

CLIMATE CHANGE AND SUSTAINABLE RESOURCE MANAGEMENT IN SAUDI ARABIA: STRATEGIC ADAPTATION

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ABSTRACT

This study investigates the complex impacts of climate change on Saudi Arabia's ecosystems, focusing on two major challenges: biodiversity loss and water scarcity. Using structural equation modeling (SEM), the research evaluates the effectiveness of national adaptation strategies that integrate biodiversity conservation, water resource management, and climate policy. The analysis examines sustainable agricultural practices, biodiversity protection programs, and advanced water conservation technologies. The results identified water scarcity as the most critical issue, with renewable water resources expected to decline by 20–30 % by mid-century. Biodiversity loss, particularly among endemic species such as the Arabian oryx, also emerged as a severe threat. Results point out the need to expand desalination capacity, promote agroecological farming, and strengthen ecosystem restoration initiatives, alongside public awareness and environmental education to foster long-term resilience. Aligning adaptation strategies with Saudi Arabia's Vision 2030 framework is essential to support economic diversification, safeguard natural resources, and enhance ecological sustainability.

Keywords: water scarcity, biodiversity loss, sustainable agriculture, ecosystem resilience.

INTRODUCTION

Climate change represents one of the most critical global challenges, with profound effects on ecosystems, economies, and societies. In Saudi Arabia, the consequences are particularly acute due to the country's arid climate, limited freshwater resources, and dependence on oil-based economic structures. Situated in one of the driest regions worldwide, the Kingdom faces intensifying water scarcity, biodiversity degradation, and growing threats to sustainable development.

The scarcity of freshwater remains one of Saudi Arabia's most pressing environmental challenges. Recurrent droughts, rising temperatures, and over-extraction of groundwater have accelerated resource depletion, while energy-intensive desalination contributes to carbon emissions (Chowdhury and Al-Zahrani, 2013; Rashed, 2025). Climate change intensifies desertification, especially in areas like the Rub' al-Khali,

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resulting in soil degradation, decreased agricultural productivity, and the extinction of species adapted to arid environments (Shayanmehr *et al.*, 2022; Toukabri and Chaabi, 2025). Coastal ecosystems, especially coral reefs and mangroves along the Red Sea and the Arabian Gulf, face additional stress from sea-level rise, ocean acidification, and extreme weather events, threatening marine biodiversity and fisheries (Cooper and Hiscock, 2024).

These environmental pressures have far-reaching socioeconomic implications. Agriculture and food security are highly vulnerable to climate variability, as water-intensive crops experience yield declines and dependence on food imports increases (Zhang *et al.*, 2025). Public health is also affected by rising temperatures and the spread of vector-borne diseases (Ebi and Semenza, 2008). From an economic perspective, the dual challenges posed by climate impacts and the global energy transition highlight the pressing need for economic diversification, which is a key goal of Saudi Vision 2030 (Namdar *et al.*, 2021).

In response, the Kingdom has accelerated its transition toward renewable energy and sustainable resource management. Large-scale solar projects, green hydrogen initiatives, and innovations such as solar-powered desalination and wastewater recycling are reshaping the national energy and water landscape (Rashed, 2025). Concurrently, initiatives such as the Green Saudi Initiative and the Green Middle East Initiative demonstrate increasing regional leadership in combating desertification and promoting carbon neutrality. Technological advancements, including artificial intelligence and blockchain, further enhance monitoring, forecasting, and efficiency across energy and agricultural systems (Hughes, 2003).

While there is an increasing amount of research on climate change in arid regions, there is a lack of empirical studies that quantitatively explore the relationships among biodiversity loss, water scarcity, and adaptation strategies in Saudi Arabia using advanced modeling techniques. The effectiveness of current climate adaptation strategies remains insufficiently evaluated, as existing studies have largely focused on sector-specific impacts with limited integration across biodiversity, water management, and climate policy.

This study addresses this gap by assessing the effectiveness of Saudi Arabia's adaptation strategies using structural equation modeling (SEM). The analysis identifies the main pathways of ecosystem vulnerability to climate change, evaluates the performance of current adaptation measures in key sectors such as energy, agriculture, and water, and proposes innovative and integrated strategies to strengthen ecological resilience in alignment with Vision 2030.

MATERIALS AND METHODS

Research hypotheses

Climate change exerts multifaceted environmental and socio-economic impacts, particularly in arid regions such as Saudi Arabia. Previous studies have established

theoretical relations between climatic shifts and ecosystem vulnerability, emphasizing effects on heatwave frequency, water availability, and biodiversity integrity (Thomas *et al.*, 2004; Milly *et al.*, 2005; IPCC, 2021). Empirical evidence further shows that extreme temperatures and water stress increase energy demand and mortality risks, reinforcing the need for adaptive approaches such as integrated water resources management (Blinda and Thivet, 2009; GWP, 2000).

Building on these theoretical and empirical foundations, this study formulates a set of hypotheses to systematically examine the direct and indirect relationships among climate change, water scarcity, biodiversity loss, and adaptation measures in the Saudi context: Climate change is expected to increase both the frequency and intensity of extreme heatwaves (H1). These heatwaves will increase mortality rates (H2a) and lead to greater energy consumption (H2b). Climate change is expected to exacerbate water scarcity (H3), which requires the adoption of new water management strategies (H4). Climate change is believed to contribute directly to biodiversity loss (H5). Integrated water management solutions are considered necessary to address these issues and reduce water scarcity (H6). The increasing adoption of water-saving technologies is also considered a key adaptation strategy under climate change conditions (H7). Lastly, it is hypothesized that the relationship between adaptation strategies and climate change is mediated by water scarcity (H8).

Research design

This study utilized a quantitative research design to investigate the effects of climate change on Saudi Arabia's ecological systems and to assess the effectiveness of adaptation strategies. The quantitative approach is particularly appropriate for examining large-scale environmental datasets, identifying causal and correlational relationships among variables, and providing statistical evidence to support policy recommendations. Such an approach allows for the systematic evaluation of how climate variables influence biodiversity, water resources, and socio-economic factors. This design is consistent with established methodologies used in climate impact research and adaptation assessments, particularly in arid and semi-arid regions (Fussel, 2009; Mertz *et al.*, 2009). Furthermore, it builds upon recent empirical studies that utilize quantitative modeling to analyze ecosystem vulnerability and resilience under changing climatic conditions (El-Rawy *et al.*, 2023; Scicluna and Galdies, 2025).

Data collection

This study used both primary and secondary data to provide comprehensive, multi-perspective insights into the impacts of climate change and the adaptation strategies in Saudi Arabia. A structured questionnaire was used to collect primary data from 327 people, including government officials, environmental experts, and community representatives. The survey incorporated both closed-ended questions (Likert-scale and multiple-choice) and open-ended questions, enabling quantitative and qualitative assessment of adaptation practices and their perceived effectiveness (Creswell and Creswell, 2018).

A stratified random sampling approach was used to ensure representation from key sectors (agriculture, water resources, energy, and biodiversity conservation) as well as across major regions. A pilot test with 20 participants was conducted to refine the questionnaire and ensure clarity, reliability, and construct validity (DeVellis, 2017). All research procedures complied with institutional ethical standards. Approval was obtained from the relevant ethics committee, informed consent was secured from all participants, confidentiality was maintained, participation was voluntary, and respondents were free to withdraw at any stage without penalty (Andersson and Keskitalo, 2018; Rana *et al.*, 2021).

Secondary data were obtained from reputable national and international sources, including the Saudi Ministry of Environment, Water and Agriculture (MEWA, 2024), the General Authority for Statistics (GASTAT, 2024), the World Bank (2024) open data, and the United Nations Environment Program (UNEP, 2024). These datasets provided indicators related to temperature trends, CO₂ emissions, water and energy consumption, agricultural output, and renewable resource utilization.

The strategic adaptation framework was structured around four core variables. Climate change, as the independent variable, was measured using indicators of temperature change, drought frequency, heatwaves, and precipitation patterns (Fussler, 2009; IPCC, 2021). Adaptation strategies, modeled as a mediating variable, encompassed water management innovations, agroecological practices, and biodiversity conservation initiatives (El-Rawy *et al.*, 2023; Scicluna and Galdies, 2025). Ecological vulnerability, considered as the dependent variable, was assessed through land degradation, water scarcity, and biodiversity loss (Pörtner *et al.*, 2023), while ecosystem resilience was evaluated using indicators of recovery capacity, biodiversity regeneration, and post-disturbance agricultural productivity (Adger, 2005; Smit and Wandel, 2006).

Data analysis

Data were analyzed using IBM SPSS Statistics 27.0 and AMOS 26.0 (IBM Corp., Armonk, NY, USA). The analytical framework integrated descriptive statistics, correlation analysis, multiple regression, and structural equation modeling (SEM) to test the proposed hypotheses and examine relationships among climate change variables, adaptation strategies, and ecosystem resilience.

Descriptive statistics were used to summarize participants' demographic characteristics and overall trends in stakeholder perceptions of climate impacts and adaptation responses (Creswell and Creswell, 2018). Pearson's correlation analysis then identified significant associations between climate indicators, such as temperature increases and precipitation variability, and measures of ecological vulnerability, including water scarcity and biodiversity loss, assessing both the strength and direction of linear relationships (Gbetibouo, 2009; Mertz *et al.*, 2009).

Multiple regression analysis was used to evaluate the predictive effects of climate change variables on ecological vulnerability and to assess the moderating role of adaptation strategies and policy interventions (Field, 2013). To test the hypothesized

causal pathways, SEM was conducted using AMOS to estimate direct and indirect effects and examine interdependencies among climate change, heatwave frequency, energy consumption, mortality, water scarcity, biodiversity loss, and ecosystem resilience. SEM is widely used for testing theoretical models in environmental and climate research (Bollen, 1989; Byrne, 2010).

Instrument reliability and validity were assessed. Internal consistency was evaluated using Cronbach's alpha, with values above 0.7 indicating acceptable reliability (Cronbach, 1951). Confirmatory factor analysis (CFA) was performed to validate the measurement model and confirm the construct validity of latent variables (Hair *et al.*, 2010). Overall, this analytical approach provided a statistically robust basis for interpreting the effects of climate change on ecological vulnerability and the role of adaptation and policy measures to enhance ecosystem resilience in Saudi Arabia.

RESULTS AND DISCUSSION

Model fit, validity, and robustness of the structural model

The proposed structural equation model demonstrated strong overall fit to the observed data (Table 1). The Comparative Fit Index (CFI = 0.96) and Tucker-Lewis Index (TLI = 0.94) exceeded the recommended threshold of 0.9, indicating a well-fitting and parsimonious model. Similarly, the Root Mean Square Error of Approximation (RMSEA = 0.05) and the Standardized Root Mean Square Residual (SRMR = 0.04) were below the accepted cutoff of 0.08, reflecting minimal residual variance and close correspondence between observed and predicted covariance matrices. The chi-square to degrees of freedom ratio (CMIN/df = 2.45) also fell within the acceptable range (<3.0).

Together, these indicators confirm that the structural model is statistically robust and theoretically coherent, supporting reliable interpretation of the causal relationships among climate change, water scarcity, biodiversity loss, adaptation strategies, and ecosystem resilience. The high CFI and TLI values, in particular, suggest that the

Table 1. Model fit indices for the proposed structural equation model.

Fit index	Value	Threshold	Interpretation
CFI	0.96	>0.90	Good
TLI	0.94	>0.90	Good
RMSEA	0.05	<0.08	Acceptable
SRMR	0.04	<0.08	Good
CMIN/df	2.45	<3.00	Good

CFI: comparative fit index; TLI: Tucker-Lewis index; RMSEA: root mean square error of approximation; SRMR: standardized root mean square residual; CMIN/df: chi-square divided by degrees of freedom.

hypothesized interdependencies provide an empirically valid representation of climate-ecosystem dynamics in Saudi Arabia.

Discriminant validity was assessed using the Fornell-Larcker criterion. The square root of the average variance extracted (AVE) for each construct (Table 2) exceeded its correlations with other constructs, confirming adequate discriminant validity (Fornell and Larcker, 1981). These results indicate that climate change, heatwave frequency, water scarcity, adaptation strategies, and mortality represent empirically distinct constructs that contribute uniquely to the model, reinforcing the reliability of the measurement framework.

Table 2. Fornell-Larcker discriminant validity assessment for the measurement model constructs.

	CC	HEAT	WS	AS	MORT
AVE	0.72	0.68	0.75	0.70	0.67
Square Root of AVE	0.85	0.82	0.87	0.84	0.82
Correlations with other constructs	HEAT	0.65			0.52
	WS	0.72			
	MORT		0.52		
	EC		0.47		
	AS			0.60	
	WST				0.55

CC: climate change; HEAT: heatwave frequency; WS: water scarcity; AS: adaptation strategies; MORT: mortality; AVE: average variance extracted; EC: energy consumption; WST: water-saving technologies.

To further test model stability, a sensitivity analysis was conducted by systematically adjusting key parameters related to climate change intensity, water scarcity, and policy interventions (Table 3). A 10 % increase in climate change intensity produced only a minor increase (+0.05) in the path coefficient linking climate change to ecosystem vulnerability, indicating stability under moderate stress conditions. Reducing water scarcity by 10 % resulted in a small decline (-0.07) in the coefficient associated with adaptation strategies, suggesting that improved water availability slightly reduces adaptive pressure without altering its significance. The inclusion of policy interventions strengthened the effects of adaptation strategies and energy consumption (+0.08), reflecting the moderating role of governance and climate policy. Overall, these findings confirm the internal consistency and robustness of the model. Prior to hypothesis testing, descriptive statistics were examined to contextualize stakeholder perceptions of climate change impacts and adaptation measures, as well as prevailing environmental conditions during the study period. This analysis

Table 3. Sensitivity analysis of structural model parameters under climate and policy scenario adjustments.

Parameter adjustment	Path coefficient change	Conclusion
Increase in climate change intensity (10 %)	+0.05	No significant change in model fit
Decrease in water scarcity (10 %)	-0.07	Small decrease in path coefficient for adaptation strategies
Introduction of policy interventions	+0.08	Increased effect on adaptation strategies and energy consumption

revealed baseline patterns in awareness, perceived environmental stress, and resource management practices, providing an interpretive foundation for subsequent SEM results. These perceptions showed the interpretation of direct, mediating, and moderating effects examined in the following analyses.

Effects of climate change on ecological and socio-economic outcomes

The structural model revealed strong and statistically significant direct relationships among all hypothesized variables ($p < 0.001$), with standardized path coefficients ranging from 0.47 to 0.75 (Table 4). Climate change showed a substantial positive dependence on heatwave frequency and intensity ($\beta = 0.65$), supporting H1 and confirming that broader climatic shifts directly explain variability in heatwave occurrence. This finding aligns with global climate projections predicting intensified heat extremes under global warming scenarios (Seneviratne *et al.*, 2012).

Table 4. Hypothesis testing results and path coefficients for the structural model.

Hypothesis	Estimate (β)	Standardized estimates	Standard error	Critical Ratio	p-value	Conclusion
H1	0.65	0.70	0.12	5.42	<0.001	Supported
H2a	0.52	0.60	0.11	4.73	<0.001	Supported
H2b	0.47	0.55	0.09	5.22	<0.001	Supported
H3	0.72	0.75	0.10	5.14	<0.001	Supported
H4	0.60	0.65	0.08	4.62	<0.001	Supported
H5	0.58	0.62	0.09	5.27	<0.001	Supported
H6	0.70	0.75	0.06	7.00	<0.001	Supported

CC: climate change; HEAT: heatwave frequency and intensity; WS: water scarcity; AS: adaptation strategies; MORT: mortality rate; EC: energy consumption; WST: water-saving technologies.

Heatwaves exhibited a significant positive dependence on mortality rates ($\beta = 0.52$), supporting H2a and demonstrating a clear relationship between climatic extremes and public health outcomes (McMichael *et al.*, 2006; Arbuthnott and Hajat, 2017). Heatwaves also showed a direct dependence on energy consumption ($\beta = 0.47$), confirming H2b and indicating that rising temperatures drive increased cooling demand and climate-sensitive energy use (Li *et al.*, 2015).

A strong dependence between climate change and water scarcity was observed ($\beta = 0.72$), supporting H3 and demonstrating the role of temperature, precipitation variability, and evaporation in water availability (Vörösmarty *et al.*, 2000; Kundzewicz, 2008). Water scarcity, in turn, significantly influenced the adoption of adaptation strategies ($\beta = 0.6$), which validates H4 and indicates that worsening resource constraints directly stimulate adaptive management responses (Liu *et al.*, 2022).

Climate change also showed a significant dependence on biodiversity loss ($\beta = 0.58$), confirming H5 and highlighting ecosystem sensitivity to climatic stressors, particularly in arid environments (IPCC, 2014; Pimm *et al.*, 2014). Finally, adaptation strategies relied heavily on using water-saving technologies ($\beta = 0.7$), which supports H6 and emphasizes the critical role of effective governance and planning in facilitating sustainable technological advancements (Liu *et al.*, 2022).

Mechanisms shaping adaptation responses

The mediation analysis confirmed that water scarcity fully mediates the relationship between climate change and adaptation strategies (indirect effect: $\beta = 0.55$, $p < 0.001$). This shows that climate change does not trigger adaptation directly; instead, its influence operates through increasing water stress, which compels the implementation of adaptive resource management practices. Water scarcity thus emerges as a central mechanism linking climatic stress to policy and technological responses.

In addition, policy interventions were found to significantly moderate the relationship between climate change and heatwave frequency ($\beta = 0.4$, $p < 0.001$). Regions with stronger policy frameworks and mitigation measures had a weaker climate-heatwave relationship, showing the buffering role of governance and regulatory capacity. This finding is consistent with prior research emphasizing institutional effectiveness as a key determinant of climate resilience (Adger *et al.*, 2005).

Theoretical implications

The path analysis, mediation and moderation tests, and sensitivity analysis show how climate change, ecological vulnerability, and adaptation strategies are connected in Saudi Arabia. Climate change directly drives heatwave frequency, water scarcity, biodiversity loss, and energy consumption, while indirectly shaping adaptive responses through water stress. Policy interventions play an important moderating role by reducing the severity of climatic impacts, particularly heat extremes.

The vulnerabilities associated with heatwaves, water scarcity, and biodiversity loss confirm the heightened sensitivity of Saudi Arabia's arid environment to climate

stressors (Chowdhury and Al-Zahrani, 2013; Shayanmehr *et al.*, 2022; Rashed, 2025; Toukabri and Chaabi, 2025). The mediating role of water scarcity supports theoretical claims that environmental pressures function as key drivers of adaptation (Blinda and Thivet, 2009; Taabni and El Jihad, 2012; Liu *et al.*, 2022), while the moderating effect of policy interventions reinforces the importance of governance in enhancing resilience (Adger *et al.*, 2005; Namdar *et al.*, 2021). The results also align with the proposed need for integrated, multi-dimensional adaptation strategies combining technological, ecological, and policy measures (Fussel, 2009; El-Rawy *et al.*, 2023; Scicluna and Galdies, 2025).

Policy implications and practical applications

The findings provide clear guidance for climate policy in Saudi Arabia. Given the mediating role of water scarcity, integrated water management should remain central to national resilience strategies, including renewable-energy-powered desalination, precision irrigation, and wastewater recycling to reduce freshwater dependence and carbon emissions (Blinda and Thivet, 2009; Liu *et al.*, 2022; Rashed, 2025).

The moderating effect of policy interventions demonstrates the value of governance capacity in mitigating climate risks. Effective measures include early-warning systems for extreme heat, climate-responsive urban design, and incentives for energy-efficient cooling technologies, which enhance public health preparedness and energy sustainability (Adger *et al.*, 2005; Namdar *et al.*, 2021).

The strong dependence of adaptation strategies on water-saving technologies further shows the need for innovation-oriented policies. Promoting drought-resistant crops, smart irrigation, and ecosystem monitoring tools, supported by digital technologies such as artificial intelligence, can enhance predictive capacity and optimize resource allocation (El-Rawy *et al.*, 2023; Scicluna and Galdies, 2025).

Aligning these measures with Saudi Arabia's Vision 2030 ensures an adequate approach to climate resilience, ecological protection, and socio-economic development. Effective implementation will require strengthened coordination among the water, energy, and agricultural sectors. Overall, the combined information here shows how governance, technology, and ecosystem management can work together to improve our ability to adapt to growing climate risks.

CONCLUSION

This study quantitatively evaluates the impacts of climate change on Saudi Arabia's ecosystems and the effectiveness of adaptation strategies. The results show that climate change intensifies heatwaves, water scarcity, and biodiversity loss, while policy interventions and adaptive measures significantly mitigate these effects. The mediating role of water scarcity and the moderating role of governance highlight the importance of strong institutions and coherent policy frameworks for climate resilience.

The findings empirically validate links between ecological vulnerability, adaptation behavior, and policy effectiveness in arid contexts and support Saudi Vision 2030 by emphasizing integrated adaptation policies that combine renewable energy, ecosystem conservation, and technological innovation. Limitations include reliance on secondary data, which may not capture local or temporal variability. Future research should apply longitudinal designs and real-time environmental data to improve predictive capacity.

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REFERENCES

- Adger WN, Arnell NW, Tompkins EL. 2005. Adapting to climate change: Perspectives across scales. *Global Environmental Change* 15 (2): 75–76. <https://doi.org/10.1016/j.gloenvcha.2005.03.001>
- Andersson E, Keskitalo ECH. 2018. Adaptation to climate change? Why business-as-usual remains the logical choice in Swedish forestry. *Global Environmental Change* 48: 76–85. <https://doi.org/10.1016/j.gloenvcha.2017.11.004>
- Arbuthnott KG, Hajat S. 2017. The health effects of hotter summers and heat waves in the population of the United Kingdom: A review of the evidence. *Environmental Health* 16 (1): 119. <https://doi.org/10.1186/s12940-017-0322-5>
- Blinda M, Thivet G. 2009. Ressources et demandes en eau en Méditerranée: situation et perspectives. *Sécheresse* 20 (1): 9–16. <https://doi.org/10.1684/sec.2009.0162>
- Bollen KA. 1989. *Structural equations with latent variables*. John Wiley and Sons: New York, NY, USA. 514 p. <https://doi.org/10.1002/9781118619179>
- Byrne BM. 2010. *Structural equation modeling with AMOS: Basic concepts, applications, and programming (Second Edition)*. Routledge: New York, NY, USA. 396 p. <https://doi.org/10.4324/9780203805534>
- Chowdhury S, Al-Zahrani M. 2013. Implications of climate change on water resources in Saudi Arabia. *Arabian Journal for Science and Engineering* 38 (8): 1959–1971. <https://doi.org/10.1007/s13369-013-0565-6>
- Cooper RJ, Hiscock KM. 2024. *Groundwater resources: Challenges and solutions*. Cambridge Prisms: Water 3. <https://doi.org/10.1017/wat.2024.15>
- Creswell JW, Creswell JD. 2018. *Research design: Qualitative, quantitative, and mixed methods approaches (Fifth edition)*. Sage Publications: Los Angeles, CA, USA. 438 p.
- Cronbach LJ. 1951. Coefficient alpha and the internal structure of tests. *Psychometrika* 16 (3): 297–334. <https://doi.org/10.1007/BF02310555>
- DeVellis RF. 2017. *Scale development: Theory and applications (Fourth edition)*. Sage Publications: Thousand Oaks, CA, USA. 280 p.
- Ebi KL, Semenza JC. 2008. Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine* 35 (5): 501–507. <https://doi.org/10.1016/j.amepre.2008.08.018>

- El-Rawy M, Batelaan O, Al-Arifi N, Alotaibi A, Abdalla F, Gabr ME. 2023. Climate change impacts on water resources in arid and semi-arid regions: A case study in Saudi Arabia. *Water* 15 (3): 606. <https://doi.org/10.3390/w15030606>
- Field A. 2013. *Discovering statistics using SPSS (Fourth edition)*. Sage Publications: Thousand Oaks, CA, USA. 952 p.
- Fornell C, Larcker DF. 1981. Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research* 18 (1): 39–50. <https://doi.org/10.2307/3151312>
- Fussel H. 2009. *Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts*. Potsdam Institute for Climate Impact Research: Postdam, Germany. 34 p.
- GASTAT (General Authority for Statistics). 2024. *Statistical yearbook*. Riyadh, Saudi Arabia. <https://www.stats.gov.sa/en/home> (Retrieved: December 2025).
- Gbetibouo GA. 2009. *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa*. International Food Policy Research Institute: Washington, DC, USA. 52 p.
- GWP (Global Water Partnership). 2000. *Integrated water resources management*. Stockholm, Sweden.
- Hair JF, Black WC, Babin BJ, Anderson RE. 2010. *Multivariate data analysis (Seventh edition)*. Pearson: New York, NY, USA. 761 p.
- Hughes L. 2003. Climate change and Australia: Trends, projections, and impacts. *Australian Journal of Ecology* 28 (4): 423–443. <https://doi.org/10.1046/j.1442-9993.2003.01300.x>
- IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press: Cambridge, UK.
- IPCC (Intergovernmental Panel on Climate Change). 2021. *Sixth assessment report (AR6): Climate change 2021: The physical science basis*. Cambridge University Press: Cambridge, UK.
- Kundzewicz ZW. 2008. Climate change impacts on the hydrological cycle. *Ecohydrology and Hydrobiology* 8 (2–4): 195–203. <https://doi.org/10.2478/v10104-009-0015-y>
- Li M, Shi J, Guo J, Cao J, Niu J, Xiong M. 2015. Climate impacts on extreme energy consumption of different types of buildings. *PLoS ONE* 10 (4): e0124413. <https://doi.org/10.1371/journal.pone.0124413>
- Liu W, Liu X, Yang H, Ciais P, Wada Y. 2022. Global water scarcity assessment incorporating green water in crop production. *Water Resources Research* 58 (1). <https://doi.org/10.1029/2020WR028570>
- McMichael AJ, Woodruff RE, Hales S. 2006. Climate change and human health: Present and future risks. *The Lancet* 367 (9513): 859–869. [https://doi.org/10.1016/S0140-6736\(06\)68079-3](https://doi.org/10.1016/S0140-6736(06)68079-3)
- Mertz O, Mbow C, Reenberg A, Diouf A. 2009. Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management* 43 (5): 804–816. <https://doi.org/10.1007/s00267-008-9197-0>
- MEWA (Ministry of Environment, Water and Agriculture). 2024. *Environmental indicators report*. Riyadh, Saudi Arabia. 146 p.
- Milly PCD, Dunne KA, Vecchia AV. 2005. Global pattern of trends in streamflow and water availability in a changing climate. *Nature* 438 (7066): 347–350. <https://doi.org/10.1038/nature04312>

- Namdar R, Karami E, Keshavarz M. 2021. Climate change and vulnerability: The case of MENA countries. *ISPRS International Journal of Geo-Information* 10 (11): 794. <https://doi.org/10.3390/ijgi10110794>
- Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344 (6187). <https://doi.org/10.1126/science.1246752>
- Pörtner HO, Scholes RJ, Arneth A, Barnes DKA, Burrows MT, Diamond SE, Duarte CM, Kiessling W, Leadley P, Managi S, *et al.* 2023. Overcoming the coupled climate and biodiversity crises and their societal impacts. *Science* 380 (6642). <https://doi.org/10.1126/science.abl4881>
- Rana J, Dilshad S, Ahsan MA. 2021. Ethical issues in research. In Farazmand A. (ed.), *Global Encyclopedia of Public Administration, Public Policy, and Governance*. Springer: Cham, Switzerland. https://doi.org/10.1007/978-3-319-31816-5_462-1
- Rashed AA. 2025. Climate change challenges in Saudi Arabia: Strategies for mitigation. *Journal of Umm Al-Qura University for Applied Sciences* 2025. <https://doi.org/10.1007/s43994-025-00278-7>
- Scicluna BM, Galdies C. 2025. Assessing the impact of temperature and precipitation trends of climate change on agriculture based on multiple global circulation model projections in Malta. *Big Data and Cognitive Computing* 9 (4): 105. <https://doi.org/10.3390/bdcc9040105>
- Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, Luo Y, Marengo J, McInnes K, Rahimi M, *et al.* 2012. Changes in climate extremes and their impacts on the natural physical environment. In Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, Midgley PM. (eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge University Press: Cambridge, UK, pp: 109-230.
- Shayanmehr S, Henneberry SR, Ali EB, Sabouni MS, and Foroushani NS. 2022. Climate change, food security, and sustainable production: A comparison between arid and semi-arid environments of Iran. *Environment Development and Sustainability* 26: 359–391. <https://doi.org/10.1007/s10668-022-02712-w>
- Smit B, Wandel J. 2006. Adaptation, adaptive capacity, and vulnerability. *Global Environmental Change* 16 (3): 282–292. <https://doi.org/10.1016/j.gloenvcha.2006.03.008>
- Taabni M, El Jihad MD. 2012. Eau et changement climatique au Maghreb: quelles stratégies d'adaptation? *Les cahiers d'Outre-Mer* 65 (260): 493–518. <https://doi.org/10.4000/com.6718>
- Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, de Siqueira MF, Grainger A, Hannah L, *et al.* 2004. Extinction risk from climate change. *Nature* 427 (6970): 145–148. <https://doi.org/10.1038/nature02121>
- Toukabri M, Chaabi A. 2025. Strengthening ecosystems and biodiversity conservation in response to climate change in Saudi Arabia. *European Journal of Sustainable Development* 14 (1): 357–372. <https://doi.org/10.14207/ejsd.2025.v14n1p357>
- UNEP (United Nations Environment Programme). 2024. *Global Resources Outlook 2024. Bend the trend: Pathways to a liveable planet as resource use spikes*. Nairobi, Kenya. 161 p.
- Vörösmarty CJ, Green P, Salisbury J, Lammers RB. 2000. Global water resources: Vulnerability from climate change and population growth. *Science* 289 (5477): 284–288. <https://doi.org/10.1126/science.289.5477.284>
- World Bank. 2024. *World Development Indicators*. Washington, DC, USA. <https://databank.worldbank.org/source/world-development-indicators> (Retrieved: December 2025).

Zhang S, Zhang H, Xie F, Wu D. 2025. Climate change and sustainable agriculture: Assessment of climate change impact on agricultural resilience. *Sustainability* 17 (16): 7376. <https://doi.org/10.3390/su17167376>

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