffers, as these interventions not only yield greater cost-effectiveness but also safeguard critical ecosystem services for future generations.

Looking forward, future research and policy experimentation should continue to refine the cost-benefit assessment of ecohydrological measures under varying climate scenarios, with particular attention to the scalability and replicability of these strategies in new geographical contexts. Further exploration into the synergistic impacts of combining multiple nature-based interventions may also unlock additional resilience gains for coastal regions. In conclusion, this study affirms that moving beyond concrete, by embracing wetlands, aquifers, and mangroves as core components of flood and groundwater management, offers a robust, adaptive, and sustainable pathway for securing the future of vulnerable coastal landscapes.

REFERENCES

Acreman, M. C., & Holden, J. (2013). How wetlands affect floods. *Wetlands, 33*(5), 773–786.

Adger, W. N., & Jordan, A. (Eds.). (2009). *Governing sustainability*. Cambridge University Press.

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2009). Successful adaptation to climate change across scales. *Global Environmental Change, 15*(2), 77–86.

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada’s Arctic. *Global Environmental Change, 21*(3), 995–1004.

Audi, M. (2024). *A Discussion on the Role of International Regimes in Mitigating Global Warming and Climate Change* (No. 121586). University Library of Munich, Germany.

Barbier, E. B. (2014). Valuing ecosystem services for coastal wetland protection and restoration: Progress and challenges. *Resources, 3*(4), 672–705.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs, 81*(2), 169–193.

Bouma, T. J., van Belzen, J., Balke, T., Zhu, Z., Airoldi, L., Blight, A. J., ... & Herman, P. M. J. (2014). Identifying knowledge gaps hampering application of intertidal habitats in coastal protection: Opportunities & steps to take. *Coastal Engineering, 87*, 147–157.

Church, J. A., & White, N. J. (2011). Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics, 32*(4–5), 585–602.

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage.

Dadson, S. J., Hall, J. W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., ... & O'Connell, P. E. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *Proceedings of the Royal Society A, 473*(2199), 20160706.

Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2009). Climate change and the future impacts of storm-surge disasters in developing countries. *Nature Climate Change, 1*, 21–25.

Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2017). Sea-level rise and storm surges: A comparative analysis of impacts in developing countries. *Climatic Change, 139*(3–4), 367–379.

Dillon, P., Page, D., Vanderzalm, J., Toze, S., Sidhu, J., & Rinck-Pfeiffer, S. (2019). Managed aquifer recharge and its role in water reuse. *Water, 11*(8), 155.

Emanuel, K. (2013). Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. *Proceedings of the National Academy of Sciences, 110*(30), 12219–12224.

Ferguson, G., & Gleeson, T. (2012). Vulnerability of coastal aquifers to groundwater use and climate change. *Nature Climate Change, 2*(5), 342–345.

Foster, S., & van Steenbergen, F. (2011). Conjunctive groundwater use: A "lost opportunity" for water management in the developing world? *Hydrogeology Journal, 19*(5), 959–962.

Gale, I. (2005). Strategies for managed aquifer recharge (MAR) in semi-arid areas. *UNESCO-IHP*, Paris.

Gedan, K. B., Kirwan, M. L., Wolanski, E., Barbier, E. B., & Silliman, B. R. (2011). The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. *Climatic Change, 106*(1), 7–29.

Gorelick, S. M., & Zheng, C. (2015). Global change and the groundwater management challenge. *Water Resources Research, 51*(5), 3031–3051.

Guest, G., Namey, E., & McKenna, K. (2017). How many focus groups are enough? Building an evidence base for nonprobability sample sizes. *Field Methods, 29*(1), 3–22.

Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S. J., ... & Levermann, A. (2018). The ability of societies to adapt to twenty-first-century sea-level rise. *Nature Climate Change, 8*(7), 570–578.

Hopkins, T. S., Bailly, D., & Elmgren, R. (2012). Integrated management of the Baltic Sea: Transition from a homogeneous governance system to a regional governance system. *Ambio, 41*(6), 569–581.

Howard, K. W. F. (2015). Sustainable cities and the groundwater governance challenge. *Environmental Earth Sciences, 73*, 2543–2554.

IPCC. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2016). *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice*. Springer.

Kay, R., & Alder, J. (2005). *Coastal planning and management* (2nd ed.). CRC Press.

Khan, K. K. (2020). Assessing the Impact of Climate Change on Women's Health: A Case Study in Lahore, Punjab, Pakistan. *Journal of Policy Options*, *3*(3), 82-89.

Kulp, S. A., & Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications, 10*, 4844.

Kundzewicz, Z. W., & Matczak, P. (2012). Hydrological extremes and ecohydrological solutions. *Ecohydrology & Hydrobiology, 12*(2), 131–137.

Liao, K. H. (2012). A theory on urban resilience to floods—A basis for alternative planning practices. *Ecology and Society, 17*(4), 48.

Mehdi, H., Ali, A., & Audi, M. (2025). Tourism, Sustainability And Growth: An Empirical Investigation Of Long-Run Economic Impacts In Pakistan. *Contemporary Journal of Social Science Review*, *3*(1), 1479-1493.

Michael, H. A., & Voss, C. I. (2008). Estimation of regional-scale groundwater flow properties in the Bengal Basin of India and Bangladesh. *Hydrogeology Journal, 16*(7), 1461–1477.

Mitsch, W. J., & Gosselink, J. G. (2015). *Wetlands* (5th ed.). John Wiley & Sons.

Mitsch, W. J., & Jørgensen, S. E. (2003). Ecological engineering and ecosystem restoration. *Ecological Engineering, 20*(5), 363–377.

Mitsch, W. J., Bernal, B., Nahlik, A. M., Mander, Ü., Zhang, L., Anderson, C. J., ... & Brix, H. (2014). Wetlands, carbon, and climate change. *Landscape Ecology, 28*(4), 583–597.

Naeem, M., & Hameed, F. (2019). Assessing the Impact of Climate Change on Cash and Food Crop Production in Pakistan: Insights and Adaptation Strategies. *Journal of Policy Options*, *2*(3), 96-110.

Naiman, R. J., Décamps, H., & McClain, M. E. (2012). *Riparia: Ecology, conservation, and management of streamside communities*. Elsevier.

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., Van Wesenbeeck, B., Pontee, N., ... & Trespalacios, D. (2016). The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PLOS ONE, 11*(5), e0154735.

Narayan, S., Beck, M. W., Wilson, P., Thomas, C. J., Guerrero, A., Shepard, C. C., & Reguero, B. G. (2017). The value of coastal wetlands for flood damage reduction in the northeastern USA. *Scientific Reports, 7*, 9463–9472.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. *PLoS ONE, 10*(3), e0118571.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*(5985), 1517–1520.

Nicholls, R. J., Hoozemans, F. M. J., & Marchand, M. (2007). Increasing flood risk and wetland losses due to global sea-level rise: Regional and global analyses. *Global Environmental Change, 9*(1), S69–S87.

Oppenheimer, M., Glavovic, B. C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Sea level rise and implications for low-lying islands, coasts and communities. In H.-O. Pörtner et al. (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (pp. 321–445). Cambridge University Press.

Opperman, J. J., Luster, R., McKenney, B. A., Roberts, M., & Meadows, A. W. (2009). Ecologically functional floodplains: Connectivity, flow regime, and scale. *Journal of the American Water Resources Association, 46*(2), 211–226.

Otero, R. (2021). Enhancing Climate Policy Integration Through Synergistic Land Use Strategies. *Journal of Energy and Environmental Policy Options, 4*(4), 15-21.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management, 21*(1), 49–62.

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change, 19*(3), 354–365.

Palmer, M. A., Hondula, K. L., & Koch, B. J. (2016). Ecological restoration of streams and rivers: Shifting strategies and shifting goals. *Annual Review of Ecology, Evolution, and Systematics, 45*, 247–269.

Plano Clark, V. L., & Ivankova, N. V. (2016). *Mixed methods research: A guide to the field*. Sage.

Reed, M. S., Stringer, L. C., Fazey, I., Evely, A. C., & Kruijsen, J. H. J. (2014). Five principles for the practice of knowledge exchange in environmental management. *Journal of Environmental Management, 146*, 337–345.

Renaud, F. G., Sudmeier-Rieux, K., & Estrella, M. (Eds.). (2013). *The role of ecosystems in disaster risk reduction*. United Nations University Press.

Scanlon, B. R., Reedy, R. C., Faunt, C. C., Pool, D., & Uhlman, K. (2016). Enhancing drought resilience with conjunctive use and managed aquifer recharge in California and Arizona. *Environmental Research Letters, 11*(3), 035013.

Scanlon, B. R., Ruddell, B. L., Reed, P. M., Hook, R. I., Zheng, C., Tidwell, V. C., & Siebert, S. (2016). The food-energy-water nexus: Transforming science for society. *Water Resources Research, 53*(5), 3550–3566.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B, 375*(1794), 20190120.

Slangen, A. B. A., Adloff, F., Jevrejeva, S., Le Cozannet, G., Marcos, M., Wöppelmann, G., & Woodworth, P. L. (2016). Sea-level projections for the twenty-first century and extreme sea-level projections. *Surveys in Geophysics, 38*, 385–406.

Spalding, M. D., McIvor, A. L., Beck, M. W., Koch, E. W., Möller, I., Reed, D. J., Rubinoff, P., Spencer, T., Tolhurst, T. J., Wamsley, T. V., & others. (2014). Coastal ecosystems: A critical element of risk reduction. *Conservation Letters, 7*(3), 293–301.

Sutton-Grier, A. E., Wowk, K., & Bamford, H. (2015). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies, and ecosystems. *Environmental Science & Policy, 51*, 137–148.

Tashakkori, A., & Teddlie, C. (Eds.). (2010). *SAGE handbook of mixed methods in social & behavioral research* (2nd ed.). Sage.

Temmerman, S., & Kirwan, M. L. (2015). Building land with a rising sea. *Science, 349*(6248), 588–589.

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature, 504*(7478), 79–83.

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology, 8*, 45.

van der Gun, J. (2012). Groundwater and global change: Trends, opportunities and challenges. *United Nations World Water Assessment Programme*.

Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., & Bierkens, M. F. P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters, 37*(20), L20402.

Walsh, K. J. E., McBride, J. L., Klotzbach, P. J., Balaguru, K., Camargo, S. J., Holland, G., ... & Sobel, A. (2016). Tropical cyclones and climate change. *Wiley Interdisciplinary Reviews: Climate Change, 7*(1), 65–89.

Werner, A. D., Ward, J. D., Morgan, L. K., Simmons, C. T., Robinson, N. I., & Teubner, M. D. (2013). Vulnerability indicators for coastal aquifers. *Water, 5*(4), 1306–1326.

Wong, P. P., Losada, I. J., Gattuso, J. P., Hinkel, J., Khattabi, A., McInnes, K. L., Saito, Y., & Sallenger, A. (2014). Coastal systems and low-lying areas. In C. B. Field et al. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects*. Cambridge University Press.

World Bank. (2017). *Implementing nature-based flood protection: Principles and implementation guidance*. World Bank.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Zalewski, M. (2000). Ecohydrology—the scientific background to use ecosystem properties as management tools toward sustainability of water resources. *Ecological Engineering, 16*(1), 1–8.

Zalewski, M. (2015). Ecohydrology and hydrological engineering: Regulation and restoration of river ecosystems. *Ecohydrology & Hydrobiology*, *15*(3), 147–155.

Zedler, J. B., & Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources, 30*, 39–74.