



## ASSESSING THE IMPACT OF CLIMATE CHANGE ON RIVER SYSTEMS – A REVIEW OF HYDROLOGICAL MODELING APPROACHES

LALWANI P.K.<sup>1\*</sup>, PATEL V.M.<sup>2</sup>, CHADEE A.A.<sup>3</sup>, JHA S.<sup>4</sup>, TRIPATHI R.<sup>5</sup>

<sup>1</sup> PhD Scholar, Gujarat Technological University, Ahmedabad, India

<sup>2</sup> Professor, Department of Civil Engineering Shantilal Shah Engineering College, Bhavnagar, India

<sup>3</sup> Lecturer, Department of Civil and Environmental Engineering, University of the West Indies, Saint Augustine Campus, Trinidad and Tobago

<sup>4</sup> Assistant Professor, Department of Civil Engineering, Lalbhai Dalpatbhai College of Engineering, Ahmedabad, India.

<sup>5</sup> Assistant Professor, Department of Civil Engineering, Madam Mohan Malaviya University of Technology, Gorakhpur, India.

*prashant.lalwani86@gmail.com*

---

Research Article – Available at <http://larhyss.net/ojs/index.php/larhyss/index>

Received July 12, 2025, Received in revised form February 18, 2026, Accepted February 20, 2026

---

### ABSTRACT

Climate change affects the physical environment, ecosystem and human life. Changes in climate, impacts the atmosphere, hydrosphere, lithosphere and biosphere eventually, but from the last couple of decades the intensity of impacts is considerable in various ways such as global warming, rise in sea water level, extreme events etc. Hydrosphere is one of the most affected areas due to environmental anomalies in climate change. For better understanding of the climate change impact on the hydrosphere, the river system study is required. The issue of environment and climate change is very renowned. Moreover, it has been observed that the climate is continuously changing its pattern. In this review, we aim to understand the effects of climate change on the western part of India along with the global climate change. Computers and geospatial technologies have made it possible to understand the changes in climate in the past, as well as in the future, with the aid of different hydrological models.

**Keywords:** Climate change, Runoff, Hydrological Modelling, Flood risk, Climatology, River systems, geospatial technologies, India.

## **INTRODUCTION**

Climate change has become a persistent global phenomenon, evidenced by continuous alterations in water resources and environmental variables such as temperature and precipitation (Bouguerra and Benslimane, 2017; Assemian et al., 2021; Remini, 2020; 2024; Nakou et al., 2023). These shifts directly and indirectly influence human health, socio-economic development, and ecological stability (Patel et al., 2021; Mehta and Yadav, 2024; Ande et al., 2025). Anthropogenic activities are accelerating climate disturbances worldwide, despite mitigation efforts, with billions of people being affected. Current projections warn of alarming climate scenarios over the next two decades, particularly with the global temperature rise approaching 1.5°C (2.7°F). Addressing these risks requires proactive political commitment, as adaptation is neither automatic nor guaranteed (Callahan, 2025; Chadee et al., 2023; Mehta et al., 2023a; Mehta and Yadav, al., 2023b). This requires urgent actions such as developing regional climate models (RCMs) (Kouao et al., 2020; Pang and Tan, 2023), including diagnosis (Choukrani et al., 2018), projection of climate variability as already recommended by Oga et al. (2016) and Doumounia et al. (2020), vulnerability and adaptation strategies (Nichane and Khelil, 2015), statistical adjustment models (Nassa et al., 2021), strong simulation models (Mah et al., 2024), and groundwater and surface water management (Paulo Monteiro and Costa Manuel, 2004; Pandey et al., 2022; Kouloughli and Telli, 2023; Qureshi et al., 2024).

Among the various environmental parameters, rainfall plays a vital role in both climatic systems and hydrological processes, influencing ecosystems and human livelihoods (Benkaci et al., 2020; Adja et al., 2021; Mohamed et al., 2022; Mehta and Yadav, 2023c; Bong et al., 2023; Baudhanwala et al., 2024; Atallah et al., 2024). The increasing concentration of greenhouse gases has caused the Earth's mean surface temperature to rise by approximately 1°C (ranging between 0.8°C and 1.2°C) since the pre-industrial era (Hood, 2007; Mehta and Yadav, 2022a; Baudhanwala et al., 2023). This warming trend has disrupted the global hydrological cycle, significantly impacting freshwater availability at multiple spatial and temporal scales (Mehta and Yadav, 2022b; Pastagia et al., 2025; Sahu et al., 2024). Accordingly, accurate streamflow projections under changing climatic conditions are crucial, especially in arid regions, to ensure efficient water resource management (Benslimane et al., 2011; Mehta and Yadav, 2021; Xiang et al., 2022; Pastagia et al., 2023; Berrezel et al., 2023). In recent years, considerable research has focused on modeling future climate scenarios and evaluating their impact on surface runoff, typically through hydrological model-based impact assessments (Pastagia et al., 2022; Benali Khodja and Ferdjouni, 2024; Mehta et al., 2025).

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Change, 2007) confirms that human activities have significantly increased atmospheric, oceanic, and terrestrial temperatures by elevating well-mixed greenhouse gas (GHG) concentrations (Dawson and Spannagle, 2020; Patel et al., 2024). Many relevant studies have already pointed out the impact of climate change, associated with anthropic and anthropogenic activities, on aquifers and surface water resources (Haouchine et al., 2021; Adjagodo et al., 2016; Laghzal et al., 2019). In India, and in many countries worldwide, climate change studies indicate critical implications for freshwater systems

due to altered rainfall patterns, increased surface temperatures, changes in groundwater recharge (El Moukhayar et al., 2015; Bemoussat et al., 2017; Remini, 2019; Chibane and Ali-Rahmani, 2015), seasonal runoff shifts, and enhanced evaporation (Singh and Kumar, 2018). The country's diverse climatic zones, from the alpine Himalayas to tropical and arid regions, contribute to its complex and regionally varied climate response (Nayak and Takemi, 2022; Patel et al., 2024).

Historical records show that between 1951 and 2010, India experienced average temperatures exceeding 25°C and daily precipitation levels ranging from 3 to 5 mm. Future projections using Atmospheric General Circulation Models (AGCMs) forecast a temperature increase of 4-5°C and a precipitation increase of 2-45% for the period 2051-2110 relative to 1951-2010 (Nayak and Takemi, 2022; Shaikh et al., 2022). In addition, land use/land cover (LULC) models predict an increase of 40-50 mm in monthly rainfall by 2100, alongside the conversion of 0.071 million sq. km of natural land to agricultural and urban uses. Flood-prone areas may increase by 122% (equivalent to 0.15 million sq. km), underscoring the severity of extreme events (Saidi et al., 2012; Waikhom et al., 2023).

Climate change is profoundly intensifying the global hydrological cycle, fundamentally altering precipitation patterns and increasing the frequency, magnitude, and unpredictability of floods and flash floods (Hachemi and Benkhaled, 2016; Remini, 2023; Ezz, 2025; Do et al., 2025). As atmospheric temperatures rise, the capacity of air to hold water vapor increases, leading to heavier and more concentrated rainfall events. This shift does not necessarily imply uniform increases in total annual rainfall, but rather a redistribution characterized by prolonged dry periods followed by extreme downpours. Such changes amplify surface runoff, overwhelm natural infiltration capacities, and significantly elevate peak discharges in river systems. River floods are becoming more severe due to intensified rainfall clustering, accelerated snowmelt, altered seasonal runoff timing, and, in coastal zones, the compounding influence of sea-level rise that reduces drainage efficiency.

Even more alarming is the increased occurrence of flash floods, which develop rapidly within small catchments or urban areas following short-duration, high-intensity storms (Hafnaoui et al., 2022; Gassi and Saoudi, 2023). These events produce destructive flow velocities, limited warning time, and high human vulnerability, particularly in densely populated regions where land sealing and inadequate drainage infrastructure prevent effective water absorption. The growing instability of precipitation regimes undermines the historical assumption of hydrological stationarity upon which traditional flood design standards were based, rendering past return-period estimates increasingly unreliable (Benkhaled et al., 2013).

Consequently, flood risk is no longer governed solely by meteorological variability but by a complex interaction of climate dynamics, land-use change, urban expansion, deforestation, wetland degradation, and aging hydraulic infrastructure (Nezzal et al., 2015; Ayari et al., 2016; Bekhira et al., 2019; Abd Rahman et al., 2023; Athmani et al., 2025). The urgent need to improve risk protection demands a shift from rigid flood defence approaches toward adaptive, resilience-based flood management frameworks

that integrate dynamic climate projections into engineering practice (Hountondji et al., 2019). Modern flood management must combine structural measures such as reservoirs (Mezener et al., 2022; Zegait and Pizzo, 2023a; Mehta et al., 2023b; Panchal and Suryanarayana, 2025), levees, diversion channels, and detention basins with nature-based solutions including watershed reforestation, floodplain restoration, wetland conservation, and green urban infrastructure that enhance infiltration and attenuate peak flows. Advanced forecasting systems employing radar monitoring, satellite rainfall estimation, hydrological modelling, and artificial intelligence are essential to provide early warning and reduce casualties (Boulghobra, 2013; Cherki, 2019; Benslimane et al., 2020; Aroua, 2020; Baudhanwala et al., 2023; Ben Said et al., 2024).

Equally critical is the implementation of land-use regulation that restricts development in high-risk flood zones and encourages climate-adaptive urban planning. Combating floods requires integrated watershed management that treats upstream and downstream processes as interconnected components of a single system, climate-informed infrastructure design with increased safety margins and flexible operating rules, modernization of urban drainage systems to accommodate extreme rainfall intensities, and strengthened community preparedness supported by education and emergency planning. Financial risk-transfer mechanisms and adaptive governance frameworks must complement engineering solutions to ensure sustainable recovery and long-term resilience. Floods are natural hydrological processes that cannot be entirely prevented; however, their impacts can be substantially mitigated through proactive planning, scientifically grounded modelling, and coordinated policy action (Zegait and Pizzo, 2023b). In the context of accelerating climate change, the transition from reactive flood control toward anticipatory flood resilience is no longer optional but an essential imperative for protecting lives, infrastructure, and economic stability in vulnerable regions worldwide.

Globally, climate change is recognized as a defining challenge of our era, with the potential for long-term, irreversible transformations. In response, the 2015 Paris Agreement (COP21) sought unified international action, with 196 countries committing to limit global warming to below 2°C, ideally to 1.5°C, and to achieve carbon neutrality by mid-century. The European Union, for instance, has pledged to cut GHG emissions by at least 20% by 2020 and 40% by 2030 compared to 1990 levels, supported by robust legislative frameworks (Campagna and Fiorito, 2022).

Hydrological models are essential tools for quantifying the impacts of climate change, helping policymakers devise strategies for mitigation, adaptation, and sustainable water management across river basins (Bhusal et al., 2025; Chadee et al., 2024; Chadee et al., 2025). For example, Vadodara District in Gujarat experienced severe floods in 2013 and 2019, with annual rainfall reaching 1439 mm and 1427 mm respectively. Projections indicate that rainfall events exceeding 1622 mm have a recurrence interval of 25 years, highlighting the increasing frequency of extreme events (Shah et al., 2021; Chadee et al., 2021).

In western India, river basins like Sabarmati and Luni, spanning parts of Gujarat and Rajasthan, face acute water scarcity. Other basins such as Mahi, Pennar, and Tapi also report persistent shortages (Popova, 2019). The lower Tapi Basin exhibited significant annual rainfall trends: 2.185 mm/year (1928-2013), 4.181 mm/year (1955-2013), and 5.495 mm/year (1970-2013), suggesting an intensified climate signal during the latter half of the 20th century and early 21st century (Chandole et al., 2019).

Localized studies in the Watrak and Mazum river watersheds confirm climate change effects such as increased annual rainfall, intensified precipitation during July and August, and delayed onset and withdrawal of the monsoon season, a clear indication of seasonal drift (Joshi et al., 2019). In the upper Sabarmati catchment, while many extreme rainfall indices remain statistically insignificant at the 95% confidence level, seasonal variability could still substantially influence regional hydrology (Sharma et al., 2020). The agriculture and water sectors in arid western India remain particularly vulnerable to these changes (Machiwal et al., 2019).

## **Climate Change**

The changes in the Earth's climate/Environment have been happening since the Earth's origin (Lipczynska-Kochany, 2018). "Climate" term refers to global, long-term (years or decades) environmental conditions due to natural causes or anthropogenic cause over seasons. Climate change is classified by a wide range of temperature and precipitation trends and also other ingredient such as pressure and humidity level in the surrounding environment. (Lipczynska-Kochany, 2018). Latest by mid-1800s, scientists have known that CO<sub>2</sub> is one of the prime greenhouse gases of importance to Earth's energy balance. Results from measurements of CO<sub>2</sub> in the atmosphere and in air trapped in ice show that atmospheric CO<sub>2</sub> rose by more than 40% from 1800 to 2019. Measurements of various forms of carbon disclose that this increase is due to manmade activities. Other greenhouse gases (notably methane and nitrous oxide) are also amplified as a result of manmade activities. As per IPCC AR5 report, if emissions follow their present trajectory path, without either technological or regulatory reduction, then the best estimate is that the worldwide average temperature will hit a further 2.6 to 4.8 °C (4.7 to 8.6 °F) at the end of the century (Collados-Lara et al., 2022).

## **Vulnerability**

Vulnerability is a core concept in climate change research, as it helps identify the extent to which natural and human systems are likely to be affected by climate-related hazards. The idea of vulnerability extends far beyond climate studies and is widely applied across several interdisciplinary domains such as disaster risk reduction, sustainability science, ecosystem management, public health, poverty and development, food and livelihood security, and land-use change (Füssel, 2007).

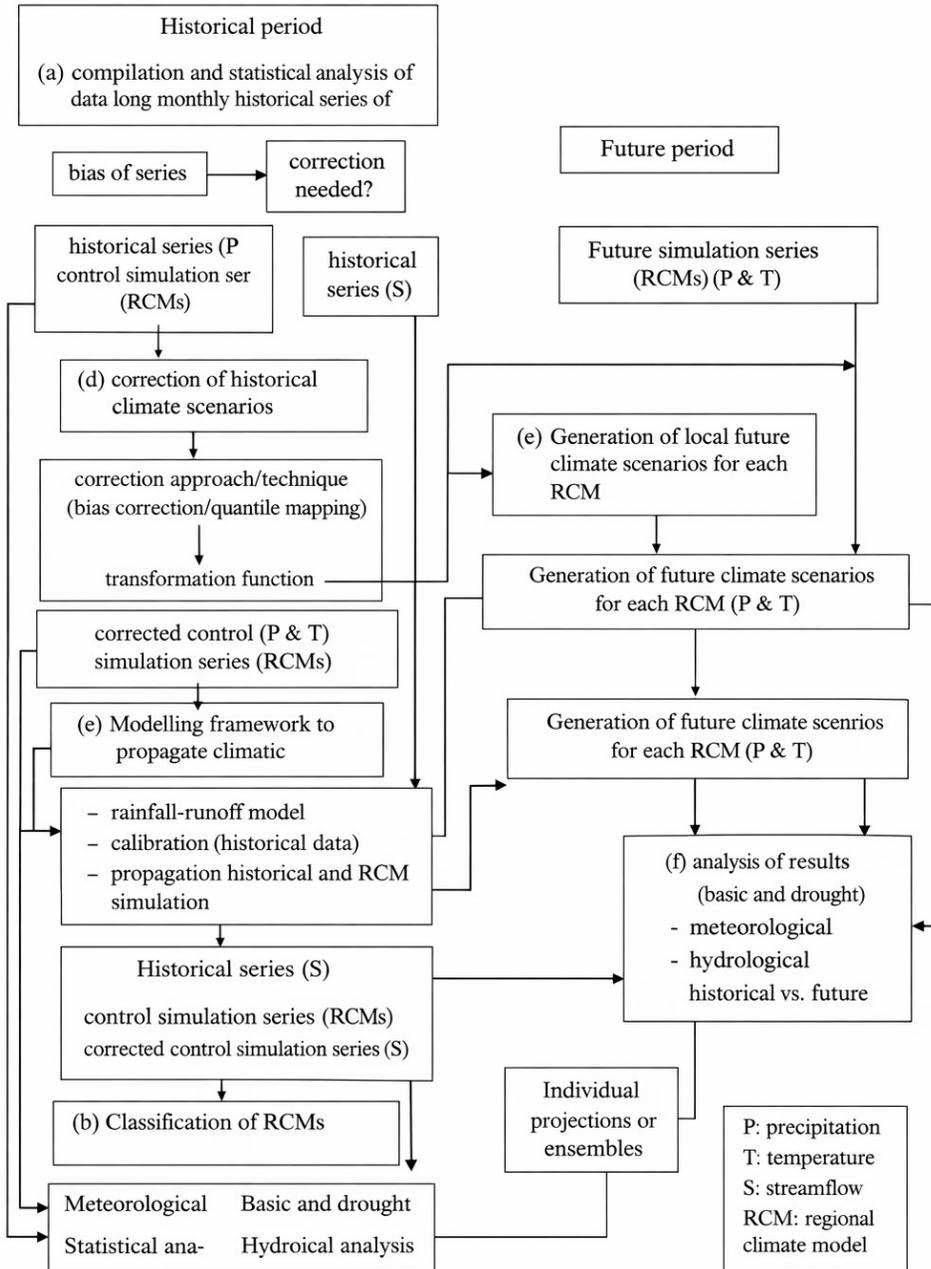
In the context of climate change, vulnerability reflects the degree to which a system, whether ecological, social, or economic, is exposed to climate risks, sensitive to those risks, and capable of adapting to them. These three elements, exposure, sensitivity, and

adaptive capacity, form the basis for most vulnerability assessments. For instance, a farming community located in a drought-prone region may be highly exposed and sensitive due to its dependence on rainfall, but its vulnerability will also depend on its access to resources, technology, and institutional support to adapt.

Understanding vulnerability is crucial for designing effective adaptation strategies, prioritizing vulnerable regions or populations, and supporting sustainable development goals. Therefore, a clear and comprehensive discussion on vulnerability strengthens climate change impact assessments and ensures that policy responses are both targeted and equitable.

## **METHODOLOGY**

Fig. 1 outlines a systematic framework designed to evaluate the impacts of climate change on hydrological systems through the integration of observational data, climate projections, bias correction techniques, and hydrological modelling. The framework is divided into two distinct phases: The Historical Period and the Future Period.



**Figure 1: Flow chart of the proposed methodology for the assessment of future meteorological and hydrological droughts (Collados-Lara et al., 2022)**

In the Historical Period, the initial step (Step A) involves gathering and analyzing long-term monthly records of precipitation (P), temperature (T), and streamflow (S). These observational datasets are compared against control simulations from Regional Climate Models (RCMs) to identify any consistent deviations or biases. If biases are detected, Step B applies correction methods, such as quantile mapping or other statistical transformation techniques, to adjust the simulated P and T data.

Following this, Step C utilizes a calibrated hydrological model (e.g., a rainfall-runoff model) that is driven by both observed data and bias-corrected RCM outputs to simulate hydrological responses. In Step D, the RCMs are assessed for their accuracy in replicating climate variables and hydrological indicators, including drought characteristics, using statistical evaluation metrics.

The Future Period begins with Step E, where outputs from Global Climate Models (GCMs) are dynamically downscaled using RCMs to create localized future climate projections for P, T, and S. These projections are then run through the previously calibrated hydrological model to estimate future hydrological behaviour.

In the final stage (Step F), simulations from both historical and future periods are compared to evaluate changes in meteorological trends, hydrological responses, and drought patterns. This analysis can be conducted using either individual models or ensemble approaches.

Overall, this framework enables a comprehensive and scientifically sound assessment of climate change impacts on water resources, supporting the development of effective adaptation and planning strategies.

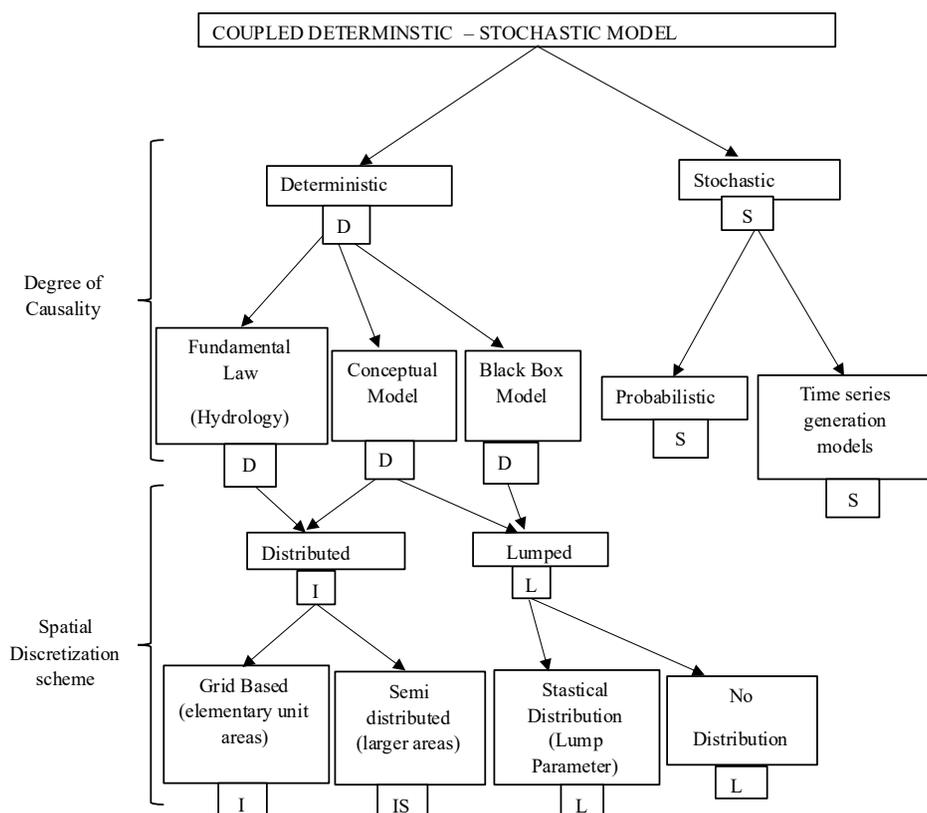
## **HYDROLOGICAL MODELLING**

The policy makers are always looking for predictions about the possible impacts of climate change on water resources. Integrated environmental models, combining climatic and hydrologic models, are generally utilised for this purpose (Buytaert et al., 2009).

A model is a simple way to replicate the real-world system (Vinet and Zhedanov, 2011). The best model is the one which gives results near to the real-world with the use of optimum parameters and model complication. Models are mainly used for predicting system conduct and understanding different hydrological procedures. A model carries many parameters that define the characteristics of the model (Devia et al., 2015). As presented in Fig. 2, various advanced models and computer applications have been developed to assist in the long-term planning, design, and management of water resources. These tools play a vital role in predicting, analyzing, and controlling different aspects of water resource systems. (WMO, 1990).

The past of hydrological modelling spans from rational methods to recent distributed physically meaningful models. During the model development, input-output models, now called data-driven models, have developed into artificial neural network (ANN) models and data-driven mechanistic (DBM) models, starting from the simple unit hydrograph

(Todini, 2011). From the last sixty to seventy years’ research in the area of hydrology and water resources has been highly concerned with the evolution of mathematical models and with their application for different intent such as hydrological forecasting, data extrapolation in time and space, and the prediction and assessment of the effects of human-induced on the natural hydrological regime (Zakwan et al., 2022). The more hydrological models evolved, the more it became clear that a gap existed between theory and practice, that is, between the models and their practical application (Zakwan et al., 2022).



**Figure 2: Classification of hydrological models in terms of purpose, degree of casualty and applied direction (WMO, 1990)**

A hydrological balance model is described to disseminate various climate scenarios (historical, control, corrected control and futures) in order to evaluate hydrological series (streamflow series) and their basic and drought statistics (Collados-Lara et al., 2022).

Rainfall-runoff models are distinguished based on model input, parameters, and the extent of physical theories applied in the model. It can be distinguished as a lumped and distributed model based on the model parameters as a purpose of space and time and deterministic and stochastic models based on the other criteria (Devia et al., 2015).

## **INTEGRATING CLIMATE AND HYDROLOGICAL MODELS FOR FUTURE PROJECTIONS**

With advancements in modelling techniques, hydrological models have become a crucial component in transforming meteorological Quantitative Precipitation Forecasts (QPFs) into flood forecasts at specific river cross-sections (Todini, 2011). The increasing pressure exerted by climate change has also driven the integration of hydrological models into General Circulation Models (GCMs), which simulate future climatic scenarios by numerically representing the dynamic interactions of the Earth's climate system (Zinyengere et al., 2017).

However, GCM outputs often contain systematic biases, primarily arising from simplifications in the representation of geophysical processes, assumptions in parameterization, and computational limitations (Hengade et al., 2018). To enhance their reliability, bias correction methods are employed, particularly quantile-based remapping techniques, which adjust GCM-derived predictors to align with observed data (Li et al., 2010; Hengade et al., 2018). This process ensures that discrepancies between observed and model-simulated climate variables are minimized.

To accurately assess future hydrological conditions at a regional or basin scale, downscaling techniques are applied. These methods refine coarse-resolution GCM outputs to produce high-resolution datasets. Two primary approaches exist: dynamic downscaling using Regional Climate Models (RCMs), which are physically based but computationally intensive; and statistical downscaling, which is computationally efficient due to its reliance on empirical relationships (Buytaert et al., 2009; Hay et al., 2011; Chen et al., 2012). Improving both climatic and hydrological modelling frameworks, along with refining downscaling techniques, is essential for better understanding and responding to future climate scenarios.

Regional climate change projections are foundational for assessing the potential impacts and associated risks of climate change. These projections form a critical component of comprehensive assessments conducted by the Intergovernmental Panel on Climate Change (IPCC). Despite several global initiatives aimed at producing such projections, widespread usability among impact assessment communities and stakeholders remains limited, presenting an opportunity to enhance the integration between climate projections and risk assessments (Change, 2007).

Detecting trends in hydrological time series is essential for understanding long-term climate-induced changes. Numerous statistical methods exist for trend detection, broadly categorized into parametric and non-parametric approaches. While parametric methods assume data normality, non-parametric tests such as the Mann-Kendall (MK) test are

widely used due to fewer assumptions. However, the MK test's reliability may be compromised in the presence of serial correlations within the data (Zakwan et al., 2022; Machiwal et al., 2019).

Substantial progress has been made in the quantitative representation of hydrological phenomena—from early empirical models like the Rational Method to sophisticated distributed, physics-based models. Nonetheless, ongoing research is required to address uncertainties in model predictions and to reconcile differing modelling approaches, particularly under climate change conditions (Todini, 2011).

In this context, the Coupled Model Intercomparison Project (CMIP), coordinated by the World Climate Research Programme, plays a pivotal role in understanding the behavior, variability, and feedback mechanisms within the climate system (Stevens, 2024). CMIP's focus includes modelling atmospheric cycles, evaluating climate sensitivity, simulating extreme events, and reducing model biases through correction techniques (Ju et al., 2025). More than 100 CMIP6 models have been developed by climate researchers globally to improve the understanding of climate change processes and their impacts.

## **CONCLUSION**

Through an extensive review of literature, it is evident that the impact of climate change is an ongoing and dynamic phenomenon, having roots in the very origin of Earth's environmental systems. Among the most affected natural components are river systems, which are highly sensitive to variations in key environmental parameters such as rainfall, temperature, and sea level. Rapid urbanization and anthropogenic activities have intensified the stress on natural ecosystems, prompting compensatory shifts in climatic patterns. These shifts manifest as rising global temperatures, increasing sea levels, irregular precipitation patterns, declining agricultural productivity, frequent droughts and floods, and accelerated glacier melt. Since the beginning of the 20th century, both temperature and rainfall extremes have shown a marked upward trend, and projections indicate that these changes will become more pronounced by the end of the 21st century. Rivers, being vital for sustaining human life and ecosystems, are particularly vulnerable, with water resources in regions like western India experiencing significant adverse effects.

Hydro-meteorological modeling has emerged as a crucial tool for policy formulation and decision-making in the face of these challenges. According to the Intergovernmental Panel on Climate Change (IPCC), there are currently thousands of simulation models available globally. However, with continuous advancements in technology and the availability of updated historical data, these models require regular refinement. The objective is to enable high-resolution, localized simulations that can replicate river-specific climatic conditions and provide reliable future projections. Such modeling efforts are essential for developing effective adaptation and mitigation strategies in response to evolving climate realities.

### **Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### **REFERENCES**

- ABD RAHMAN A.N., OTHMAN F., WAN JAAFAR W.J., AHMED ELSHAFIE A.H.K. (2023). An assessment of floods' characteristics and patterns in Pahang, Malaysia, *Larhyss Journal*, No 55, pp. 89-105.
- ADJA M.G., ASSANDE A.A., DJEMIN E.J., SORO S.I., JOURDA J.P. (2021). Contribution of a GIS to mapping and spatial-temporal characterization of rainfall variability: case of the northern part of Ivory Coast, *Larhyss Journal*, No 47, pp. 119-132.
- ADJAGODO A., AGASSOUNON DJIKPO TCHIBOZO M., KELOME AHOANGNIVO N., LAWANI R. (2016). Flow of pollutants linked to anthropic activities and risks on worldwide surface water resource (literature review), *Larhyss Journal*, No 28, pp. 7-23. (In French)
- ANDE R., BIRBAL P.Y., KANNAN S., MEHTA D., NIGAM M. (2025). Assessment of Groundwater Storage and Urban Temporal Variations using GRACE Satellite Data: Case Study of Cooum river basin, India, *Journal of Environmental Informatics Letters*, Vol. 14, No. 1, pp. 1-19.
- AROUA N. (2020). Flood risk reduction strategy in Algiers a brief modern history (XVIthC -XIXthC), *Larhyss Journal*, No 43, pp. 73-89.
- ASSEMIAN A.E., DJE BI DOUTIN S., SAMAKÉ Y. (2021). Consequences of the effects of climate change on water resources in a humid tropical zone of central eastern Côte d'Ivoire, *Larhyss Journal*, No 45, pp. 95-105.
- ATALLAH M., DJELLOULI F., HAZZEB A. (2024). Rainfall-runoff modeling using the HEC-HMS model for the Mekerra wadi watershed (N-W Algeria), *Larhyss Journal*, No 57, pp. 187-208.
- ATHMANI H., BOUKEHLIFI KOUIDER D., BENSEFIA S., DJAFRI S.A. (2025). Flood risk assessment in arid regions based on hydraulic modeling with HEC-RAS. case study of wadi Tamda in Doucen, Algeria, *Larhyss Journal*, No 61, pp. 81-109.
- AYARI K., DJEBBI M., CHAKROUN H. (2016). Flood risk mapping of the city of El Bab Medjez by the overflow of the Medjerda, *Larhyss Journal*, No 25, pp. 285-307. (In French)
- BAUDHANWALA D., KANTHARIA V., PATEL D., MEHTA D., WAIKHOM S. (2023). Applicability of SWMM for Urban Flood Forecasting A Case Study of The Western Zone of Surat City-India, *Larhyss Journal*, No. 20, pp. 159-171.

BAUDHANWALA D., MEHTA D., KUMAR V. (2024). Machine learning approaches for improving precipitation forecasting in the Ambica River basin of Navsari District, Gujarat, *Water Practice & Technology*, Vol. 19, No. 4, pp. 1315-1329.

BEKHIRA A., HABI M., MORSLI B. (2019). The management of flood risk and development of watercourses in urban areas: case of the town of Bechar, *Larhyss Journal*, No 37, pp. 75-92. (In French)

BEMMOUSSAT A., ADJIM M., BENSOUFLA F (2017). Use of the ZYGOS model for the estimation of groundwater recharge in Sikkak watershed (Northern west of Algeria), *Larhyss Journal*, No 30, pp. 105-119. (In French)

BENALI KHODJA M., FERDJOUNI N. (2024). Assessment of the meteorological drought in the northern part of Algeria “case of the Isser wadi watershed, *Larhyss Journal*, No 58, pp. 39-54.

BENKACI T., MEZENNER N., DECHEMI N. (2020). Exploration of maximum likelihood method in extreme rainfall forecasting using four probability distributions, the case of northern Algeria, *Larhyss Journal*, No 43, pp. 57-72.

BENKHALED. A., REZGUI. Z., SAKHRAOUI. F. (2013). Floods in Abiod wadi: analysis of database, *Larhyss Journal*, No 14, pp. 179-191.

BEN SAID M., HAFNAOUI M.A., HACHEMI A., MADI M., BENMALEK A. (2024). Evaluating the effectiveness of the existing flood risk protection measures along wadi Deffa in El-Bayadh city, Algeria, *Larhyss Journal*, No 59, pp. 7-28.

BENSLIMANE M, HAMIMED A., KHALDI A. EL ZERAY W. (2011). Methodological approach to evaluating wetland water management policy in the case of Chott Chergui (southwest Algeria), *Larhyss Journal*, No 22, pp. 167-181.

BENSLIMANE M., BERREKSI A., BENMAMAR S., BOUACH A. (2020). Flood risk numerical simulation of Bejaia city urban zone (Algeria), *Larhyss Journal*, No 42, pp. 167-178.

BERREZEL Y.A. ABDELBAKI C., ROUISSAT B., BOUMAAZA T., KHALDOON A.M. (2023). Decision support system for the management of water distribution networks a case study of Tourville, Algeria, *Larhyss Journal*, No 54, pp. 7-24.

BHUSAL S., SHRESTHA S., ARYAL, T. (2025). Climate change impacts on flood hazards and surface-subsurface water interactions in the Lancang Mekong River Basin, *Journal of Hydrology*, Vol. 658, Paper ID 133082.

BONG C.H.J., LIEW S.C., SIM J.E., TEO F.Y. (2023). Trend and statistical analysis of annual maximum daily rainfall (AMDR) for Sarawak River basin, Sarawak, Malaysia, *Larhyss Journal*, No 53, pp. 183-197.

BOUGUERRA S.A., BENSLIMANE N. (2017). Characterization of drought weather in climate semiarid: case of watershed wadi Boumessaoud (N-W Algeria), *Larhyss Journal*, No 29, pp. 95-110. (In French)

BOULGHOBRA N. (2013). Developing a protection plan against the riverine flood risk in urban area the case of Skikda (north-east Algeria), *Larhyss Journal*, No 13, pp. 31-45.

BUYTAERT W., CÉLLERI R., TIMBE L. (2009). Predicting climate change impacts on water resources in the tropical Andes: Effects of GCM uncertainty, *Geophysical Research Letters*, Vol. 36, No 7, pp. 1-5.

CALLAHAN C.W. (2025). Present and future limits to climate change adaptation, *Nature Sustainability*, Vol. 8, pp. 336-342.

CAMPAGNA L.M., FIORITO F. (2022). On the impact of climate change on building energy consumptions: A meta-analysis, *Energies*, Vol. 15, No 1.

CHADEE A., NARRA M., MEHTA D., ANDREW J., AZAMATHULLA H. (2023). Impact of climate change on water resource engineering in Trinidad and Tobago, *Larhyss Journal*, No 55, pp. 215-229.

CHADEE A.A., ALI B., MALLIKARJUNA V., JAMEEL M., AZAMATHULLA H.M. (2024). Application of the analytic hierarchy process for the selection of recycling rainwater/household grey water to improve SIDS sustainability targets, *Modeling Earth Systems and Environment*, Vol. 10, No. 2, pp. 1883-1895.

CHADEE A.A., CHADEE X.T., RAY I., MWASHA A., MARTIN H.H. (2021). When parallel schools of thought fail to converge: The case of cost overruns in project management. *Buildings*, Vol. 11, No. 8, 321

CHADEE A.A., SEECHARAN L.S., MARTIN H. (2025). Leading the Transition Towards Sustainable Affordable Public Housing (SAPH) in Small Island Developing States (SIDS), *Sustainability*, Vol. 17, No. 18, Paper ID 8203.

CHANDOLE V., JOSHI G.S., RANA S.C. (2019). Spatio-temporal trend detection of hydro-meteorological parameters for climate change assessment in Lower Tapi River Basin of Gujarat State, India, *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 195, pp. 105-130.

CHANGE O.C. (2007). Intergovernmental panel on climate change, *World Meteorological Organization*, Vol. 52, No. 1, pp. 1-43.

CHEN H., XU C.Y., GUO S. (2012). Comparison and evaluation of multiple GCMs, statistical downscaling and hydrological models in the study of climate change impacts on runoff, *Journal of Hydrology*, Vols. 434-435, pp. 36-45.

CHERKI K. (2019). Daily and instantaneous flood forecasting using artificial neural networks in a north-west Algerian watershed, *Larhyss Journal*, No 40, pp. 27-43.

CHIBANE B., ALI-RAHMANI S.E. (2015). Hydrological based model to estimate groundwater recharge, real- evapotranspiration and runoff in semi-arid area, *Larhyss Journal*, No 23, pp. 231-242.

- CHOUKRANI G., HAMIMSA A., SAIDI M.E., BABQIQI A. (2018). Diagnosis and future projection of climate change in arid zone. case of Marrakech-Safi region (Morocco), Larhyss Journal, No 36, pp. 49-63. (In French)
- COLLADOS-LARA A.J., GOMEZ-GOMEZ J.D.D., PULIDO-VELAZQUEZ D., PARDO-IGUZQUIZA E. (2022). An approach to identify the best climate models for the assessment of climate change impacts on meteorological and hydrological droughts, Natural Hazards and Earth System Sciences, Vol. 22, No 2, pp. 599-616.
- DAWSON B., SPANNAGLE M. (2020). The Complete Guide to Climate Change, Book, 1<sup>st</sup> Edition, Routledge Publishing, London and New York, pp. 448-449.
- DEVIA G.K., GANASRI B.P., DWARAKISH G.S. (2015). A review on hydrological models, Aquatic Procedia, International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE), 12-14 March, Mangalore (Surathkal), Karnataka, India, Vol. 4, pp. 1001-1007.
- DO T.V.H., PHAM H.G., KIEU Q.L., TRAN T.N.H. (2025). The typical mechanisms and factors leading to flash floods in small watersheds in the mountainous region of Vietnam, a case study in the CHU VA stream watershed, Larhyss Journal, No 61, pp. 141-168.
- DOUMOUNIA A., ZEB A., DAMIBA L., ZOUGMORE F, NIKIEMA M. (2020). Climate variability analysis in the Nouhao sub-basin in eastern center of Burkina Faso, Larhyss Journal, No 41, pp. 57-69. (In French)
- EL MOUKHAYAR R., BAHIR M., CARREIRA P. (2015). Estimation of groundwater recharge in arid region through hydrochemistry and isotope: a case study Kourimat basin Morocco, Larhyss Journal, No 23, pp. 87-104.
- EZZ H. (2025). Unexpected flooding in Mersa Matruh, Egypt - Investigating causes, hydrological analysis, and flood risk assessment, Larhyss Journal, No 61, pp. 371-399.
- FÜSSEL H.M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research, Global Environmental Change, Vol. 17, No 2, pp. 155-167.
- GASSI K.A.A., SAOUDI H. (2023). The effect of the physical parameterization schemes in WRF-ARW on the quality of the prediction of heavy rains that cause flooding, application on eastern Algeria, Larhyss Journal, No 56, pp. 123-137.
- HACHEMI A., BENKHALED A. (2016). Flood-duration-frequency modeling application to wadi Abiodh, Biskra (Algeria), Larhyss Journal, No 27, pp. 277-297.
- HAFNAOUI M.A., MADI M., BEN SAID M., BENMALEK A. (2022). Floods in El Bayadh city: causes and factors, Larhyss Journal, No 51, pp. 97-113.
- HAY L.E., MARKSTROM S.L., WARD-GARRISON C. (2011). Watershed-scale response to climate change through the twenty-first century for selected basins across the United States, Earth Interactions, Vol. 15, No 17, pp. 1-37.

HENGADE N., ELDHO T.I., GHOSH S. (2018). Climate change impact assessment of a river basin using CMIP5 climate models and the VIC hydrological model, *Hydrological Sciences Journal*, Vol. 63, No 4, pp. 596-614.

HOOD R. (2007). *Global warming, Book: A Companion to Applied Ethics*, Frey R.G. and Wellman C.H. Editions, Wiley Blackwell Publishing, Malden, Massachusetts, USA, pp. 674-684.

HOUNTONDJI B., CODO F.P., DAHOUNTO S.V.H., GBAGUIDI T.B. (2019). Flood management in urban environment: case of the Cotonou city in Benin, *Larhyss Journal*, No 39, pp. 333-347. (In French)

JOSHI G.S., MAKHASANA P., SHAH S. (2019). Analysis of long-term rainfall in the watersheds of Mazam and Watrak River in a Sabarmati River Basin, India, for climate change assessment, *Proceedings of the World Environmental and Water Resources Congress 2019*, May 19-23, Pittsburgh, Pennsylvania, USA, pp. 312-324.

doi :10.1061/9780784482346.032

JU Y., AZAD N., DING W., HE H. (2025). Progress and trends in Coupled Model Intercomparison Project (CMIP) research: A bibliometric analysis, *Agriculture (Switzerland)*, Vol. 15, No 8, pp. 1-17.

KOUAO J.M., KOUASSI A.M., DEKOULA S.C., ASSEUFI B.D. (2020). Analysis of the climate regionalization of the ivory coast in a changing climate context, *Larhyss Journal*, No 41, pp. 233-259. (In French)

KOULOUGHLI C.E., TELLI A. (2023). Modern water supply management techniques and methods: a review, *Larhyss Journal*, No 55, pp. 7-23.

LAGHZAL A., SALMOUN F., BOUDINAR B., ARGAZ A. (2019). Potential impact of anthropogenic activities on groundwater in the Tangier-Tetouan-Alhoceima region (Morocco), *Larhyss Journal*, No 34, pp. 39-50.

LI H., SHEFFIELD J., WOOD E.F. (2010). Bias correction of monthly precipitation and temperature fields from Intergovernmental Panel on Climate Change AR4 models using equidistant quantile matching, *Journal of Geophysical Research Atmospheres*, Vol. 115, No 10.

LIPCZYNSKA-KOCHANY E. (2018). Effect of climate change on humic substances and associated impacts on the quality of surface water and groundwater: A review, *Science of the Total Environment*, Vols. 640-641, pp. 1548-1565.

MACHI WAL D., GUPTA A., JHA M.K., KAMBLE T. (2019). Analysis of trend in temperature and rainfall time series of an Indian arid region: comparative evaluation of salient techniques, *Theoretical and Applied Climatology*, Vol. 136, Nos 1-2, pp. 301-320.

MAH D.Y.S., ALHADI H.F., BATENI N., TEO F.Y. (2024). Model simulation of dry stormwater detention pond with IPCC AR6 projected climate change scenarios, *Larhyss Journal*, No 60, pp. 151-169.

- MEHTA D., CALOIERO T., YADAV S., KUMAR V. (2025). Rainfall temporal variability and drought analysis by means of the Standardized Precipitation Index in Ganganagar District, Rajasthan, India. *Frontiers in Climate*, Vol. 7, Paper ID 1702356.
- MEHTA D., HADVANI J., KANTHARIYA D., SONAWALA P. (2023a). Effect of land use land cover change on runoff characteristics using curve number: A GIS and remote sensing approach, *International Journal of Hydrology Science and Technology*, Vol. 16, No. 1, pp. 1-16.
- MEHTA D., ACHOUR B., PASTAGIA J., AZAMATHULLA H., VERMA S. (2023b). Review of reservoir operation, *Larhyss Journal*, No 56, pp. 193-214.
- MEHTA D., YADAV S. (2024). Rainfall runoff modelling using HEC-HMS model: case study of Purna river basin, *Larhyss Journal*, No. 59, pp. 101-118.
- MEHTA D., YADAV S.M. (2021). An analysis of rainfall variability and drought over Barmer District of Rajasthan, Northwest India, *Water Supply*, Vol. 21, No 5, pp. 2505-2517.
- MEHTA D., YADAV S.M. (2022b). Temporal analysis of rainfall and drought characteristics over Jalore District of S-W Rajasthan, *Water Practice and Technology*, Vol. 17, No 1, pp. 254-267.
- MEHTA D.J., YADAV S.M. (2022a). Long-term trend analysis of climate variables for arid and semi-arid regions of an Indian State Rajasthan, *International Journal of Hydrology Science and Technology*, Vol. 13, No 2, pp. 191-214.
- MEHTA D.J., YADAV S.M. (2023b). Meteorological drought analysis in Pali District of Rajasthan State using standard precipitation index, *International Journal of Hydrology Science and Technology*, Vol. 15 No 1, pp. 1-10.
- MEHTA D.J., YADAV S.M. (2023c). Trend Analysis of Drought Events Over the Sirohi District in Western Rajasthan of India. In: Timbadiya, P.V., Singh, V.P., Sharma, P.J. Editions, *Climate Change Impact on Water Resources, HYDRO 2021, Lecture Notes in Civil Engineering*, Vol. 313. Springer, Singapore.
- [https://doi.org/10.1007/978-981-19-8524-9\\_21](https://doi.org/10.1007/978-981-19-8524-9_21)
- MEZENNER N., BENKACI T., BERMAD A., DECHEMI N. (2022). Dam reservoir operation optimization using genetic algorithm and principal component analysis simulation model - case of dam Ghrib, *Larhyss Journal*, No 51, pp. 145-160.
- MOHAMED M.A., EL AFANDI G.S., EL-MAHDY M.E.S. (2022). Impact of climate change on rainfall variability in the Blue Nile basin, *Alexandria Engineering Journal*, Vol. 61, No 4, pp. 3265-3275.
- NAKOU T.R., SENOU L., ELEGBEDE B., CODO F.P. (2023). Climate variability and its impact on water resources in the lower mono river valley in Benin from 1960 to 2018, *Larhyss Journal*, No 56, pp. 215-234.

NASSA R.A.K., KOUASSI A.M., BOSSA S.J. (2021). Analysis of climate change impact on the statistical adjustment models of extreme rainfall case of Ivory Coast, Larhyss Journal, No 46, pp. 21-48.

NAYAK S., TAKEMI T. (2022). Assessing the impact of climate change on temperature and precipitation over India, Book: Wadi Flash Floods, Challenges and Advanced Approaches for Disaster Risk Reduction, Springer Singapore publication, pp. 121-142.

NEZZAL F., BELKEBIR R., BENHAIDA A (2015). Risk of flooding in the watershed of the Oued Hamiz (Bay of Algiers), Larhyss Journal, No 22, pp. 81-89. (In French)

NICHANE M., KHELIL M.A. (2015). Climate change and water resources in Algeria - vulnerability, impact and adaptation strategy, Larhyss Journal, No 21, pp. 25-33. (In French)

OGA Y.M.S., ADJA M., YAPI A.F., KPAN J.G., BAKA D. (2016). Projection of climate variability by 2050 in the coastal area in the southeast of ivory coast (Abidjan in Aboisso), Larhyss Journal, No 25, pp. 67-81. (In French)

PANCHAL S.L., SURYANARAYANA T.M.V. (2025). Optimized operation of a multipurpose reservoir by evolutionary algorithm for Panam reservoir project in eastern Gujarat, India, Larhyss Journal, No 61, pp. 31-52.

PANDEY P., MISHRA R., CHAUHAN R.K. (2022). Future prospects in the implementation of a real-time smart water supply management and water quality monitoring system, Larhyss Journal, No 51, pp. 237-252.

PANG J.M., TAN K.W. (2023). Development of regional climate model (RCM) for Cameron highlands based on representative concentration pathways (RCP) 4.5 and 8.5, Larhyss Journal, No 54, pp. 55-70.

PASTAGIA J., MEHTA D. (2022). Application of innovative trend analysis on rainfall time series over Rajsamand district of Rajasthan state, *Water Supply*, Vol. 22, No 9, pp. 7189-7196.

PASTAGIA J., MEHTA D., CHADEE A., VERMA S., RATHOD A. (2025). Application of the IPTA Method for Detecting Precipitation Changes under a Changing Climate A Case Study Approach. Larhyss Journal, No 63, pp. 155-174.

PASTAGIA J.H., MEHTA D.J. (2023). Long term trend analysis on precipitation in Ajmer District of Rajasthan State, India, *International Journal of Hydrology Science and Technology*, Vol. 16, No 4, pp. 409-421.

PATEL A., PRAJAPATI K., CHADSANIYA J., MEHTA D., WAIKHOM S. (2024). Innovative Polygon Trend Analysis Method: A Case Study of the South Gujarat Region, *Journal of Environmental Informatics Letters*, Vol. 11, No 1, pp. 38-46.

PATEL P.S., RANA S.C., JOSHI G.S. (2021). Temporal and spatial trend analysis of rainfall on Bhogavo River watersheds in Sabarmati lower basin of Gujarat, India, *Acta Geophysica*, Vol. 69, No 1, pp. 353-364.

- PATEL S., MEHTA D., KUMAR V., PATEL S., TIWARI D.K. (2024). Trend analysis of precipitation and drought characteristics over Churu district of northeast Rajasthan, India, *Journal of Water and Climate Change*, Vol. 15, No 9, pp. 4457-4475.
- PAULO MONTEIRO J., COSTA MANUEL S. (2004). Dams' groundwater modelling and water management at the regional scale in a coastal mediterranean area (the southern Portugal region – Algarve), *Larhyss Journal*, No 3, pp. 157-169.
- POPOVA K. (2019). Climate change and water availability in agriculture, Institute of Physics (IOP) Conference Series: Earth and Environmental Science, UK, United Kingdom, Vol. 274, No 1, pp. 1-7, Paper ID 012117.
- QURESHI H.U., ABBAS I., SHAH S.M.H., TEO F.Y. (2024). Hydrologic evaluation of monthly and annual groundwater recharge dynamics for a sustainable groundwater resources management in Quetta city, Pakistan, *Larhyss Journal*, No 60, pp. 27-53.
- REMINI B. (2019). The Oasis of El Guerrara (Algeria): irrigation and recharge of the aquifers ensured by the floods, *Larhyss Journal*, No 40, pp. 135-163. (In French)
- REMINI B. (2020). Algeria: the climate is changing, the water is becoming scarce, what to do? *Larhyss Journal*, No 41, pp. 181-221. (In French)
- REMINI B. (2023). Flash floods in Algeria, *Larhyss Journal*, No 56, pp. 267-307.
- REMINI B. (2024). Can we ensure water security in the era of climate change? *Larhyss Journal*, No 60, pp. 297-308.
- SAHU R.T., MEHTA D.J. (2024). Impact of coastal inundation due to rise in sea level: A case study of Surat City, India, *Water Practice & Technology*, Vol. 19, No. 5, pp. 1753-1768.
- SAIDI M.E.M., BOUKRIM S., FNGUIRE F., RAMROMI A. (2012). Surface flows on the high atlas of Marrakech - case of extreme flows, *Larhyss Journal*, No 10, pp. 75-90. (In French)
- SHAH N.V., PATEL Y.S., BHANGAONKAR P.D. (2021). Assessing impact of climate change on rainfall patterns of Vadodara District, Gujarat, India, *Journal of Physics: Conference Series (JPCS)*, Institute of Physics (IOP) Publishing, United Kingdom (UK), Vol. 1714, No 1, pp. 1-7.
- SHAIKH M.M., LODHA P., LALWANI P., MEHTA D. (2022). Climatic projections of Western India using global and regional climate models, *Water Practice and Technology*, Vol. 17, No 9, pp. 1818-1825.
- SHARMA A., KUMAR M., HASTEER N. (2020). Applications of GIS in management of water resources to attain zero hunger, *Book: Advances in Water Resources Engineering and Management, Lecture Notes in Civil Engineering Series*, Springer Singapore Publishing, Vol. 39, pp. 211-218.
- SINGH U.K., KUMAR B. (2018). Climate change impacts on hydrology and water resources of Indian River basin, *Current World Environment*, Vol. 13, No 1, pp. 32-43.

STEVENS B. (2024). A Perspective on the Future of CMIP, AGU Advances, The American Geophysical Union (AGU) Publishing, Vol. 5, No 1, Paper ID e2023AV001086.

TODINI E. (2011). History and perspectives of hydrological catchment modelling, *Hydrology Research*, Vol. 42, Nos 2-3, pp. 73-85.

VINET L., ZHEDANOV A. (2011). A “missing” family of classical orthogonal polynomials, *Journal of Physics A: Mathematical and Theoretical*, Institute of Physics (IOP) Publishing, UK, United Kingdom, Vol. 44, No 8, pp. 1-16, Paper ID 085201.

WAIKHOM S.I., YADAV V.K., CHADEE A.A., VARMA V. (2023). Variability in trends of streamflow and precipitation in the Narmada River Basin over the past four decades, *Water Supply*, Vol. 23, No 3, pp. 1495-1518.

WMO. (World Meteorological Organization). (1990). Hydrological models for water-resources system design and operation, *Operational Hydrology Report No 34*, Geneva, Switzerland, pp. 1-90.

XIANG Y., WANG Y., CHEN Y., ZHANG Q. (2022). Impact of Climate Change on the Hydrological Regime of the Yarkant River Basin, China: An Assessment Using Three SSP Scenarios of CMIP6 GCMs, *Remote Sensing*, Vol. 14, No 1.

ZAKWAN M., PHAM Q.B., BONACCI O., DURIN B. (2022). Application of revised innovative trend analysis in lower Drava River, *Arabian Journal of Geosciences*, Vol. 15, No 8.

ZEGAIT R., PIZZO H.S. (2023a). Flood control reservoir using VBA simulation case of Idles basin in southern Algeria, *Larhyss Journal*, No 53, pp. 41-60.

ZEGAIT R., PIZZO H.S. (2023b). Flood control using VBA simulation case of Idles basin in southern Algeria, *Larhyss Journal*, No 53, pp. 41-60.

ZINYENGERE N., THEODORY T.F., GEBREYES M., SPERANZA C.I. (2017). Introduction: Framing climate change impacts on African agriculture (Introductory chapter), Book: *Beyond Agricultural Impacts: Multiple Perspectives on Climate Change and Agriculture in Africa*, Zinyengere N., Theodory T.F., Gebreyes M., Speranza C.I. Editions, Academic Press Publishing, Elsevier, 404p. ISBN: 9780128126227.