Historical climate change events and their influence on water resources management

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Abstract

Alterations to Water Resources (WR) are vital for all economic sectors. Climate Change (CC) will influence the timing and volume of WR availability in the environment, negatively impacting its quality. Storms, droughts, and changing trends of WR scarcity—defined as insufficient availability or inadequate quality of WR at the appropriate time to meet demand—are all essential considerations in assessing the future economic growth potential of the study region. The handling of WR will grow increasingly critical as several sectors endeavor to mitigate the danger of WR scarcity under rising CC. This research examines the observed alterations in the WR supplies of the study region and the anticipated changes in their accessibility and quality due to future climatic conditions. The study area usually gets wetter, with the expected rise mainly occurring in winter and spring. Increased WR consumption throughout summer will heighten the probability of WR scarcity and necessitate enhanced WR management strategies. The study area could gain from investing in techniques to improve short-term WR retention, thereby preserving excess WR from winter and spring to mitigate summer deficits.

Keywords: Climate change, Water resources, Water management, Sustainability

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Introduction

The ample Water Resource (WR) supply has facilitated agricultural output and met the state's inhabitants and ecosystem requirements (Zhang *et al.,* 2023). Climate Change (CC) is anticipated to significantly impact the WR cycle, leading to considerable alterations that influence various facets of the state's economic life (Saidova *et al.,* 2024). Recent catastrophic storms have illustrated the disruptive impacts of warming temperatures on several critical financial assets. For instance, the severe drought led to a loss exceeding 28% in maize production and over 22% in the cultivation of soybeans, along with consequential impacts on enterprises dependent on these crops. Catastrophic flooding in the state resulted in over $2 billion in damages (Trivedi *et al.,* 2022). Intense stormwater and underground flooding ensued due to excessive rainfall (Prasad and Roopashree, 2023).

CC is anticipated to exacerbate drought intensity and flood occurrence, impacting agricultural output, aquatic environments, navigating, and water-related infrastructures. Winters and springtime are expected to become more humid, potentially postponing agricultural sowing and intensifying flooding, mainly if increased precipitation occurs as rain rather than snow (Lourens, 2021). Historical assessments indicate a rise in severe storms in the territory, specifically (Suljić and Kovčić, 2018). Alterations in weather patterns are anticipated to impact WR quality adversely. Significant runoff events transporting nutrients, silt, and toxic substances to streams and elevated summer and autumn temperatures promote algal proliferation in aquatic systems (Short and Short, 2021).

This research presents a synopsis of WR-related assets and a comprehensive assessment of their potential impacts due to CC by the decade's end (Hu and Sinniah, 2024). The research offers insights into possible strategies for minimizing and coping with CC (Robles *et al.,* 2015). The analysis indicates that CC significantly impacts WR availability and economic activity. The study suggests that warming temperatures exert pressure on WR supplies, and incorporating CC into statewide infrastructure design could be advantageous (Kender *et al.,* 2021).

Components of CC

The Earth's climate system is inherently changing and has undergone continuous changes since before industrialization, primarily due to anthropogenic activities and, to a lesser extent, natural causes. The comprehension of the CC system has been impeded by the intricate, interrelated characteristics of its various components, such as the environment, biosphere, cryosphere, and hydrosphere (Wei-Liang and Ramirez, 2023). The primary physical factors influencing the climate are atmospheric structure, cloud effects, and radiation forcing. The causes of warming temperatures can be categorized as natural or manmade (Figure 1).

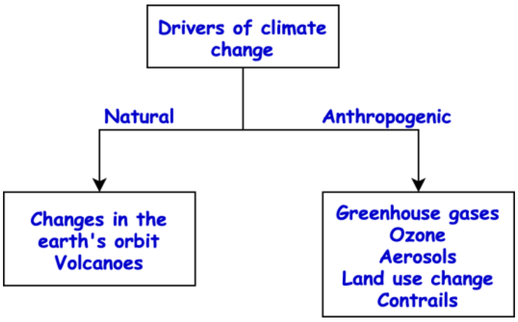

Figure 1: Factors influencing the CC.

Variations in Earth's Orbit

The increasing agreement on the escalation in mean temperature has recently been a topic of discourse, with academics predominantly attributing such changes to manmade emissions (Iglesias *et al.*, 2021). This fluctuation in the Earth's standard deviation can be attributed to both long-term and temporary natural processes, which are recognized to have caused a shift in the worldwide average temperature of 6°C during glaciated and interglacial times. However, such cycles require an exceptionally extended duration to produce discernible mean temperature changes. Solar radiation is chiefly characterized by key factors: the ellipsis of Earth's orbit and the tilt, location, and precession of Earth's axial rotations, which account for fluctuations in the time of the center. These typically minor alterations hardly influence the long-term mean temperature.

Volcanic Activity

The eruption of volcanoes is an unavoidable phenomenon that contributes to warming the planet by releasing numerous tracer elements straight into the environment, resulting in changes to atmospheric chemical makeup (Praveenraj *et al.*, 2024). Although volcanoes are located in specific places worldwide, their impacts can disseminate broadly through gasses, dust, and ash that readily enter the environment. Due to air circulation trends, explosions at mid-latitudes or high latitudes significantly influence the entire hemisphere (Pan *et al.*, 2023). In contrast, tropical volcanoes have an extraordinarily substantial effect on the climate system in both halves. Dust and volcanic ash particles diminish the amount of sunlight reaching the Earth's surface, resulting in temperature drops in the troposphere and altering atmospheric circulation processes. Volcanic activity releases substantial Greenhouse Gases (GHG), such as CO_2 and WR vapor. Such eruptions do not significantly alter the atmospheric concentrations of these gases. Historically, periods of intense volcanic activity have markedly increased atmospheric CO_2 concentrations and contributed to CC (Yasmin *et al.*, 2022; Trisiana, 2024).

Emissions of GHG

Demographic growth has been a significant factor in the rise of concentrations of GHG in the atmosphere (Gao, Xiao and Li, 2024). The warming effect is a natural phenomenon. Expedited human activities increase GHG emissions, leading to a surge in their baseline concentration (Salokhiddiov *et al.*, 2020). Solar radiation and volcanic activity are natural variables, while GHG emissions, alterations in how land is used, and contamination of nutrients are anthropogenic elements influencing the environment. Aerosols also influence CC by collecting or dispersing incoming solar radiation, leading to warmer or cooler effects (Iyengar and Bhattacharya, 2024; Prabhudeva and Hariharan, 2024).

Alterations in Land Utilization

Human activities during the industrial era have altered land-use patterns, significantly affecting the albedo characteristics of terrestrial surfaces, primarily due to afforestation and forest destruction (Krishnan and Patel, 2023). Substantial logical evidence indicates that these changes have increased surface albedo, leading to a net negative radiative impact of -0.18 W/m². Land-use modifications have diminished surface albedo, resulting in net positive radiation forcing due to reforestation and the abandoning of pastures (Assegid and Ketema, 2023). Besides direct thermal forcing, such operations have induced indirect forcing consequences for the climate system, modifications in the cycling of carbon, and variations in dust particle emissions due to impacts on the WR cycle. Regions with extensive irrigation typically influence surface temperatures and precipitation trends by altering energy distribution between visible and latent warming (Magruder *et al.*, 2024). Irrigation-induced direct radiative forcing is beneficial or detrimental, contingent upon the interplay between surface temperatures and enhanced cloudiness impacts (Kumar and Rao, 2024).

Identified Patterns in WR

An examination of historical data regarding WR indicates that circumstances have been evolving recently.

Trends in Precipitation

The median yearly rainfall has risen over the past century, with an increase of 35.3 mm annually since 1970 in the entire territory. The most significant rises have occurred in the southern and west-central regions of the state. The national typical rainfall has risen in all seasons, with the least increase occurring in winter. Trends are rarely consistent across the state, particularly during spring and fall. Winter rainfall has risen in the state's northern region and diminished, whilst the reverse trend has been observed in spring. Multiple investigations have also documented a rise in the frequency of days with intense precipitation throughout the nineteenth century.

Trends in Streamflow

Statistics from the Geological Service streamflow monitoring stations were examined to identify trends in the yearly mean WR flow for the territory over 32 years. Trend evaluation revealed that 98 out of 110 stations exhibited a rising flow over a 32-year timeframe; however, only 27 of these patterns are statistically significant at the 91% confidence level, as determined by the Mann-Kendall statistical identification of trends experiment. There was considerable clustering near the state core and the city specifically. The attribution of patterns of streamflow measurements to CC is complex, as land use and administration practices (e.g., development, enhanced drainage, evolving industrial activities) within a watershed significantly influence the local flow of streams. The rising patterns align with the across-the-state rainfall increase and correspond with the trends observed by those who restricted their research to sites with little land use alterations and the median and average flow trends identified. New studies evaluating the flow of stream patterns in anthropogenically altered and wild streams indicate that warming temperatures exert a comparable influence across both systems.

Trends in Freshwater

A comparable study was performed on the observations of WR table depth beneath the land area from subsurface surveillance wells. Five of the 33 assessed sites significantly reduced the yearly average WR stage. The Mann-Kendall testing determined six had statistically substantial rises. A distinct geographic trend emerged, with all sites exhibiting substantial falling trends in the northern half of the territory. Most sites showing increasing trends were found in the southern quarter. This indicates the heightened freshwater extraction in the province is depleting WR tables, despite augmented precipitation enhancing aquifer reserve. The logical framework of the research is illustrated in Figure 2.

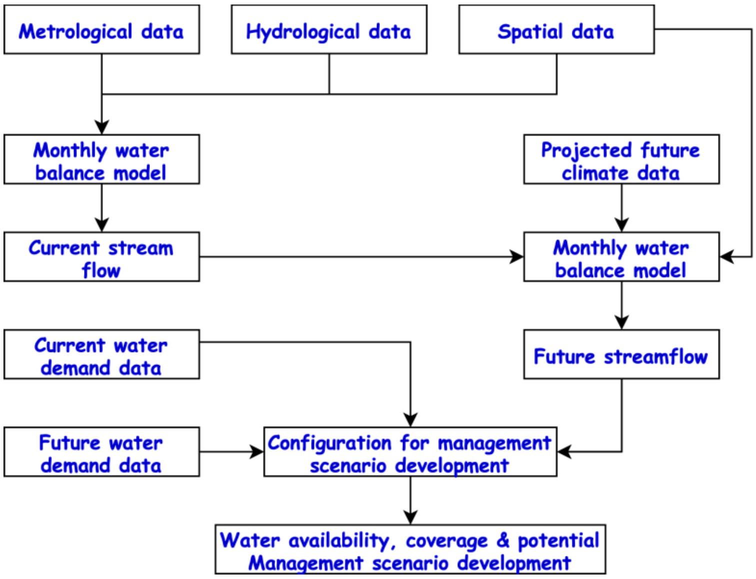

Figure 2: Conceptual model.

Outcomes and Deliberations

Precipitation

The outcomes of the inter-annual rainfall patterns for the RCP-2.6, RCP-4.5, and RCP-8.5 models are illustrated in Figure 3a. It demonstrated that in RCP-2.6, precipitation is not much impacted. However, RCP-4.5 experienced a rise, and RCP-8.5 experienced a drop in precipitation. The ambiguity in the long-term inter-annual total yearly rainfall trend needs an examination of monthly dispersion to comprehend the impact of CC. Examining the quarterly variation in rainfall across the three situations elucidates a pattern in how it falls. The monthly trends for situations RCP-4.5 and RCP-8.5 distinctly demonstrate a potential reduction in rainfall during the rainy period and an increase during the dry months (Figure 3b). The decrease in precipitation was especially significant during the Kiremt period. The research indicates that the seasonality shift can be substantial in RCP-8.5. The monthly research suggests that the volume influences the typical commencement and conclusion of the rainfall season throughout the wet and dry seasons. This has significant consequences for rainfed farming and surface WR availability for agriculture.

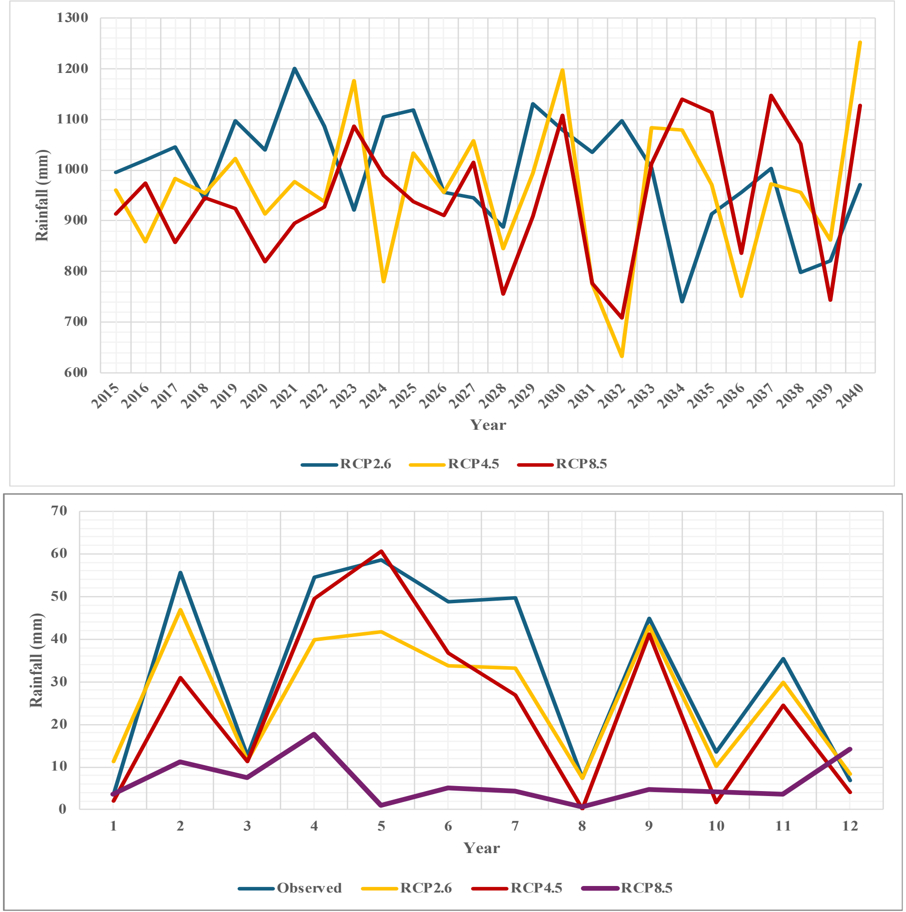

Figure 3: Rainfall analysis.

Thermal Measurement

Figure 4 illustrates the trend in the mean temperature variation from 2015 to 2040. The mean temperature across all scenarios exhibits an upward trend, with a more pronounced rate of increase anticipated in the RCP-8.5 prediction. The mean temperature is projected to rise by more than 1.7 °C for the RCP-8.5 situation and 1.8 °C for the RCP-4.5 situation. The rise in the RCP-2.6 situation was below 0.7 °C. The yearly rising temperature pattern resulted from increased evapotranspiration and decreased soil moisture, indicating WR stress. This requires resolution through suitable adaptation strategies.

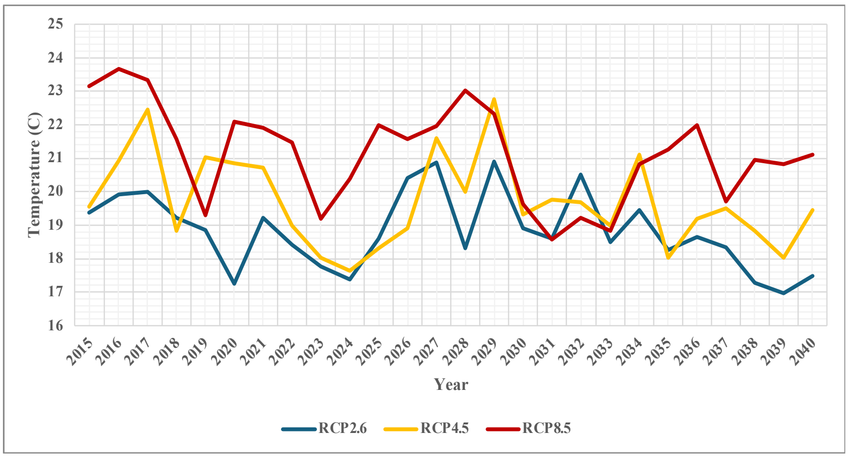

Figure 4: Temperature analysis.

Discussion

National and International Interconnections

In the forthcoming decades, alterations in WR demand will converge with CC, exerting further strain on WR availability. WR consumption is anticipated to rise in some areas of the state owing to urban expansion, a rise in the general population, ongoing development in businesses and industries, and heightened demand for irrigation. The research employed population growth forecasts to calculate future WR consumption for regions by extrapolating non-linear historical trends in WR utilization effectiveness (WR usage per capita) according to established methodologies. 2060 compared to 2020, WR consumption is anticipated to rise significantly in the home and public sectors, and counties are forecast to see substantial population increases (62-111%). Likewise, WR consumption in the irrigation industry is anticipated to rise until 2060 as the area under irrigation keeps growing. Tensions have arisen between unincorporated regions and the burgeoning dairy business; irrigation WR consumption is expected to increase by 73% by 2065. WR consumption in industry and business industries is expected to rise, with usage projected to exceed twofold (114% increase).

Rising irrigation demand will probably be met by groundwater, while industrial and business WR needs growth from combining both sources. Enhanced rainfall between winter and springtime will aid in sustaining WR supply; these assets are not evenly distributed throughout the state, resulting in different access to WR resources. Heightened wintertime and springtime rainfall will be counterbalanced by augmented demand from evaporation during summer, leading to an escalating necessity for effective control of WR throughout the calendar year's arid periods and considering solutions that enhance inter-seasonal storage capabilities. These modifications underscore the necessity for synchronized adaptation and mitigation strategies to safeguard the state's WR supplies and alleviate impacts on the state's financial system.

Strategies for Adaptation as well as Mitigation

WR Provision

Future estimates persist and, in certain instances, exacerbate the trend of increased precipitation during winter and spring, while summertime precipitation remains relatively stable or diminishes. Future estimates suggest inconsistent conditions (i.e., no systematic alteration in rainfall) in late spring and early summertime but consistently less precipitation in the final weeks of summer. Alongside heightened evapotranspiration during the growing period, WR supplies are anticipated to face more significant strain after summer, notwithstanding the rise in yearly rainfall in most regions. The objective is to enhance the handling of typically plentiful WR supplies and establish storage solutions that reconcile the surplus of springtime with shortages in summertime and early fall.

Many optimal sites for surface WR dams have already been created in the region; therefore, enhanced management of these current assets serves as a strategy for adjusting to heightened summer drought conditions. Possible methods for enhancing preservation in the territory involve sustained expenditure on healthy soil efforts and the augmented implementation of drainage WR conservation procedures, particularly where underground drainage is limited outside the periods when field activities necessitate reduced WR charts for availability. This can enhance WR retention in fields, diminishing the necessity for watering and offering WR quality advantages, such as the more significant volatilization of ammonia into the atmosphere rather than surface waters. Investing in facilities to enhance groundwater aquifer refuel, such as infiltrated basins, can also augment winter and spring WR reserves for utilization during the fall and spring. These strategies are particularly significant given the rising irrigation demands, as enhanced pumping across a broader area could lead to a markedly diminished WR table, depletion of WR from current shallow wells in unrestricted aquifers, and elevated pumping expenses. Adapting encompasses supplementary municipal stormwater management techniques aimed at diminishing stormflow and enhancing infiltration, facilitating WR transfer from progressively wetter winters to dryer summers, and mitigating impacts in both periods. Urban regions that enhance aquifer recharge by capturing more rain throughout winter and spring might provide retained WR to municipal holes. Future alterations in yearly and seasonal rainfall, particularly regarding extremes, must be considered when developing facilities, as it is generally more feasible to incorporate these considerations into fresh designs than modifying old systems.

Quality of Water

Given the likelihood of increased sediment and nutrient influx to WR bodies, implementing pollutant and prevention measures becomes more essential, alongside a reevaluation of agricultural nitrogen management methods. Contemporary standard operating procedures demonstrate significant sensitivity to CC variability, and their efficacy is anticipated to diminish under future circumstances. Elevated penetration rates during wintertime, which improve subsurface nutrient routes, and the heightened probability of flooding from higher spring precipitation are expected to be two principal factors constraining the effectiveness in future years. Modifying management strategies (e.g., implementing cover plants) and enhancing environmental resilience within ecosystems will be essential for mitigating adverse impacts on WR quality.

Conclusion

The study region is anticipated to undergo a rising trend in yearly rainfall, which is estimated to escalate across all future CC forecasts. WR administration will gain significance as the variability in accessibility to WR intensifies and demand escalates. The principal results of this paper are outlined below:

- Inter-seasonal WR control will become significant as spring and fall surpluses are succeeded by shortages in autumn and summer. Enhanced short-term WR handling can alleviate spring floods and saturated circumstances; optimizing storing or replenishment of groundwater guarantees surplus WR availability throughout the growth season.

- The general pattern of daily flow of streams for streams is projected to grow by the century's conclusion. The spike in indicated and minimal flows resulting from overall drier annual developments indicates greater surface WR availability; however, the rise in high flows and the heightened risk of more significant peak levels suggest that WR facilities are jeopardized and could profit from assessment regarding anticipated future flows. The retention of WR will be influenced by heightened infiltration early in the year, notably where soil snow and icy cover will diminish.
- Although wetter yearly circumstances are anticipated, the necessity for drought mitigation will escalate as summer potential for evapotranspiration surpasses the soil's current moisture. Enhanced data on the preservation of groundwater and its long-term accessibility variations would be advantageous, as underground storage seems to be declining, particularly in the state's northern regions.

Current Best Management Practices for regulating WR quality are anticipated to become less successful due to alterations in seasonal WR supply and the proliferation of irrigation. Adverse spring weather conditions are likely to exceed the capacity of specific circumvent others due to heightened subsurface drainage rates. Effective management of drainage WR methods significantly contributes to resolving these difficulties.

States need improved methods and equipment to predict WR usage fluctuations and demand and enhanced collaborative oversight of the WR supply. The investigated area possesses adequate WR to flourish against CC. However, achieving equilibrium in seasonal and spatial WR utilization across different sectors would be crucial for effective planning in the future.

References

Assegid, W. and Ketema, G., 2023. Assessing the Effects of Climate Change on Aquatic Ecosystems. *Aquatic Ecosystems and Environmental Frontiers*, *1*(1), pp.6-10.

Gao, G., Xiao, R. and Li, Y., 2024. Influences of extreme rainfall events on the nutrient and chlorophyll-a dynamics in coastal regions. In *Current Trends in Estuarine and Coastal Dynamics* (pp. 339-383). Elsevier. https://doi.org/10.1016/B978-0-443-21728-9.00012-0

Hu, X. and Sinniah, S., 2024. The Role of Green Risk Management Approaches in Promoting Green and Sustainable Supply Chain Management. *Natural and Engineering Sciences*, *9*(2), pp.33-54. https://doi.org/10.28978/nesciences.1569144

Iglesias, V., Braswell, A.E., Rossi, M.W., Joseph, M.B., McShane, C., Cattau, M., Koontz, M.J., McGlinchy, J., Nagy, R.C., Balch, J. and Leyk, S., 2021. Risky development: Increasing exposure to natural hazards in the United

States. *Earth's future*, *9*(7), p.e2020EF001795. https://doi.org/10.1029/2020EF001795

Iyengar, S. and Bhattacharya, P., 2024. Assessing the Effects of Climate Change on Population Displacement and Migration Patterns in Coastal Communities. *Progression journal of Human Demography and Anthropology*, *2*(4), pp.15-21.

Kender, S., Bogus, K., Pedersen, G.K., Dybkjær, K., Mather, T.A., Mariani, E., Ridgwell, A., Riding, J.B., Wagner, T., Hesselbo, S.P. and Leng, M.J., 2021. Paleocene/Eocene carbon feedbacks triggered by volcanic activity. *Nature communications*, *12*(1), p.5186. https://doi.org/10.1038/s41467-021-25536-0

Krishnan, M., and Patel, A., 2023. Circular Economy Models for Plastic Waste Management in Urban Slums. *International Journal of SDG's Prospects and Breakthroughs*, *1*(1), pp.1-3.

Kumar, R. and Rao, P., 2024. Intelligent 3d Printing for Sustainable Construction. *Association Journal of Interdisciplinary Technics in Engineering Mechanics*, *2*(3), pp.22-29.

Lourens, L.J., 2021. The variation of the Earth's movements (orbital, tilt, and precession) and climate change. In *Climate change* (pp. 583-606). Elsevier. https://doi.org/10.1016/B978-0-12-821575-3.00028-1

Magruder, L.A., Farrell, S.L., Neuenschwander, A., Duncanson, L., Csatho, B., Kacimi, S. and Fricker, H.A., 2024. Monitoring Earth's climate variables with satellite laser altimetry. *Nature Reviews Earth & Environment*, *5*(2), pp.120-136. https://doi.org/10.1038/s43017-023-00508-8

Pan, Y., Zhang, H., Wang, C. and Zhou, Y., 2023. Impact of land use change on regional carbon sink capacity: Evidence from Sanmenxia, China. *Ecological Indicators*, *156*, p.111189. https://doi.org/10.1016/j.ecolind.2023.111189

Prabhudeva, T. and Hariharan, R., 2024. A Systematic Review and Meta-Analysis of Tuberculosis Patients: Perspectives of Pharmacists Towards Sustainability. *Clinical Journal for Medicine, Health and Pharmacy*, *2*(4), pp.1-10.

Prasad, B.S.V., and Roopashree, H.R., 2023. Energy Efficient Secure Key Management Scheme for Hierarchical Cluster Based WSN. *Journal of Internet Services and Information Security*, *13*(2), pp.146-156. https://doi.org/10.58346/JISIS.2023.I2.009

Praveenraj, D.D.W., Prabha, T., Ram, M.K., Muthusundari, S. and Madeswaran, A., 2024. Management and Sales Forecasting of an E-commerce Information System Using Data Mining and Convolutional Neural Networks. *Indian Journal of Information Sources and Services*, *14*(2), pp.139-145. https://doi.org/10.51983/ijiss-2024.14.2.20

Robles, T., Alcarria, R., De Andrés, D.M., De la Cruz, M.N., Calero, R., Iglesias, S., and Lopez, M., 2015. An IoT based reference architecture for smart water management processes. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and*

Dependable Applications, *6*(1), pp.4-23.

Saidova, K., Abdullayeva, S., Yakubova, D., Gudalov, M., Abdurahmonova, K., Khudoykulova, H., Mukhammadova, G., and Zokirov, K., 2024. Assessing the Economic Benefits of Climate Change Mitigation and Adoption Strategies for Aquatic Ecosystem. *International Journal of Aquatic Research and Environmental Studies*, *4*(S1), pp.20-26. https://doi.org/10.70102/IJARES/V4S1/4

Salokhiddiov, A., Khakimova, P., Ismailov, M., Razzakov, R. and Mirzaqobulov, J., 2020, July. Impact of Climate Change on Irrigated Agriculture in steppe Zones of Uzbekistan. In *IOP Conference Series: Materials Science and Engineering* (Vol. 883, No. 1, p. 012073). IOP Publishing. http://doi: 10.1088/1757-899X/883/1/012073

Short, J.R. and Short, J.R., 2021. Hurricane Katrina, Infrastructure Deficit and the Costs of Climate Change. *Stress Testing the USA: Public Policy and Reaction to Disaster Events*, pp.37-86. https://doi.org/10.1007/978-3-030-65999-8_3

Suljić, N., and Kovčić, O., 2018. Analysis of Time Oscillations of Water on Lake Modric as a Multi-Purpose Reservoir. *Archives for Technical Sciences*, *1*(18), pp.31–40.

Trisiana, A., 2024. A Sustainability-Driven Innovation and Management Policies through Technological Disruptions: Navigating Uncertainty in the Digital Era. *Global Perspectives in Management*, *2*(1), pp.22-32.

Trivedi, P., Batista, B.D., Bazany, K.E. and Singh, B.K., 2022. Plant–microbiome interactions under a changing world: responses, consequences and perspectives. *New Phytologist*, *234*(6), pp.1951-1959. https://doi.org/10.1111/nph.18016

Wei-Liang, C. and Ramirez, S., 2023. Solar-Driven Membrane Distillation for Decentralized Water Purification. *Engineering Perspectives in Filtration and Separation*, *1*(1), pp.16-19.

Yasmin, N., Jamuda, M., Panda, A.K., Samal, K. and Nayak, J.K., 2022. Emission of greenhouse gases (GHGs) during composting and vermicomposting: Measurement, mitigation, and perspectives. *Energy Nexus*, *7*, p.100092. https://doi.org/10.1016/j.nexus.2022.100092

Zhang, Y., Long, H., Chen, S., Ma, L. and Gan, M., 2023. The development of multifunctional agriculture in farming regions of China: Convergence or divergence?. *Land Use Policy*, *127*, p.106576. https://doi.org/10.1016/j.landusepol.2023.106576