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**REVIEW**

# The Role of Hydrological and Water Resources Surveying in Climate Resilience: A Comprehensive Review of Methodologies and Future Directions

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## ABSTRACT

The water resources surveying and hydrological is required to understand and manage the impacts of climate change on the water systems. This review discusses the ways in which such surveys can be used in improving climate resilience, procedures, practices, and opportunities. The innovations of the traditional ground-based surveys into the modern hydrological survey are the current technologies, remote sensing, Geographic Information Systems (GIS), and real-time sensor networks, which allow scanning the water resources in an extensive, accurate, and timely way. These high-level methods would help manage water systems with substantial data in the prediction of floods, droughts and other water hazards caused by climate change. In addition, a hydrological survey plays a very crucial role during the climate adaptation and mitigation process since it illuminates the sustainable level of water use and the sustainability of the ecosystem. Despite the tremendous development in the use of survey techniques, there remain problems of data gaps, the high cost of using the technique, and data integration enhancement. The future of hydrological surveying is to take advantage of the emerging technologies, encourage more stakeholder cooperation, and sustainable practices to enhance access to and use of data. This review determines the significance of hydrological surveying in the construction of climate resilience and presents the contribution of how future improvements in technology and cooperation can empower the management of water resources in the climate change environment.

***Keywords:*** Hydrological Surveying; Climate Resilience; Water Resources; Remote Sensing; Sustainable Water Management

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# 1. Introduction

The issue of the global climate crisis poses a very serious threat to the water resources, which fuels the occurrence and intensity of extremities regarding water like floods, drought, and water scarcity[1,2]. With the growing temperature and the changing precipitation patterns, the issue of water resources and their management has officially become a critical one. Water in its various manifestations is a core element in climate resilience plans as it is a key component in agricultural, energy, urban planning, and ecosystem services. Nevertheless, the dramatic increase in the variability and change in the climate has revealed the weaknesses in existing water management frameworks, and this has prompted the recommendation of new and precise techniques of hydrological surveying. Hydrological surveys give the necessary data and information that would make decisions possible, allowing for the evaluation of the availability, quality, and distribution of water, predict the consequences of climate changes in water resources[1,3]. While hydrology provides the scientific understanding of water movement, hydrological surveying serves as the critical applied practice of diagnosing the current state of water systems, providing the essential 'vital signs' needed to anticipate, absorb, and recover from climate-induced water shocks.

Hydrological and water resources surveying form a significant instrument in handling the effects of climate change on the availability and distribution of water resources[4]. Through such surveys, the dynamic movement of water in different landscapes, such as in river basins, wetlands, and aquifers, is monitored, and also, the underlying trends assist in determining the water resources management. With increasing water-related problems due to climate change, precise information from hydrological surveys would not be negotiable in determining risks and formulating adaptive measures. These surveys are essential in the design and implementation of climate resilience measures, which seek to reduce the effects of extreme weather conditions and provide sustainability in the long term.

Although there has been an increased appreciation of the relevance of hydrological surveys in climate, the approaches that have been adopted in hydrological surveys have largely changed over the years. The conventional approaches to collecting data, including in-situ monitoring stations and manual measurements, are being complemented and, in most cases, substituted by the sophisticated technologies that can be used to collect data comprehensively and in real-time. Satellite technology, remote sensing, sensor networks, and advanced hydrological modeling have widened the horizons and accuracy of water resource surveys, giving data that can be applied in a very wide variety of applications, such as flood forecasting, drought prediction, etc. Nevertheless, there are also challenges associated with the implementation of new technologies into hydrological surveys, specifically, the quality of data, its availability, and the possibility of filling the gaps between various levels of observation[5].

Though much has been done, a thorough assessment of the conditions of hydrological and water resources surveying methodology, both classical and contemporary, has not been investigated completely in the framework of climate resilience[6,7]. This review aims to cover this gap by critically reviewing the existing methodologies, identifying the strengths and weaknesses of the method, as well as their contribution to climate resilience. In so doing, it will attempt to provide the information on how hydrological surveys are likely to contribute to enlightening water management practices and policies in the face of accelerated environmental change.

This is a timely review because an urgent response to the rising impact of climate change on the water resources is required. It builds on a broad range of recent literature to provide a comprehensive view of the processes used in hydrological surveying and how the latter can be used to increase climate resilience. The overall objective is to give a clearer and detailed description of how the water resources surveys can be applied to reduce the vulnerability to water disasters, improve the usage of water, and enhance adaptive capacities in regions that have been the most sensitive to climatic changes. The framework of this review is premised on the introduction of key spheres of hydrological and water resources surveying, and how they aid in making the climate more resilient. The paper begins with a summary of the hydrological surveying and water resources management, its history, and the way it has evolved. It is based on this that we shall discuss further the methodologies which are now being implemented in hydrological surveys, the traditional methods of in-situ techniques, as well as the new innovative technologies[8–10].

The next point in this review will be the application of these methods in reference to climate resilience. This involves considering how they help minimize water-related climatic risks such as floods and droughts, and also to adapt to climate change in the future. Among all the main points that are going to be presented in this section, one will be to know the use of hydrologic surveys in decision making aimed at water resources management, with the assistance of facilitating the exchange of information in the policy, forecasting models, and interventions in the areas that experience water shortages or frequently[11,12].

In addition, the review will find out the emerging trends in the hydrological surveying practice, including artificial intelligence (AI) usage, big data processing, and the Internet of Things (IoT)[13]. All these transformations are changing the way hydrological data is recorded, analyzed, and used in real-time applications. Through these developments, the review shall provide an idea of the further enhancement of the hydrological surveys and how they can be useful in the procedures of climate resilience.

Finally, the review will be used as a general source of materials for all researchers, policymakers, and practitioners in water resource management and climate resilience. It will help in coming up with improved and stronger strategies of surveying and managing water in rapidly changing climatic conditions by identifying the loopholes in the existing strategies and giving recommendations to be applied in future research. In conclusion, one can state that the importance of hydrological and water resources surveying in the creation of the climate resilience cannot be overestimated. As the present climate change is reshaping the hydrological environment, we should strive to gain more knowledge of the water systems and enhance the current toolkit to survey and manage the resources. With the help of the improvement of the methods, strategies, and technological innovations, hydrological surveys can be converted into even more powerful tools for protecting water security and ensuring the sustainability of ecosystems and communities on the planet. It is the purpose of this review to provide the requisite knowledge to ensure that this vision is attained, to establish the future of hydrological surveying in climate resilience terms.

# 2. Hydrological and Water Resources Surveying: An Overview

## 2.1. Definition and Importance

To provide conceptual clarity, this review adopts dome operational definitions. Hydrological surveying refers to the systematic acquisition of quantitative data on hydrological variables (precipitation, streamflow, groundwater levels, soil moisture, water quality parameters) at specific locations and times using standardized measurement techniques (in-situ instruments, remote sensing, sensor networks). Water resources surveying encompasses hydrological surveying while also incorporating assessments of water infrastructure (reservoirs, canals), water use patterns (agricultural, industrial, domestic), and socio-economic dimensions (water demand, governance structures). Hydrological monitoring denotes the sustained, long-term observation of hydrological variables at fixed stations to detect trends and variability. These activities are distinct from integrated water resource management (IWRM) , which represents the broader governance and decision-making framework that utilizes survey data.

The scientific action of gathering information involved in the distribution, movement, and quality of water within the hydrological cycle on the earth is known as hydrological surveying[14]. It covers a broad spectrum of activities to comprehend the flow of water in the natural system, e.g., rivers, lakes, wetlands, and aquifers. To contextualize the measurement targets of hydrological surveying, **Figure 1** summarizes the major storages and fluxes of the hydrological cycle that surveys seek to quantify. Hydrological surveying is particularly significant because it enables the provision of the basic data for the administration of the water resources. Proper and prompt information on the availability and flow of water, storage capacity, and water quality is critical towards the sustainability of water use and the control of the effects of extreme weather occurrences worsened by climate change[1].

The survey of water resources is not only conducive to the management of water to be consumed by human beings, agriculture, and industry, but also crucial for maintaining the ecosystems that depend on the constant water resources[16].

A hydrological survey will enable scientists and policymakers to know the water availability in the future, predict the location of floods or droughts, and determine the vulnerability of various regions to water risks associated with climate change. These understandings form part of creating and applying adaptive measures to boost resilience to climate change, whereby societies and the environment are resilient enough to endure and recover following disruptions caused by water.

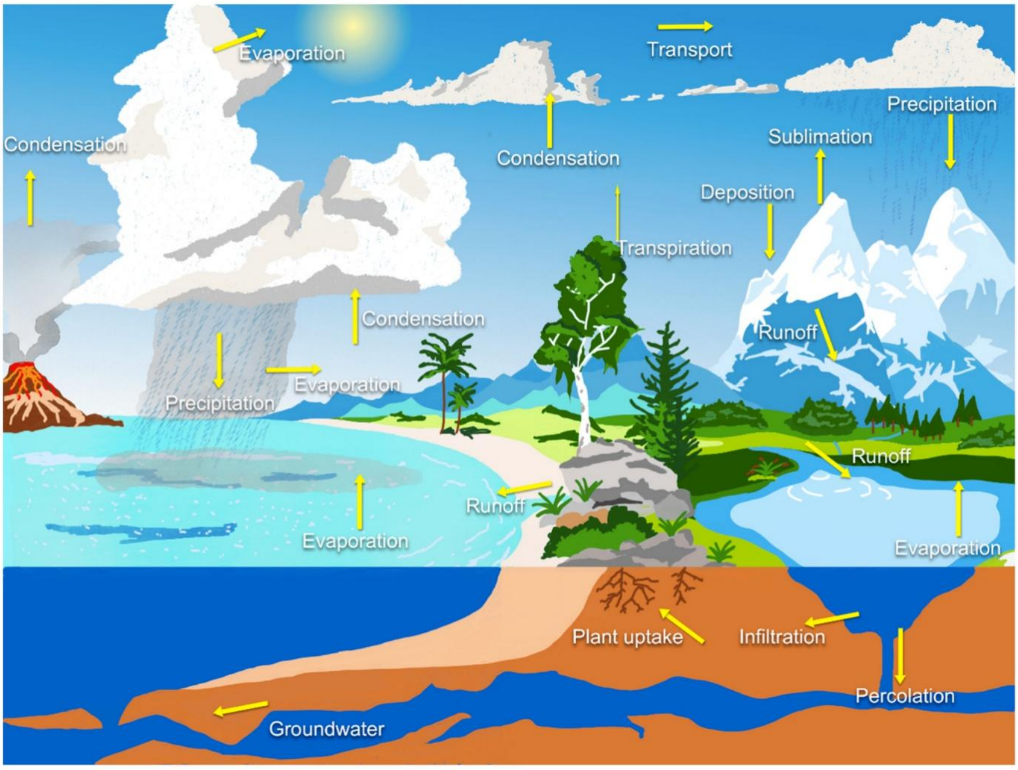


**Figure 1.** Conceptual schematic of the hydrological cycle and key storages/fluxes relevant to water-resources surveying (precipitation, evapotranspiration, runoff, infiltration, groundwater recharge and discharge)[15].

## 2.2. Historical Development

Hydrological surveying is not a recent activity, and it started much earlier in ancient civilizations, where the value of water in agriculture and habitation was discovered. The first hydrological survey was rudimentary, and it was done using direct observation and barehanded observation to identify the flow of rivers and the quantity of groundwater. The early societies, such as the Egyptians, the Mesopotamians, and the Indus Valley, developed rudimentary techniques of water resource management, such as building canals, reservoirs and irrigation systems. The methods of this type, however, were not so thorough and could not be as accurate as the large-scale management of water required[17].

The scientific study of hydrology came up in the 17th and 18th centuries, when the movement of water became measurable more precisely, as mathematical techniques were invented and natural science was established. In hydrology, the concept of the water cycle was introduced in the 19 th century, and it was first introduced by Edmund Halley and Henri Darcy. There was an invention of such devices as rain gauges, flow meters, and piezometers, and these tools assisted to gain more accurate count of information on these facets of nature, such as precipitation, flow of streams, and groundwater level[18].

Computational modeling and statistical analysis became the revolution of hydrology in the 20 th century. Hydrology models, which are based on the simulation of the flow and distribution of water in various landscapes, proved very useful in estimating the supply of water and the effect of alterations in land-use, urbanization, and changing climates. The use of remote sensing technologies in the second half of the 20th century also expanded the scope of hydrological surveying since it was now possible to track the water systems on a massive scale, both with the help of satellites and aerial platforms [19,20].

## 2.3. Key Objectives of Hydrological Surveys

The primary objective of hydrological surveys is to arrive at reasonable information that will be useful in water resources management [14]. These surveys are aimed at learning the mechanics of the hydrological cycle, i.e., precipitation, infiltration, evaporation processes, and runoffs. Hydrological surveys provide the entire picture of the water system in a certain region by collecting information about the quality and the quantity of water. It is significant data to plan and control the water use in other areas, such as agriculture and industry, as well as water distribution within a city. The principal variables typically targeted by hydrological and water-resources surveys are summarized in **Table 1**, linking each parameter to its operational value for climate-resilience planning.

**Table 1.** Core hydrological and water-quality parameters commonly measured in water-resources surveys, representative measurement techniques, and relevance to climate-resilience decisions.

| Parameter | Description | Measurement Technique | Importance of Climate Resilience |
|---|---|---|---|
| Precipitation | The amount of rain falling over a specific area | Rain gauges, satellite imagery | Helps forecast water availability, flooding risks |
| Streamflow/Discharge | Volume of water flowing through rivers | Flow meters, gauging stations, and remote sensing | Key for flood prediction and water supply management |
| Groundwater Levels | Depth of the water table in aquifers | Piezometers, boreholes | Essential for understanding groundwater reserves |
| Water Quality | Chemical composition of water (e.g., pH, turbidity) | Sensors, laboratory testing | Important for assessing pollution and ecosystem health |
| Soil Moisture | Amount of water retained in soil | Soil moisture sensors, remote sensing | Critical for agricultural water management |

The hydrological surveys are also useful in determining the effect of climate change on water resources [21]. Climate change has the potential to alter the pattern of rainfall and frequency of extreme weather conditions, as well as cause a change in the availability and distribution of water resources. Hydrological surveys are also important in determining regions that are prone to flooding, drought, or lack of water supply, so that early warning systems can be designed and measures to mitigate against the vulnerable populations can be put in place. Moreover, such surveys assist in the planning of land-use and infrastructure development so that the water management plans can be incorporated into the wider plans of climate adaptation.

Water quality is another important purpose of hydrological surveying. Water quality is a significant issue in most areas where it is polluted by agricultural runoff, industrial wastes, and untreated sewage. These parameters measured in hydrological surveys are the pH, dissolved oxygen, turbidity, and the levels of the contaminant (e.g., nitrates, heavy metals, etc.) [22–26]. These surveys are effective in detecting sources of pollution and evaluating the success of water treatment and pollution control measures by conducting surveys on the water quality on a regular basis.

## 2.4. Evolution of Surveying Techniques

Techniques in hydrological surveying have dramatically changed over the years due to improvements in technology and increasing calls to have more precise and detailed data. Manual measures of river discharge and groundwater level have been replaced with the modern techniques that provide more resolution data and real-time monitoring.

The use of remote sensing technologies has been described as one of the most important achievements in hydrological surveying [5,27]. Platforms (e.g., Landsat and Moderate Resolution Imaging Spectroradiometer—MODIS) offered by satellites allow for the provision of invaluable information regarding land cover, water bodies, and alterations in the hydrological landscape. The technologies can be used in monitoring large, remote, or inaccessible regions, thereby enabling the gathering of data on a global basis. Remote sensing is relevant to evaluating the effects of climate change on water resources, especially in that it offers a measurable and identical technique of monitoring the changes in land utilization and vegetation cover, as well as the water bodies over a period.

In addition to remote sensing, Geographic Information Systems (GIS) developments have transformed the way hydrological information is perceived and understood [28,29]. GIS technology enables integration of various categories of data, such as precipitation, temperature, soil type, and topography, and comes up with a detailed model of the hydrology systems. These models can model the water flow over different landscapes and therefore help the researchers in making predictions about how climatic or land use changes will affect the water availability and its distribution.

Hydrological surveying has also been changed by the technologies of sensors. The innovations in wireless sensors, including the mentioned ones, have made it feasible to gather information on such parameters as streamflow, groundwater levels, and water quality in real time. They can also be installed in remote or inaccessible locations, and there can be constant monitoring of such sensors without being manipulated. Besides, sensors and Internet of Things networks have allowed gathering and examining vast amounts of hydrological data in real-time and making instant and more effective decisions [30].

### 2.5. Challenges in Hydrological Surveying

Although the increase in technology is extremely significant in enhancing the quality and standard of the surveys developed in hydrology, several challenges still exist [31]. Among the most significant issues, one must note that the data from various sources should be integrated. Integration of ground-based measurements, satellite data, and sensor data implies highly complicated procedures of data processing and data analysis. It is important that these sources of data can be synchronized and harmonized, as the result of this was the formation of plausible results.

The other is accessibility and availability of hydrological information, especially in the developing areas, which could be poor in infrastructure to collect and monitor the same [32,33]. Hydrological survey is scarce in large areas across the world, and the information is either obsolete or unavailable. Without this information, it is not easy to evaluate the effect that climate change has on the available water resources or to plan the potential measures that can be taken to manage the water.

Another issue is the high cost and sophistication of the new surveying technologies [33]. An example is remote sensing, which is a very expensive undertaking in terms of investing in satellite images and software to work with, which is not accessible to every region and organization. Equally on the same note, sensor networks can be expensive both to deploy and to maintain, and they might consume resources. Nevertheless, despite these challenges, hydrological surveying is an important instrument in the area of climate resiliency in the study of water resources. Since the current technological progress is taking place, the capability to overcome these barriers and the presence of hydrological surveys will become extremely relevant to the creation of the climate-resistant environment, and the usage of the water resources in the way they should be used worldwide.

## 3. Methodologies in Hydrological and Water Resources Surveying

### 3.1. Traditional Methods

Traditional methods of hydrological surveying have been the main means of domination by the water resource management for centuries. Field-based measurements are the primary methods of those techniques, and they presuppose observation and recordings of hydrological parameters at some point. The primary instruments of the traditional hydrological survey that were used to quantify the specific components of the hydrological cycle are rain gauges, flow meters, and piezometers [34].

Another significant element of the water cycle is precipitation, which is gauged by rain gauges, and precipitation influences the stream flow, groundwater recharge, and soil moisture [15]. The application of these gauges to measure the amount of rain that falls within a given period of time is very handy in studying the trends of precipitation in an area, as well as in determining the long-term and short-term water availability. Flow meters or gauging stations are required in the determination of the quantity of water flowing through streams and rivers, since these measurements are normally made as streamflow. Gauging stations are installed in various locations at appropriate places across a river, and the gauging stations monitor the alteration of water level, and their results are utilized to determine the flow and discharge volume rates.

Piezometers that are employed to measure the depth of groundwater are essential in understanding the behavior of the aquifer and the availability of groundwater. They are installed in wells or boreholes and give data on the changes in the depth of the water table. Through having an eye on the variations in the level of groundwater with time, hydrologists are able to determine the impact of precipitation, evaporation, and human activities such as irrigation or industrial extraction of water on groundwater [35].

With all these advantages, there are various constraints associated with traditional methods, especially on spatial coverage and real-time data collection. This is because there are huge or distant regions that are not monitored due to the fixed measurement stations. Also, most of these methods are manual, which may result in delays in data processing, thus restricting them from supporting real-time decision-making. **Table 2** summarizes methodological disparities between field-based and technology-enabled approaches, and illustrates trade-offs between the spatial coverage, temporal resolution, and constraints of implementation.

**Table 2.** Comparison of traditional and modern hydrological and water-resources surveying methodologies, including typical data products, strengths, limitations, and enabling technologies.

| Technique | Type of Data Collected | Advantages | Limitations | Technologies Used |
|---|---|---|---|---|
| Ground-Based Measurement (e.g., rain gauges, flow meters) | Precipitation, streamflow, groundwater levels | Cost-effective, long-established methodology | Limited spatial coverage, time-consuming | Manual instruments, analog devices |
| Remote Sensing (Satellite, Unmanned Aerial Vehicle, UAV) | Surface water extent, soil moisture, vegetation, and flood events | Large-scale data collection, real-time monitoring | High initial cost, requires technical expertise | Satellites, drones, optical/radar sensors |
| IoT Sensors | Water quality (pH, turbidity), water flow, temperature | Real-time monitoring, automated data collection | High installation and maintenance costs | IoT devices, wireless sensors, and real-time data |
| Hydrological Modeling | Streamflow predictions, water availability, and water quality | Simulates future scenarios, integrates multiple data sources | Requires accurate input data and model complexity | Computer models, simulation software |

## 3.2. Modern and Advanced Techniques

The recent few years have seen the hydrological surveying improve a lot with the coming up of modern technologies that have offered them with better precision, better spatial coverage, and the ability to deliver real-time information [36]. One of the most radical inventions is the application of remote sensing technologies, according to which it is now possible to look after the water systems at a large scale through satellite images, aerial services, and drones. These technologies have revolutionized hydrological surveying, and more information is now possible to be gathered on areas that are inaccessible or remote.

The hydrological parameters that can be provided in great detail using remote sensing systems installed on satellites such as those operated by the National Aeronautics and Space Administration (NASA) and the European Space Agency include a number of hydrological parameters [37,38]. One of them is the possibility of satellites to track the territory's water area, track the flow of large water bodies like lakes and rivers, and identify the well-being of the vegetation, which is critical in the diagnosis of the situation of water resources. The land cover and water bodies changes can be monitored, and therefore the scientists are able to analyze the long-term water availability trends, which is also important in the management of water resources in the face of climate change.

Among satellite data, unmanned aerial vehicles (UAVs), also known as drones, are also emerging as a rapidly gaining survey instrument of hydrology [38,39]. The sensors and cameras on these drones can capture high-resolution images and data of areas that are difficult to access, such as floodplains, wetlands, or mountainous areas. These platforms have been especially useful in monitoring local water bodies and collecting data about streams, water quality, and changes in land use.

Hydrological modeling is another advanced technique, which is now widespread in the present management of water resources [40]. Models are used to simulate the behavior of water systems with respect to the impact of precipitation, temperature, land use, and soil characteristics. Once the hydrologists have put such variables in a computer-based model, predicting the response of a watershed or an aquifer to a change in weather, land use, or human activity is possible. The models are important to the management of water resources in a changing climate because they are applicable in predicting the future water supply, establishing the impact of extreme processes like floods or droughts, and assessing the functionality of various water management methods.

Moreover, Geographic Information Systems coupled with a hydrological model have been useful in visualizing and analyzing the complex hydrological data. With the help of GIS, it is possible to map watersheds, river systems, and aquifer systems, which will enable the determination of the vulnerable points and the development of certain intervention strategies [41]. The combination of GIS and hydrological models is a powerful instrument in extrapolating the movement of water within landscapes and making the assessment of the potential impacts of land-use change on the water reserves.

### 3.3. Data Integration and Big Data Approaches

The presence of big data and the implementation of advanced data analytics may be regarded as one of the most significant advances in terms of contemporary hydrological surveying [42]. Hydrological systems are complicated in their nature, and there are many other factors that can cause movement of water, its quality, and availability. To have the complete picture of these systems, hydrologists are supposed to research on giant volumes of hydrological data that will encompass ground-based measurements, remote sensing, sensor networks, and climate models.

The big data methods enable capturing and processing real-time data from different sources, and as a result, a more dynamic and responsive management of water resources is enabled. Examples include the integration of sensor networks, which allow continuous monitoring of hydrological parameters like streamflow, groundwater levels, and water quality. These sensors are also commonly linked via the Internet of Things, whereby real-time data is transmitted and can be analyzed and decisions made instantly. This is especially relevant in flood forecasting, whereby timely information can be used to determine upcoming flood incidents and to direct emergency response operations [43].

Machine learning and artificial intelligence are increasingly involved in the analysis of hydrological data. The technologies may be used to process large and complex datasets, detecting patterns and trends that may not be realized immediately by human analysts. AI algorithms may be applied to forecast future water availability with historical data, identify abnormalities in the quality of water, and optimize water distribution systems. Hydrological models can also be improved by machine learning models that refine the inputs and parameters that are used in the simulation of water flow and distribution [44,45].

The combination of big data and AI can make the process of hydrological survey alteration. These technologies can improve decision-making and water management strategies by offering more accurate, real-time data to analyze and improve the water management strategies. An example is the optimization of water use in agriculture, which can be done using predictive models that operate under the influence of big data to ensure that the distribution of the water stream is efficient and does not generate waste. On the same note, real-time water quality monitoring may aid in detecting the sources of pollution earlier, and therefore, intervention and mitigation can be done in good time [46].

### 3.4. Challenges and Limitations in Current Methodologies

Although there are many merits of the modern method of surveying, it does not lack difficulties. The high expense of advanced technologies is also one of the major constraints. Remote sensing platforms, satellite images, and sensor networks are expensive to finance, and this cannot be afforded by all areas, especially those that have a low resource base. The difficulty of such technologies also requires expert knowledge and training, which makes them even less accessible. The other difficulty is the assimilation of data from various sources. Despite the improvement in data collection and analysis, it is very hard to integrate the data acquired into a coherent and useful format. The differences in the data resolution, its quality, and the scale may cause inconsistencies, and it is vital to make sure that data from different sources can be merged effectively so that the analysis will be accurate [40,47].

Furthermore, the amount of information posed by the contemporary methods of data collection can be overwhelming to the traditional system of data processing. Interpretation and analysis of this data in a sensible manner requires a high level of computational power and complex algorithms, which are not necessarily available or affordable, particularly in developing countries [48].

Lastly, though it is impossible to deny that new surveying methods are more thorough and efficient, they cannot possibly substitute the worth of the traditional methods, especially in those regions with a low infrastructure or where remote sensing data might be questioned. The integration of the modern and the traditional approaches is of critical importance in order to make sure that the hydrological surveys will not only be correct, but also available in different geographical areas.

# 4. Hydrological Surveying in the Context of Climate Resilience

## 4.1. Understanding Climate-Related Water Risks

The changes are being severe on the global water resources due to climate change, and knowledge about the changes is vital in developing climate resilience [49]. Climate change is especially sensitive to water systems, where changes in precipitation patterns, increase in temperatures, and effects of extreme events, e.g., floods, droughts, etc., can have a profound impact on the amount and quality of water availed as human consumption, agriculture, and ecosystems. These changes are not equally felt throughout the country, and certain areas are exposed to a greater amount of water through more rainfall, while others are affected by a reduction in rainfall and long spells of dry weather. The main climate-related water hazards and their observable hydrological signatures are synthesized in **Figure 2**, motivating why targeted surveying is essential for risk diagnostics.

The hydrological surveys are important to the identification and evaluation of water risks associated with climate. Hydrological surveys can generate valuable data by observing the changes in the amounts of precipitation, streamflow, groundwater levels, and water quality, which can be applied to assess the impact of climate change on the water resources [50]. Specifically, they are useful in determining places that are vulnerable to water scarcity, flooding, or poor quality of water, which are aggravated by climatic changes. As an example, the increase in the intensity of rainfall may also cause flash floods, whereas the long dry periods may also decrease the river levels and lower the groundwater levels. In either scenario, the reality about these dynamics is that when the water resources are well-known and thoroughly understood through proper surveys, then water resources planning and management can be better.

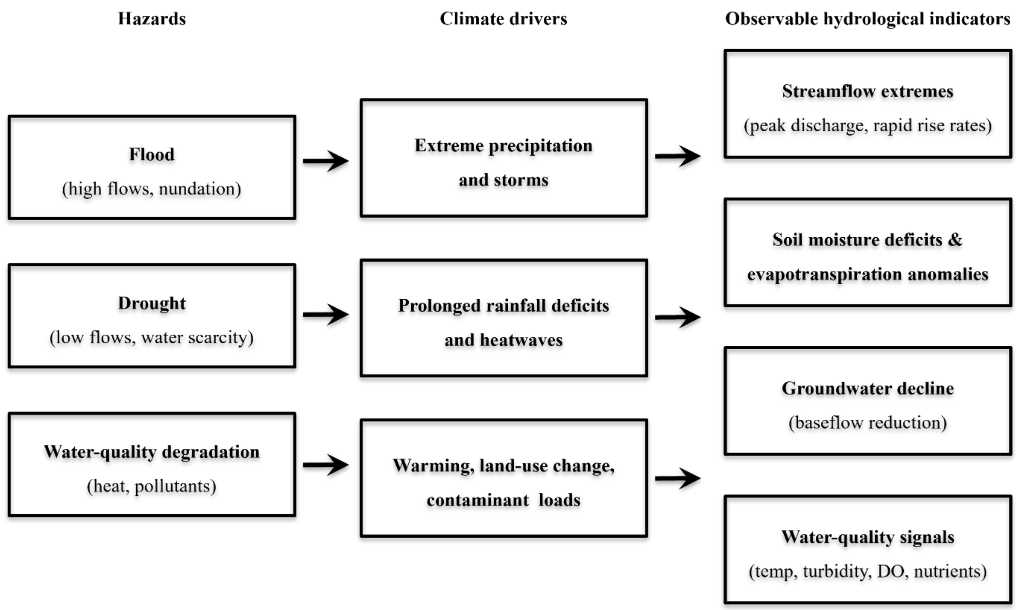


**Figure 2.** Synthesis diagram (or map concept) of climate-related water risks and their hydrological signatures, linking hazards (flood, drought, water-quality degradation) to observable indicators (streamflow extremes, soil moisture deficits, groundwater decline).

Moreover, hydrological surveys are also used in assessing the vulnerability of communities and regions to water-based climatic risks. The surveys can ascertain the detrimental levels beyond in which the water systems could stop coping with the availability and quality of water by evaluating the sensitivity of the systems to the change in temperature, precipitation, and land use. The data is essential in designing adaptation mechanisms to help mitigate the impacts of climate change, either in terms of water conservation systems, water infrastructures, or flood management systems [51,52].

## 4.2. Role of Surveying in Climate Adaptation and Mitigation

The hydrological surveys also assist in climate adaptation and mitigation, as well, since they will be included in the information that can be utilized in making decisions that will, in turn, improve water management in the changing climatic conditions. In terms of the adaptation view, the future availability of water resources is predicted with the help of hydrological surveys, and a direction is laid down ahead in order to guarantee the water security in the perspective of climate variability. To illustrate, groundwater monitoring surveys and streamflow dynamic surveys can be used to anticipate potential water shortage and intervene beforehand, and formulate drought management policies. Similarly, the contents of the hydrological surveys could be used to design flood control activities through the construction of reservoirs, floodwalls, and early warning to protect the lives of the vulnerable population [53].

Besides the element of adaptation, hydrological surveys also play a significant role in reducing the climate change. Hydrological surveys can be undertaken in a sustainable manner where water management is done so that the carbon footprint of water usage in agriculture, energy, and industry is reduced to a minimum. In a way, the indicative nature of the flow of water in irrigation systems, when understood, can lead to the efficiency of water consumption that will minimize the amount of energy required to pump and treat the water. Besides, hydrological data can also be used in designing renewable energy systems, such as hydropower, to develop the necessary information about the river flows and seasonality of water supply. In this manner, hydrological surveys can be adopted in addition to climate change adaptation to mitigate the effects of climate change through sustainable water management [54,55]. The output of hydrological surveys is operational climate services in a variety of fields; **Table 3** summarizes the main areas of application and related benefits of resilience.

**Table 3.** Typical applications of hydrological surveying to climate adaptation and mitigation, and typical use-cases, and resilience results.

| Application | Description | Example | Impact on Climate Resilience |
|---|---|---|---|
| Flood Forecasting and Management | Using hydrological data to predict and mitigate floods | Use of streamflow data for flood early warning systems | Reduces loss of life and property damage from floods |
| Drought Monitoring and Management | Assessing water shortages and planning water use | Groundwater level monitoring in drought-prone regions | Enables proactive water conservation and relief efforts |
| Agricultural Water Management | Efficient use of water resources for irrigation | Use of soil moisture data for precision agriculture | Improves crop yields while reducing water waste |
| Ecosystem Protection and Restoration | Monitoring water quality and flow to protect ecosystems | Wetland conservation based on hydrological data | Enhances biodiversity and ecosystem services |

Also, hydrologic surveys are crucial to sustaining ecosystem services that are essential in reducing climate change. Healthy wetlands, forests and watersheds are carbon sinks, which trap large volumes of carbon dioxide into the atmosphere. Hydrological surveys allow observation of the health of these ecosystems to assess the capacity to keep on carrying out such functions, which is critical in the mitigation strategies related to climate [56].

## 4.3. Case Studies

The case studies that have been implemented in most parts of the world indicate that hydrological surveys play a significant role in facilitating resilience to climate. One such example is flood forecasting and management in the United States, where hydrological surveys are used [57]. Flood predictions based on real-time hydrological data like streamflow data, precipitation data, and remote sensing data have enabled the National Weather Service to make more precise predictions on floods and thus, lead to a better response time and loss of life. In areas having frequent rising, hydrological surveys will be useful in providing valuable information on the dynamics of a river, water storage capacity, and floodplain mapping that will be applied in the design of flood mitigation facilities such as levees, dams, and diversion channels.

The Indians have also applied the hydrological surveys in order to cope with the water crisis brought about by climate change[58,59]. The National Water Development Agency has carried out extensive research on river basins and groundwater systems in definition of the effect of the changing rainfall patterns on the availability of water. This water conservation policy has, to date, affected water conservation policies such as rainwater harvesting projects and the construction of check dams, which have helped to improve the water security in the rural areas. In addition, the hydrological surveys and climate models have created better forecasts of drought and floods, which allows more active management of water resources.

The other interesting example is the application of hydrological survey in the development of water management strategies in agricultural development in sub-Saharan Africa[60,61]. In other regions, such as the Sahel and East Africa, the International Water Management Institute (IWMI) has conducted a massive hydrological survey in which occasional rainfalls and increasing droughts have been quoted as significant problem to food production. Such surveys and satellite information, coupled with hydrological models, have been employed in creating water-saving irrigation systems, increasing water storage operations, and examining the stress of agriculture on climatic impacts.

It is observed through these case studies that hydrological surveys have a role to play in climate resilience in a range of locations, both flood management in the developed world and water resilience solutions in dry areas. Such surveys are key in making sure that the decision makers introduce the most efficient and focused climate adaptation plans that can be relied on to increase human and ecological resilience due to the availability of the required data.

### 4.4. Challenges in Implementing Hydrological Surveying for Climate Resilience

Although hydrological surveys are vital in creating climate resilience, several obstacles exist to their large-scale adoption, and these are particularly important in areas where climate change is highly likely. Infrastructure and resources in the developing countries are among the main issues, and where accurate hydrological data is likely to be the most needed. Lack of monitoring stations in those regions, access to modern technologies, and lack of funds to collect and analyze data may hamper the efficiency of hydrological surveys. In the absence of detailed information about water resources, it is hard to evaluate the total scope of climate-related risks or take proactive measures to manage them[62]. Notwithstanding the evident advantages, the implementation is not even, with the most frequent impediments and direction of the practical solutions being summarized in **Table 4**.

**Table 4.** Major technical and institutional barriers to implementing hydrological surveying for climate resilience and corresponding solution directions.

| Challenge | Description | Impact on Hydrological Surveying | Potential Solutions |
|---|---|---|---|
| Data Gaps and Inaccessibility | Lack of comprehensive data in remote or underdeveloped regions | Limited ability to monitor water systems and predict climate-related risks | Investment in low-cost sensors, expansion of monitoring networks |
| High Costs and Resource Requirements | Advanced surveying technologies are expensive and resource-intensive | Restricted access to state-of-the-art monitoring tools in developing countries | Collaboration between public and private sectors, use of low-cost technologies |
| Data Integration and Compatibility | Difficulty in combining data from various sources (e.g., sensors, satellites, models) | Inaccurate or incomplete analysis of water systems | Development of standardized data formats, better data processing tools |
| Climate Change Uncertainty | Unpredictability in future climate patterns affects the accuracy of models | Challenges in making long-term predictions for water resource management | Use of ensemble models, incorporation of climate variability in predictions |

A major challenge is not uncertainty, but how uncertainty propagates through the climate–hydrology–decision chain. In this context, uncertainty stems from future climate and socio-economic scenarios, structural differences among climate and hydrological models, parameter estimation, and limitations in observational data. These uncertainties affect estimates of streamflow extremes, groundwater recharge, drought persistence, and water quality, thereby influencing infrastructure design, reservoir operation, drought planning, and ecosystem management. For this reason, hydrological surveying for climate resilience should support robust decision-making through ensemble modeling, sensitivity analysis, uncertainty communication, and adaptive management pathways rather than single deterministic predictions[63].

Moreover, the technical problems of combining the hydrological data obtained in various sources, including ground-based measurements, remote sensing, and climate models, are also challenging. To make sure that these datasets are compatible and can be successfully synthesized to make decisions, it is necessary to have highly computational tools and skills, which are not always available in resource-restricted environments[48].

Finally, increased liaisons between hydrologists, policymakers, and local communities are required to see that the information produced with the help of hydrological surveys is utilized properly. In most situations, this is due to the missed chances to use the survey data towards climate resilience planning because of the absence of communication and coordination between the stakeholders[64].

### 4.5. The Future of Hydrological Surveying for Climate Resilience

In the future, the future of hydrological surveying as a part of climate resilience will be the further development and more integration of new technologies. Sensor networks, real-time monitoring innovations, and artificial intelligence innovations have immense potential in enhancing the accuracy and timeliness of hydrological information[65,66]. In what way, as an example, the mass communication of low-end sensors and IoT devices would deliver more responsive and adaptable water management policies, by providing real-time information on water quality and flow.

Moreover, remote sensing opportunities, including drones and high-resolution satellite images, would give an opportunity to monitor the water resources at the global level. As the availability and cost of these technologies decrease, we will be able to observe water systems in a more holistic manner in remote and data-poor regions to deliver valuable data to climate resiliency. Besides, these hydrological data, together with other environmental data, such as climate projections, land-use patterns, ecosystem health, etc., will allow making more holistic approaches to climate resilience possible[8]. This is the combined strategy that will help in developing more multi-sectoral adaptation strategies that will help respond to short-term and long-term impacts of climate change on the water resources.

## 5. Future Directions in Hydrological and Water Resources Surveying

### 5.1. Emerging Technologies

The hydrological surveying is rapidly evolving due to the new emerging technologies, which are bound to alter the manner in which water resources can be tracked, evaluated, and controlled. One of the most promising technologies in the field has been the next-generation remote sensing technologies. The satellite high-resolution cameras and the new aerial cameras, such as those operated by drones and UAVs (Unmanned Aerial Vehicles), are providing unprecedented capability in tracking water resources around the globe[39,67]. With the help of such technologies, it is possible to make a full observation of the surface water bodies, recharge areas of groundwater, and even tiny hydrological entities (like wetlands) that were hard to observe before.

Now, synthetic aperture radar satellites or optical imaging sensor satellites can detect the changes in water bodies at the low level and detect flood cases and the water content of water in the soil[68]. These systems are particularly applicable in the observation of long-term hydrological cycles and extreme weather because they give almost real time and continuous calls. The information is necessary in forecasting water supply, regions prone to flooding, and reaction to disaster management.

Along these same lines, remote sensing and the Internet of Things are being incorporated in the real-time monitoring of hydrological parameters[69]. The IoT devices can be used in rivers, lakes, and underground aquifers to provide real-time observation of such parameters as water quality, temperature, and flow. This data can be relayed in real-time to the central databases, and it can be processed and used to provide water management decisions. Popularization of the IoT technologies will probably make the high-quality hydrological data accessible to the masses and enable more localized and specific decision-making (particularly in inaccessible and underrepresented regions). Hydrological surveying is also being conducted by machine learning (ML) and artificial intelligence. These technologies can process large quantities of information to unveil trends, how water will be sustained in the future, as well as the detection of anomalies in the water systems. To use the example, AI-based models can be utilized to reproduce the extent to which the different climatic conditions will affect the river systems, and therefore, it is feasible to anticipate the occurrence of droughts, floods, or changes in the amount of groundwater. Machine learning algorithms can be integrated into hydrological models to achieve more precise outcomes, automatically process all data, and allocate resources in a water management system in the most appropriate way [70].

Further development of these new technologies will lead to far more precise, comprehensive, and available hydrological surveys and the development of more adaptive and data-driven mechanisms of controlling water resources. An integrated architecture that links multi-source observations to decision-ready products is outlined in **Figure 3**, highlighting where interoperability and analytics govern system performance.

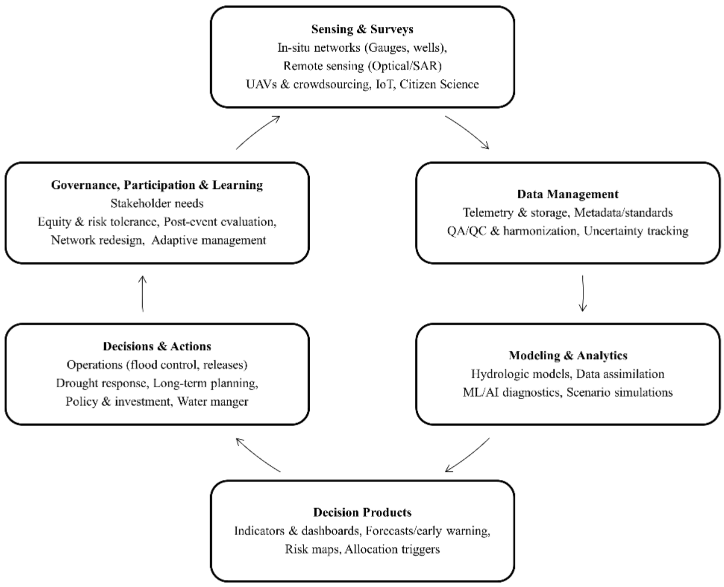


**Figure 3.** Data integration framework for climate-resilient hydrological surveying, showing how in situ observations, remote sensing, IoT streams, and models are harmonized into products for forecasting and decision support.

## 5.2. Increasing Stakeholder Collaboration

With the growing complexity of water resource matters under climate change conditions, it will take more cooperation among different stakeholders, such as hydrologists, climatologists, policymakers, urban planners, and residents, to accomplish effective hydrological surveying [64,71]. Among the most important directions of hydrological surveying in the future, one may single out the enhancement of interdisciplinary collaboration to make sure that the data provided in the survey is accurate, as well as relevant and applicable to various domains.

In particular, the interaction of the hydrologists and the climate scientists will be required to integrate the hydrological information with the climatic models, which will enable drawing more precise conclusions about the response of the water systems to the changed climatic conditions. In such a way, such an integrated approach will be able to increase the accuracy of the flood forecasts, drought projections, and water management in the regions that are particularly prone to the effects of climate. Hydrological surveys can provide significant data inputs to climate models, and climate models can facilitate the determination of the regions that can be vulnerable to water shortage or severe weather, and utilize this information to apply more targeted and active water management strategies [72,73].

Collaboration between governments, local communities, and private companies is the other avenue that is important in regard to collaboration. The active participation of the population and the business organization would contribute to the increased number of hydrological surveillance devices in the developing and less developed nations, where the need for accurate data on water is especially urgent. Water management is a common activity in local communities, and when people are involved in developing and implementing a hydrological survey, it will lead to more effective, community-based solutions [74].

In addition, transnational cooperation will gain greater significance as climate change reduces and makes water resources scarce and contentious [75]. The most essential water resources of the world, like rivers and aquifers, cut across national boundaries of more than one country. These common resources should be used in a sustainable manner, so there is a need to cooperate regionally. Countries can share hydrological data to encourage cooperation in the management of transboundary water systems, prevent conflicts, and provide fair access to water.

## 5.3. Sustainable Practices in Water Surveying

With the increasing need to have more and widespread hydrological surveys, it is critical to consider the sustainability of these surveying activities in terms of both their environmental and economic aspects [76]. Conventional techniques of collecting data, including manual measurements and physical installation of monitoring stations, can be of great environmental impact, especially when there is a lot of field work and sensitive or remote locations have to be covered. Environmental effects of vast survey activity, e.g., the carbon footprint of transportation, or the way electronic waste from the outdated equipment is disposed of, etc., should also be taken into consideration.

To address these issues, there is increasingly more focus on coming up with more sustainable practices in hydrological surveying. The carbon footprint of survey operations can be mitigated by incorporating low-impact technologies, including sensors that run on solar energy and are used to transmit data with minimal energy consumption. Also, with developments in satellite-based remote sensing, the data contained in large regions is available without having to conduct massive field work, which lowers the environmental cost of the conventional surveying technique [77].

One more feature of sustainability in hydrological surveying is the data handling [78]. With the growing amount of data created by the use of modern survey methods, it will be necessary to have the data stored, processed, and shared in a way that is environmentally responsible. The system of cloud-based storage and data-sharing can be used to manage hydrological data in a secure, efficient, and sustainable manner, allowing for greater access and utilization in different regions.

Sustainability also relates to the incorporation of hydrological questionnaires with larger environmental monitoring procedures, in which water resources are handled as a part of the health of the ecosystem. As an illustration, the conservation of wetlands, forests, and other water-based ecosystems can be associated with surveys monitoring the water quality and biodiversity. Hydrological surveying has the potential to be useful in water management as well as environmental sustainability by means of adopting an integrated approach [79].

## 5.4. Addressing Gaps and Knowledge Needs

Although the level of improvement in the hydrological surveying is immense, there are still numerous knowledge gaps in the water systems, and especially on climate change. It also enjoys a high volume of spaces, especially in developing countries, which are deficient in enough hydrological information in order to utilize water resources. The creation of overall hydrologic monitoring networks should be one of the priorities in such spheres. The ability to come up with data collection, processing, and analysis is the key to the improvement of water management, and the international institutions, states, and non-governmental organizations need to cooperate to ensure that the regions are not left out of the game.

Furthermore, the interaction between hydrological parameters and other parameters used in the environment, such as land-use change, ecosystem health, and socio-economic parameters, needs further research [56,80]. Such a holistic solution would enable a better understanding of how water systems interact with other environmental and human systems, and therefore lead to more holistic water management practices, including the consideration of ecological and social aspects.

Increasing demands on evidence-based solutions to overcome gaps in data in real-time monitoring systems are also growing. Although there has been increased progress in technologies such as IoT sensors and satellite remote sensing, they are, in most cases, expensive and might not be accessible everywhere. Low-cost, scalable data gathering and real-time data monitoring in underserved areas will have a drastic impact on our potential to control the water resources in response to global warming.

Lastly, there is an area of further study of the creation of adaptive water management practices incorporating hydrological surveys within wider climate resilience schemes. Hydrological surveys by studying the interaction between water systems and other processes in the environment can potentially provide sufficient information for developing more adaptable, responsive management systems that are better prepared to deal with the unpredictability of climate [81].

## 6. Conclusion

Surveying hydrological and water resources is important to address the increasingly perplexing issues of climate change. As the water systems of the world are constantly impacted by the alterations in climate that are increasingly manifested by droughts, floods, and changing patterns of precipitation, as it turns out, the availability of accurate and prompt hydrological information is the key to controlling these resources and their sustainability in the future. This literature review has detailed the evolution of hydrological surveying through the years, beginning with the traditional surveying techniques of groundwater to the most recent technological methods of remote sensing, Internet of Things, and AI-based analytics, which are changing the process of surveying and managing water resources.

The fact that the modern surveying tools and techniques have been synthesized with the old tools allows for a more diversified and comprehensive answer to the information on the water systems in the climate resilience avenue. Other methods of massive monitoring are remote sensing and real-time sensor networks, where critical information could be accessed and utilized to make both local, regional, and global decisions. Such technological inventions can allow predicting the floods, controlling the droughts, and allocating water efficiently. Moreover, one should not underestimate the role of hydrological surveys in the climate adaptation and mitigation process, since a hydro survey not only contributes to the optimization of water use in all the sectors, but also helps in the development of resiliency plans that would ensure the safety of the human and ecological system.

The review, however, states that there are massive challenges. Information that is not readily available, especially in the developing world, is a barrier to efficient management of water. The advanced technologies are very complex and expensive, and the problems about integration of the data and its accessibility are also there, providing more challenges to the mass implementation. In an attempt to break these barriers, there should be closer interaction between the scientists, the policymakers, and the local communities so that the hydrological information can be applied in line with it and the innovative solutions can be extended to all parts of the country, that is, those parts most threatened by climate change.

The hydrological survey looks gigantic in the future. Only the emergence of satellite technologies, drone surveillance, and artificial intelligence will be able to bring the accuracy, timeliness, and coverage of information on water resources. These developments, combined with an increasingly anxious awareness of sustainable ways of conducting the surveys, will enable making an even larger number of responsive and data-driven decisions on how to improve the resilience of the climate. It will also be particularly evident to build interdisciplinary cooperation and become water-knowledge networks to abolish the existing gaps and develop a holistic, resilient, adaptive water management approach that will be more adaptive to the unpredictable conditions of the shifting climate.

In a nutshell, climate resilience is based on hydrological and water resources surveying. With the world having to confront the extended effects of climate change, the use of these surveys will remain essential to the security of the water resources, their efficiency, and the increase in our capacity to adapt to the unpredictable future. Further innovations in creating new surveying instruments, business alliances, and long-term endeavors will make sure that hydrologic surveys will be a handy tool in water security and weather resistance in the near future.

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The author declares no conflict of interest.

## References

[1] Sivakumar, B., 2011. Global climate change and its impacts on water resources planning and management: Assessment and challenges. Stochastic Environmental Research and Risk Assessment. 25(4), 583–600.

[2] Parvaze, S., Kumar, R., Khan, J.N., et al., 2023. Climate change, drought, and water resources. In: Singh, V.P., Jhajharia, D., Mirabbasi, R., et al. (Eds.). Integrated Drought Management, Volume 1: Assessment and Spatial Analyses in Changing Climate. CRC Press: Boca Raton, FL, USA. pp. 541–568.

[3] Wood, A.W., Lettenmaier, D.P., Palmer, R.N., 1997. Assessing climate change implications for water resources planning. Climatic Change. 37(1), 203–228.

[4] Hagemann, S., Chen, C., Clark, D.B., et al., 2013. Climate change impact on available water resources obtained using multiple global climate and hydrology models. Earth System Dynamics. 4(1), 129–144.

[5] Duan, W., Maskey, S., Chaffe, P. L., et al., 2021. Recent advancement in remote sensing technology for hydrology analysis and water resources management. Remote Sensing. 13(6), 1097.

[6] Vogel, R.M., Lall, U., Cai, X., et al., 2015. Hydrology: The interdisciplinary science of water. Water Resources Research. 51(6), 4409–4430.

[7] Wagener, T., Sivapalan, M., Troch, P.A., et al., 2010. The future of hydrology: An evolving science for a changing world. Water Resources Research. 46(5), W05301.

[8] Granata, F., Di Nunno, F., 2025. Pathways for hydrological resilience: Strategies for adaptation in a changing climate. Earth Systems and Environment. 10, 203–231.

[9] Rogers, D.P., Tsirkunov, V.V., 2013. Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services. World Bank Publications: Washington, DC, USA.

[10] Tauro, F., Selker, J., van de Giesen, N., et al., 2018. Measurements and observations in the XXI century (MOXXI): Innovation and multi-disciplinarity to sense the hydrological cycle. Hydrological Sciences Journal. 63(2), 169–196.

[11] Giupponi, C., Sgobbi, A., 2013. Decision support systems for water resources management in developing countries: Learning from experiences in Africa. Water. 5(2), 798–818.

[12] Hipel, K.W., Ben-Haim, Y., 2002. Decision making in an uncertain world: Information-gap modeling in water resources management. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews). 29(4), 506–517.

[13] Abera, L., 2025. The Growing Role of Artificial Intelligence in Tomorrow's Urban Hydrological Infrastructure (Institute for Homeland Security Report No. 2025-1009). Institute for Homeland Security, Sam Houston State University: Huntsville, TX, USA.

[14] Yang, D., Yang, Y., Xia, J., 2021. Hydrological cycle and water resources in a changing world: A review. Geography and Sustainability. 2(2), 115–122.

[15] Levizzani, V., Cattani, E., 2019. Satellite remote sensing of precipitation and the terrestrial water cycle in a changing climate. Remote Sensing. 11(19), 2301.

[16] Cosgrove, W.J., Loucks, D.P., 2015. Water management: Current and future challenges and research directions. Water Resources Research. 51(6), 4823–4839.

[17] Vuorinen, H.S., Juuti, P.S., Katko, T.S., 2007. History of water and health from ancient civilizations to modern times. Water Science and Technology: Water Supply. 7(1), 49–57.

[18] Hut, R., 2013. New Observational Tools and Datasources for Hydrology: Hydrological Data Unlocked by Tinkering [PhD Thesis]. Technische Universiteit Delft: Delft, The Netherlands.

[19] Singh, V.P., 2018. Hydrologic modeling: Progress and future directions. Geoscience Letters. 5(1), 15.

[20] Pietroniro, A., Prowse, T.D., 2002. Applications of remote sensing in hydrology. Hydrological Processes. 16(8), 1537–1541.

[21] Yang, N., Men, B., Lin, C., 2011. Impact analysis of climate change on water resources. Procedia Engineering. 24, 643–648.

[22] Gao, L., Li, D., 2014. A review of hydrological/water-quality models. Frontiers of Agricultural Science and Engineering. 1(4), 267–276.

[23] Nayar, R., 2020. Assessment of water quality index and monitoring of pollutants by physico-chemical analysis in water bodies: A review. International Journal of Engineering Research and Technology. 9(1), 178–185.

[24] Aslam, M.A., Abbas, M.S., Mustaqeem, M., et al., 2024. Comprehensive assessment of heavy metal contamination in soil-plant systems and health risks from wastewater-irrigated vegetables. Colloids and Surfaces C: Environmental Aspects. 2, 100044.

[25] Khan, M.N., Aslam, M.A., Muhsinah, A.B., et al., 2023. Heavy metals in vegetables: Screening health risks of irrigation with wastewater in peri-urban areas of Bhakkar, Pakistan. Toxics. 11(5), 460.

[26] Khan, M.N., Aslam, M.A., Zada, I., et al., 2023. Statis-

tical analysis and health risk assessment: Vegetables irrigated with wastewater in Kirri Shamozai, Pakistan. Toxics. 11(11), 899.

[27] Tang, Q., Gao, H., Lu, H., et al., 2009. Remote sensing: Hydrology. Progress in Physical Geography. 33(4), 490–509.

[28] Thakur, J.K., Singh, S.K., Ekanthalu, V.S., 2017. Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. Applied Water Science. 7(4), 1595–1608.

[29] Wang, X., Xie, H., 2018. A review on applications of remote sensing and geographic information systems (GIS) in water resources and flood risk management. Water. 10(5), 608.

[30] Wong, B.P., Kerkez, B., 2016. Real-time environmental sensor data: An application to water quality using web services. Environmental Modelling & Software. 84, 505–517.

[31] Liu, Y., Weerts, A.H., Clark, M., et al., 2012. Advancing data assimilation in operational hydrologic forecasting: Progresses, challenges, and emerging opportunities. Hydrology and Earth System Sciences. 16(10), 3863–3887.

[32] Ekeu-wei, I.T., 2018. Evaluation of hydrological data collection challenges and flood estimation uncertainties in Nigeria. Environment and Natural Resources Research. 8(2), 44.

[33] National Research Council of the National Academies, 2012. Challenges and Opportunities in the Hydrologic Sciences. National Academies Press:Washington, DC, USA.

[34] Groves, C., 2007. Hydrological methods. In: Goldscheider, N., Drew, D. (Eds.). Methods in Karst Hydrogeology: IAH: International Contributions to Hydrogeology. CRC Press: London, UK. pp. 45–64.

[35] Nistor, M.M., Rahardjo, H., Satyanaga, A., et al., 2020. Investigation of groundwater table distribution using borehole piezometer data interpolation: Case study of Singapore. Engineering Geology. 271, 105590.

[36] McCabe, M.F., Rodell, M., Alsdorf, D.E., et al., 2017. The future of Earth observation in hydrology. Hydrology and Earth System Sciences. 21(7), 3879–3914.

[37] Ndehedehe, C., 2022. Satellite Remote Sensing of Terrestrial Hydrology. Springer: Cham, Switzerland.

[38] Ali, M.H., Popescu, I., Jonoski, A., et al., 2023. Remote sensed and/or global datasets for distributed hydrological modelling: A review. Remote Sensing. 15(6), 1642.

[39] Mishra, V., Avtar, R., Prathiba, A.P., et al., 2023. Uncrewed aerial systems in water resource management and monitoring: A review of sensors, applications, software, and issues. Advances in Civil Engineering. 2023(1), 3544724.

[40] Ramirez, D., 2025. Advancements and challenges in hydrological modeling. Journal of Earth Science & Climatic Change. 16(12), 984.

[41] Gururani, D.M., Kumar, Y., Abed, S.A., et al., 2023. Mapping prospects for artificial groundwater recharge utilizing remote sensing and GIS methods. Water. 15(22), 3904.

[42] Chen, J., Chen, S., Fu, R., et al., 2022. Remote sensing big data for water environment monitoring: Current status, challenges, and future prospects. Earth's Future. 10(2), e2021EF002289.

[43] Munawar, H.S., Hammad, A.W., Waller, S.T., 2022. Remote sensing methods for flood prediction: A review. Sensors. 22(3), 960.

[44] Chang, F.-J., Chang, L.-C., Chen, J.-F., 2023. Artificial intelligence techniques in hydrology and water resources management. Water. 15(10), 1846.

[45] Marshall, S.R.O., Tran, T.N.D., Tapas, M.R., et al., 2025. Integrating artificial intelligence and machine learning in hydrological modeling for sustainable resource management. International Journal of River Basin Management. 1–17. DOI: https://doi.org/10.1080/15715124.2025.2478280

[46] Kamyab, H., Khademi, T., Chelliapan, S., et al., 2023. The latest innovative avenues for the utilization of artificial intelligence and big data analytics in water resource management. Results in Engineering. 20, 101566.

[47] Yaseen, Z.M., 2023. A new benchmark on machine learning methodologies for hydrological processes modelling: A comprehensive review for limitations and future research directions. Knowledge-Based Engineering and Sciences. 4(3), 65–103.

[48] Nath, N.K., Das, P., Mishra, L.R., et al., 2024. Hydrological modeling and simulation for water resource assessment. In: Yadav, A.K., Yadav, K., Singh, V.P. (Eds.). Integrated Management of Water Resources in India: A Computational Approach: Optimizing for Sustainability and Planning. Springer: Cham, Switzerland. pp. 43–58.

[49] Khan, T., Samiullah, M., Rouf, I., et al., 2024. The nexus of water scarcity and climate change: Understanding interconnected challenges and formulating resilient strategies. International Journal of Environmental Science. 7(3), 57–68.

[50] Tinazzi, I., 2024. Water Scarcity, Migrations and Climate Change: An Assessment of Their Nexus [Master's Thesis]. Ca' Foscari University of Venice: Venice, Italy.

[51] Mishra, R.K., 2023. Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies. 4(3), 1–78.

[52] Bojer, A.K., Abshare, M.W., Mesfin, F., et al., 2025. Assessing climate and land use impacts on surface water yield using remote sensing and machine learning. Scientific Reports. 15(1), 18477.

[53] Hou, W., Zhang, S., Yin, J., et al., 2024. Research on challenges and strategies for reservoir flood risk prevention and control under extreme climate conditions.

Water. 16(23), 3351.
[54] Yu, L., Liu, S., Wang, F., et al., 2022. Strategies for agricultural production management based on land, water and carbon footprints on the Qinghai-Tibet Plateau. Journal of Cleaner Production. 362, 132563.
[55] Elgendy, M., Hassini, S., Coulibaly, P., 2024. Review of climate change adaptation strategies in water management. Journal of Hydrologic Engineering. 29(1), 03123001.
[56] El Jeitany, J., Pacetti, T., Caporali, E., 2024. Evaluating climate change effects on hydrological functionality and water-related ecosystem services. Ecohydrology. 17(4), e2557.
[57] Li, Z., Gao, S., Chen, M., et al., 2022. Spatiotemporal characteristics of US floods: Current status and forecast under a future warmer climate. Earth's Future. 10(10), e2022EF002700.
[58] Swain, S., Taloor, A.K., Dhal, L., et al., 2022. Impact of climate change on groundwater hydrology: A comprehensive review and current status of the Indian hydrogeology. Applied Water Science. 12(6), 120.
[59] Todmal, R.S., 2024. Hydrological changes in the drought-prone region of Maharashtra (India): Implications for sustainable water use. Singapore Journal of Tropical Geography. 45(1), 107–128.
[60] Banda, V.D., Dzwairo, R.B., Singh, S.K., et al., 2022. Hydrological modelling and climate adaptation under changing climate: A review with a focus in Sub-Saharan Africa. Water. 14(24), 4031.
[61] Tidjani, A.M., Tovihoudji, P.G., Akponikpe, P.B., et al., 2025. Systematic synthesis of knowledge relating to the hydrological functioning of inland valleys in Sub-Saharan Africa. Water. 17(2), 193.
[62] Jeuken, A., Ray, P., Penning, E., et al., 2023. Challenges for upscaling hydrological effectiveness of nature-based solution for adaptation to climate change in watersheds. Aquatic Ecosystem Health & Management. 26(2), 19–32.
[63] Alizadeh, O., 2022. Advances and challenges in climate modeling. Climatic Change. 170(1), 18.
[64] Nardi, F., Cudennec, C., Abrate, T., et al., 2022. Citizens and hydrology (CANDHY): Conceptualizing a transdisciplinary framework for citizen science addressing hydrological challenges. Hydrological Sciences Journal. 67(16), 2534–2551.
[65] Miller, T., Durlik, I., Kostecka, E., et al., 2025. Integrating artificial intelligence agents with the internet of things for enhanced environmental monitoring: applications in water quality and climate data. Electronics. 14(4), 696.
[66] Biazar, S.M., Golmohammadi, G., Nedhunuri, R.R., et al., 2025. Artificial intelligence in hydrology: Advancements in soil, water resource management, and sustainable development. Sustainability. 17(5), 2250.
[67] de Oliveira Farias, M., Cirilo, J.A., Neto, A.R., 2025. Unmanned aerial vehicles (UAVs) in water resources management: A systematic review. Revista de Gestão Social e Ambiental. 19(5), e012237.
[68] Albertini, C., Gioia, A., Iacobellis, V., et al., 2022. Detection of surface water and floods with multispectral satellites. Remote Sensing. 14(23), 6005.
[69] Bandara, R.M.P.N.S., Jayasignhe, A.B., Retscher, G., 2025. The integration of IoT (Internet of Things) sensors and location-based services for water quality monitoring: A systematic literature review. Sensors. 25(6), 1918.
[70] Drogkoula, M., Kokkinos, K., Samaras, N., 2023. A comprehensive survey of machine learning methodologies with emphasis in water resources management. Applied Sciences. 13(22), 12147.
[71] Pahl-Wostl, C., 2007. Transitions towards adaptive management of water facing climate and global change. Water Resources Management. 21, 49–62.
[72] Meresa, H., Zhang, Y., Tian, J., et al., 2023. An integrated modeling framework in projections of hydrological extremes. Surveys in Geophysics. 44(2), 277–322.
[73] Reddy, P.K.K., Harikeerthan, M.K., Nayak, S.G., et al., 2026. Improvisation in climate model selection and effective hydrological modelling in face of climate change: A case study of Seonath river Basin, India. Journal of the Indian Society of Remote Sensing. 54(3), 919–938.
[74] Ali, M.A., Kamraju, M., 2024. The role of community participation in sustainable integrated water resources management: Challenges, opportunities, and current perspectives. In: Yadav, A.K., Yadav, K., Singh, V.P. (Eds.). Integrated Management of Water Resources in India: A Computational Approach: Optimizing for Sustainability and Planning. Springer: Cham, Switzerland. pp. 325–344.
[75] Aamer, F., 2023. Water security: Diplomacy, global cooperation, and effective management of shared rivers. Konrad-Adenauer Foundation & Stimson Center: Düsseldorf, Germany.
[76] Ortiz-Partida, J.P., Fernandez-Bou, A.S., Maskey, M., et al., 2023. Hydro-economic modeling of water resources management challenges: Current applications and future directions. Water Economics and Policy. 9(1), 2340003.
[77] Aravinda, K., Sravanthi, J., Lakhanpal, S., et al., 2024. Water and hydrology: Challenges, sustainable strategies and future trends. E3S Web of Conferences. 552, 01135.
[78] Parenti, C., Rossi, P., Soldati, M., et al., 2022. Integrated geomatics surveying and data management in the investigation of slope and fluvial dynamics. Geosciences. 12(8), 293.
[79] Makanda, K., Nzama, S., Kanyerere, T., 2022. Assessing the role of water resources protection practice for sustainable water resources management: A review.

Water. 14(19), 3153.
[80] Babaremu, K., Taiwo, O., Ajayi, D., 2024. Impacts of land use and land cover changes on hydrological response. TWIST. 19(1), 256–267.
[81] Xia, J., Dong, Y., Zou, L., 2022. Developing socio-hydrology: Research progress, opportunities and challenges. Journal of Geographical Sciences. 32(11), 2131–2146.