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REVIEW ARTICLE

Agronomic and environmental dimensions of large-scale irrigation projects for sustainable agriculture

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Abstract

Across the world, large-scale irrigation projects (LSIPs) have revolutionized agriculture by ensuring food security and effective water resource management. Climate change including an increase in extreme weather events and altered rainfall patterns, has become a major challenge for the sustainability of agriculture. Thus, this paper deals with the prospects and concerns that revolve around LSIPs and urges the development of climate-resilient strategies. Sustainable water management strategies, water pricing, participatory irrigation management, technological inclusions like AI-, remote sensing- and IoT-based irrigation ensure precise and efficient water use. Hydrological models such as hydrologic engineering center-hydrologic modeling system (HEC-HMS), soil and water assessment tool (SWAT) and others help in understanding water resource dynamics. Case studies on China's Three Gorges Dam, Egypt's Aswan High Dam, Australia's Murrumbidgee Irrigation Area and the Colorado river basin projects in the USA and Mexico reflect towering engineering feats and remarkable socio-economic transformations. While these infrastructures have advanced flood control, irrigation and hydropower generation, they have also highlighted the need for balanced development approaches that prioritize environmental integrity and social well-being. Thus, drawing from past lessons, integrating various adaptive management, community engagement and modern technologies and hydrological models are essential factors for sustaining agricultural productivity, water security and rural development in this rapidly changing and growing world.

Keywords: climate change; ecology; environmental science; large-scale irrigation projects; river basins; water

Introduction

The need for food production, coupled with the expanding global population, underscores the essential role of LSIPs in ensuring a steady water supply for agricultural activities (1). The convergence of agricultural production, environmental sustainability and socio-economic development is highly dependent on the efficient management of LSIPs (2). Sustainable water management is a foundational component of climate-resilient agricultural systems. Various geographical factors influence hydrological processes. These range from water availability for basic needs to advanced scientific innovations. Hence, diving deeper into their study the dimensions of LSIPs in influencing agronomic and environmental conditions of a geographical location is indispensable. Population surge and climate change have made it compulsory to use resources effectively. There are numerous ways to increase agricultural production and irrigation efficiency that yield more profit for farmers in a stable and sustainable manner. Smart farming practices fulfill the gap created by precision agriculture (3, 4). LSIPs are not a one-person task to manage; they require a systemic approach involving government bodies, scientists, engineers and local people. They start with sources of water which include rivers, reservoirs, groundwater and even recycled wastewater in some modern projects, such as the South Gila Valley Irrigation Project of Arizona near the Colorado river (5, 6).

The major characteristics of hydrology (7) include precipitation (8), runoff, infiltration, evaporation and evapotranspiration (9, 10), water balance, streamflow and many more (11). Likewise, the important components of LSIPs are headworks, maincanals and secondary canals, distribution networks and drainage systems (12). They also comprise water use efficiency, which depends on conveyance and application efficiency from the source of irrigation to the targeted site (13). Irrigation scheduling indicates when and how much to irrigate, which helps estimate water requirement for various crops. Water conservation techniques should be followed for year-round crop cultivation (14). Soil, water and environmental quality assessments, along with socio-economic parameters, determine the success of LSIPs (15). LSIPs aim to store, move and distribute water for domestic, industrial and agricultural practices effectively. LSIPs also elevate water to different topographic locations and generate income through water rights and hydropower for energy production (16). Periodical Environmental Impact Assessments (EIA) are necessary to identify the ecological effects of LSIPs (17). All such activities help cultivate crops profitably even in arid and rainfed regions, which not only increase agricultural production but also enhance the general standard of living of the beneficiaries (18).

Regular monitoring, desiltation, repairing structures, pumping station maintenance, efficient water and drainage management, user participation, capacity building and other modern technologies like remote sensing and automation ensure the success of LSIPs (19). Hence, when implementing a new irrigation project, dozens of prospects and concerns must be considered. This review elucidates in depth to assess the major factors, opportunities and challenges in planning, implementing and managing LSIPs, with a focus on modern technologies, sustainability and stakeholder involvement.

Methodology

The data were sourced from a variety of platforms, including Google Scholar, ResearchGate, TNAU e-Library and Scopus. Access to leading e-journal platforms like MDPI, Elsevier, Springer, Taylor & Francis, John Wiley and specialized platforms such as CeRA, Indian Journals, DOAJ and Web of Science was facilitated through TNAU e-Library. The keywords used in the search included hydrology, large-scale irrigation projects and simulation models analyzing aspects like evapotranspiration, rainfall, drought, flood, water inflow and outflow, return flow and water storage on a global scale. A thorough screening process took approximately two and a half months to identify relevant articles and journals published by reputable publishers that were related to the review.

Nearly 645 academic resources, including research and review articles, thesis and reports were collected from various sources and 117 were selected based on the impact of the papers and reports, which provided the necessary information available for inclusion in this review, spanning the period from 1968-2025 (Fig. 1). This paper reviews the agronomic and environmental dimensions of LSIPs in reforming the regional developments, as well as associated concerns and possible solutions. It also focuses on different hydrological models, modern techniques and technologies used for the maintenance of such projects. Some of the notable case studies included are the Yangtze river valley irrigation system (China) (20), the Nile river irrigation projects (Egypt) (21), the Murrumbidgee irrigation area (Australia) (22) and the lower Colorado river basin irrigation projects (United States/Mexico) (23), which were selected by the authors and analysed based on their historical importance, project scale and remarkable impacts on agriculture and water management.

LSIPs interventions helps overcome climate risks, transforms poorly productive, low-income, water-scarce into a year-round multi -cropped cultivation and also reduces migration. This transformation confirms assured irrigation, enhanced food security, improved income cum standard of living and boosts overall regional GDP. Ultimately, irrigation empowers agricultural sustainability and rural prosperity (Fig. 2).

Climate resilience in irrigation systems

Changing climate has made a significant impact on water resources and LSIPs. It has also altered rainfall patterns, increased temperatures and caused frequent extreme weather events. This necessitates the development of climate-resilient infrastructure, such as dams and canals, to ensure sustained water availability. Groundwater depletion, short-term water surpluses due to glacial melt and seawater intrusion into canal-fed lands in coastal regions are leading to climate-induced water scarcity. Meanwhile, projected changes in climate indicate a decreased agricultural yield by 2050 and 2100. This creates the need for alternative irrigation strategies to overcome such yield losses (24). One such important practical way is the adoption of sustainable water management practices that include irrigation scheduling methods like regulated deficit irrigation, deficit irrigation and the conjunctive use of multi-quality water. Advanced technologies, remote sensing, IoT sensors, AI- and machine learning-mediated smart irrigation systems help ensure precise water use. Solar-powered irrigation systems also cut down costs and conserve energy (25, 26). Various agroforestry methods should be included in agricultural systems for long-term sustainability (27).

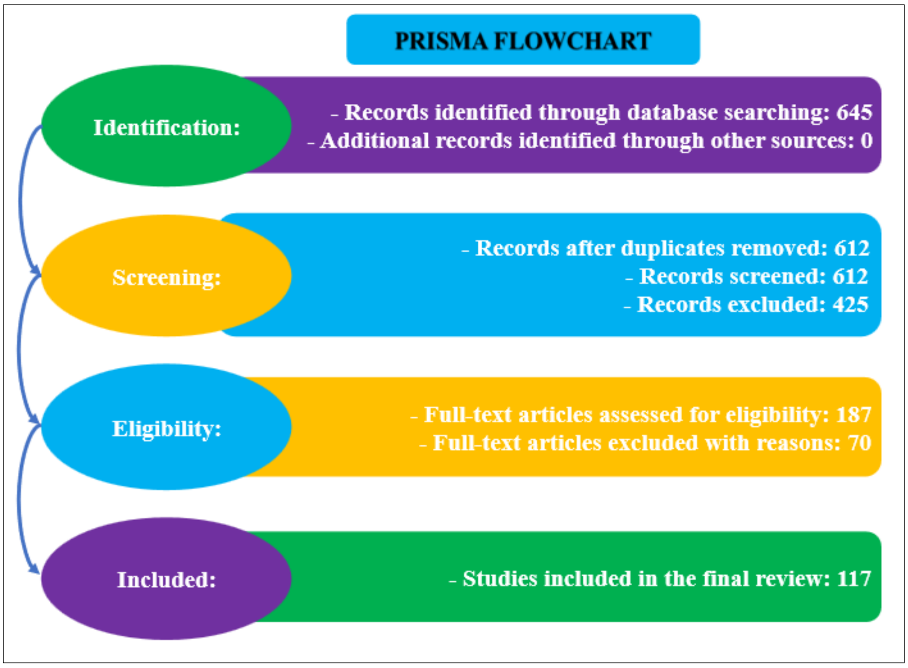

Fig. 1. PRISMA flowchart of the literature selection process.

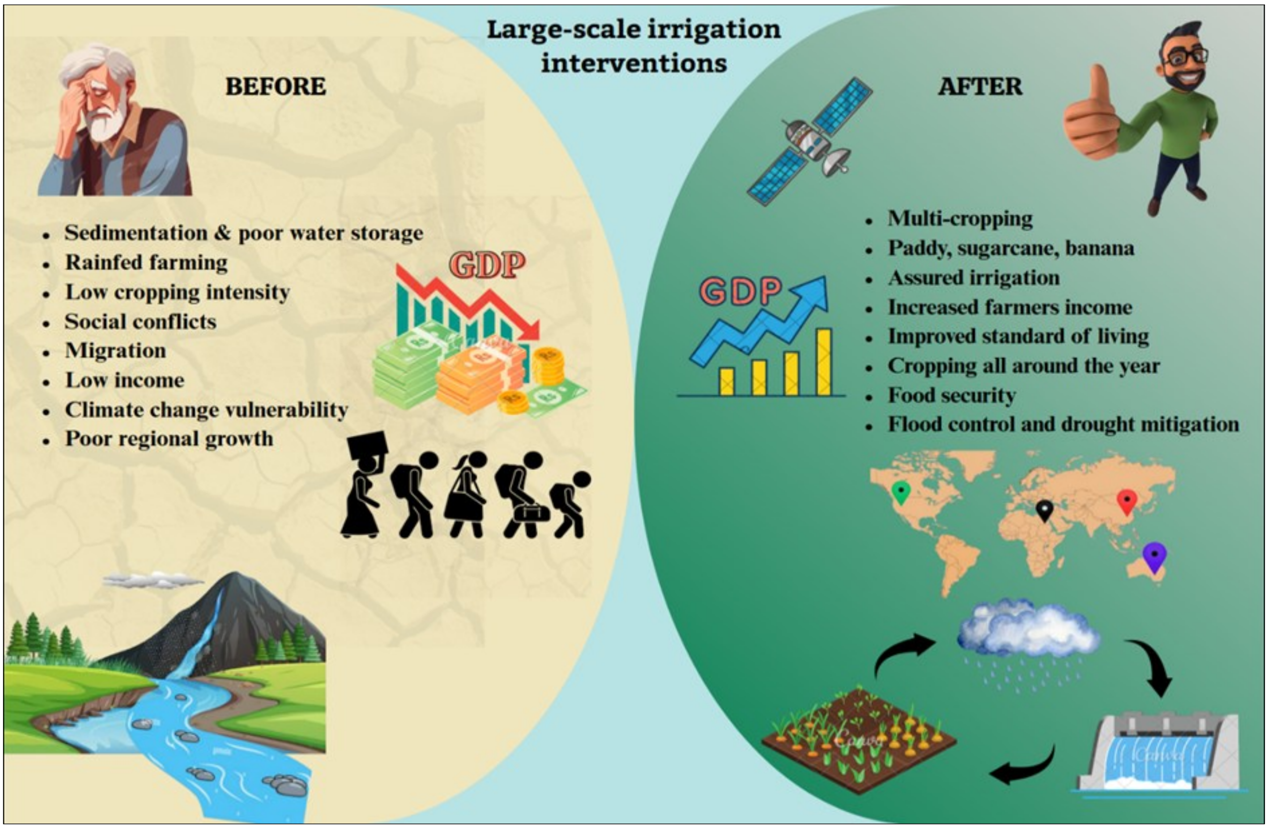

Fig. 2. Graphical abstract of agronomic and environmental dimensions of large-scale irrigation interventions.

Engaging local people i.e. through participatory irrigation management and water pricing, ensures equitable and efficient water distribution. On the other hand, substances like zeolites, nanoclay and antitranspirants help conserve water in areas with limited water resources (28). Adopting such practices will help increase water-use efficiency.

Models for irrigation projects assessment

The most commonly used models for assessing LSIPs are the HEC-HMS (29) and SWAT (30) for simulating runoff, water flow and estimating water availability and storage. Trend analyses of rainfall patterns were conducted using the Mann-Kendall test and Sen's slope estimator (31, 32). The drought indices calculator (DrinC) is useful for predicting and identifying possible drought severity and its duration (33). Estimation of reservoir evaporation can be performed using the Penman equation, based on databases like GRanD and GRSAD (34).

Artificial neural network (ANN) models were utilized for reservoir inflow forecasting, along with other methods such as principal component analysis (PCA) and adaptive-network-based fuzzy inference systems (ANFIS) to forecast streamflow (35, 36). Additionally, the co-active neuro-fuzzy inference system (CANFIS) to enhance the accuracy of inflow forecasting (37). This was achieved through a comparative evaluation of two AI-based models: ANN and ANFIS.

Bathymetric surveys, along with GIS tools, are used for reservoir sedimentation assessment (38). Downscaled and bias-corrected climate projections using global climate models (GCMs) were generated by adopting the techniques such as hybrid multiple linear regression and statistical downscaling model (SDSM). Tools like SDSM and SWAT (30) are used to assess the impacts of projected climate on hydrology using observed climate and streamflow data respectively (39), while multivariate analysis techniques such as PCA and hierarchical clustering are applied for water quality assessment (40). The most accurate satellite and reanalysis products identified for the region, such as climate hazards group infrared precipitation with station data (CHIRPS) can be used (41).

Geospatial and remote sensing technologies

Sentinel-2 data and machine learning classifiers with object-based LULC classification have enhanced environmental monitoring, supporting sustainable development and natural resource management (42). Groundwater quality using geospatial and statistical approaches were assessed (43). Floods were mapped using the Sentinel-1A satellite's C-band SAR sensor, leveraging its capability to detect flood extent regardless of weather conditions or cloud cover (44). Sentinel-1A satellite data, processed with GIS tools, were used to map flood-affected areas. Ground truth data were used to identify dB values for the flood-pixel classication (45).

Land surface temperature (LST) and normalized difference water index (NDWI) of MODIS datasets were used for drought monitoring evaluation (46). A spatiotemporal analysis of the water-spread areas in tanks was conducted using Sentinel-1A SAR imagery, while NDVI data from Sentinel-2 were used to categorize crop health (47). The water-spread area of tanks, vital for irrigation and groundwater recharge, was estimated using Sentinel-1A SAR data. Processed with SNAP software, these data were used to map the water-spread area was through a threshold-based approach (48, 49). Reference evapotranspiriation (ET) data from the FAO were analyzed using the AgERA5 dataset to assess the annual and seasonal dynamics of reference ET (50). Daily actual ET was computed using the surface energy balance algorithm for land (SEBAL) (51). Traditional drought indices like standardized precipitation index (SPI) rely only on precipitation, potentially missing key factors. Incorporating both temperature and precipitation, standardized precipitation evapotranspiration index (SPIE) improves assessment by offering a more complete view under changing climate conditions (52).

Agricultural drought was analyzed using CHIRPS monthly precipitation data to evaluate duration, extent, severity and lag time. Enhanced vegetation index (EVI) data from MODIS and SPI at a one-month scale supported accurate drought vulnerability assessments (53). Using CROPWAT 8.0, crop water demand and supply were analyzed to propose a net irrigation scheme, revealing that the paddy showed the highest water demand (872.1 mm/ha) in non-system tanks, while sugarcane had the highest (1046.7 mm/ha) in system tanks (54). Sentinel-2 optical data and ground-truth information were used for crop diversification assessment in the major tank ayacut area. Crops were identified through pixel-based classification and further classified using Random Forest algorithms (55). Multi-temporal Sentinel-1A SAR data was used to estimate rice area. Temporal backscatter (dB) signatures were generated using fully automated MAPscape software to distinguish rice from other crops (56).

When considering LSIPs, spatial monitoring is indispensable in mapping rivers, canals, distributaries, delineation of catchments areas, command areas and even drainage networks. Satellite imageries and GIS tools enables continuous tracking of water availability, irrigated areas, crop water requirement and stress analysis using ET and NDVI estimation. Apart from that, disaster risk mapping, yield monitoring and the integration of socio-economic and natural resource data geospatial data are also possible (25, 57, 58).

Prominent global case studies

The example LSIPs cover a diverse geographical range, including projects in China, Egypt, the United States and Australia, reflecting the global significance of irrigation projects across different regions, as they are representing some of the largest and most influential ones in terms of scale and impact on water management and agriculture (Fig. 3).

Three Gorges Dam of Yangtze river valley irrigation system (China)

Three Gorges Dam (TGD), the largest engineering project in China and the largest dam structure in the world since 2006, reached its full hydroelectric power generating capacity in 2012 (59). The main aim of the TGD was to prevent flooding in the Yangtze basin and it caused a significant reduction in annual average emissions of CO_2, CH_4 and N_2O over a 4300 km stretch of the Yangtze River (59). Using the CASA model, the terrestrial net primary productivity (NPP) of the TGD area was found to be increasing during 2000–2015 and climate change and land-use patterns may have contributed to carbon sequestration (60). Green infrastructure provides support for ecological restoration (61). Hydroelectric power production achieved its full capacity with all 32 turbine generator units operational. With the addition of two extra generators, the dam reached a total capacity of 22500 megawatts, solidifying its status as the world's most productive hydroelectric dam. The hydroelectric plant shattered records by producing 111.88 terawatt-hr of electricity in a single year, marking an unprecedented milestone in annual power generation volume (62).

The construction of the TGD was fraught with controversy, as it caused the displacement of at least 1.3 million people and the destruction of natural features and approximately 1200 rare historical, architectural and archaeological sites (63). The reservoir has also been blamed for an increased risk of landslides and earthquakes, while waste from nearby cities pollutes the reservoir (20). Advocates for the construction of numerous smaller and more cost-effective dams argued that this approach would allow the government to fulfill its primary objectives without exposing itself to significant risks (64). Lowland terraces are primarily used for paddy rice cultivation, while upland areas support cereals and rapeseed. The region also cultivates tea and other cash crops, along with mixed vegetables, fruit orchards and aquaculture in ponds and small reservoirs. Table 1 provides brief insights on different models and their usage in the TGD.

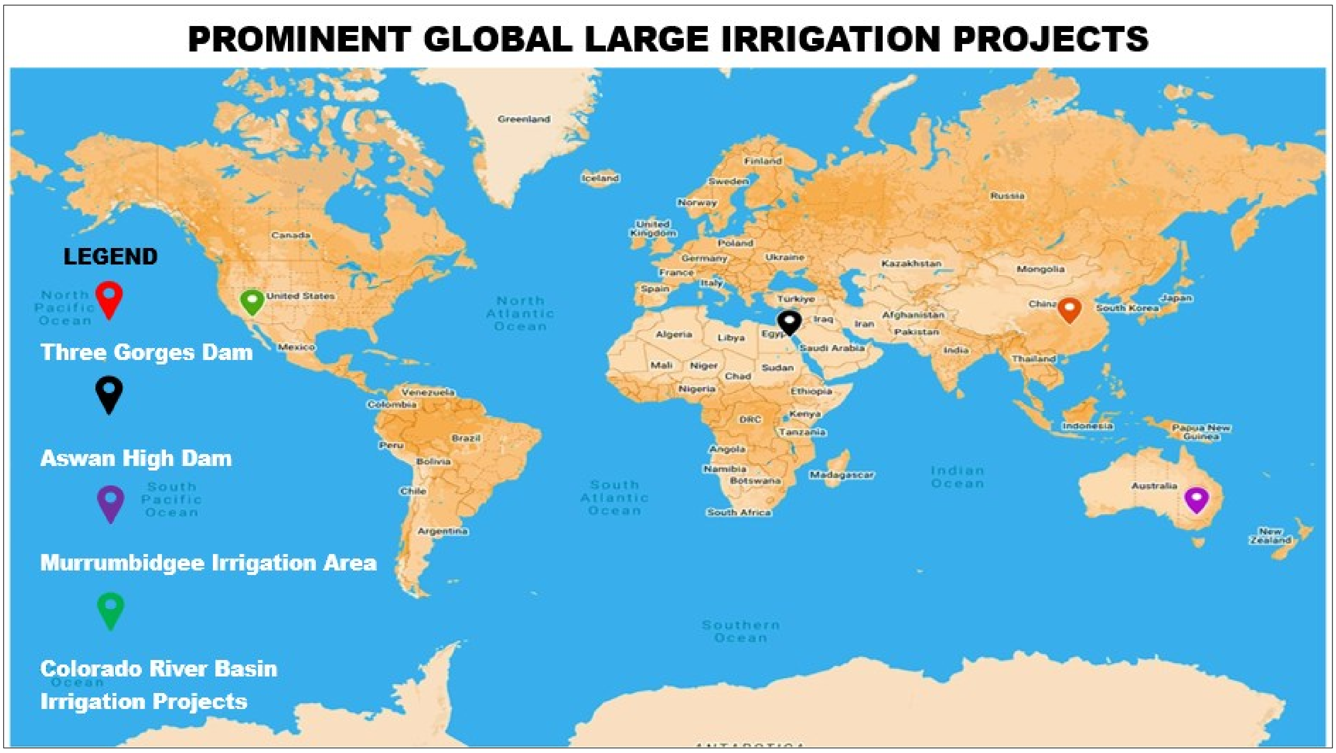

Fig. 3. Case studies of the prominent global large-scale irrigation projects.

Table 1. Models employed in analysing the hydrology of TGD

Key findings	Methodology	References
To gauge stream flow and sediment uncertainty. Sediment forecasts more uncertain, especially when wet compared to streamflow.	Merged generalized likelihood uncertainty estimation (GLUE) with soil and water assessment tool (SWAT) model	(65)
Generated monthly discharges at Yichang station for 2003–2011. Hydrological droughts downstream slightly aggravated by TGR's initial operation (2003–2011). Hydrological drought index series calculated using standardized streamflow index method.	Two-parameter monthly water balance model	(66)
Created coupled model of hydrodynamics operation on streamflow and distributed time variable gain model between 1970 and 2018. Annual average relative deviation of TGD flow compared to natural state: ~24 %. Dam's operation intercepted high flood peaks during flood season.	Large-scale coupled model of hydrological and hydrodynamic processes	(67)
Created model to assess hydrological consequences. Dam operation decreased maximum daily flood peak by up to 26.2 %. Generated ~94.27 TWh of electricity annually. Increased downstream water supply by up to 22 % during dry season.	Large-scale linked hydrological-hydrodynamic and hydropower simulations-dam operation model	(68)

The Aswan High Dam of nile river project (Egypt)

Constructed in 1861, as the delta barrage scheme and underwent subsequent extensions and enhancements, marking a pivotal moment in modern Nile valley irrigation. The aim was to elevate the water level upstream to facilitate irrigation canals and regulate navigation. The Aswan high dam (AHD) aimed to regulate the Nile's flow for agriculture, hydroelectric power and flood protection (21). Feature four locks to aid navigation, housing a hydroelectric power plant (HEP) generates over 345 MW of power (69, 70). With a HEP capacity of 2100 megawatts, it stores water in lake Nasser to control levels, with Egypt receiving the majority share of allocated water resources (71). Navigation in Sudan is challenged by cataracts, particularly between the Egyptian border and lake Nasser and from Khartoum to Juba in South Sudan where the dam facilitates it (72). The critics argue that the dam caused downstream erosion, coastal erosion in the delta, saltwater intrusion, waterlogging and reduced fish populations (73). Despite controversy, proponents emphasize the dam's importance for water and power supply security. Supporting up to two cropping cycles each year, the region cultivates major crops such as cotton, sugarcane, rice, wheat, maize and sorghum, along with extensive areas of vegetables, fruit orchards (including date palm, citrus, mango and guava) and various fodder crops. Table 2 below offers succinct insights into various models and their applications in the AHD.

Murrumbidgee irrigation area (Australia)

Established in 1912, the Murrumbidgee catchment, nestled within the Murray–Darling basin covering an extensive area of 32440 square miles including 1000 square miles of fertile farmland supporting a diverse agricultural landscape, including livestock pastures, vineyards, citrus orchards, wheat fields and cotton plantations (79). The Water Management Act (2000) made marked shift in water management and regulations that helps access water by the farmers.

The Water Act (1912) regulated water use as farmers were competed to access flowing water which often caused conflicts and inequitable distribution. It also introduced licensing system that the farmers need official permission from the government as it gave power to the government to monitor, allocate, protect water resources and plan the activities (80). Though some hesitations were there to the tail end farmers, activities of floodplain restoration projects pulled farmers to collaborate with the authorities.

The recent trends showed a significant increase in water usage by irrigated cotton in the Murrumbidgee catchment of New South Wales than other crops like vegetables, rice, grapevines and dairy (22). The overall reductions in return flows were to be less than 20 % of the total proposed irrigation efficiency savings (81). Irrigation efficiency projects reduce seepage to groundwater (with off-farm and on-farm seepage reduction by 19 % and 53 %) but not all

Table 2. Models employed in analysing the hydrology of AHD

Study description	Methodology	References
Estimate evaporation and recorded 5.70 mm day^{-1} to 7.05 mm day^{-1} of evaporation.	Water-balance, energy budget, bulk aerodynamic (Dalton), combination (Penman), complementary	(74)
Used ANFIS model trained on historical data to forecast Nile River inflow at Aswan High Dam. Compared with an artificial neural network (ANN) model, demonstrated higher accuracy, especially for extreme inflows.	Adaptive neuro-fuzzy inference system (ANFIS) model	(75)
Assessed irrigation demands in Egypt and Sudan along the Nile. Revealed substantial water consumption and projected demands surpassing available resources. Urged holistic water management strategies.	SPARE: WATER model	(76)
Analyzed terrain models for extracting watersheds using WMS and ARC-GIS. Showed ARC-GIS as more accurate. Calculated dam water volume using DEM from Shuttle Topographic Radar Mission (STRM) and HEC l hydrological model.	Watershed modeling system (WMS), ARC-GIS, digital elevation model (DEM), HEC l hydrological model	(77)
Developed a 1D hydraulic model using HEC-RAS program to study dam break scenarios, estimate output hydrograph and route flood wave from Aswan Dam to Esna barrage. Highlighted concerns of catastrophic outcomes with high flow releases.	1D hydraulic model using HEC-RAS program	(78)
Studied a revised water balance model for the Aswan High Dam Reservoir. Verified using remote sensing data, bias-corrected reanalyzed data and in situ gauge data. Recorded temperature trends and developed machine learning models for inflow/outflow data adjustments.	Combination of heterogeneous information sources, machine learning models	(69)

seepage reductions will translate in reduction and charge ground water.

The conjunctive use of water option faces challenges in stakeholder processes, cost minimization, social benefits and equity and suggested financial incentives or greater stakeholder involvement could enhance acceptance (82). Nearly 300000 ha of area was degraded by dams, diversions and floodplain development. Water diverted from the Murrumbidgee river for irrigation and various other reasons highly changed the natural flows which impacted the wetlands and their associated waterbirds and aquatic biota. Yanga nature reserve faces a considerable loss of floodplain vegetation due to water scarcity. On the other hand, it also caused catastrophic death of fishes in the Murray-Darling basin (83). Hence, the naturally location specific biome should be conserved (84).

Similarly, environmental changes due to irrigation like salinization, waterlogging affects groundwater quality (82). Thus, conservation policies are needed without interfering the natural flows for preventing further ecological degradation (85). One such initiative is the Commonwealth Water Act (2007) which facilitated yearly water allocation for compulsory use of water for environmental reclamation. Since 2012, it is regulated by the Murray-Darling basin authority by the basin plan (81). The basin plan replaced the initial cap with the establishment of a sustainable diversion limit (SDL) on the volume allocated for consumptive uses (80, 86). The water market expansions facilitated by water reform packages in 1994 and 2004 enabled users to trade water across connected valleys and state borders, contributing to sustainable water use in the Murray–Darling basin (81). Major irrigated crops include rice (medium and long grain), cotton, wheat, barley, canola, soybeans, corn and various vegetables and fodder crops. The region also hosts extensive orchards and vineyards producing citrus, stone fruits, nuts (walnuts, almonds) and about 20 % of Australia's wine grapes and 90 % of New South Wales' citrus output. Table 3 offers concise overviews of different models and their utilization in the Murrumbidgee irrigation area (MIA).

Colorado river basin irrigation projects (United States/Mexico)

The Colorado river basin lies between USA and Mexico occupies an area of approximately 250000 square miles (93). Colorado river basin irrigation (CRBI) project is a critical resource for agriculture, domestic purposes, hydropower production, recreation, fish and wildlife habitat and other benefits (23). Of the total volume, 70 % of Colorado river water was used for agriculture and around 35 and 40 million people rely on the same water resource (94). With the complex set of compacts, federal laws, court decisions, decrees, contracts and regulatory guidelines, the "Law of the River" provide a regional water plan, for the satisfaction of the requirements of the Mexican Water Treaty (95, 96). Due to climate change, streamflows are anticipated to decrease, leading to proposed water-use reductions, mainly targeting agriculture, which currently consumes over 60 % of the basin's water (97). Major crops of CRBI include alfalfa (dominant and key for beef and dairy feed), grass hay, corn (mainly for livestock feed), cotton, winter vegetables, leafy greens, orchards (citrus,

Table 3. Models employed in analysing the hydrology of MIA

Study description	Methodology	References
Assess flood frequency and duration. Found significant impacts from major irrigation off-takes, altering upstream and downstream flow characteristics.	Analysis of natural daily flow data	(87)
Demonstrated the effectiveness of the SFI in managing hydrologic drought. Used (GPDF) and (GAM) to analyze river flow data.	Standardised flow index (SFI), Gamma probability distribution function (GPDF), generalized additive models (GAM)	(88)
Investigated the impact of flow alteration by dams on the Lowbidgee wetland fed by the Murrumbidgee River.	Integrated flow and flood modeling (IFFM), structural change analysis	(89)
Developed a coupled socio-hydrologic system model to simulate the pendulum swing between agricultural development and environmental restoration in the Murrumbidgee River Basin.	Stylized, quasi-distributed, parsimonious coupled socio-hydrologic system model	(90)
Examined combined impacts of climate change and land use on sub-catchments of the Murray-Darling Basin.	SWAT model	(91)
Used SIMHYD model with data from GCMs to predict future runoff in the Murrumbidgee River catchment. Analyzed impacts of climate change and emissions scenarios on runoff.	Simplified hydrolog (SIMHYD) model, general circulation models (GCMs), representative concentration pathway (RCP) scenarios	(92)

Table 4. Models employed in analysing the hydrology of CRBI

Study description	Methodology	References
Assessed climate change impact on hydrology and water resources of the Colorado River Basin using an ensemble approach with downscaled output from 11 GCMs. Studied temperature and precipitation changes.	Ensemble approach with downscaled output from 11 GCMs	(98)
Examined the impact of climate variability and change on the Colorado River flow using a system dynamics model with inputs from 16 GCMs and 3 emission scenarios. Evaluated implications on Lake Mead levels and probabilities of supply curtailments.	System dynamics model, analysis of global climate models (GCMs)	(99)
Investigated climate change effects on water resources in the Upper Colorado River Basin (UCRB) using the SWAT model and 16 GCMs under the A2 emission scenario. Projected declines in spring and summer streamflow with implications for water resources and ecosystems.	SWAT model, analysis of global climate models (GCMs)	(100)
Predicted drought severity using general circulation models (GCMs) and compared results with those derived from natural flow estimates calculated by reclamation.	General circulation models (GCMs)	(101)
Evaluated three generations of global climate models (GCMs) in simulating temperature, precipitation and drought variability in the Upper Colorado River Basin. Analyzed persistent biases and the impact of bias correction on CMIP6 model performance.	Analysis of global climate models (GCMs), bias correction	(102)
Provided detailed information on streamflow, water table depth, snow water equivalent (SWE) and evapotranspiration (ET) using an integrated hydrological model, ParFlow-CLM. Validated dataset useful for studying water dynamics in the Colorado River basin.	Integrated hydrological model (ParFlow-CLM)	(103)

grapes, dates) and vineyards. Presented herein is a Table 4 delineating various models and their roles in CRBI.

Discussion

LSIPs that include various rivers, reservoirs, dams play a marvelous role in transforming the agriculture landscape and promote rural development by ensuring food security all over the world by allocating water resources for different sectors. But currently undergoing climate change have made it difficult for their management, long term sustainability. Case Studies including the TGD in China (20), the AHD in Egypt (21), the MIA in Australia (79) and the CRBI in the USA and Mexico (93) exemplify large-scale interventions in water management. While these projects have significantly contributed to flood control, power generation and agricultural development, they have also raised concerns about their environmental impacts. The TGD (20), despite its impressive capacity for electricity generation (62) and flood prevention (20), has been criticized for its adverse effects on local ecosystems and cultural heritage sites due to forced displacement and ecological disruption (63). The AHD caused severe downstream soil and coastal erosions and decreased fish populations (21, 73). Meanwhile in MIA, at the cost of habitat loss of local beings, ecological degradations like salinization and waterlogging changed agriculture's landscape (82). Similarly, CRBI observed projected decrease in streamflows threatening availability of water for all sectors including agriculture (97).

Advanced modelling and modern remote sensing techniques and appropriate policy decisions helps overcome the complex of hydrological and socio-economic concerns (104, 105). Deploying machine learning algorithms into hydrological-hydrodynamic models to operate LSIPs for water resource management increase water use efficiency (WUE) and reduce environmental degradation (106). The international treaties inked pave way for the regulation of water allocation among USA and Mexico (107, 108). United hands stakeholder engagement and participatory approaches are very important to sustainably and successfully manage LSIPs (109). Though inherent controversies are there in the MIA, collaboration among the authorities and local communities achieved the goals by joining hands (110). But still concerns like migration, equitable water distribution persists (111). Holistic approaches that considers social equity, economic development and environmental conservation enables the achievement of LSIPs goal (64, 112). Climate-resilient cropping patterns and adoption of water-saving technologies such as drip and sprinkler irrigation also need to be encouraged in LSIPs command areas. Switching from water-intensive crops like paddy and sugarcane to less water-demanding crops such as millets, pulses and oilseeds in regions facing water scarcity can ensure better water sustainability. To reduce the pressure on water resources, it is advisable to go with the diversified farming as it increases farmers income and food system resilience.

Hydrological and climate models like SWAT (65), HEC-HMS (29), ANN (35) based models enable accurate prediction of watershed responses at various climate scenarios. Likewise, stochastic weather generators and climate downsclaing models like SDSM enables policy makers to create frameworks by integrating future climate variability into their irrigation strategies (30). In addition, the use of soil amendments and innovative materials like zeolites, biochar, antitranspirants and nanoclays increase efficiency in water usage in agriculture especially in arid and semi-arid regions and can aid in moisture retention and reduce irrigation requirements. In addition to the above discussed ways, integrating information and communication technologies (ICTs) like real-time monitoring through IoT devices, remote sensing-based irrigation scheduling and decision support systems enable reduced water waste and optimized alloction (28, 25).

Decentralized water management strategies such as participatory irrigation management (PIM) and water user associations (WUAs), which represent bottom-up approaches—when effectively integrated with government agencies, technical guidance and capacity building in canal distribution, maintenance and crop planning, can ensure efficient water use, reduce conflicts and improve the operational efficiency of LSIPs. Thus, the sustainability of future LSIPs will highly be depend on the above discussed integrated approaches that balance and harmonize economic growth and social-economic betterment of a region.

Conclusion

LSIPs are inevitable for the transformation of agriculture, ensuring food security and effective water resource management. The case studies on the Three Gorges Dam, Aswan High Dam, Murrumbidgee Irrigation Area and the Colorado River Basin Projects highlight the project scale, historical importance and technological advancements that have reformed agriculture, water management, thereby improving socio-economy of these regions. In addition, the paper also discusses the different hydrological models used to manage the LSIPs, along with their prospects and concerns.

Changing climate severely impacts LSIPs, with rising temperatures and an increased occurrence of extreme weather events, which worsen the conditions. It destabilizes the availability of water, agricultural production and rural livelihoods. This creates a need for the climate-resilient and sustainable irrigation strategies. Advanced technologies like AI, remote sensing, IoT, ML and solar-powered systems make it easier to cope. Substances like zeolites, nanoclay and anti-transpirants enable water conservation in the water-scarce areas. Likewise, the spatial and temporal monitoring of LSIPs using remote sensing and hydrological models is essential for creating site-specific policy frameworks.

Hydrological models include HEC-HMS, SWAT, ANN and CANFIS, along with trend analyses like Mann-Kendall tests and drought severity evaluations using DrinC, which help understand water resource behaviour and dynamics. Better prediction of climate impacts on LSIPs is possible by integrating GCM with downscaling methods like SDSM. Remote sensing and GIS techniques using Sentinel-1A SAR, Sentinel-2 optical data, MODIS datasets and tools like SEBAL have strengthened the continous monitoring of land, water spread, crop health and disaster risks. Hence the paper reviewing on the agronomic and environmental dimensions of LSIPs elucidates the need for such projects wherever possible to improve water conservation, management, agricultural productivity, regional development and general standard of living rural economies.

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Authors' contributions

GM led the conceptualization of the review, collected and synthesized literature, drafted the manuscript and prepared tables and figures. SP supervised the work, provided guidance on the conceptual framework, critically reviewed the manuscript and handled correspondence. APS contributed to the content on agronomic practices and crop-specific examples and reviewed and edited relevant sections. DM supported the geospatial analysis and mapping aspects and provided technical inputs on irrigation project evaluation. SS assisted with hydrological data validation, manuscript editing and technical verification of irrigation and water management sections. KPR contributed to integrating environmental sustainability and irrigation management data and reviewed the manuscript. VV assisted with literature review, formatting, proofreading and preparation of tables and figures.

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References

1. Wang J, Zhu Y, Sun T, Huang J, Zhang L, Guan B, et al. Forty years of irrigation development and reform in China. Aust J Agric Resour Econ. 2020;64(1):126-49. https://doi.org/10.1111/1467-8489.12334
2. Hatamkhani A, Moridi A. Optimal development of agricultural sectors in the basin based on economic efficiency and social equality. Water Resour Manag. 2021;35(3):917-32. https://doi.org/10.1007/s11269-020-02754-7
3. Maja MM, Ayano SF. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. Earth Syst Environ. 2021;5:271-83. https://doi.org/10.1007/s41748-021-00209-6
4. Karunathilake EMBM, Le AT, Heo S, Chung YS, Mansoor S. The path to smart farming: innovations and opportunities in precision agriculture. Agriculture. 2023;13(8):1593. https://doi.org/10.3390/agriculture13081593
5. Schultz B, De Wrachien D. Irrigation and drainage systems research and development in the 21st century. Irrig Drain. 2002;51(4):311-27. https://doi.org/10.1002/ird.67
6. DeJong DH. The sword of Damocles? The Gila River Indian Community Water Settlement Act of 2004 in historical perspective. Wicazo Sa Rev. 2007;22(2):57-92. https://doi.org/10.1353/wic.2007.0017
7. Brutsaert W. Hydrology. Cambridge: Cambridge University Press; 2023.
8. Samykannu V, Pazhanivelan S. Validation of PERSIANN precipitation product using TAWN rain gauge network over different agro-climatic zones in Tamil Nadu. Madras Agric J. 2021;108(7-9):321-6. https://doi.org/10.29321/MAJ.10.000513
9. Karishma CG, Kannan B, Nagarajan K, Panneerselvam S, Pazhanivelan S. Spatial and temporal estimation of actual evapotranspiration of Lower Bhavani Basin, Tamil Nadu using Surface Energy Balance Algorithm for Land Model. J Appl Nat Sci. 2022;14(2):566-74. https://doi.org/10.31018/jans.v14i2.3412
10. Venkadesh S, Pazhanivelan S. Microclimatic studies on cropped area using flux tower. Indian Farmer. 2021;8(4):310-5.
11. Vasumathi V, Kalpana R, Pazhanivelan S, Kumaraperumal R, Priya MV, Varshini PA. A review on wetlands–threats, conservation, strategies and policies. Madras Agric J. 2023;110(1):58-66. https://doi.org/10.29321/MAJ.10.000715
12. Moya TB. Resilience of irrigation systems to climate variability and change: a review of the adaptive capacity of Philippine irrigation systems. DLSU Bus Econ Rev. 2018;28:102-20. https://doi.org/10.59588/2243-786X.1555
13. Koech R, Langat P. Improving irrigation water use efficiency: a review of advances, challenges and opportunities in the Australian context. Water. 2018;10(12):1771. https://doi.org/10.3390/w10121771
14. Shaw SK, Sharma A, Khatua KK, Oliveto G. An integrated approach to evaluating crop water requirements and irrigation schedule for optimizing furrow irrigation design parameters in Kurnool district, India. Water. 2023;15(10):1801. https://doi.org/10.3390/w15101801
15. Van Vliet MT, Thorslund J, Strokal M, Hofstra N, Flörke M, Ehalt Macedo H, et al. Global river water quality under climate change and hydroclimatic extremes. Nat Rev Earth Environ. 2023;4(10):687-702. https://doi.org/10.1038/s43017-023-00472-3
16. Snaddon CD, Davies BR, Wishart MJ, Meador ME, Thoms M. A global overview of inter-basin water transfer schemes, with an appraisal of their ecological, socio-economic and socio-political implications, and recommendations for their management. Water Research Commission Report No. TT120/00. Pretoria: Water Research Commission; 1999.
17. Xu X, Tan Y, Yang G. Environmental impact assessments of the Three Gorges project in China: issues and interventions. Earth Sci Rev. 2013;124:115-25. https://doi.org/10.1016/j.earscirev.2013.05.007
18. Williams TO, Faures JM, Namara R, Snyder K. Large-scale irrigated farming system: the potential and challenges to improve food security, livelihoods and ecosystem management. In: Farming systems and food security in Africa. 2019. p. 423-49. https://doi.org/10.4324/9781315658841-13
19. Kumar P, Choudhury D. Innovative technologies for effective water resources management. In: Izah SC, Ogwu MC, Loukas A, Hamidifar H, editors. Water crises and sustainable management in the global south. Singapore: Springer; 2024. p. 555-94. https://doi.org/10.1007/978-981-97-4966-9_18
20. Li K, Zhu C, Wu L, Huang L. Problems caused by the Three Gorges Dam construction in the Yangtze River basin: a review. Environ Rev. 2013;21(3):127-35. https://doi.org/10.1139/er-2012-0051
21. Eldardiry H, Hossain F. A blueprint for adapting high Aswan dam operation in Egypt to challenges of filling and operation of the Grand Ethiopian Renaissance dam. J Hydrol. 2021;598:125708. https://doi.org/10.1016/j.jhydrol.2020.125708

22. Godfrey SS, Nordblom T, Ip RHL. Business risk profiles for irrigated cotton in the Murrumbidgee catchment of southern New South Wales. In: L B, B C, editors. System solutions for complex problems: proceedings of the 20th Australian Agronomy Conference; 2022 Sep 18–22; Toowoomba, Queensland. Australian Society of Agronomy; 2022. Article 472. p. 481.

23. Butler A, Fulp T, Prairie J, Witherall A. Water resources management in the Colorado River Basin. In: Handbook of catchment management. 2nd ed. Wiley; 2021. p. 441-63. https://doi.org/10.1002/9781119531241.ch18

24. Madhavan G, Pazhanivelan S, Madhupriya S, Akchaya K. The impact of climate change on agricultural productivity. In: Comprehensive insights into environmental science. Vol. 1. Stella International Publication; 2024. Chapter 1.

25. Dhanaraju M, Chenniappan P, Ramalingam K, Pazhanivelan S, Kaliaperumal R. Smart farming: Internet of Things (IoT)-based sustainable agriculture. Agriculture. 2022;12(10):1745. https://doi.org/10.3390/agriculture12101745

26. Panneerselvam S, Pazhanivelan S, Ragunath KP, Kumaresan P, Balakrishnan N. Remote sensing and GIS-based water resource monitoring for sustainable crop intensification and diversification. In: GIScience for the sustainable management of water resources. 1st ed. Apple Academic Press; 2022. https://doi.org/10.1201/9781003284512-3

27. Sobola OO, Amadi DC, Jamala GY. The role of agroforestry in environmental sustainability. IOSR J Agric Vet Sci. 2015;8(5):20-5.

28. Elseedy M, Mohammed RY, El-Sherpiny MA, Taha AA. Enhancing crop resilience to drought stress: antitranspirants, zeolite and water conservation strategies for strategic crop productivity. J Soil Sci Agric Eng. 2023;14(9):267-74. https://doi.org/10.21608/jssae.2023.233004.1186

29. Sahu MK, Shwetha HR, Dwarakish GS. State-of-the-art hydrological models and application of the HEC-HMS model: a review. Model Earth Syst Environ. 2023:1-23. https://doi.org/10.1007/s40808-023-01704-7

30. Bhuvaneswari K, Geethalakshmi V, Lakshmanan A, Srinivasan R, Sekhar NU. The impact of El Nino/Southern Oscillation on hydrology and rice productivity in the Cauvery Basin, India: application of the soil and water assessment tool. Weather Clim Extremes. 2013;2:39-47. https://doi.org/10.1016/j.wace.2013.10.003

31. Agarwal S, Suchithra AS, Singh SP. Analysis and interpretation of rainfall trend using Mann-Kendall's and Sen's slope method. Indian J Ecol. 2021;48(2):453-7.

32. Sen PK. Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc. 1968;63(324):1379-89. https://doi.org/10.1080/01621459.1968.10480934

33. Mehta D, Yadav SM. An analysis of rainfall variability and drought over Barmer district of Rajasthan, northwest India. Water Supply. 2021;21(5):2505-17. https://doi.org/10.2166/ws.2021.053

34. Tian W, Liu X, Wang K, Bai P, Liu C, Liang X. Estimation of global reservoir evaporation losses. J Hydrol. 2022;607:127524. https://doi.org/10.1016/j.jhydrol.2022.127524

35. Kasiviswanathan KS, Sudheer KP, Soundharajan BS, Adebayo JA. Implications of uncertainty in inflow forecasting on reservoir operation for irrigation. Paddy Water Environ. 2021;19:99-111. https://doi.org/10.1007/s10333-020-00822-7

36. Moradi AM, Dariane AB, Yang G, Block P. Long-range reservoir inflow forecasts using large-scale climate predictors. Int J Climatol. 2020;40(13):5429-50. https://doi.org/10.1002/joc.6526

37. Allawi MF, Hussain IR, Salman MI, El-Shafie A. Monthly inflow forecasting utilizing advanced artificial intelligence methods: a case study of Haditha Dam in Iraq. Stoch Environ Res Risk Assess. 2021;35(11):2391-410. https://doi.org/10.1007/s00477-021-02052-7

38. Samiyev L, Allayorov D, Atakulov D, Babajanov F. The influence of sedimentation reservoir on hydraulic parameters of irrigation channels. IOP Conf Ser Mater Sci Eng. 2020;883:012031. https://doi.org/10.1088/1757-899X/883/1/012031

39. Gebrechorkos SH, Bernhofer C, Hülsmann S. Climate change impact assessment on the hydrology of a large river basin in Ethiopia using a local-scale climate modelling approach. Sci Total Environ. 2020;742:140504. https://doi.org/10.1016/j.scitotenv.2020.140504

40. Abdel-Fattah MK, Abd-Elmabod SK, Aldosari AA, Elrys AS, Mohamed ES. Multivariate analysis for assessing irrigation water quality: a case study of the Bahr Mouise Canal, Eastern Nile Delta. Water. 2020;12(9):2537. https://doi.org/10.3390/w12092537

41. Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, et al. The climate hazards infrared precipitation with stations-a new environmental record for monitoring extremes. Sci Data. 2015;2:150066. https://doi.org/10.1038/sdata.2015.66

42. Tassi A, Vizzari M. Object-oriented LULC classification in Google Earth Engine combining SNIC, GLCM, and machine learning algorithms. Remote Sens. 2020;12(22):3776. https://doi.org/10.3390/rs12223776

43. Barathkumar S, Sellamuthu KM, Sathiyabama K, Malathi P, Kumaraperumal R, Devagi P, et al. Groundwater quality assessment in selected polluted hotspots of Tamil Nadu, India using geospatial and statistical approaches. Desalination Water Treat. 2025;322:101047. https://doi.org/10.1016/j.dwt.2025.101047

44. Kuntla SK. An era of Sentinels in flood management: potential of Sentinel-1, -2, and -3 satellites for effective flood management. Open Geosci. 2021;13(1):1616-42. https://doi.org/10.1515/geo-2020-0325

45. Sneka K, Pazhanivelan S, Ragunath KP, Raju M, Suganthi A, Satheesh S. Flood inundation mapping using Sentinel-1A satellite data in major blocks of Mayiladuthurai District, Tamil Nadu, India. Int J Plant Soil Sci. 2023;35(19):592-8. https://doi.org/10.9734/ijpss/2023/v35i193589

46. Rafiei Sardooi E, Azareh A, Eskandari Damaneh H, Skandari Damaneh H. Drought monitoring using MODIS land surface temperature and normalized difference vegetation index products in semi-arid areas of Iran. J Rangel Sci. 2021;11(4):402-18.

47. Ma C, Johansen K, McCabe MF. Monitoring irrigation events and crop dynamics using Sentinel-1 and Sentinel-2 time series. Remote Sens. 2022;14(5):1205. https://doi.org/10.3390/rs14051205

48. Manivannan DV, Jagadeeswaran R, Pazhanivelan S, Kumaraperumal R, Raju M, Pangayar Selvi R. Estimation of water spread area in selected tanks of Cuddalore District of Tamil Nadu using Sentinel-1A SAR data. Int J Environ Climate Change. 2023;13(9):3130-6. https://doi.org/10.9734/ijecc/2023/v13i92555

49. Sakthivel S, Sivamurugan AP, Pazhanivelan S, Ragunath KP, Suganthi A. Assessment of tank water spread area in Cheyyar sub basin using Sentinel-1A data. Int J Environ Climate Change. 2023;13(9):2896-904. https://doi.org/10.9734/ijecc/2023/v13i92524

50. Pelosi A, Aceto G, Aprile A, Chirico GB. Evaluation of the performance of the global weather dataset AgERA5 for sustainable water management in agriculture: A focus on reference evapotranspiration. In: International Conference on Computational Science and Its Applications. Cham: Springer Nature Switzerland; 2025. p. 283–293. https://doi.org/10.1007/978-3-031-97663-6_25

51. Elkatoury A, Alazba AA, Radwan F, Kayad A, Mossad A. Evapotranspiration estimation assessment using various satellite-based surface energy balance models in arid climates. Earth Syst Environ. 2024;8(4):1347-69. https://doi.org/10.1007/s41748-024-00501-1

52. Kamruzzaman M, Almazroui M, Salam MA, Mondol MA, Rahman MM, Deb L, Kundu PK, et al. Spatiotemporal drought analysis in Bangladesh using the standardized precipitation index (SPI) and standardize precipitation evapotranspiration index (SPEI). Sci Rep. 2022;12(1):20694. https://doi.org/10.1038/s41598-022-24146-0

53. Janarth S, Jagadeeswaran R, Pazhanivelan S, Kannan B, Ragunath

KP, Sathiyamoorthy NK. Assessment of agricultural drought in Tamil Nadu using remote sensing techniques. Agric Sci Digest. 2025;45(1):178-86. https://doi.org/10.18805/ag.D-6007

54. Madhurima U, Karunakaran KR, Sureshkumar D, Pazhanivelan S, Panneerselvam S. Dynamic water requirements for optimal cropping pattern under tank command areas in Andhra Pradesh, India. Agric Res J. 2024;61(4):584-94. https://doi.org/10.5958/2395-146X.2024.00072.9
55. Vairavamani M, Muthumanickam D, Pazhanivelan S, Kumaraperumal R, Ragunath KP. Crop diversification assessment in tank ayacut areas of lower Palar sub-basin of Chengalpattu District, Tamil Nadu, India using geo-spatial techniques. Int J Environ Climate Change. 2023;13(10):968-80. https://doi.org/10.9734/ijecc/2023/v13i102744
56. Prakash MA, Pazhanivelan S, Muthumanickam D, Ragunath KP, Sivamurugan AP. Mapping rice area in the Cauvery Delta Zone of Tamil Nadu using Sentinel-1A synthetic aperture radar data. Int J Environ Climate Change. 2023;13(10):195-204. https://doi.org/10.9734/ijecc/2023/v13i102630
57. Panneerselvam S, Pazhanivelan S, Rajavel M, Vincent S, Kumaresan P, Balakrishnan N. Remote sensing and GIS based water resource monitoring and climate resilient technology for enhancing rice productivity. J Agrometeorol. 2022;24(4):491-8.
58. Pazhanivelan S, Geethalakshmi V, Samykannu V, Kumaraperumal R, Kancheti M, Kaliaperumal R, et al. Evaluation of SPI and rainfall departure based on multi-satellite precipitation products for meteorological drought monitoring in Tamil Nadu. Water. 2023;15(7):1435. https://doi.org/10.3390/w15071435
59. Ni J, Wang H, Ma T, Huang R, Ciais P, Li Z, et al. Three Gorges Dam: friend or foe of riverine greenhouse gases? Natl Sci Rev. 2022;9(6):nwac013. https://doi.org/10.1093/nsr/nwac013
60. Yu D, Shi P, Shao H, Zhu W, Pan Y. Modelling net primary productivity of terrestrial ecosystems in East Asia based on an improved CASA ecosystem model. Int J Remote Sens. 2009;30(18):4851-66. https://doi.org/10.1080/01431160802680552
61. Liao Q, Wang Z, Huang C. Green infrastructure offset the negative ecological effects of urbanization and storing water in the Three Gorges Reservoir area, China. Int J Environ Res Public Health. 2020;17(21):8077. https://doi.org/10.3390/ijerph17218077
62. Hennig T, Wang W, Magee D, He D. Yunnan's fast-paced large hydropower development: A powershed-based approach to critically assessing generation and consumption paradigms. Water. 2016;8(10):476. https://doi.org/10.3390/w8100476
63. Zhang X, Dong Z, Gupta H, Wu G, Li D. Impact of the Three Gorges Dam on the hydrology and ecology of the Yangtze River. Water. 2016;8(12):590. https://doi.org/10.3390/w8120590
64. Edmonds RL. The Sanxia (Three Gorges) Project: the environmental argument surrounding China's super dam. Glob Ecol Biogeogr Lett. 1992;2(4):105-25. https://doi.org/10.2307/2997637
65. Shen ZY, Chen L, Chen T. Analysis of parameter uncertainty in hydrological and sediment modeling using GLUE method: a case study of SWAT model applied to Three Gorges Reservoir Region, China. Hydrol Earth Syst Sci. 2012;16:121-32. https://doi.org/10.5194/hess-16-121-2012
66. Li S, Xiong L, Dong L, Zhang J. Effects of the Three Gorges Reservoir on the hydrological droughts at the downstream Yichang station during 2003–2011. Hydrol Processes. 2013;27(26):3981-93. https://doi.org/10.1002/hyp.9541
67. Yang L, Zeng S, Xia J, Wang Y, Huang R, Chen M. Effects of the Three Gorges Dam on the downstream streamflow based on a large-scale hydrological and hydrodynamics coupled model. J Hydrol Reg Stud. 2022;40:101039. https://doi.org/10.1016/j.ejrh.2022.101039
68. Zeng S, Liu X, Xia J, Du H, Chen M, Huang R. Evaluating the hydrological effects of the Three Gorges Reservoir based on a large-scale coupled hydrological-hydrodynamic-dam operation model. J Geogr Sci. 2023;33:999-1022. https://doi.org/10.1007/s11442-023-2117-7
69. Goharian E, Shaltout M, Erfani M, Eladawy A. Developing an optimized policy tree-based reservoir operation model for High Aswan Dam reservoir, Nile River. Water. 2022;14(7):1061. https://doi.org/10.3390/w14071061
70. Alnaqbi SA, Alasad S, Aljaghoub H, Alami AH, Abdelkareem MA, Olabi AG. Applicability of hydropower generation and pumped hydro energy storage in the Middle East and North Africa. Energies. 2022;15(7):2412. https://doi.org/10.3390/en15072412
71. Dam AH, Nile R, Nasser L. Aswan High Dam. 2024.
72. Tvedt T. The Nile: History's greatest river. London: Bloomsbury Publishing; 2021. https://doi.org/10.5040/9780755616824
73. Elshinnawy IA, Almaliki AH. Vulnerability assessment for sea level rise impacts on coastal systems of Gamasa Ras El Bar area, Nile Delta, Egypt. Sustainability. 2021;13(7):3624. https://doi.org/10.3390/su13073624
74. Sadek MF, Shahin MM, Stigter CJ. Evaporation from the reservoir of the High Aswan Dam, Egypt: a new comparison of relevant methods with limited data. Theor Appl Climatol. 1997;56:57–66. https://doi.org/10.1007/BF00863783
75. El-Shafie A, Taha MR, Noureldin A. A neuro-fuzzy model for inflow forecasting of the Nile River at Aswan High Dam. Water Resour Manage. 2007;21:533–56. https://doi.org/10.1007/s11269-006-9027-1
76. Multsch S, Elshamy ME, Batarseh S, Seid AH, Frede HG, Breuer L. Improving irrigation efficiency will be insufficient to meet future water demand in the Nile Basin. J Hydrol Reg Stud. 2017;12:315–30. https://doi.org/10.1016/j.ejrh.2017.04.007
77. Kamal MM, Elhifnawy HE, Elsharkawy AS, Mousa OM. Assessment of hydrological analysis using WMS versus Arc-GIS. In: Proc 12th Int Conf Civil Architecture Eng. 2018. p. 1–10. https://doi.org/10.21608/iccae.2018.30059
78. Helwa AM, Elgamal MH, Ghanem AH. Dam break analysis of Old Aswan Dam on Nile River using HEC-RAS. Int J Hydrol Sci Technol. 2020;10(6):557–85. https://doi.org/10.1504/IJHST.2020.110568
79. Stewardson MJ, Guarino F. Basin-scale environmental water delivery in the Murray–Darling, Australia: A hydrological perspective. Freshw Biol. 2018;63(8):969–85. https://doi.org/10.1111/fwb.13102
80. Coles NA, Camkin J. Irrigation developments in Australia: historical development of irrigation. In: Handbook of irrigation hydrology and management. CRC Press; 2023. p. 3–31. https://doi.org/10.1201/9781003353928-2
81. Walker GR, Horne AC, Wang QJ, Rendell R. Assessing the impact of irrigation efficiency projects on return flows in the south-eastern Murray–Darling Basin, Australia. Water. 2021;13(10):1366. https://doi.org/10.3390/w13101366
82. Allan C, Khan S, Davidson B. Assessing social acceptability of management options for harmonising irrigation with environmental concerns: A pilot study from the Murrumbidgee Valley, Australia. Water SA. 2008;34(4):517-22. https://doi.org/10.4314/wsa.v34i4.183665
83. Furlan EM, Baumgartner LJ, Duncan M, Ellis I, Gruber B, Harrisson K, et al. Swinging back from the brink? Polygamous mating strategies revealed for an iconic threatened freshwater fish. Sci Total Environ. 2024;930:170808. https://doi.org/10.1016/j.scitotenv.2024.170808
84. Boys CA, Rayner TS, Baumgartner LJ, Doyle KE. Native fish losses due to water extraction in Australian rivers: evidence, impacts and a solution in modern fish- and farm-friendly screens. Ecol Manage Restor. 2021;22(2):134–44. https://doi.org/10.1111/emr.12483
85. Kingsford RT, Thomas RF. Destruction of wetlands and waterbird populations by dams and irrigation on the Murrumbidgee River in arid Australia. Environ Manage. 2004;34(3):383–96. https://

doi.org/10.1007/s00267-004-0250-3

86. Murray-Darling Basin Authority. Guide to the Murray-Darling Basin Plan. Canberra (Australia): MDBA; 2010. https://doi.org/10.1080/00049180500325702
87. Frazier P, Page K, Read A. Effects of flow regulation in flow regime on the Murrumbidgee River, south-eastern Australia: an assessment using a daily estimation hydrological model. Aust Geogr. 2005;36(3):301–14. https://doi.org/10.1080/00049180500325702
88. Wen L, Rogers K, Ling J, Saintilan N. The impacts of river regulation and water diversion on the hydrological drought characteristics in the Lower Murrumbidgee River, Australia. J Hydrol. 2011;405(3–4):382–91. https://doi.org/10.1016/j.jhydrol.2011.05.037
89. Ren S, Kingsford RT. Modelling impacts of regulation on flows to the Lowbidgee floodplain of the Murrumbidgee River, Australia. J Hydrol. 2014;519:1660–7. https://doi.org/10.1016/j.jhydrol.2014.09.003
90. van Emmerik THM, Li Z, Sivapalan M, Pande S, Kandasamy J, Savenije HHG, et al. Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee River basin, Australia. Hydrol Earth Syst Sci. 2014;18:4239–59. https://doi.org/10.5194/hess-18-4239-2014
91. Saha P. Hydrological modeling to assess water availability in the Murrumbidgee catchment in response to different climate and land use change scenarios [thesis]. Bathurst (Australia): Charles Sturt University; 2015. 143 p.
92. Muhury N, Ayele GT, Balcha SK, Jemberie MA, Teferi E. Basin runoff responses to climate change using a rainfall-runoff hydrological model in Southeast Australia. Atmosphere. 2023;14(2):306. https://doi.org/10.3390/atmos14020306
93. Kuhn E, Fleck J. The Colorado River: The Story of a Quest for Certainty on a Diminishing River. 2nd ed. Boulder (CO): Johnson Books; 2007.
94. Herman-Mercer N, Bair L, Hines M, Restrepo-Osorio D, Romero V, Lyde A, et al. Human factors used to estimate and forecast water supply and demand in the Upper Colorado River Basin. Reston (VA): US Geological Survey; 2023. Report No.: 2023-5015. https://doi.org/10.3133/sir20235015
95. MacDonnell LJ. The law of the Colorado River: coping with severe sustained drought, Part II. 2021.
96. Juricich R. Colorado River Basin governance, decision making, and alternative approaches. In: World Environmental and Water Resources Congress 2020. Reston (VA): American Society of Civil Engineers; 2020. p. 121–30. https://doi.org/10.1061/9780784482957.013
97. Frisvold GB, Duval D. Agricultural water footprints and productivity in the Colorado River Basin. Hydrology. 2023;11(1):5. https://doi.org/10.3390/hydrology11010005
98. Christensen NS, Lettenmaier DP. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. Hydrol Earth Syst Sci. 2007;11:1417–34. https://doi.org/10.5194/hess-11-1417-2007
99. Dawadi S, Ahmad S. Changing climatic conditions in the Colorado River Basin: implications for water resources management. J Hydrol. 2012;430:127–41. https://doi.org/10.1016/j.jhydrol.2012.02.010
100. Ficklin DL, Stewart IT, Maurer EP. Climate change impacts on streamflow and subbasin-scale hydrology in the Upper Colorado River Basin. PLoS One. 2013;8(8):e71297. https://doi.org/10.1371/journal.pone.0071297
101. Salehabadi H, Tarboton D, Kuhn E, Udall B, Wheeler K, Rosenberg D, et al. The future hydrology of the Colorado River Basin. The Future of the Colorado River Project. 2020. https://doi.org/10.4211/hs.6d351874f16947609eab585a81c3c60d
102. Pierce DW, Cayan DR, Goodrich J, Das T, Munévar A. Evaluating global climate models for hydrological studies of the Upper Colorado River Basin. J Am Water Resour Assoc. 2022;58(5):709–34. https://doi.org/10.1111/1752-1688.12974
103. Tran H, Zhang J, O'Neill MM, et al. A hydrological simulation dataset of the Upper Colorado River Basin from 1983 to 2019. Sci Data. 2022;9:16. https://doi.org/10.1038/s41597-022-01123-w
104. Beven K. How to make advances in hydrological modelling. Hydrol Res. 2019;50(6):1481–94. https://doi.org/10.2166/nh.2019.134
105. Chang FJ, Guo S. Advances in hydrologic forecasts and water resources management. Water. 2020;12(6):1819. https://doi.org/10.3390/w12061819
106. Kumar V, Kedam N, Sharma KV, Mehta DJ, Caloiero T. Advanced machine learning techniques to improve hydrological prediction: a comparative analysis of streamflow prediction models. Water. 2023;15(14):2572. https://doi.org/10.3390/w15142572
107. Purvis L, Dinar A. Are intra-basin and inter-basin water transfers a sustainable policy intervention for addressing water scarcity? Water Secur. 2020;9:100058. https://doi.org/10.1016/j.wasec.2019.100058
108. Wilder MO, Varady RG, Gerlak AK, Mumme SP, Flessa KW, Zuniga-Teran AA, et al. Hydrodiplomacy and adaptive governance at the US-Mexico border: 75 years of tradition and innovation in transboundary water management. Environ Sci Policy. 2020;112:189–202. https://doi.org/10.1016/j.envsci.2020.05.013
109. Alamanos A, Rolston A, Papaioannou G. Development of a decision support system for sustainable environmental management and stakeholder engagement. Hydrology. 2021;8(1):40. https://doi.org/10.3390/hydrology8010040
110. Swainson B, De Loë R, Kreutzwiser R. Sharing water with nature: insights on environmental water allocation from a case study of the Murrumbidgee catchment, Australia. Water Altern. 2011;4(1):15–32.
111. Pienaar GW, Hughes DA. Linking hydrological uncertainty with equitable allocation for water resources decision-making. Water Resour Manage. 2017;31:269–82. https://doi.org/10.1007/s11269-016-1523-3
112. Lu Z, Feng Q, Xiao S, Xie J, Zou S, Yang Q, et al. The impacts of the ecological water diversion project on the ecology-hydrology-economy nexus in the lower reaches in an inland river basin. Resour Conserv Recycl. 2021;164:105154. https://doi.org/10.1016/j.resconrec.2020.105154

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