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Review

Geospatial Technology for Sustainable Agricultural Water Management in India—A Systematic Review

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Abstract: Effective management of water resources is crucial for sustainable development in any region. When considering computer-aided analysis for resource management, geospatial technology, i.e., the use of remote sensing (RS) combined with Geographic Information Systems (GIS) proves to be highly valuable. Geospatial technology is more cost-effective and requires less labor compared to ground-based surveys, making it highly suitable for a wide range of agricultural applications. Effectively utilizing the timely, accurate, and objective data provided by RS technologies presents a crucial challenge in the field of water resource management. Satellite-based RS measurements offer consistent information on agricultural and hydrological conditions across extensive land areas. In this study, we carried out a detailed analysis focused on addressing agricultural water management issues in India through the application of RS and GIS technologies. Adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, we systematically reviewed published research articles, providing a comprehensive and detailed analysis. This study aims to explore the use of RS and GIS technologies in crucial agricultural water management practices with the goal of enhancing their effectiveness and efficiency. This study primarily examines the current use of geospatial technology in Indian agricultural water management and sustainability. We revealed that considerable research has primarily used multispectral Landsat series data. Cutting-edge technologies like Sentinel, Unmanned Aerial Vehicles (UAVs), and hyperspectral technology have not been fully investigated for the assessment and monitoring of water resources. Integrating RS and GIS allows for consistent agricultural monitoring, offering valuable recommendations for effective management.

Keywords: agricultural water management; remote sensing; Geographic Information Systems; India; climate change

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1. Introduction

Water, a crucial natural resource, is facing growing strain globally. This is attributed to various factors, such as rising populations; excessive agricultural irrigation leading to overuse and salinization; population growth in arid regions with limited water supply; very high pollution from urban areas, agriculture, and industry; increased human and industrial demand; and impacts of climate change. Moreover, surface water resources suffer from irregularity, scarcity, and unequal distribution [1]. In order to tackle the expected impacts of climate change on water and agriculture, especially while fulfilling diverse and competitive water needs, it is essential to implement smart water management approaches [2]. By relying on scientific evidence, agricultural water management can play a vital role in minimizing unsustainable water usage. It aids in improving water resilience and facilitates adaptation to climate change challenges [3]. Crop water stress disrupts essential physiological processes, emphasizing the importance of efficient water management to maintain equilibrium in agronomy, hydrology, and climatology. This is especially critical in areas where irrigation is indispensable for achieving the desired crop quality and yield. To enhance irrigation management and scheduling, it is essential to have a precise understanding of the quantity and timing of the water supply, which can be assessed through an accurate spatial evaluation of plant water stress [4,5]. Efficient agricultural water management practices are essential to expand irrigation coverage in India. Effectively managing water resources poses a significant challenge for countries like India. Developing water resources necessitates tackling vital aspects such as storage, conservation, and subsequent utilization [6].

Mismanagement of the water supply and other natural resources makes drought, a serious natural calamity, much worse [7]. However, rainfall patterns vary significantly in terms of both location and timing across the country. Intense, concentrated rainfall in a short period leads to devastating floods, while delayed and sparse rainfall results in drought conditions [8]. Considering the potential adverse effects of global climate change on water resources, the risks to food security, human resource employment, and power security are increasingly pronounced [9,10]. Therefore, it is imperative to assess future water availability at various spatial and temporal scales to effectively address these challenges. Agricultural drought significantly impacts the economies of agrarian nations such as India, where over 68% of the population relies on agriculture [11]. Approximately 16% of India's total land area is prone to drought, affecting around 50 million people annually [12,13]. An effectively developed mitigation and preparedness strategy is essential for decision makers to mitigate the impact of drought. Therefore, monitoring the onset, duration, intensity, and extent of drought has become crucial in managing its adverse effects on agricultural production [14,15]. India experienced devastating famines due to droughts in the last century [7]. Additionally, the unsustainable depletion of groundwater, crucial for irrigation, is anticipated to worsen agricultural challenges amid climate change, severely disrupting routine farming activities [16].

The crop evapotranspiration (ET) phenomenon is pivotal in the exchange of energy among crops, soil, water, and the atmosphere, and is crucial in studies related to energy exchange and water resource management [17,18]. Traditional methods have limitations in offering a wide-ranging spatial distribution of ET across large areas. However, advancements in satellite remote sensing techniques based on energy balance algorithms have enhanced the ability to map ET at a finer scale [19]. Efficient irrigation scheduling is crucial in the cultivation of different crops to prevent water wastage. In the past, different empirical equations and lysimeters were used to estimate crop ET. However, these methods were limited as they were point-based and could not be applied at a regional scale. To conserve water, it is essential to adopt new technologies for accurate monitoring of irrigation needs across large areas. Advanced geospatial techniques offer a solution by enabling regional estimation of crop water requirements in a shorter time, overcoming the limitations of traditional methods [9]. This helps farmers optimize irrigation schedules, preventing both overwatering and water scarcity, which directly impacts crop yield and quality. Runoff estimation in agricultural water management is vital for efficient water use. Understanding runoff patterns aids in erosion control, preserving soil fertility and structure. Proper estimation supports strategic crop selection, ensuring that farmers choose crops suited to local water availability, leading to sustainable agricultural practices [20]. Additionally, runoff estimation assists in managing water resources effectively, enabling the construction of reservoirs and facilitating the overall planning of irrigation systems. The use of satellite imageries to map natural resources, such as water bodies, has become increasingly significant. Water bodies are subject to intense utilization, necessitating regular monitoring for sustainable management. Identifying and mapping water bodies is essential for various purposes, including accurate surface water estimation and ensuring their sustainable use [21].

Water scarcity and climate change intensify the vulnerability of rainfed agriculture, impacting food production [22]. Soil moisture deficit significantly impacts agricultural productivity and hydrological processes [23]. To tackle these challenges, rainwater harvesting emerges as a vital solution. Food security requires a consistent supply of water, especially in areas with high population density. This can be achieved by capturing rainwater to combine surface and groundwater [24,25]. Rainwater harvesting not only stabilizes agricultural output but also enhances productivity and aids in restoring degraded lands. In India, both agricultural and domestic sectors are increasingly dependent on groundwater, leading to the depletion of this vital resource [26–28]. Rainwater harvesting stands out as a premier solution for enhancing both surface and groundwater resources [29–31]. In addition to the different traditional methods, geospatial technologies like RS and GIS have recently become important resources for acquiring spatio-temporal meteorological and crop status information [4,32]. RS data significantly enhance monitoring efforts by offering timely, comprehensive, cost-effective, and repetitive insights into the Earth's surface. The acquisition of precise spatio-temporal meteorological and crop data is indispensable for precise analysis, forecasting, and agricultural planning. It plays a vital role in making informed decisions concerning irrigation scheduling, crop stress management, disaster readiness, and the preservation of natural resources and ecosystems in diverse regions [5]. The overarching objective of sustainable agriculture is to achieve a harmonious balance between available land resources and crop requirements, with a strong emphasis on optimizing resource usage to ensure sustained productivity over an extended period. Although traditional methods of gathering weather and crop growth data are reliable, they come with the drawback of being labor-intensive and time-consuming [23]. In such circumstances, geospatial technology, specifically RS and GIS, proves highly effective for gathering and managing extensive spatio-temporal data through satellite data, digital maps, and simulation models [9]. Because of its ability to provide data quickly and repeatedly, this technology has many benefits. It facilitates speedy analysis and the creation of useful information for planners and decision makers [33].

This study investigates innovative methods for identifying agricultural water management challenges to provide a precise assessment of the research background. It explores existing remote sensing datasets, methodological approaches, and GIS applications. The systematic literature review, conducted following Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, ensures a thorough overview of the subject matter.

2. Research Method and Literature Search

Systematic Literature Review

In order to comply with the PRISMA criteria, we used a rigorous systematic literature review technique in this review paper. Our primary objective was to explore research studies pertaining to the integration of RS and GIS technologies in the context of agricultural water management. The PRISMA framework consists of four distinct stages—identification, screening, eligibility, and inclusion [5]. Three research questions are the primary source of this review article: (1) What specific agricultural water management challenges in India are addressed through geospatial technology? (2) Which primary RS datasets and tools are utilized to analyze issues related to agricultural water management? (3) What is the progress and future scope of geospatial technology to manage agricultural water management in India? We conducted a comprehensive literature search by exploring different databases, like Web of Science, Science Direct, MDPI, Springer, Scopus, and Google Scholar. Our search focused on specific keywords like "evapotranspiration estimation", "water productivity estimation", "drought management", "runoff estimation", "water resource mapping", "waterlogged areas mapping", "rainwater harvesting", "soil moisture estimation". We specifically identified these keywords in the titles, abstracts, and keywords of the articles. Furthermore, our focus was specifically on research articles published in the English language concerning India. As a result, we excluded papers published in languages other than English, review articles, preprints, chapters, and master's and doctorate dissertations/theses from our analysis. In adherence to the PRISMA guidelines, a total of 60 research articles were identified and chosen, a process outlined in the form of the flowchart depicted in Figure 1. In the process of selection, we applied exclusion criteria similar to those utilized in recent review studies [5,34–36].

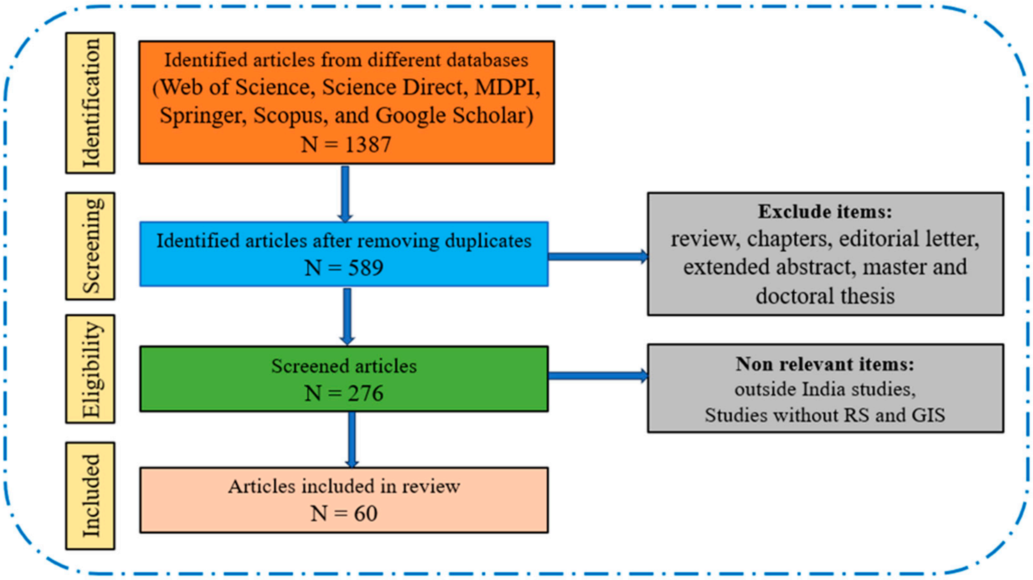

Figure 1. Flowchart of methodology adopted for selection of articles for review considering PRISMA guidelines.

The notable increase in published research concerning the utilization of geospatial technology in agricultural water management in India signifies the achievement of a distinct level of expertise in this domain. As depicted in Figure 2, this trend emphasizes significant advancements in geospatial technology, including the accessibility of high-resolution satellite datasets. These developments highlight the maturation of geospatial technology applications in the realm of agricultural water management, underscoring the depth of knowledge and technological progress within the country.

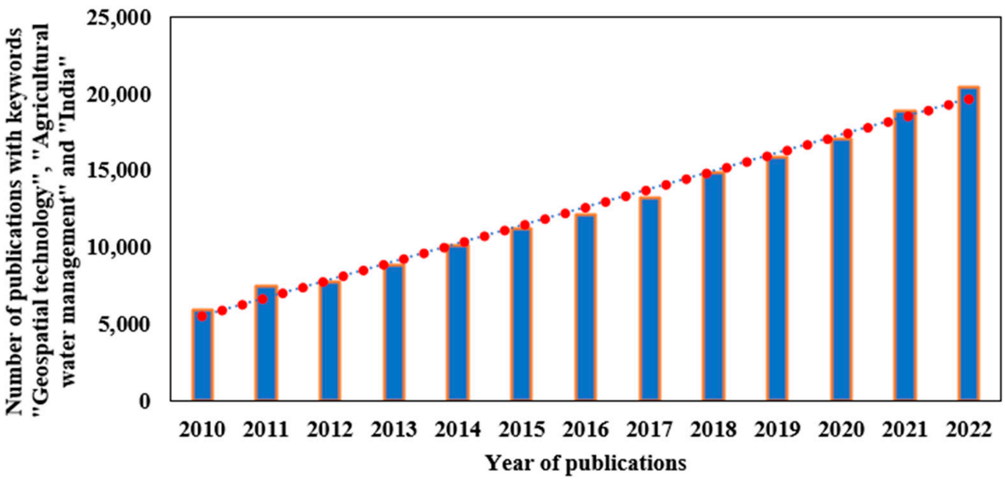

Figure 2. Number of publications with keywords "Geospatial technology", "Agricultural water management" and "India" from the year 2010 to 2022 as per Google Scholar search results. The red dots are the data points over the years.

Different remote sensing-based indices used based on stress in plants, soil moisture, evaporation, precipitation, temperature, and water bodies are presented in Table 1. The data and products identified in this review useful for agricultural water management are presented in Table 2.

Table 1. List of the different remote sensing-based indices used in this review based on stress in plants, soil moisture, evaporation, precipitation, temperature, and water bodies.

Abbreviation	Meaning
Plants	
NDVI	Normalized Difference Vegetation Index
VCI	Vegetation Condition Index
VHI	Vegetation Health Index
CDI	Composite Drought Index
NDMI	Normalized Difference Moisture Index
Soil moisture	
SMI	Soil Moisture Index
SWDI	Soil Water Deficit Index
SMDI	Soil Moisture Deficit Index
LSWI	Land Surface Water Index
SASI	Shortwave Angle Slope Index
VSWI	Vegetation Supply Water Index
NVSWI	Normalized Vegetation Supply Water Index
Evaporation	
ET	Evapotranspiration
ESI	Evaporative Stress Index
Precipitation	
SPI	Standardized Precipitation Index
Temperature	
LST	Land Surface Temperature
TCI	Temperature Condition Index
Water bodies	
WRI	Water Ratio Index
NDWI	Normalized Water Difference Index
MNDWI	Modified Normalized Water Difference Index
SDI	Streamflow Drought Index
NDDI	Normalized Difference Drought Index

Table 2. List of the different remote sensing-based sensors and products identified in this review for agricultural water management.

Abbreviation	Meaning
MODIS	Moderate Resolution Imaging Spectroradiometer
PCA	Principal component analysis
GRACE	Gravity Recovery and Climate Experiment
GLDAS	Global Land Data Assimilation System
SMAP	Soil Moisture Active Passive
INSAT	Indian National Satellite
IRS	Indian Remote Sensing
TRMM	Tropical Rainfall Measuring Mission
TIRS	Thermal Infrared Sensor
OLI	Operational Land Imager
TM	Thematic Mapper
MSS	Multi-Spectral Sensor
ETM	Enhanced Thematic Mapper
AWiFS	Advanced Wide Field Sensor
SAR	synthetic aperture radar

Table 2. *Cont.*

Abbreviation	Meaning
GLEAM	Global Land Evaporation Amsterdam Model
IMD	India Meteorological Department
LISS	Linear Imaging and Self Scanning sensors
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
AVHRR	Advanced Very High-Resolution Radiometer
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey
SOI	Survey of India

3. Results

The selected studies were classified into different categories, namely, evapotranspiration (ET), irrigation water requirement, and water productivity estimation; drought assessment and monitoring; runoff estimation from agriculture watersheds; water body and waterlogged area mapping; identification of suitable sites for groundwater recharge and rainwater harvesting; and soil moisture estimation.

3.1. Evapotranspiration (ET), Irrigation Water Requirement, and Water Productivity Estimation

In both irrigated and rain-fed agriculture, determining when and how much water to supply, as well as finding the optimal sowing time based on soil moisture and precipitation, is crucial. Estimating irrigation water demand primarily relies on ET procedures. Besides precipitation, ET is a vital component of the hydrological budget. Ground-based methods like lysimeters, eddy covariance, and the Bowen ratio are employed to measure actual ET (AET) with high temporal resolution at specific points. However, extending these methods to obtain spatial AET distribution at a basin scale is challenging and costly in terms of installation and maintenance. Satellite imagery, on the other hand, provides essential data for estimating spatial AET distribution at fine resolution. This is achieved through satellite-based physical, empirical, and semi-empirical models, spanning from basin to global scales [37]. To address the worldwide issue of water scarcity, the crop water footprint (WF) has become a crucial tool. It enables policymakers to analyze water usage effectively, encouraging justified and sustainable water use. Policymakers can more effectively plan, manage, and conserve water resources by having a better understanding of how surface and groundwater resources are used throughout the industrial process [38]. Different geospatial technology-based studies identified in this review for ET, irrigation water requirement, and water productivity estimation in India are presented in Table 3.

Table 3. Geospatial technology-based studies for estimation of ET, irrigation water requirement and water productivity.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Junagadh, Gujarat State	Landsat-7, -8 data, Climatic data from Junagadh Agricultural University	2014	RS-based surface energy balance algorithm for land (SEBAL) algorithm was used to estimate crop ET	SEBAL-based actual ET can serve as a valuable tool for irrigation scheduling within canal irrigation commands, enhancing water use efficiency	[39]

Table 3. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
2	Kangsabati reservoir command in West Bengal State	SRTM DEM, Landsat-8, IMD weather data	2015	Evaluated the applicability of the simplified surface energy balance index (S-SEBI) method for determining spatially distributed daily ET	The crop coefficient-based approach proves beneficial for specific points when sufficient data is accessible. Conversely, the S-SEBI method is applicable in regions with limited data, enabling the estimation of spatially distributed ET	[40]
3	Panchmahal district of Gujarat	Sentinel-2 multispectral data, Climate data from main maize research station of Anand Agricultural University, Gujarat	2020–2021	Utilized satellite RS-based vegetation index to assess the crop acreage and crop water requirements of the predominant maize crop	Crop water requirement maps generated through multispectral vegetation indices from RS are valuable tools for evaluating crop water usage at both regional and field levels	[18]
4	Tarafeni South Main Canal (TSMC) irrigation command area of West Bengal	Landsat-5 TM data, SOI toposheets	2011	Crop ET was estimated on the basis of NDVI. Kc maps were prepared by using NDVI	This approach enables precise irrigation by matching water supply with crop demand, conserving water in late growth stages and enhancing canal system efficiency	[41]
5	Indian Sundarban Biosphere Reserve	Landsat-8 OLI, SRTM DEM, MODIS ET data	2020	Estimated the spatial distribution of daily ET by using the (Mapping Evapo Transpiration at high resolution with internalized Calibration (METRIC) model	The study incorporates an innovative approach to validate the effectiveness of this method in water conservation. It also utilizes satellite-based technology, providing efficient tools for integrated evapotranspiration estimation	[42]
6	Kondamallepally Mandal, Nalgonda district of Telangana State	Landsat-8 data	2020	Estimation of ET using simplified surface energy balance (SSEB) model	The obtained ET data have value for diverse applications, including the evaluation of water productivity	[43]

Table 3. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
7	Agricultural farm, New Delhi	Landsat-8,9 data	2021–2023	ET was estimated using the simplified SEBI model and then then compared to eddy covariance measurements over a semi-arid agricultural farm	The S-SEBI model accurately maps ET with high precision across pixels, making it perfect for integrating into irrigation scheduling	[19]
8	Upper Baitarani River Basin, Odisha State of India	SRTM DEM, FAO soil map, rainfall and weather data from IMD, streamflow data from Central Water Commission (CWC) of India	1991–2011	Assessed water footprints like blue water flow, green water flow, and green water storage spatio-temporally using the SWAT model	Awareness about the water footprint provides a clear and multidisciplinary framework for evaluating and enhancing water policy decisions	[6]
9	Banjar River watershed, Mandla district of Madhya Pradesh	Global weather data	2000–2013	Quantified the green, blue, and grey water footprints of crops cultivated in the study area for comparative analysis with other studies	This comparative analysis would assist policymakers and relevant government agencies in maximizing crop yields by effectively utilizing both surface and groundwater resources	[44]
10	Manipur State of India	Soil, irrigation, and weather data from different sources	2011–2020	The paddy yield and water footprint were quantified under varying rainfall conditions utilizing the AquaCrop GIS software	The AquaCrop model precisely forecasted rice yield and water footprint under different rainfall conditions	[45]
11	Bansloi River basin on eastern edge of the Chota Nagpur Plateau	Landsat-8 OLI, Weather data from IMD and World weather online data	2018–2019	The crop water requirement assessment (CropWRA) model was developed as a valuable tool for evaluating the satisfied degree of crop water requirements considering crop, hydrological, climate, and DEM data	The CropWRA model proves a valuable tool for promoting sustainable water resource management, facilitating the development of irrigation infrastructure and integrating various modern technologies for agricultural advancement	[46]

Table 3. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
12	Konkan region of Maharashtra State of India	Weather and crop data	2015–2016	Evaluation of the water and carbon footprint of onion crops cultivated under varied irrigation conditions	This research serves as a foundation for optimizing water usage efficiency and reducing the carbon and water footprint linked to onion cultivation	[47]
13	Narayanpur command area of Gulbarga and Raichur districts of Karnataka	Sentinel-2 MSI data, climate data from IMD	2018–2019	Satellite data was used to classify major crops using a supervised algorithm. SEBAL was used to determine crop ET. Assessed the irrigation performance in canal command area	This finding suggests that, during the Kharif season, crops receive sufficient irrigation compared to the Rabi season in the study area	[17]

3.2. Drought Assessment and Monitoring

Drought is a natural, recurring aspect of the climate, exhibiting varying characteristics and impacts across regions. It is a climatic anomaly marked by insufficient moisture due to factors like low or erratic rainfall and increased water demand. When insufficient rainfall and soil moisture impede timely cultural practices and healthy crop growth during the growing season, an agricultural drought occurs. Drought directly affects the crop area, production, and farm jobs. Insufficient sowing, delayed planting, and poor crop growth due to lack of soil moisture result in decreased yields, significantly impacting livelihoods [48]. Around 53% of India's agriculture depends on rainfall, making droughts a major issue for the country's rain-reliant farmers and causing severe water crises [49]. Drought is anticipated to worsen due to predicted climate change, leading to an expansion in drought-affected areas. This escalation could significantly and adversely impact agriculture [50]. The most dependable method for addressing drought-related issues at the local and global levels is clearly monitoring the drought. By ensuring long-term gains in agricultural output, this approach improves livelihoods [51]. Reducing the global risk of drought, particularly in arid and semi-arid areas, requires assessment and monitoring. These are vital for effective management of natural resources and agriculture [52]. The constraints of conventional drought monitoring indices complicate the assessment and monitoring of agricultural drought. RS-based indices have given rise to a novel method for assessing and keeping track of agricultural droughts [53]. To effectively execute methods for managing water resources, it is imperative that scientific research should be conducted to determine the severity of the drought [54]. Different geospatial technology-based studies identified in this review for drought assessment and monitoring in India are presented in Table 4.

Table 4. Geospatial technology-based studies for drought assessment and monitoring in India.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Marathwada region of Maharashtra State	Terra MODIS (500-m resolution) data, precipitation, and streamflow data	1980–2014	SPI, SDI, and VCI were combined to prepare the composite drought index using PCA	A comprehensive approach, integrating multiple indicators, is essential for a more precise assessment of drought conditions	[55]
2	Sabarmati and Brahmani River basin	Terrestrial water storage and groundwater storage anomalies from GRACE satellite, daily gridded precipitation, maximum and minimum temperatures, MODIS evapotranspiration, and NDVI	1951–2017	Constructed an integrated drought index that amalgamates the indicators of meteorological, hydrological, and agricultural droughts, incorporating considerations for groundwater storage	Integrated drought indices can be utilized effectively to monitor and assess droughts in India, both in the present and future climate scenarios	[11]
3	Godavari River basin	GLDAS and SMAP enhanced Level-3 surface and ERA5 soil moisture product	2015–2020	Compared the SMAP and GLDAS soil moisture time series with the ERA5 soil moisture product for the study period	Both SWDI and SMDI demonstrate proficiency in discerning the spatial distributions of dry and wet conditions	[56]
4	Entire India	SASI images derived using MODIS surface-reflectance data	2001–2012	MODIS data were used for the determination of fractional wetness using NDVI and SASI	A fractional wetness approach developed using MODIS data is capable of forewarning of early season agricultural drought condition	[57]
5	Gujarat, Maharashtra, and Karnataka	NDVI from INSAT 3A, rainfall product from KALPANA-1, MODIS LST, and ET data	2009–2013	A combined deficit index developed from antecedent rainfall deficit and deficit in monthly vegetation vigor	A combined deficit index serves as a valuable indicator for evaluating late-season regional agricultural drought by capturing the lagged relationship between water supply and crop vigor	[58]
6	Tamil Nadu	Terra-derived MODIS-based surface reflectance and LST data, GLDAS–NOAH land surface data, and TRMM rainfall data	2000–2013	Compared satellite-derived indices like NDWI, NMDI, and NDDI with in-situ rainfall and SPI data	A combined approach using multiple indices can effectively serve as a proxy for identifying vegetation stress	[59]

Table 4. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
7	Bikaner city of Rajasthan	Landsat 5 TM and 8 OLI/TIRS data	1990–2020	VCI, TCI, and VHI utilized for monitoring drought-prone areas	Necessity of implementing real-time drought monitoring systems based on VCI for effective drought management	[60]
8	Marathwada Region	Actual ET and ESI data collected from GLEAM, rainfall extracted from IMD	1980–2020	SPI is considered for characterizing drought occurrences at multiple time frames	SPI proves more adept at detecting drought occurrences when observed over longer time frames compared to shorter durations	[61]
9	Entire India	TRMM rainfall data, MODIS NDVI data	1998–2010	NDVI and LSWI for mapping drought-induced changes	RS data can help to assess drought frequency and intensity, guiding the strategic deployment of technologies to enhance productivity in regions vulnerable to drought	[62]
10	Raichur district of Karnataka	MODIS LST and NDVI data	2002–2012	Agricultural drought assessment using combination of LST and NDVI data	The integration of NDVI and other indices like LST offers valuable insights for agricultural drought monitoring, serving as an effective early warning system for farmers	[63]
11	Prakasam district of Andhra Pradesh	MODIS NDVI and LST data	2007–2020	SMI is calculated using LST data	Integrated use of SMI, SPI, and NDVI anomaly presents a near-real-time indicator for identifying water deficit conditions in soils with both light and heavy textures	[64]
12	Rayalaseema region of Andhra Pradesh	CHIRPS rainfall and MODIS NDVI data	2000–2018	Agricultural drought monitoring using indices like SPI, NDVI, LST, TCI, VCI, VHI, VSWI, and NVSWI	VSWI obtained from satellite data is effective in mapping and keeping track of agricultural drought in semi-arid regions	[65]

3.3. Runoff Estimation from Agriculture Watersheds

The Soil Conservation Service-Curve Number (SCS-CN) model, developed by the U.S. Bureau of Agriculture, National Resources Conversion Service (NRCS), stands as the predominant and widely adopted method for estimating direct runoff. This model is extensively employed to assess direct runoff in small agricultural watersheds for specific rainfall events [66]. It needs less input data; hence, different models like the Soil and Water Assessment Tool (SWAT), Environmental Policy Integrated Climate (EPIC), Agricultural Non-Point Source Pollution (AGNPS), and Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) models use the SCS-CN method for runoff estimation [67,68]. This method has gained widespread acceptance and is extensively utilized in numerous hydrologic studies. It is employed for estimating surface runoff, particularly in ungauged agricultural watersheds, determining soil erosion vulnerability, and studying the spatio-temporal variations in land use/land cover (LULC) patterns [69]. Different geospatial technology-based studies identified in this review for drought assessment and monitoring for India are presented in Table 5.

Table 5. Geospatial technology-based studies for runoff estimation from agricultural watersheds in India.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Kalu watershed, Ulhas River basin, Maharashtra	IRS (LISS-III) and ASTER DEM	1999–2002	The effectiveness of three slope-adjusted curve number models and the original SCS-CN method was assessed using LISS-III and ASTER DEM data	RS and GIS techniques enhance the accuracy of SCS-CN model inputs, enabling more precise runoff predictions	[70]
2	Krishna River basin of Peninsular India	Weather data from IMD, SRTM-DEM	1970–2005	SWAT-CUP (SWAT-Calibration Uncertainty Programme) was designed specifically for calibrating and validating the SWAT model	Emphasized the importance of choosing suitable climate models in regional investigations to analyze the lengthening of monsoon rainfall and variations in the maximum long-term mean Indian Summer Monsoon rainfall and surface runoff	[71]
3	Doddahalla watershed of Krishna basin, Karnataka	TRMM and IMD rainfall, Cartosat-1 CartoDEM, IRS LISS III data	2008–2012	Runoff simulation is carried out using the HEC-HMS hydrological simulation model, integrating RS and GIS techniques	These models are most valuable in ungauged watersheds and water-scarce regions where limited monitored data exist. They are crucial for accurate runoff estimation, which is vital for sustaining water resources	[72]
4	Koraiyar Basin, Tamil Nadu, India	Landsat TM, ETM+, OLI/TIRS, rainfall data from water resource department, Chennai	1986–2016	Geospatial technology is employed to analyze land use and land cover (LULC) changes and their effects on surface runoff by utilizing multi-dated Landsat satellite images spanning from 1986 to 2016	The study concludes that alterations in LULC result in increased runoff volume within the basin, even when the extreme rainfall remains constant, indicating the significant impact of changing LULC conditions	[73]

Table 5. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
5	Sind River basin, Madhya Pradesh	LANDSAT-8 for LULC, Survey of India (SOI) toposheets, global weather data	2005–2014	SCS-CN and GIS techniques are employed for estimating rainfall–runoff relationship	The SCS-CN method has demonstrated remarkable efficiency, requiring minimal time and expertise to manage extensive datasets. This approach proves superior in identifying potential sites for artificial recharge structures	[74]
6	Pappiredipatti watershed, Tamil Nadu	IRS -LISS III for LULC, toposheet (SOI), rainfall data from public works department, Dharmapuri	2000–2014	Estimation of rainfall–runoff relationship by integrating the SCS-CN method and remote sensing and GIS techniques	The SCS-CN method was validated as a superior method, demanding minimal time and resources to manage extensive datasets and assess larger environmental areas for selecting sites for artificial recharge structures	[75]
7	Koyna River basin in Satara district, Maharashtra	LANDSAT-7 for LULC, Survey of India (SOI) toposheets, ASTER DEM, FAO global soil data, rainfall from Maharashtra Agriculture department	1999–2011	Estimation of LULC change impact on runoff generation and study of applicability of SCS-CN method for runoff estimation	This method is valuable for identifying changes in land use/land cover over time and understanding their impact on runoff generation. It emphasizes the significance of making rainwater harvesting structures to facilitate groundwater recharge	[53]

3.4. Water Body and Waterlogged Area Mapping

India relies heavily on agriculture, making efficient water usage vital. However, a significant portion of water is wasted due to insufficient understanding of crop water requirements and the absence of effective water management. Monitoring water resources and surface water availability is crucial to understanding temporal water storage. Mapping surface water bodies using satellite imagery has become essential, providing rapid and timely information about surface water bodies. RS offers a valuable tool, offering quick insights into water resources, aiding in efficient management and conservation efforts [76,77]. When there is an excessive amount of moisture or water content, the crop root zone is deprived of adequate aeration, resulting in waterlogging. This causes high water tables and surface ponding, which makes the land useless. Plant growth is directly hampered by this circumstance, which lowers agricultural yield. The degree and length of waterlogging in agricultural fields can significantly reduce the yield of crops. Salinization and alkalinization are intimately related to waterlogging, which makes it extremely dangerous for irrigated agriculture to continue. It impacts roughly 6 million hectares of India’s arable land [78]. Before determining the best course of action, it is imperative that these waterlogged areas must be carefully investigated. Traditionally, ground surveys are used to map waterlogged areas, but they are neither cost-effective nor timely for large regions. Combining GIS with satellite RS offers a productive real-time substitute for tracking and determining the size of areas that are inundated. Different geospatial technology-based studies identified in this review for mapping surface water bodies and waterlogged areas in India are presented in Table 6.

Table 6. Geospatial technology-based studies for water body and waterlogged area mapping in India.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Godavari Delta, Andhra Pradesh	Landsat-5 TM	2005–2019	NDWI and MNDWI were used for mapping and change detection of water bodies	NDWI and MNDWI are highly efficient indicators for monitoring and mapping surface water bodies. They not only help identify changes but also serve as a warning against relying on moisture content to extract soil moisture from water bodies	[79]
2	Chennai, Tamil Nadu	Landsat-4 MSS, 5 TM, 8 OLI data	1977–2016	WRI, NDWI, and MNDWI were used for the assessment of the spatio-temporal variations of surface water bodies	The use of indices like WRI, NDWI, and MNDWI in conjunction with satellite images offers reliable spatio-temporal information when applied to RS data, allowing for precise analysis and monitoring of water resources over time	[80]
3	Parts of Krishna and Godavari River basins	Resourcesat-2 AWiFS data	2004–2014	Water bodies were extracted using an automated extraction algorithm	RS and GIS techniques prove to be valuable alternatives to traditional methods for monitoring and characterizing surface water bodies	[81]
4	Telangana State	Landsat-8 data	2013–2019	Temporal changes in waterbody surface areas were identified using indices such as NDVI, NDWI, and MNDWI, and a random forest machine learning algorithm	The machine learning algorithm is vital for planning crops, evaluating restoration efforts, monitoring floods, and understanding land use impact on water resources	[82]

Table 6. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
5	Nainital Lake of Uttarakhand State	Landsat-7, -8 data	2001–2018	Dynamic change in the water spread area is investigated using NDWI, MNDWI and WRI. The non-parametric Mann–Kendall trend test was also applied	These indices rapidly indicate extraction of water bodies, while Mann–Kendall and Sen's slope estimator prove efficient in determining trends and their magnitudes in hydrological data	[83]
6	Nagarjuna Sagar reservoir, Andhra Pradesh	Landsat-5, -8 data	1989–2017	Extracted surface water body area using NDVI, NDMI, NDWI, MNDWI, and unsupervised classification	The accuracy assessment revealed that MNDWI outperforms other index methods, providing superior results	[84]
7	Lower Gandak command of Bihar	Landsat-5, -7, and -8, IRS-1D, IRS-P6	2000–2020	Supervised classification is used to classify water bodies from other land use classes. NDVI, NWDI, and MNWDI were also used to enhance water features from collected data	Immediate action is advised to transform waterlogged areas into permanent water bodies with reduced surface area while maintaining their maximum volume. These bodies can be utilized for irrigation, ecological purposes, and various economic activities	[78]
8	Moyna basin, Purba Medinipur district, West Bengal	Landsat-5 TM, ASTER data	2009	Mapped waterlogged area on the basis of supervised classification and NDVI, NDWI, and modified NDWI or NDMI	Satellite images can identify and map waterlogged areas through supervised classification, NDVI, NDWI, and modified NDWI or NDMI	[85]
9	Muzaffarpur district of Bihar	IRS P6, LISS-III data, TRMM 3B43 rainfall data	1998–2009	The surface extent of salt-affected and waterlogged areas was identified and delineated through the analysis of multi-temporal satellite images during both pre-monsoon and post-monsoon seasons	RS and GIS provide an efficient platform for comprehending intricate relationships among hydro-geological factors that influence the severity of waterlogging and salt-affected areas in the region	[86]

Table 6. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
10	Gosaba Island, Sundarban, West Bengal	Landsat-1 MS, Landsat-8 OLI data	2017	RS and GIS techniques were used for identifying spatio-temporal changes in drainage networks and congestion patterns by overlaying multi-temporal vector layers. Drainage induced waterlogging problems were assessed	This analysis can enhance farmers' livelihoods by harnessing waterlogging as an opportunity for integrated rice and fish farming	[87]
11	Vaishali district of North Bihar	Landsat-5 TM data	1998, 2006	The areas affected by surface waterlogging were identified using the NDWI technique	The spatio-temporal analysis of waterlogging dynamics conducted in this study can provide valuable insights for protective measures against waterlogging problems	[88]

3.5. Identification of Suitable Sites for Groundwater Recharge and Rainwater Harvesting

Water, an indispensable resource in our daily lives, is becoming increasingly scarce in both rural and urban areas. This scarcity is primarily due to reduced infiltration rates caused by deforestation and extensive surface paving. Despite India having a substantial amount of surface water, limitations in topography and other factors restrict its storage [89]. In areas where surface water is scarce, groundwater becomes a crucial alternative for water supply. However, excessive groundwater extraction has led to declining water levels in many areas, escalating both investment and operational costs. Addressing this issue involves artificially recharging potential aquifers, which can alleviate the problem to some extent. Rainwater harvesting and artificial groundwater recharge have become cornerstone tactics for the long-term viability of freshwater resources, which include surface and groundwater. The best sites for artificial recharge have been identified through a number of studies [90,91]. Different geospatial technology-based studies identified in this review for mapping and identification of suitable sites for groundwater recharge and rainwater harvesting in India are presented in Table 7.

Table 7. Geospatial technology-based studies for identification of suitable sites for groundwater recharge and rainwater harvesting.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Semi-arid region of Anantapur district, Andhra Pradesh	Landsat-8 data, SOI toposheets	2012	Identified artificial recharge sites using different thematic layers as good, moderate to good, moderate, and poor for artificial recharge	Artificial recharge sites can be successfully identified using geospatial technology	[92]

Table 7. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
2	Peddavagu River basin, Telangana State	SRTM DEM, Environmental Systems Research Institute (ESRI) land cover, IMD rainfall	2018	Assessed groundwater potential zones (GWPZs) and identified suitable areas for artificial recharge using a combination of GIS, analytic hierarchy process (AHP), and fuzzy AHP	The results will be useful for decision makers and local communities for responsible use of groundwater resources. This knowledge enables sustainable planning and management, ensuring the availability and viability of these resources for future generations	[93]
3	Mahesh River basin comes under Akola and Buldhana districts in Maharashtra	IRS-P6 LISS-III satellite data, SOI toposheets	2010–2015	GWPZs were created using different thematic layers. Different thematic layers were combined for groundwater exploration and watershed management	The zoning maps depicting groundwater potential and artificial recharge hold significance for initiatives related to soil and water conservation projects, watershed development programs, and the management of groundwater resources	[94]
4	Mand catchment of Mahanadi basin in Chhattisgarh	SOI toposheet, Sentinal-2, SRTM-DEM, rainfall, soil map, runoff data	2021	GWPZs were identified with nine thematic layers using the Multi-Criteria Decision Analysis (MCDA) method with geospatial technology	The integration of GIS provides an efficient platform for the comprehensive analysis of diverse datasets in the realm of groundwater management and planning	[95]
5	Namakkal district of Tamil Nadu	SOI toposheet, soil map	2005	Weighted index overlay analysis (WIOA) was applied by integrating the thematic layers for delineation of GWPZs	The findings from groundwater level observations in designated GWPZs reveal the effectiveness of RS and GIS in identifying recharge sites	[96]
6	Upper Betwa Watershed, Raisen district of Madhya Pradesh	SRTM-DEM, Landsat-8 OLI data, soil map	2016	The groundwater recharge potential map was created by overlaying thematic maps using the weighted index overlay (WIO) method	RS and GIS techniques serve as efficient tools for appraising groundwater potential, aiding in the identification of optimal locations for groundwater withdrawal wells to meet water demands	[97]

Table 7. *Cont.*

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
7	Bokaro district of Jharkhand	Landsat 5-TM satellite data, SRTM DEM, rainfall data, soil map	2003–2013	An integrated approach using RS and GIS methods is employed to map groundwater potential zones and identify suitable sites for artificial recharge	The conclusive findings indicate favorable groundwater zones in the study area, holding significant implications for improved planning and management of local groundwater resources	[98]
8	Alwar district of Rajasthan	IRS Resourcesat-2 LISS III data, ASTER-DEM, soil data	2016	Rainwater harvesting sites were identified using DEM, LULC, soil map, drainage map, and depression map with the SCS-CN method	This approach saves time, significantly reduces costs by minimizing earthwork expenses, and can be applied in the planning of efficient water resource management strategies	[99]
9	Upper Kangsabati Watershed, West Bengal	SRTM-DEM, IRS LISS-III, SOI toposheet, IMD rainfall	2004–2017	Estimation of surface runoff using SCS-CN analysis and identification of suitable locations for rainwater collection	Geospatial technology can effectively support sustainable watershed development and water resource management efforts	[100]
10	Mirzapur, Chandauli, and Sonbhadra districts of Uttar Pradesh State	SRTM-DEM, IMD rainfall, soil data from National Bureau of Soil Survey and Land Use Planning (NBSS-LUP)	1980–2020	Determined optimal zones for surface water storage and groundwater recharge to boost irrigation water supply, employing geospatial tools and AHP	Strategic water management planning through MCDA and GIS improves surface and groundwater resources. This approach enhances agricultural land use possibilities	[101]
11	Kandi subdivision of Murshidabad district, West Bengal State	IMD rainfall, Resoursesat-2 satellite data, SOI toposheets	2015–2016	Implemented fuzzy AHP to assign weights to different criteria essential for selecting appropriate sites for rainwater harvesting	Utilizing multi-criteria analysis with fuzzy logic provides a comprehensive evaluation for both rainwater harvesting structures and site selections	[102]
12	West Midnapur, Purulia and Bankura regions of West Bengal	Landsat-7 satellite data, ASTER DEM, soil data from NBSS-LUP, rainfall data from Agriculture department of state	2011	Weights were allocated to thematic layers, specifically those related to slope and runoff coefficient, and these features were ranked accordingly	This study will prove valuable for policymakers, aiding them in allocating government funds according to administrative boundaries	[103]

3.6. Soil Moisture Estimation

At both micro and mega scales, soil moisture is essential for maintaining life-sustaining processes in ecosystems [104]. Its levels exhibit significant variability across both space and time, contingent upon factors such as topography, soil composition, land cover, and climate. Monitoring the moisture content of the soil in the root zone, which controls crop growth, provides important information about possible moisture shortages. Therefore, regular monitoring of soil moisture levels is essential, enabling efficient irrigation practices that enhance crop productivity and facilitate accurate yield forecasts. It is essential to have precise and accurate knowledge of soil moisture at different scales for agricultural purposes, flood monitoring, and soil health understanding. Measuring this parameter is imperative in agriculture, particularly for early detection of drought conditions, enabling timely interventions and warnings [105]. Different geospatial technology-based studies identified in this review for soil moisture estimation are presented in Table 8.

Table 8. Different geospatial technology-based studies identified in this review for soil moisture estimation.

Sr. No.	Location	Data/ Products Used	Time/ Period	Approach	Outcome	References
1	Maiyur and Sampathinallur villages, Tamil Nadu	Sentinel-1A SAR data	2022	SAR Sentinel-1A data were used to determine soil moisture using the Water Cloud Model	This model suggests ideal crops for vast and intricate areas by analyzing projected moisture content	[23]
2	Kosi River basin, North Bihar	Sentinel-1A, 1B SAR data	2020	Assessed the capability of C-band Sentinel-1 SAR data in estimating soil surface moisture during the dry season in both bare soil and vegetated agricultural fields	The findings from this study have practical applications in monitoring soil surface moisture, crop water utilization, irrigation planning, water management, droughts, floods, and soil erosion	[106]
3	Rewari district, Haryana	MODIS LST and NDVI data, Landsat-7 ETM + data	2013	Employed a triangular network method for soil moisture estimation	Mapping soil moisture levels within crop fields is achievable using satellite data inputs	[107]
4	Rupnagar, Punjab	Sentinel 1 A, C-band SAR data	2017–2019	SAR data with V and VH polarization channels were used for surface soil moisture estimation and validated with NDMI	The results demonstrate that dual-polarized SAR data can effectively model soil moisture estimation, particularly when fields are fallow or crops are in their early growth stage	[2]
5	Damodar River basin (boundary of West Bengal and Jharkhand)	MODIS NDVI and LAI data, IMD rainfall and temperature data	2009–2018	Satellite-based National Hydrological Model-India (NHM-I) water demand module was developed to determine irrigation water needs on the basis of soil moisture deficit	The NHM-I will offer a platform for evaluating irrigation demands and soil moisture levels over both space and time	[108]

This review article encompassed a total of 60 studies. The selected articles showed significant diversity in their content and scope. The research covered various parts of India, spanning almost all of the country's land area, as shown in Figure 3. Most of the studies were conducted in West Bengal, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Gujrat, Madhya Pradesh, and Bihar, and a few were conducted in Orissa. Additionally, single studies were conducted in other states of the country.

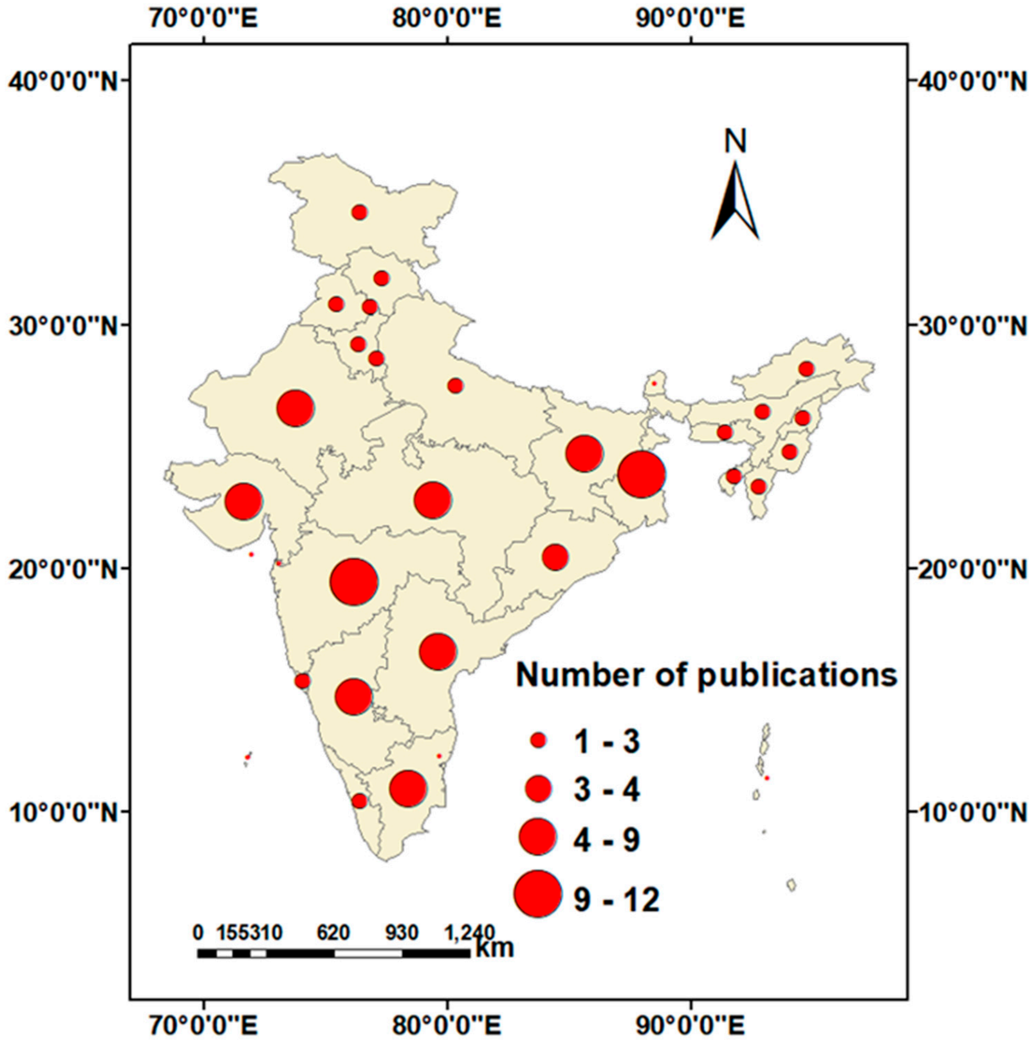

Figure 3. Selected geospatial technology-based articles related to agricultural water management conducted in different parts of India.

The distribution of the selected studies was examined annually, as shown in Figure 4. The trajectory of research in India regarding the integration of geospatial technologies shows significant fluctuations. As depicted in Figure 4, there was no consistent increase in studies between 2014 and 2020. However, in 2021, there was a notable surge in selected studies, marking a significant 18.33% increase. This trend peaked in 2022, with an increase of 23.33%. The rising number of published studies reflects a notable level of expertise and proficiency in geospatial technology in India. The widespread use of these modern methods bodes well for the nation's long-term objectives pertaining to sustainable and profitable agriculture activities.

Over the years, data and products from numerous satellites and sensors have been employed for agricultural water management in India, as shown in Figure 5. In more than half of the selected studies, Landsat MSS/TM/ETM+/OLI satellite data were utilized. The 30 m spatial resolution and 16-day revisit cycle provided invaluable data for water resource management. Terra and Aqua (MODIS) are also widely used because they cover a larger area per scene, have satellite images available for the entire study period, and provide frequent data. Similarly, IRS satellites, particularly LISS III (23.5 m) and LISS IV (5.8 m), have been extensively employed in water management studies, specifically for monitoring water resources. These selected articles address different issues of agricultural water management, as shown in Figure 6. The percentage of studies selected to address different areas of agricultural water management in India is shown in Figure 6. The temporal scale of selected studies for data analysis concerning water management is shown in Figure 7. About 62% of the selected studies considered multi-year data and 38% of studies considered single-year data for addressing different water management issues. A variety of indices were utilized in the selected articles to target various facets of agricultural water management in India, and the distribution of selected articles among different remote sensing categories is depicted in Figure 8. Among the individual indices documented, NDVI emerged as the predominant choice for water management in the region, followed by NDWI as the second most frequently employed index. The most commonly utilized data source is multi-sensor type remote sensing followed by optical remote sensing for water management.

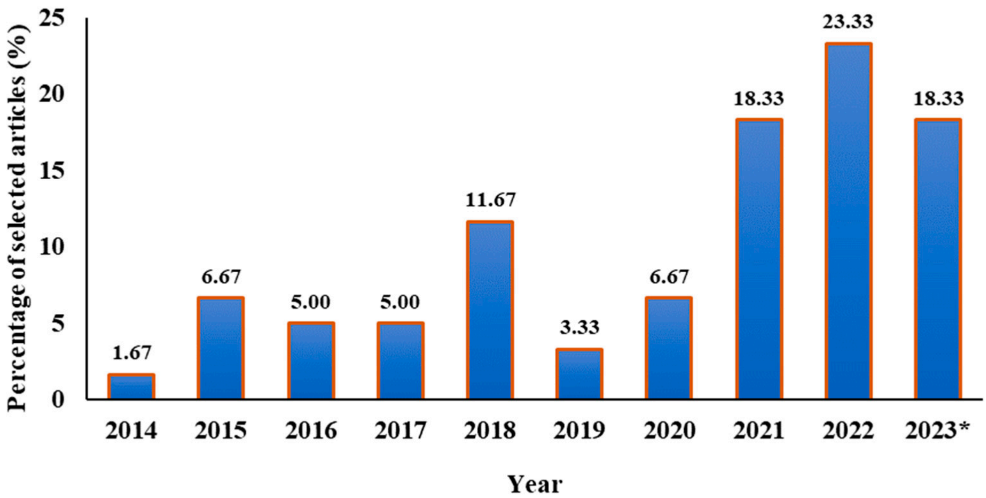

Figure 4. Bar chart representing the percentage of recently published selected articles considered for review (* as of September 2023).

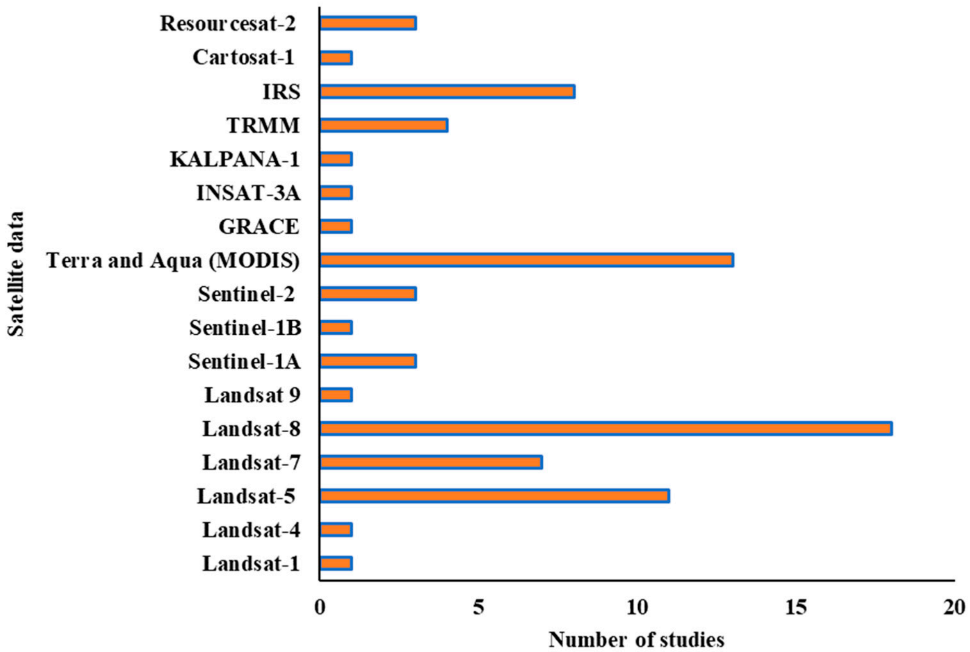

Figure 5. Satellite data/products used in selected articles for agricultural water management in different parts of India.

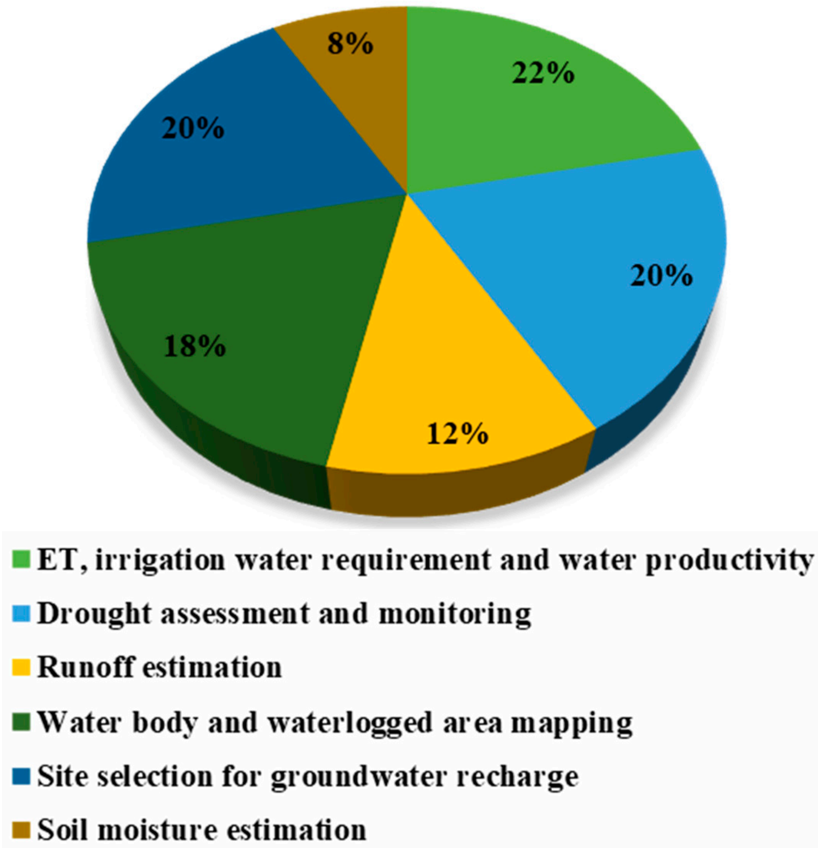

Figure 6. Percentage of studies selected to address different areas of agricultural water management in India.

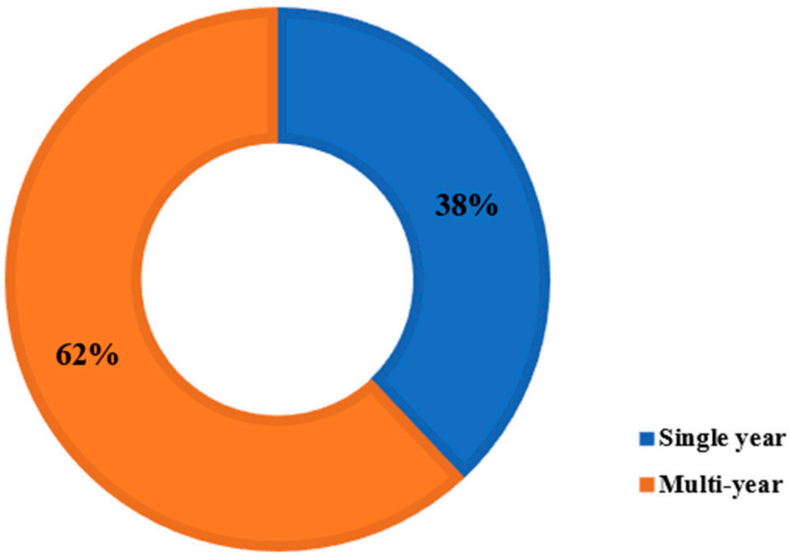

Figure 7. Percentage of single- and multi-year studies considered in this review.

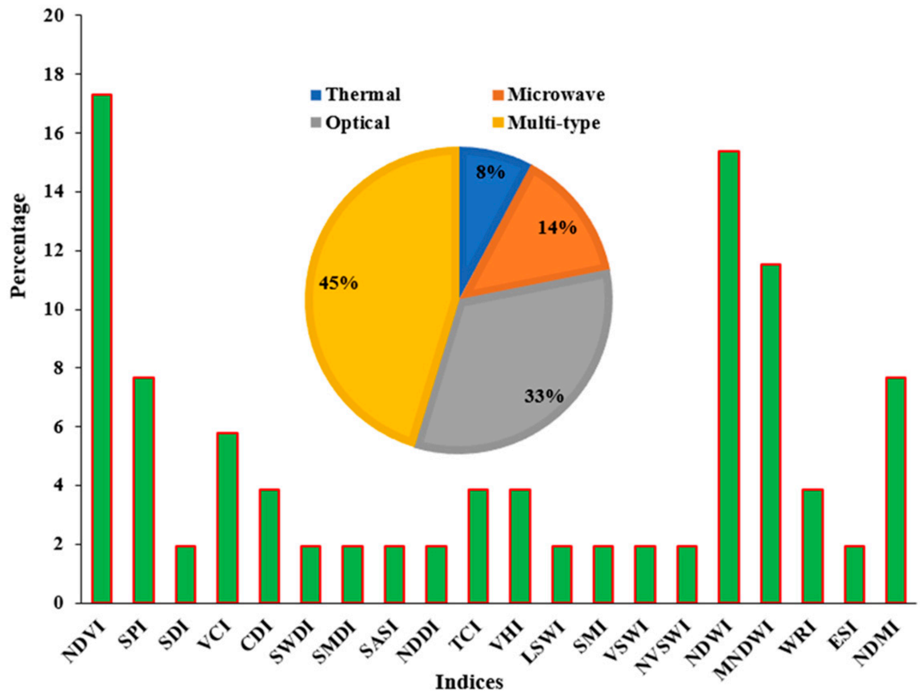

Figure 8. The bar chart represents different indices used in the selected articles for addressing different areas of water management in India while the pie chart illustrates the percentage of selected articles across various remote sensing categories.

4. Discussion

India encounters water stress in many areas due to the limited utilization of its accessible water resources, with only a small fraction being effectively utilized [109]. Accurate, comprehensive, and timely agricultural information is crucial for decision making in a country like India, involving all stakeholders [110]. The long-term viability of agriculture depends on the sustainable management of available water resources. Therefore, it is essential to conduct a thorough and realistic assessment of water usage within the constraints of the limited available resources, coupled with careful future planning [111]. Improving water use efficiency in agriculture is crucial for sustainable water resource management. Implementing effective agricultural water management techniques on a regional scale is challenging due to the absence of real-time data on soil moisture and evapotranspiration. However, this challenge can be addressed through the utilization of geospatial technology [112,113]. Soil moisture is vital for plant growth, playing a key role in the hydrological cycle. Accurate measurement of this factor is crucial for agriculture, enabling early detection of drought warnings [105]. Assessing soil moisture changes over time and space is vital for pinpointing regions and periods facing significant water stress [114]. Soil moisture and vegetation water content are fundamental elements in studies concerning vegetation, drought, and climate change. Their significance is paramount in research within these fields [115]. The rising demand for irrigation has elevated the importance of estimating consumptive water use through geospatial techniques in the field of irrigation water management. Over the years, irrigation and agricultural applications have successfully used geospatial data [116]. Real-time irrigation scheduling can be achieved with the use of geospatial technology [117].

Due to significant fluctuations in climatic conditions, crops often experience various stresses, resulting in decreased productivity and yearly fluctuations. In such circumstances, the swift advancements in geospatial technology play a vital role in monitoring crop growth, identifying and managing different stress factors, and estimating regional yields. These technologies are essential for sustaining natural resources and agricultural productivity [33]. The growth of water-intensive crops, excessive irrigation, poor maintenance of drainage systems, and inadequate surface and subsurface drainage are the main causes of the waterlogging in the area [118]. For mapping areas that are flooded, conventional techniques such as ground surveys are employed; however, they are not economical or timely for studies conducted on a regional scale. A better real-time option for monitoring and determining the size of flooded areas is to integrate satellite remote sensing with GIS [119]. Analyzing surface runoff based on rainfall is a significant challenge in hydrological modeling, and is essential for water resource development, planning, and management. The surface runoff model dependent on rainfall is crucial for planning the development of water resources [120]. Precisely assessing surface runoff in watersheds, whether gauged or ungauged, is imperative for strategic planning and the implementation of water conservation structures [121]. Rapid urbanization has significantly reduced rainwater infiltration into the sub-soil, leading to a drastic decline in groundwater recharge. Consequently, rainwater harvesting has become essential due to the inadequacy of surface water to meet our needs, forcing us to rely heavily on groundwater. Rainwater harvesting refers to the purposeful collection and storage of rainwater, essentially augmenting groundwater reservoirs through human-made structures designed to capture and utilize rainwater effectively [122].

Traditional methods for gathering weather and crop growth data are reliable but laborious and time-consuming. In recent times, the integration of RS and GIS technologies has emerged as indispensable for obtaining spatio-temporal meteorological and crop status data, thereby augmenting conventional methodologies. RS data significantly aids monitoring by offering timely, comprehensive, cost-effective, and repetitive Earth surface information [33]. RS has substantiated its significant utility in the mapping and surveillance of agricultural land utilization, outperforming conventional methodologies in terms of cost-effectiveness and the expeditious provision of data across expansive territories. Satellite-based remote sensing, with its repetitive and multispectral nature, stands out as an ideal option for monitoring dynamic agricultural resources. For planners and policymakers, timely and reliable data on agricultural water management are essential for efficient and timely agricultural development, as well as for making critical decisions [110]. Satellite remote sensing provides significant prospects for the observation of land surface conditions and the monitoring of water resource status across diverse spatial and temporal scales. There is a growing necessity to harness RS technology for accurately estimating crop water requirements in irrigation areas [109]. RS stands out as one of the few techniques capable of offering representative measurements of numerous essential physical parameters, ranging from a specific point to an entire continent [123,124].

Advancements have been observed in the identification, mapping, and monitoring of water resources through the use of remotely sensed data over the years, as depicted in Figure 5. In our analysis, we found that a significant portion of research has predominantly utilized multispectral sensors. These sensors include a range of instruments like Landsat, MODIS, and IRS, with only a few studies opting for the use of Sentinel, TRMM, etc. The significant development of Earth-monitoring technologies is responsible for this research achievement. In terms of management, these technologies are economical and time-efficient. The abundance of data sources is a result of the availability of various instruments and missions. The dominance of the multispectral-based approach can be attributed to (a) the availability of extensive data from various satellite missions since the first Landsat mission in the 1970s, (b) a substantial number of free-of-cost optical sensors with improved resolution, particularly in recent years, and (c) the straightforward interpretation of data. Landsat sensors have proven particularly valuable for evaluating and monitoring water resources. It is important to acknowledge that the effectiveness of medium- and low-spatial-resolution sensors may be limited in detecting and mapping water resources, especially when dealing with areas smaller than the size of a pixel. The Landsat and Sentinel datasets, known for their improved spatial resolutions, have been traditionally employed for water resource management. While their images are freely available, handling them can be challenging due to their large file sizes. In the past, platforms like Earth Explorer from USGS or Sentinel–Copernicus Open Access Hub were used, but with the rise of cloud platforms like Google Earth Engine, managing and processing the entire dataset has become simpler. High-resolution images are now easily accessible, providing extensive coverage for large areas worldwide. MODIS is crucial for mapping changes in water resources at a broad spatial resolution. Its accessibility and extended operational period make it valuable for large-scale, long-term, and seasonal monitoring. Despite these advantages, using the MODIS sensor comes with challenges. One challenge is linking the coarse spatial resolution it offers with on-the-ground field data. Moreover, the sensor encounters difficulties when trying to effectively monitor small areas. The IRS satellite series provides high-resolution data useful for many applications, including natural resource management.

Cloud cover and limited temporal and spatial resolution are common challenges for multispectral sensors like Landsat sensors. Drones, on the other hand, operate at a lower altitude and can collect data over remote areas, meaning they are unaffected by cloud cover. Studies employing drones to manage water resources are currently lacking. Therefore, using drones to monitor water resources and comparing their performance with satellite sensors is necessary. In future studies, combining remotely sensed data with physical-based hydrologic models can lead to more effective water resource management and decision making. Further research is crucial to develop advanced models that use multi-source data and improved algorithms. Progress in Earth-observation technology, marked by enhanced image acquisition features, has steadily broadened our capability to identify the Earth's features. Instruments like Sentinel-1 SAR offer a chance to combine optical and radar data, enhancing mapping capabilities even on cloudy days. It is crucial to monitor regions like semi-arid environments where significant rainfall happens during particular wet seasons. The integration of Sentinel-1 and -2 (SAR and MSI) data proves beneficial at a local to regional scale, yielding enhanced outcomes when compared to relying solely on the optical sensor. Sentinel-1 and -2 sensors are available for free and have successfully monitored water resources separately [125]. However, it was found that their complete potential has not been fully utilized in the evaluation and monitoring of water resources. As per the findings of this research, there is a growing interest in evaluating, mapping, and monitoring water resources using Landsat and MODIS image platforms. However, advanced Earth-observation technologies like Sentinel data, UAVs, and hyperspectral technology have not been fully investigated for assessing and monitoring water resources. The application of these advanced technologies could be effective in keeping track of water resources.

5. Progress and Future Scope

Undoubtedly, the 2030 Agenda for Sustainable Development establishes ambitious objectives, encompassing targets such as Sustainable Development Goal (SDG)-1 (Eradication of poverty) and SDG-2 (Zero hunger), which strives to enhance agricultural productivity and implement sustainable, resilient agricultural practices. Furthermore, SDG-12 (Responsible consumption and production) directs attention towards the promotion of sustainable patterns in production and consumption. Simultaneously, SDG-13 (Climate action) and SDG-15 (Life on land) underscore the imperative for sustainable management of natural resources. To align with these objectives, it is imperative to systematically and scientifically redesign agricultural policies and programs. This redesign should aim to incentivize sustainable agricultural practices and enhance food security, ensuring the harmonious integration of ecological and economic principles for long-term agricultural viability [34]. Finding appropriate solutions for agricultural water management is crucial, particularly in countries anticipating population growth and increased production and consumption. These solutions need to focus on monitoring and addressing various aspects of agricultural water management while evaluating the effects of threats such as climate change, food security, spatial planning, and land management on the system. The diversity of data sources emphasizes the availability of instruments and missions at our disposal. The extensive adoption of the multispectral-based approach can be attributed to various factors. Firstly, there is an availability of extensive data from various satellite missions, dating back to the 1970s with the launch of the first Landsat mission. Secondly, the availability of numerous free optical sensors, with significantly improved resolutions in recent years, has bolstered this trend. Lastly, the straightforward and uncomplicated interpretation of the data has also played a significant role in the widespread adoption of this approach [126]. Optical sensors are frequently used because of their simple processing and the ease of interpreting their images. These sensors closely match human visual perception, making them a preferred option for researchers.

Due to the better spatial resolutions offered, Landsat-(5, 6, 7, 8) TM, ETM+, OLI/TIRS (30 m), IRS–LISS III (24 m), IRS–LISS IV (5.8 m), and Sentinel-1, -2 (10 m) are mostly used to address different issues of agricultural water management in India. These finer resolutions are particularly valuable for addressing water management concerns in relatively small areas. Nevertheless, the launch of Landsat-9 on 27 September 2021 has halved the revisit period, sparking expectations of increased utilization of these data in the upcoming years. Data from Terra and Aqua MODIS, offering resolutions ranging from 250 to 1000 m, are predominantly utilized owing to the wider coverage per scene, the availability of satellite imagery throughout the entire study period, and, primarily, their temporal resolution. The Terra and Aqua MODIS instruments systematically acquire imagery of the Earth's entire surface at intervals of one to two days, establishing them as indispensable tools in scientific research. Within the domain of water resource management, researchers have commonly utilized a multispectral or radar-based approach.

Even though we have made progress in using geospatial technology for long-term monitoring, there is a delay in quickly adopting modern Earth-observation methods, including Sentinel data, that are easy to access. Sentinels, with better spectral resolution and a 5-day revisit time, open up new possibilities for checking water resources every two weeks or each season. Multispectral sensors like those in Sentinel 2 and Landsat face challenges with cloudy weather and coarser spatial and temporal resolution. The future upcoming sensors, such as the NASA-ISRO SAR Mission (NISAR), can be a game-changing satellite, which will allow detailed scientific insights into sustainability for agricultural water management under climate change scenarios.

Different emerging technologies like cloud computing, augmented reality, Internet of Things (IoT), 3D GIS, mobile GIS, machine learning, artificial intelligence, hyperspectral drones and balloons, blockchain, digital twins, and robotics, as depicted in Figure 9, are poised to enhance the future of water management [127]. The evaluation and monitoring of water resources using these advanced technologies have not received considerable attention until now. Advanced algorithms and software in cloud computing can be used to comprehensively analyze field conditions for water management. Integrating GIS with the IoT is crucial for automating irrigation systems for water management. This combination promises transformative effects not only in the irrigation sector, but also across various industries. Augmented reality, a research domain merging actual surroundings with computer-generated data, enhances real-time human perception in water management. In water management, 3D GIS enhances object details and visibility by introducing an additional dimension (z-axis). The inclusion of an elevation component that is lacking in 2D maps can provide a comprehensive representation and 3D GIS technologies offer illustrative scale representations for real-world objects. Mobile GIS streamlines feasibility studies for water management, empowering field personnel to collect, store, update, edit, analyze, and present geospatial data. The integration of mobile devices, GIS software, GPS, and wireless connectivity enables internet-based GIS access. The amalgamation of RS, GIS, and artificial intelligence promotes the automation of data collection, analysis, and decision making in water management [126]. Drones, which fly lower, are not affected by clouds and can reach remote, hard-to-access areas to collect data. With the advancement of technology (the fourth industrial revolution), using drones in future studies is recommended. They offer a new and innovative way to gather real-time spatial data, especially for mapping and monitoring water resources. Balloons, when filled with helium gas, can operate at lower altitudes compared to airplanes, making them valuable for detecting small objects [36]. Digital twins can be used for the prediction of crop irrigation requirements and irrigation water management [128]. Robotics and blockchain are also useful for irrigation water management.

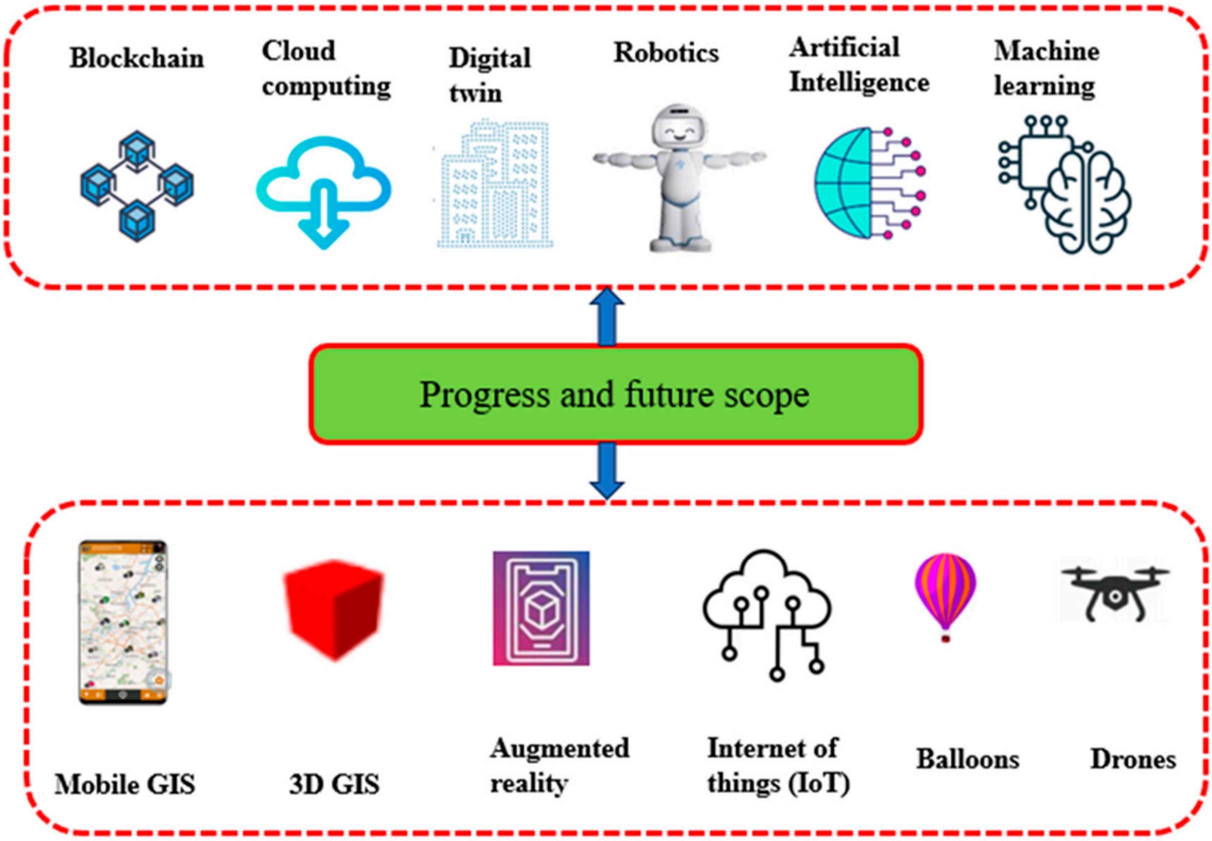

Figure 9. Technological advancements for progress and futuristic agricultural water management.

In achieving sustainable water management amidst a growing population and its increasing needs, utilizing multispectral sensor data is crucial. This information is highly valuable for professionals in water management, catchment management, and land planning. It empowers them to customize their strategies for managing land and water by taking into account spatial differences and seasonal variations in water resources.

6. Conclusions

This review encompassed 60 recently published research articles in the field of agricultural water resource management, specifically focusing on geospatial technology applications. The ever-expanding global population, coupled with pressing issues such as the consequences of ongoing climate change, exerts significant pressure on agricultural systems. Consequently, there is a growing need for advanced monitoring systems and models that can provide comprehensive insights into how countries are strategically managing spatial planning, land and water resources, and food security. In response to this need, this paper systematically evaluated cutting-edge geospatial technology solutions in this field, adhering to the rigorous guidelines outlined in the PRISMA statement. This methodological approach proved highly effective in quantifying essential information regarding various parameters of interest within the subject. The resulting information holds considerable value for forthcoming studies in the field. As the world is changing very rapidly and factors like climate change, seasonal patterns, and water scarcity are projected to become more noticeable, these factors will play a significant role in enhancing the development of precise monitoring tools.

The literature shows that geospatial technology is receiving a lot of attention for agricultural water management. We observed that different remote sensing spectral indices are used for agricultural water management in the study area. Here, we found that most of the studies focus on Landsat images, overlooking the potential of other sensors like Sentinel-1 and -2. These sensors have better revisit times and improved spatial resolution and radiometric capabilities, but they have not been explored as much. Seasonal monitoring is rendered possible by these sensors. According to the results of this study, there is an increasing interest in assessing, mapping, and monitoring water resources using Landsat and MODIS image platforms. However, more advanced Earth-observation technologies such as Sentinel data, UAVs, and hyperspectral technology have not been thoroughly explored for the assessment and monitoring of water resources in the study area. Using data from different sensors helps us learn more about water resources. Platforms like drones and helium-filled balloons enable the acquisition of high-resolution data in near real time, substantially enhancing the precision of mapping and monitoring water resources. Advancements in machine learning algorithms that reduce processing time for data will significantly improve the application of machine learning in remote sensing. Machine learning can effectively organize data obtained from systematic ground observations, sensors, meteorological instruments, and various remote sensing sources like satellites, airborne platforms, and drones. It is concluded that the fusion of cloud computing, IoT, artificial intelligence, 3D GIS, mobile GIS, augmented reality, hyperspectral drones and balloons, robotics, digital twins, and blockchain with GIS and remote sensing technologies can revolutionize agriculture, maintaining a crucial role in agricultural water management. The Google Earth Engine (GEE) platform, renowned for its ability to manage large-scale remote sensing data, stands as a valuable and time-efficient tool for water management. The effective management of water resources at both local and regional scales requires the full integration of innovative technologies and methodologies. These advancements have markedly enhanced our capability to assess and monitor water resources, thereby enabling the implementation of more efficient planning and management strategies. The advancements in geospatial technology applications have furthered our comprehension of water resources, thereby promoting sustainable water management practices. Hence, this research significantly contributes to the existing literature by offering a comprehensive analysis of the advancements in geospatial technology within the realm of agricultural water management in India, providing a holistic perspective. The advancement of new sensors, both passive and active, offering superior spatial, spectral, radiometric, and temporal resolutions, along with enhanced data integration techniques and the availability of sophisticated algorithms/software and platforms, enables the efficient utilization of geospatial technology to tackle the aforementioned challenges.

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