remote sensing

Editorial

Remote Sensing for Water Resources and Environmental Management

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Abstract: In line with the United Nations Sustainable Development Goal (SDG) 6, the main goal of the Special Issue on "Remote sensing for water resources and environmental management" was to solicit papers from a diverse range of scientists around the world on the use of cutting-edge remote sensing technologies to assess and monitor freshwater quality, quantity, availability, and management to ensure water security. Special consideration was given to scientific manuscripts that covered, but were not limited to, the development of geospatial techniques and remote sensing applications for detecting, quantifying, and monitoring freshwater water resources, identifying potential threats to water resources and agriculture, as well as other themes related to water resources and environmental management at various spatial scales. The Special Issue attracted over thirteen peer-reviewed scientific articles, with the majority of manuscripts originating from China. Most of the studies made use of satellite datasets, ranging from coarse spatial resolution data, such as the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO), to medium spatial resolution data, such as the Landsat series, ERA5, Modern-Era Retrospective Analysis for Research and Application Land version 2 reanalysis product (MERRA2), CLSM and NOAH ET, and MODIS (Moderate Resolution Imaging Spectroradiometer). Google Earth Engine (GEE) data, together with big data processing techniques, such as the remote sensing-based energy balance model (ALEXI/DisALEXI approach) and the STARFM data fusion technique, were used for analyzing geospatial datasets. Overall, this Special Issue demonstrated significant knowledge gaps in various big data image processing techniques and improved computing processes in assessing and monitoring water resources and the environment at various spatial and temporal scales.

Keywords: algorithms; climate change; droughts; environmental degradation; Earth observation; monitoring and assessment; sustainable management; water scarcity and security

Citation: Dube, T.; Shekede, M.D.; Massari, C. Remote Sensing for Water Resources and Environmental Management. *Remote Sens.* **2023**, *15*, 18. https://doi.org/10.3390/rs15010018

Received: 9 December 2022
Accepted: 16 December 2022
Published: 21 December 2022

1. Introduction

Although water resources are essential for life on Earth, the growing human population, combined with global environmental change, particularly climate change and variability, has put a strain on this finite resource and the environment [1]. Water scarcity caused by rapid population growth, droughts [2–4], erratic rainfall [5], overexploitation, and increased water pollution [6] from anthropogenic activities, such as mining and urbanization, pose a threat to the supply of usable quality and quantity of water to meet the demand [7]. This is especially concerning, given that approximately one-fifth of the world's population lives in water-stressed areas, and this trend is likely to worsen in the near future if the current trends, threats, and pressures are not fully understood and managed appropriately [2]. Fortunately, recent advances in geospatial modelling techniques, as well as an increase in readily available remotely sensed data with improved sensing characteristics (i.e., high spatial, spectral, and radiometric resolutions), have provided researchers with invaluable tools for not only monitoring and assessing the state of water resources, but the environment at various spatial scales [2]. In line with the United Nations Sustainable Development Goal (SDG) 6 of "*ensuring the availability and sustainable management of water and sanitation for all*," this Special Issue invited scientific manuscripts that focus on innovative and cutting-edge practical applications of remotely sensed data and modelling techniques in water resources and environmental management at various spatial scales. Articles that used remote sensing to assess and monitor freshwater quality, quantity, availability, and management to ensure water security were published.

The goal of this Special Issue was to solicit scientific research articles that used cutting-edge remote sensing technologies to assess and monitor freshwater quality, quantity, availability and management in order to ensure water security. Articles that benefited from recent advances in satellite technologies, as well as the easy availability and accessibility to large volumes of archival spatial datasets and data analytic techniques for water resources and environmental management, were prioritized. Special consideration was given to scientific manuscripts that covered, but were not limited to, the development of geospatial techniques and remote sensing applications for detecting, quantifying, and monitoring freshwater water resources, identifying potential threats to water resources and agriculture, as well as other themes related to water resources and environmental management at various spatial scales. The Special Issue generated widespread global interest, with the majority of articles originating from China.

This Special Issue included thirteen scientific articles on land surface and plant water-use analysis, climate change impact assessment, agriculture, wetlands, water quality and quantity, soil moisture estimation, and land-use and land-cover analysis, as well as their implications for water resources and the environment. Several satellite datasets were used, ranging from coarse spatial resolution data, such as the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO), to medium spatial resolution data that include the Landsat series, ERA5, Modern-Era Retrospective Analysis for Research and Application Land version 2 reanalysis product (MERRA2), CLSM and NOAH ET, and MODIS (Moderate Resolution Imaging Spectroradiometer). Moderate- to high-resolution data were also used. The studies applied Google Earth Engine (GEE), as well as other advanced (big) data processing techniques, such as the remote sensing-based energy balance model (ALEXI/DisALEXI approach), and the STARFM data fusion technique. In addition, the studies applied machine learning algorithms such as the random forest (RF), support vector machine (SVM), CA–Markov model, and triple collocation (TC) method, as well as statistical methods, such as the Finite Volume Coastal Ocean Model (FVCOM). This editorial review divided the published scientific articles into six major themes, the contributions of which are summarized in detail in the following sections.

2. Analysis of Agriculture and Landcover Implications for Water Resources

Several studies focused on agriculture impacts on water resources and land-cover dynamics at the catchment scale, taking advantage of the various satellite imagery and advanced image processing techniques, such as the cellular automata and Markov chain (CA–Markov) model, random forest algorithms, and cloud computing Google Earth Engine platform [7,8]. The CA–Markov model was found to be the most appropriate change/time-series model, combining the standard Markov model and cellular automata (CA) for the prediction and modelling of future LULC changes at 30 m spatial resolution and linking these changes to the state of water resources at the catchment scale. This two-pronged approach has been shown to be viable because it allows for the integration of multidate satellite data in tracing the human footprint on the environment and, in particular, water resources. Cellular automata (CA), for example, has demonstrated the ability to change and control complex spatially distributed processes, as well as a strong ability to simulate the spatio-temporal characteristics of complex systems [7,9].

Climate variability, in addition to human drivers of LULC change, has important implications on moisture and temperature variations, which determine vegetation health and water availability. The decline in potential water sources may also exacerbate droughts and increase water supply challenges in an already water-stressed catchment. For instance, Magidi et al. [8] used the GEE platform and found that there has been an increase in irrigated areas over non-irrigated areas in semi-arid areas of Mpumalanga, South Africa, putting a strain on water resource demand in the agriculture sector. The study created the first detailed provincial irrigation map by leveraging moderately high-resolution Sentinel-2 and GEE computational power, as well as advanced machine learning algorithms, to demonstrate the scale of a shift from rainfed agriculture to irrigation in the area, as well as undocumented pressure on water resources. In addition, these irrigation activities have serious impacts on wetland systems due to nutrient accumulation. For example, Dlamini et al. [10] predicted seasonal variations in the concentrations of nine foliar biochemical elements in plant leaves of key floodplain wetland vegetation types and crops in the uMfolozi floodplain system, using Sentinel-2 multispectral data.

3. Plant Water Use and Its Impact on Water Resource Availability

Plant water use is critical to the survival, productivity, and spatial distribution of various vegetation functional types. Remote sensing of plant water-use estimation is, therefore, critical in water-controlled ecosystems or dryland areas with limited water resources, as well as in soil moisture dynamics [11,12]. This Special Issue features studies that used multi-source satellite datasets and advanced data analytics techniques to estimate plant water use at various scales. Carpintero et al. [11] used the ALEXI/DisALEXI model and the STARFM data fusion technique to estimate evapotranspiration (ET) dynamics in a Mediterranean oak savanna at fine spatial and temporal resolution (30 m, daily) from 2013 to 2015. DisALEXI energy fluxes (1 km, daily) and Landsat images (60–100 m, 16 days) were compared to in situ measurements from an eddy covariance flux tower system. Overall, the modelled fluxes performed reasonably well in comparison to field observations. The use of fine-scale ET maps (30 m, daily) provides critical information on plant water-use trends that are difficult to detect at a coarser spatial resolution over heterogeneous landscapes, and may aid management decisions at the field and farm scale.

The resulting high-resolution ET maps (daily, 30 m) revealed critical information for obtaining a better understanding of the hydrological functioning of various vegetation distributions that are typically difficult to detect at a 1 km pixel resolution. This can help with water-use decisions on the farm or in the community. Ochege et al. [12] performed the first detailed regional assessment of GLEAM, ERA5, MERRA2, CLSM, and NOAH ET products using the triple collocation (TC) method. Overall, these studies revealed that in water-stressed areas, gaps in regular evapotranspiration monitoring and evaluation pose a significant challenge to agricultural water resource allocation. As a result, the use of spatial explicit techniques in estimating plant water use is critical for improved water resource management and ensuring informed appropriate plant water allocation. Such efforts will greatly enhance global change and climate change research projects, particularly when these uncharted environments located in unique climate regions of the world are specifically captured in future studies.

4. Anthropogenic and Climate Change Impacts on Water Resource

Due to the rapid development of the coastal economy and continuous urbanization, more than 60% of the world's population now lives within 200 kilometers of a coastline. As a result, the impact of anthropogenic activity on the regional environment has increased, natural resources are being exploited on a larger scale, and natural coastal areas and marine ecosystems are being pushed back by intensive economic development and coastal zone projects. Land-derived pollutants (e.g., nitrogen and phosphorus) are continuously entering waters as a result of increasing urbanization, continuous mari-culture scale-up, and rapid development of the ocean economy, resulting in water quality deterioration and eutrophication in local areas. Based on Landsat images and long-term observation data, Zhu et al. [6] developed a nutrient retrieval model for Yueqing Bay to produce a long-term series of nutrient concentration products in Yueqing Bay from 2013 to 2020, combined with support vector machine learning and water temperature and satellite spectra as input parameters. Furthermore, the study analyzed the spatiotemporal variations and driving factors. The study found that natural factors, physical effects (e.g., seasonal variations in flow field) and biological effects (e.g., seasonal differences in the intensity of plankton photosynthesis) were the main causes of seasonal differences in nutrient concentration in Yueqing Bay. The study serves as an effective reference for remote sensing dynamic monitoring of water quality, as well as technical assistance for environmental protection and remediation of similar bays. Overall, these studies have demonstrated the unique utility of multi-source remotely sensed techniques for monitoring water quality variation in coastal areas with significant anthropogenic impact. However, in the future, an updated satellite-based algorithm for water quality assessment is required to better understand nutrient variation in coastal areas.

Furthermore, regional climate change has an impact on the state of inland and coastal water bodies, as well as their water balance, which is determined by a variety of hydrometeorological and hydrogeological factors [13]. The behavior of lake and reservoir levels is an integral characteristic of changes in the water balance, which not only determines the physical and ecological state of water bodies, but also has a significant impact on coastal infrastructure and socioeconomic development in the region. Using satellite altimetry data from 1993 to 2020, studies have been conducted to investigate the interannual variability in the level of the Ladoga and Onega lakes, Europe's largest lakes located in the northwest of Russia [13]. Three specialized altimetry databases were used for this purpose, including DAHITI, G-REALM, and HYDROWEB. These altimetry databases' water level data were compared to in situ records from water level gauge stations. The study demonstrated Google Earth as a useful tool for searching for critical areas in terms of the potential impact of Ladoga and Onega Lake water level rise on Russian railway infrastructure.

5. Conclusions

In conclusion, this Special Issue has demonstrated the utility of cutting-edge remote sensing data and advanced image processing techniques in dealing with large data sets at various scales and developing automated programs for operational water resource assessment and monitoring. This is an important step towards resolving water-related issues that are critical to achieving the UN Sustainable Development Goals. The applications shown range from freshwater quality, quantity, availability, assessment, and management to ensure water security, among others. Overall, this Special Issue has demonstrated that with the availability of advanced data processing techniques and improved computing processes, day-to-day, monthly, seasonal, and long-term water resource and environmental monitoring at high spatial resolution and covering large areas is now possible.

Author Contributions: Conceptualization, T.D.; methodology, T.D., M.D.S. and C.M.; writing—original draft preparation, T.D., M.D.S. and C.M., writing—review and editing, T.D., M.D.S. and C.M.; funding acquisition, T.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the WeMAST-Wetlands Monitoring and Assessment project, which is funded by the Africa Union and the European Union through the Global Monitoring for Environment and Security (GMES) and Africa Support Programme.

Data Availability Statement: Not applicable.

Acknowledgments: This work was supported by the WeMAST-Wetlands Monitoring and Assessment project, which is funded by the Africa Union and the European Union through the Global Monitoring for Environment and Security (GMES) and Africa Support Programme.

Conflicts of Interest: The author declares no known competing interest.

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