Review

A Benchmarking Study of Irrigation Advisory Platforms

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Abstract: In the contemporary agricultural landscape, agriculture faces four pressing demands: competitiveness, ensuring food security for a growing population, environmental sustainability, and providing farmers with acceptable living conditions. To meet this global challenge, digital technologies represent a major avenue for innovation and development towards modernized digital agriculture. In this context, irrigation advisory platforms have proven to be transformational tools for both farmers and policymakers, offering insights into the appropriate crop water requirements. This article presents a benchmarking analysis of around 20 professional irrigation advisory platforms. The methodology involves selecting 20 platforms based on accessibility ensuring geographical characteristic diversity. Our findings highlight key criteria shaping the ecosystem of such platforms, including the services offered and their objectives, the types of covered crops, the target users, the form, as well as the source, the availability of the platform, and the variety of data utilized. Lastly, we discuss the main conclusions drawn from our analysis and provide insights into the challenges and future perspectives of irrigation advisory platforms in enhancing agricultural practices and sustainability.

Keywords: irrigation; benchmarking; web platform; crop water requirements; advisory

1. Introduction

Water scarcity, intensified by factors such as climate change, has emerged as a pressing global concern, impacting various sectors, including irrigated agriculture, industry, domestic use, and recreational activities. Notably, agriculture accounts for a substantial share of freshwater withdrawals, reaching approximately 70% [1] and around 90% of water consumption, escalating to as high as 95% in some developing countries, thus exerting profound effects on terrestrial ecosystems [2]. Compared to other economic sectors, agriculture is disproportionately exposed and vulnerable to adverse natural hazards, especially those that are climate related. Climate change precipitates immediate disruptions, like extreme weather events, while simultaneously instigating gradual, long-term challenges such as rising temperatures and biodiversity loss [3].

As a result, improving water usage in irrigated agriculture has become a crucial concern [4]. Balancing diverse needs while addressing environmental, economic, and societal issues necessitates the adoption of practices that safeguard water quality and reduce the transport of water laden with fertilizers and pesticides into aquifers [5]. Implementing a holistic, tailored approach for each farmer's specific conditions is imperative for maintaining the sustainability of local resources.

In certain instances, water-efficient traditional practices, such as soil conservation techniques, hold the potential to enhance environmental sustainability without necessarily reducing water usage [6]. Consequently, a partial solution unquestionably resides within digital technologies that enable the efficient utilization of water [7]. Before the rise of

information technology, farmers had to visit their farms physically to examine plants and check the moisture levels in the soil [8]. Currently, digital advancements in agriculture open up new avenues for farmers, supply chain participant's consumers included and policymakers, to boost the efficiency of irrigation through advisory systems, thereby enhancing the productivity, sustainability, and resilience of food systems [9]. From a social standpoint, it has the scope to reduce operational costs, combat poverty and hunger, and increase farmers' incomes. In terms of the economic benefits, digital technologies contribute to achieving a number of Sustainable Development Goals [10].

At the heart of this digital transformation, known as the "fourth industrial revolution", are "disruptions" such as Blockchain, the Internet of Things, artificial intelligence, or immersive reality. In the realm of the agricultural sector, the widespread use of mobile technologies, remote sensing services, and distributed computing has notably facilitated the ability of small-scale farmers to access vital resources such as information, agricultural inputs, markets, financial support, and training [11]. This surge in mobile technologies resonates with telling statistics revealing that among the poorest 20% of the population, 70% have access to a mobile phone. Furthermore, the internet is accessible to a significant portion, over 40%, of the global population [12]. The rising prevalence of smartphones, coupled with the availability of weather data, has fostered an ideal setting for the creation and implementation of smartphone applications capable of calculating crop water requirements in almost real-time. There is a noticeable shift towards the utilization of web- and software-based tools for irrigation scheduling, with the aim of accurately estimating site-specific water needs across different scales. However, the applicability of computerized irrigation technologies in the field is limited due to the reliance on desktop computers, posing a significant barrier to adoption by farmers. These innovations may necessitate additional investments in engaging external services to provide training for farmers [13,14].

Information and Communication Technologies (ICTs) encompass a diverse set of technologies that allow access to information [15], including cloud-based technologies for acquiring, transmitting, and managing data, monitoring soil–plant–atmosphere interactions and irrigation performance, as well as remotely controlling the irrigation process [16]. The swift expansion of ICTs has enabled the merging of conventional network technologies with emerging ones such as Machine to Machine (M2M), Cloud computing, Big Data, and data analytics. When these networks are integrated with accessible data, necessary applications, and a conducive environment, they have the potential to responsibly unlock tremendous innovative capabilities within the agriculture sector [17].

From low-tech approaches using mobile phones to high-tech "digital farms" integrating input from reliable data resources, a spectrum of solutions exists for improving irrigation practices. Digital agriculture not only revolutionizes farming practices but also holds the promise of fundamentally reshaping every aspect of the agrifood value chain. For example, advancements in wireless sensor networks and the Internet of Things (IoT) enable the collection of data from diverse sensors, including those measuring soil moisture, temperature, humidity, and plant parameters such as the vegetation index. These data can be accessed remotely and aggregated through a gateway before being stored in cloud databases [18]. Moreover, the adoption of digital technology allows for the mapping and continuous monitoring of soil fertility using drones, satellites, or remote sensing, thereby aiding in the prevention of soil degradation [17]. In terms of irrigation, it requires proper scheduling to be effective. The concept of Precision Irrigation (PI) introduces a novel methodology for irrigation management focusing on control systems. It aims to optimize crop yields by systematically collecting and analyzing data from weather, soil, and crops. Efficient irrigation management is implemented using technology, incorporating online fault detection, modeling the soil–water–plant system, and employing various control techniques [19]. At the stage of sales, digital marketplaces, such as e-commerce platforms, are already exponentially expanding the sales networks of agrifood products [10]. Given the impressive capabilities of ICTs outlined by the literature, many limitations exist. Smallholder farmers in developing nations frequently encounter barriers to the adoption of new

technologies [20]. The major obstacle lies in balancing the financial and social objectives of farmers [21]. Often, investments in technological improvements have incurred higher water prices [22]. Facing the high cost as an extra penalty, farmers possess the capacity to escalate groundwater extraction, consequently augmenting aquifer depletion, while concurrently absolving themselves from collective responsibility. Paradoxically, fostering higher water-use efficiency may engender a financial, environmental, and institutional problem [6]. This difficulty in investment makes it challenging for farmers to adopt new technology and upgrade their farming practices.

Nevertheless, it is imperative to acknowledge that ICTs, including mobile phones, serve as a bridge between researchers, extension agents, and farmers facilitating the exchange of knowledge and best practices [23]. Considering that it is crucial to acknowledge that smartphone adoption may still be limited in certain areas due to factors like affordability, digital literacy, and network reliability, it is noteworthy that smartphone ownership among smallholder farmers in developing countries is increasing. This trend is supported by a research study indicating a rise in smartphone ownership, attributed to decreasing smartphone costs and expanding mobile network coverage [24]. The integration of the agricultural sector with the growing use of mobile phones catalyzed policy advancements concerning mobile phone utilization across a spectrum of agricultural services [25]. This includes streamlined market accessibility, allowing farmers to connect with buyers, access pricing information, and broaden their market reach. Furthermore, by augmenting data collection and analysis, these tools enable more informed decision-making for refined agricultural practices [26] (Figure 1).
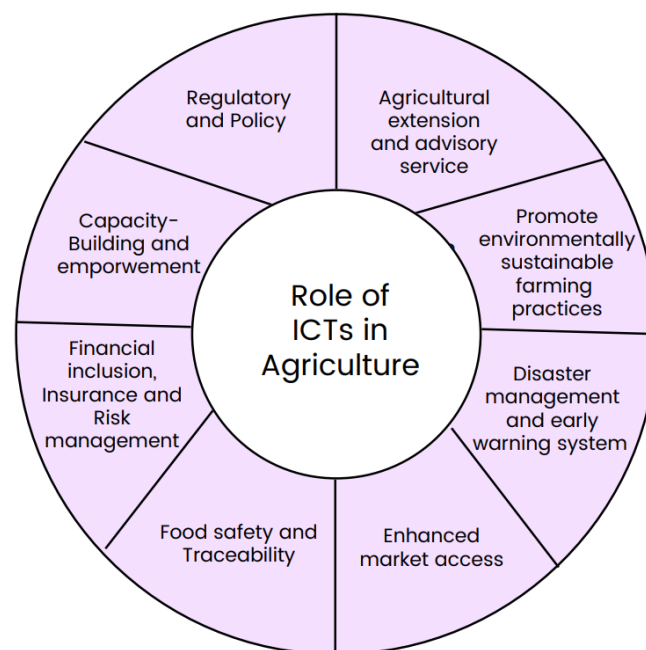

Figure 1. Role of ICTs in agriculture; source [17].

These initiatives are geared towards facilitating various agricultural activities for farmers, encompassing planning, irrigation, production, transformation, and marketing [27]. Throughout the entire system, resource management will occur in real-time within a hyperconnected framework utilizing a comprehensive set of data. This will enable ensuring traceability and coordination of value chains with utmost precision, managing each cultivated parcel and individual animal to attain optimal outcomes. Digital agriculture will engender highly productive systems capable of anticipation and adaptation to changes, notably those associated with climate change. This could lead to enhancements in food security, profitability, and sustainability [28].

Scientific inquiries into water issues have encompassed the implementation of precision technical solutions. These include buried drip irrigation, fixed sensors, sensors on drones, and decision support software to assess and deliver the appropriate amount of water to the right location [2,29]. A thorough literature review unveils numerous studies exploring the repercussions of agricultural technologies spanning several years, resulting in disparate findings. Substantial disparities in the magnitude of impact documented across these studies raise queries about the presence of unequivocal evidence in the prevailing empirical literature concerning the association between technology adoption and welfare outcomes [30].

Creating a "digital agricultural ecosystem" means setting up a supportive environment that encourages farmers and agricultural entrepreneurs to come up with new ideas [28]. It is about strengthening connections between policymakers, stakeholders, agricultural advisors, farmers, and practitioners. Even though helping farmers make their own decisions takes more time and effort, in the end, it is better than trying to force them to follow a strict set of rules [31].

In light of these challenges, this article pursues a dual and paramount objective. On the one hand, it aims to conduct an evaluation study of available irrigation advisory platforms providing readers with insights to help them in selecting an irrigation advisory platform. On the other hand, this article aspires to identify current gaps and emerging research opportunities in the field of irrigation advisory platforms to offer valuable guidance to platform developers aiming to continually enhance existing solutions and pioneer new technological advancements in the realm of irrigation advisory. At the core of this pursuit is the following question: how can the various stakeholders involved in irrigation be supported in selecting the most suitable irrigation advisory platform to meet their specific requirements? Thus, the next sections of the article are structured as follows: 'Conceptual Framework of Irrigation Advisory Platforms', 'Material and Methods', 'Results, Discussion, and Conclusion'.

2. Conceptual Framework of Irrigation Advisory Platforms

In this section, we delve into the conceptual framework of irrigation advisory platforms, exploring key aspects related to stakeholders, target audiences, as well as the structure and components of these platforms.

2.1. Stakeholders and Target Audiences

By aiding farmers in informed decision-making, irrigation decision support systems (DSSs) contribute to improved profitability through the efficient use of water resources and the attainment of maximum crop yields within a specific growing season [32]. These systems are primarily crafted to model or predict crop water requirements, presenting a spectrum of choices [33]. Two main families of tools exist: those based on modeling or water balance, and those based on on-site measurements [34]. Within this context, irrigation advisory services (IASs) are recognized as integral to DSSs, enabling stakeholders to optimize irrigation efficiency and elevate their incomes by achieving the highest possible crop yield. IASs encompass a suite of activities aimed at providing technical and professional support to farmers and agricultural operators in effectively managing cropland irrigation [35].

The significance of actively involving and engaging multiple stakeholders in agricultural research and development is widely acknowledged. Mitchell and Wood define stakeholders as groups or individuals who can influence and or be influenced by a particular goal achievement [36], while Fletcher briefly defines a stakeholder as a person with an interest in or attention to the problem [37].

Numerous studies have highlighted stakeholder experiences in irrigation water management. Here, we present examples from various regions to illustrate the complexities and challenges faced by stakeholders in this domain:

- Indonesia

A study conducted in Karanganyar Regency, Indonesia, seeks to comprehend stakeholders' involvement in irrigation water management. Integrated water resource management stands as the appropriate concept for addressing common good issues, particularly concerning irrigation water [38]. Stakeholders are expected to execute their respective roles and participate in resolving challenges related to proper irrigation water management. According to the given definition, they encompass national, provincial, and municipal authorities, alongside farmers affiliated with water user associations. The study has unveiled a transparent delineation of roles and duties among stakeholders incorporated within the irrigation team management. Nevertheless, insufficient human resources pose another hurdle encountered in irrigation water management [39]. Elaborating, bureaucratic systems characterized by inflexible structures could make it harder for stakeholders to discuss and create flexible institutions, often favoring those with the authority to manipulate participation to their advantage [40–42]. Consequently, participation might be wielded as a means to enforce policy objectives that may not necessarily align with the interests of smallholder farmers engaged in the process [43]. Meanwhile, in the Kampili Area of South Sulawesi province, Indonesia, a study delineate the anticipated roles of each stakeholder in optimizing irrigation resource management. Findings reveal a multitude of stakeholders engaged in irrigation management, with overlapping authorities, distinct interests, and varying power dynamics among them [44].

- Eastern Kenya

Similarly, the power dynamics between stakeholders, as explored in another research project [45], can significantly shape and be shaped by participatory initiatives in agricultural innovation within persistently food-insecure smallholder agricultural regions, like Eastern Kenya. Within this framework, innovation platforms have emerged as a viable strategy for fostering technological advancements and improving market accessibility. However, findings indicate substantial disparities in the accessibility and control of platform resources between smallholder farmers and other stakeholder groups, resulting in pronounced asymmetries.

- Ethiopia

At the same time, the imperative to tackle intricate agricultural challenges across various levels and within Ethiopia's broader development sector, encompassing agriculture and water management, has prompted the establishment of multi-stakeholder platforms and initiatives (MSPs). Initially, the identification of MSPs involved pinpointing relevant governmental and non-governmental entities (NGOs and private sector stakeholders) engaged in agriculture and water management. These encompass sustainable development, climate resilience, agricultural enhancement, food security and nutrition, water resource management, environmental sustainability, gender equality, and livestock (fodder) sectors. The study has elucidated an overview of three typologies of MSPs in Ethiopia, trying to highlight the similarities and differences in each scenario to find the best combination of decision-makers in agriculture and water management [46].

- Ghana

Recently, Ghana has taken strides to embrace stakeholder collaboration to enhance the irrigated agricultural sub-sector, notwithstanding the challenges impacting its performance. [47,48]. These stakeholders possess both interest and influence in key positions of importance [49]. Therefore, in this study, stakeholders are classified into three categories: (1) Key stakeholders, comprising those who hold significant influence or are vital for the success of the irrigation scheme. (2) Primary stakeholders (beneficiaries), who are directly impacted, either positively or negatively, by the outcomes of the irrigation scheme. (3) Secondary stakeholders, whose influence on the results of the irrigation scheme is marginal. The results show that many challenges affect this collaboration among them resulting in weak communication [50].

In conclusion, these examples collectively illuminate the diverse roles and array of challenges encountered by stakeholders in irrigation water management, offering valuable insights for effectively addressing these issues for future potential users, as depicted in Figure 2.
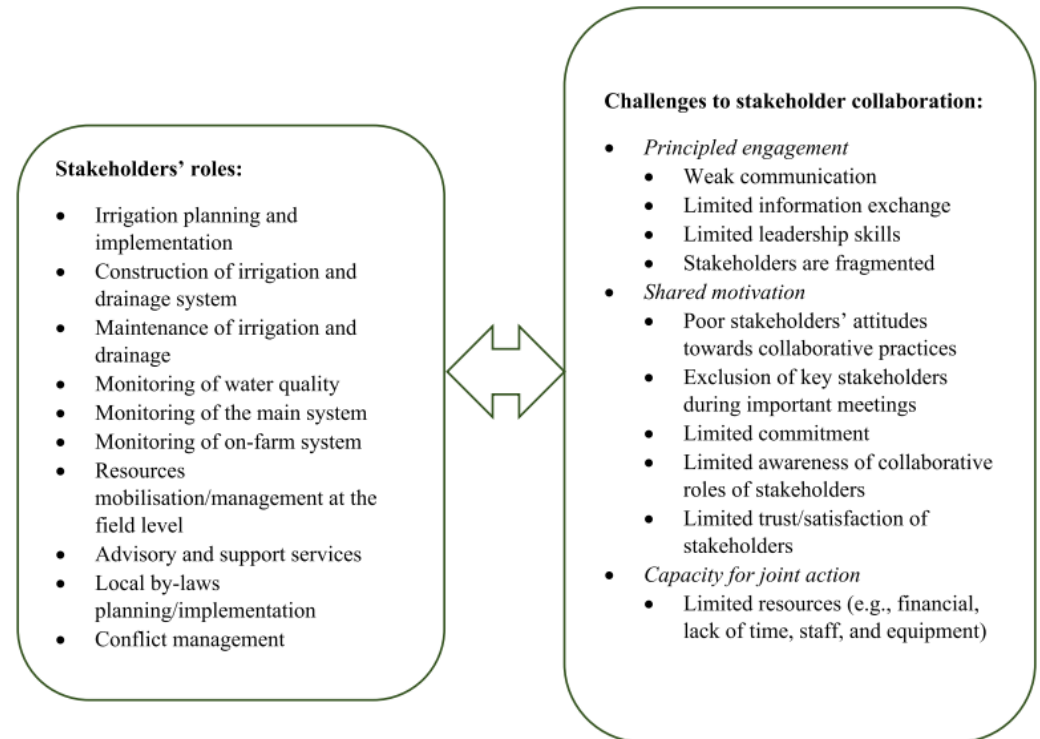

Figure 2. List of stakeholders' roles and challenges for collaboration; source [50].

2.2. Structure and Components of Irrigation Advisory Platforms

The typical architecture of an irrigation advisory platform includes six components (Figure 3); the proposed integrated framework establishes a comprehensive infrastructure for precision irrigation advisory which serves as a summary of what has been found in the literature review [51,52].
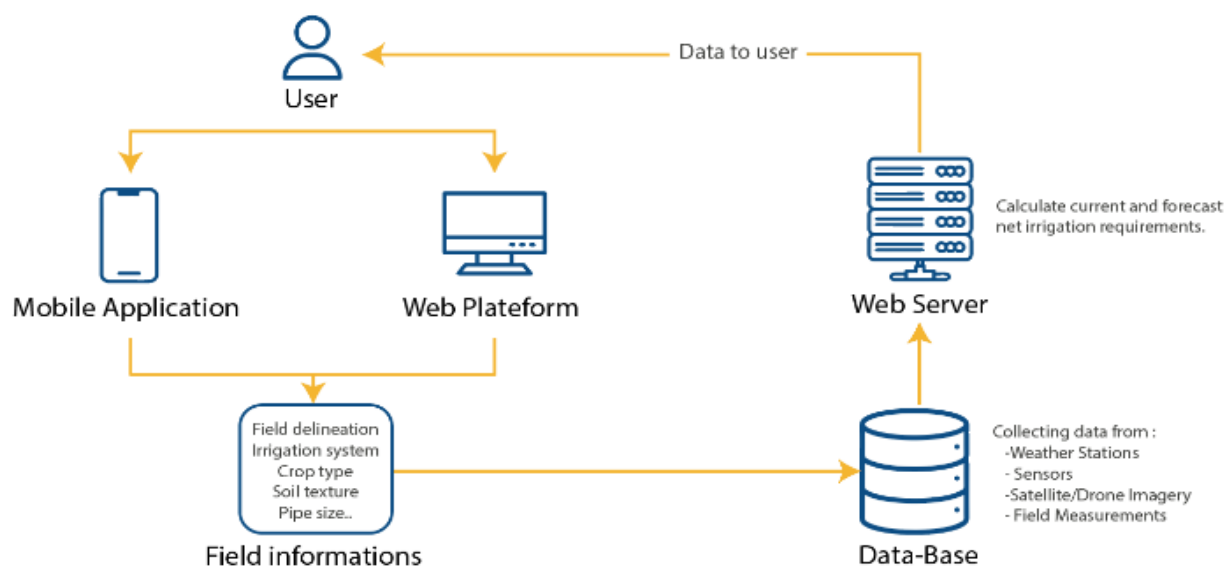

Figure 3. General architecture of a web/mobile irrigation advisory system.

- User:

This refers to anyone who uses the platform to gather advice, information, or services regarding irrigation.

- Mobile Application/Web Platform:

The mobile application and web platform extend the accessibility of the advisory system to users across diverse devices to provide a consistent and responsive user experience. These platforms are designed for seamless integration, allowing users to receive timely irrigation recommendations on-the-go.

- Field Information Management:

This component manages essential field-specific parameters critical for irrigation decision-making. Information related to the irrigation system, crop type, soil structure, pipe size, and other relevant field characteristics is systematically organized. The precise management of these variables ensures the accuracy of the advisory system's recommendations tailored to the specific requirements of each agricultural plot.

- Database:

By collecting, storing, and processing diverse data streams, including information from weather stations, sensors, satellite and drone imagery, and field measurements, the database facilitates the generation of accurate and context-aware irrigation recommendations. The integration of multiple data sources enhances the system's ability to adapt to dynamic environmental conditions.

- Web Server:

The web server acts as the computational backbone of the advisory system. It calculates both current and forecasted irrigation requirements based on the data collected from the database. Additionally, the web server facilitates the seamless communication of these recommendations to end-users through the user interface, mobile application, and web platform. Its efficiency lies in the rapid and precise computation of irrigation needs, optimizing water usage for arboricultural practices.

3. Materials and Methods

This section presents a comparative analysis of approximately twenty professional irrigation advisory platforms. As we delve into this benchmarking analysis, our aim is to offer readers a concise yet informative overview of the platforms available, for those seeking to make decisions about which platform best aligns with their specific requirements.

The Irrigation Advisory System (IAS), relying on Information and Communication Technologies (ICTs), refers to a set of measures implemented to enhance irrigation efficiency [53]. It operates based on data collected by agro-meteorological stations situated in the designated intervention areas. These stations gather real-time meteorological data or historical data, information regarding soil moisture, and crop growth data [54]. Leveraging this information, the system operates by adjusting and calibrating a soil water balance model to estimate the actual crop water requirements and, consequently, to determine the most suitable irrigation frequency and quantity to reduce evapotranspiration rates. Hence, the IAS provides specific irrigation planning recommendations that are tailored to the crops and local conditions [55].

This system involves training farmers in technical skills related to agroecological practices to reduce crop water requirements. Additionally, it includes the establishment of an irrigation advisory system that provides specific irrigation recommendations to farmers for selected crops [56].

With the intention of establishing a comparative study, the methodology employed to evaluate irrigation advisory platforms relies on a series of key steps. Firstly, our sampling strategy was designed to ensure geographical diversity, encompassing platforms from different regions such as Africa, Europe, and the Americas. We also take into account the

characteristic diversity inside the same region. This approach was guided by research [24] indicating that although Mediterranean countries (such as Egypt, Malta, Morocco, and Portugal) share common features, in terms of climate, water and land resources, and development issues, there are distinct variations among crop types, water management regulations, labor force availability, financial sustainability, and economic approaches. These findings emphasize the importance of considering specific regional contexts when selecting technologies for irrigation and water supply, facilitating the assessment of ICTs as outlined in the objectives of the paper. Secondly, the selection of these 20 platforms was motivated also by their accessibility, providing an invaluable opportunity for user experience assessment. By incorporating platforms with diverse accessibility features, our survey ensured a nuanced exploration of user engagement dynamics, which enabled the practical implications of these platforms in real-world settings. Following the consolidation of collected data, the final evaluation criteria were revised according to [57], which discusses the utilization of Agricultural Innovation Platforms for improved irrigation scheme management. Additionally, insights from [58], which focus on reviewing the functionality and target end-users of economic Decision Support Systems for irrigated cropping systems, also contributed to the refinement of our evaluation criteria. The information gathered on these platforms was based on articles and documentation provided at the products' website as well as demonstrations and free practical tests for each platform.

Our benchmarking criteria include aspects such as the services offered, the types of crops supported, the target user base, format type, data sources, and country where its available. Firstly, the services offered by these platforms, which encompass irrigation planning, guidance on efficient water usage, weather data provision, and crop yield forecasts, significantly influence their overall utility and appeal to users. Secondly, the diversity of supported crop types, from annuals to perennials, demands tailored recommendations for each crop's specific water needs and growth patterns. Additionally, understanding the targeted user base, whether individual farmers, large agricultural estates, cooperatives, or research institutions, ensures the alignment of advice and features with diverse user requirements. The format type, whether a mobile application, web-based platform, or API, plays a pivotal role in determining the ease of accessibility and a user-friendly interaction. Equally crucial are the data sources employed, like weather data, satellite imagery, and field sensors, directly impacting the accuracy and reliability of recommendations. Finally, accounting for the availability of the platform in terms of its country is essential for delivering context-specific and effective recommendations.

4. Results

A comparative table was constructed to rank each platform based on the established criteria, followed by a detailed analysis to identify the strengths and weaknesses of each solution.

Let us explore the comparative table (Table 1), which summarizes the essential characteristics of these irrigation advisory platforms, helping users and stakeholders make well-informed choices in adopting these tools for sustainable agriculture.

The table provides a comparison of various irrigation advisory platforms, detailing their distinct characteristics. Each platform is assessed based on its offered services encompassing real-time irrigation advice, meteorological data, crop-specific databases, and irrigation automation. Additionally, these platforms cater to diverse crop types such as citrus, olive, horticultural varieties, and field crops, targeting users ranging from individual farmers to agricultural advisors and large companies. Alongside data sources like satellite imagery, weather stations and IoT sensors are disclosed. Format types, including web-based and mobile applications, are specified, each platform being utilized in distinct countries. This exhaustive analysis aids potential users in gaining a holistic understanding, enabling informed selection of the most suitable irrigation management platform tailored to their specific agricultural needs.

Table 1. Comparison of available platforms in terms of defined characteristics.

Platform Name	Services	Types of Crops	Target Users	Sources	Format Type	Data Source	Availability of the Platform
AgSat	-ETo calculation every 6 h -Kc estimation through remote sensing -5-day irrigation schedule	-Horticultural -Citrus -Fruit -Peanut	-Farmers -Irrigation managers -Researchers	[59]	-Web-based application -Mobile application	-Sentinel 2 -Weather stations	Lebanon
AquaEdge	-Installation of IoT sensors -Training of operational staff -Optimized irrigation management	-Citrus	-Farmers	[60,61]	-Web-based application -Mobile application	-Weather stations	Morocco
Arvum	-Real-time crop monitoring -Validation of irrigation needs -Adaptation of fertilizers according to the phenological cycle of each crop	-Citrus -Olive -Horticulture -Fruit -Viticulture	-Farmers	[62]	Web-based application	-Capacitive probes -Weather stations -Sensors: Barometer, Anemometer, Pyranometer	France Morocco Spain
Bee2Crop	-Real-time irrigation management -Irrigation program -Detection of water leaks and abnormal consumption	-Olive and others	-Multiple user profiles	[63]	-Mobile application	-Weather stations -Sensors	Portugal
Blueleaf	-Daily water balance -Prediction of diseases affecting crops -Crop nutrient requirements	-Horticulture -Fruit	-Farmers -Agronomists	[64]	-Software -Mobile application	-Weather stations -Soil sensors and IoT	Italy
Crop Manage	-Irrigation and fertilization advice -Reduction of water and fertilizer usage by 20% to 40%	-Horticulture (27 varieties)	-Farmers	[65]	-Web-based application	-Satellite imagery -Weather stations	United States
Crop's talk	-Irrigation and fertigation plans -Climate-resilient pest and disease management	-Fruit	-Farmers	[66]	-Mobile application	-	Tunisia

Table 1. *Cont.*

Platform Name	Services	Types of Crops	Target Users	Sources	Format Type	Data Source	Availability of the Platform
EO4 Water	-Daily water balance -Field development status	-Horticulture -Sugar beet	-Farmers -Agro-industries -Machinery manufacturers	[67,68]	-Web-based application -Mobile application	-Sentinel 2 -Meteorogical forecasting models -Ground-based data	Austria
Hydrawise	-Remote control of irrigation systems -Water consumption reports -Irrigation schedules and controller logs	-	-Multiple user profiles	[69]	-Web-based application -Mobile application	-Weather stations -Sensors	United States (California)
IrrigaSys	-Weekly water balance using MOHID-land model -Weekly irrigation program	-Horticulture -Peanut -Viticulture -Corn -Sunflower	-Farmers -Irrigation Managers -Local Technicians (ARBVS)	[70]	-Web-based application -Mobile application	-Sentinel 2 -Weather forecast stations and models -Soil analysis	Portugal
IrriSat	-7-day irrigation schedule -Cartography of irrigated area	-	-Farmers -Water resource managers	[67,71]	-SIG Web-based application -Mobile application	-Sentinel 2 -Weather stations -Periodic field measurements	Italy
Irrismart	-Daily water requirement of the crop -Irrigation frequency and duration -Voice guidance in Moroccan dialect	-Horticulture (27 varieties)	-Farmers -Advisors -Agricultural technicians engineers	[72,73]	-Mobile application Android	-Satellite Data (1700 points that update every 15 min)	Morocco
Irriwatch	-Remote field parameter monitoring -8-day irrigation planning	-Fruit -Cereal	-Farm managers	[74]	-Web-based application -Mobile application	-Satellite imagery -Meteorological APIs	Netherlands
Netirrig	-Collection of meteorological data for the next 7 days -Irrigation recommendation package -Personalized water balance support	-Horticulture -Arboriculture -Viticulture -Field crops	-Farmers -Advisors -Specialists from the Chamber of Agriculture	[75,76]	-Web-based application	-Satellite imagery and vegetation indices	France

Table 1. *Cont.*

Platform Name	Services	Types of Crops	Target Users	Sources	Format Type	Data Source	Availability of the Platform
SenCrop	-Irrigation management -Anticipation of weather -related diseases -Disease and pest management	-Viticulture -Arboriculture -Cereal	-Farmers -Agriculture experts	[77]	-Web-based application -Mobile application	-Weather stations -Sensors	France
SOWIT	-Six-day Irrigation Advisory Service -Real-time Meteorological Data -Current Kc Database	-Citrus -Olive	-Farmers -Advisors -Food Companies	[78–80]	-Web-based application -Mobile application	-Mohammed VI Satellite -Capacitive probe -Drone imagery	Morocco
Spark Irrigation System	-Control of irrigation water and fertilizer quantity -Irrigation automation -Cloudy–rainy notification	-Arboriculture	-Farmers	[81]	-Spark manager software -Mobile application	-Wireless controller -Flowmeter -Pressure sensor	Morocco
SupPlant	-Soil, climate, and irrigation data -Monitoring of growth rate and stress level -Management and control tools	-Arboriculture (33 types)	-Farmers -Insurance companies -Cooperatives	[82]	-Web-based application -Mobile application	-Sensors: soil moisture, leaf, fruit, trunk -Weather stations -Satellite imagery	Morocco
Telaqua	-Remote control of irrigation systems -Daily irrigation planning and traceability -Water and electricity consumption of the system -Measurement and alert for pressure, flow, and voltage.	-Fruit -Viticulture -Citrus	-Farmers -Agronomists -Water supply specialists -Irrigation managers	[83]	-Web-based application -Mobile application	-Probes -Big Data -IoT sensors	France
Weenat	-Real-time monitoring of hydric status -Weather forecasting and historical data	-Field crops -Horticulture -Viticulture -Arboriculture	-Farmers	[84]	-Web-based application -Mobile application	-Capacitive probes -Weather stations and forecasts	France

5. Discussion

In this section, we conduct an analysis of the platforms used in this study through an exploration of the geographic scope, offered services, target crops, target users and ease of use, platforms for access, limitations, and future perspectives. By elucidating these aspects, we aim to provide valuable insights into the digital transformation of irrigation practices and its implications for sustainable agricultural development.

5.1. Geographic Scope

In discussing the geographic scope of our study, it is essential to acknowledge that our benchmarking of 20 platforms does not encompass all existing irrigation advisory platforms worldwide. The selection of these 20 platforms was conducted in a randomized manner. Figure 4 visually depicts the geographic distribution of the platforms utilized in this study, offering a contextual understanding of their global spread.

Figure 4. Worldwide distribution of irrigation advisory platforms used in this study.

However, the mere existence of these platforms is not enough; they need to be effectively adopted and utilized by farmers to realize their full potential, optimize production and reduce the environmental impact [85]. This adoption process is influenced by a variety of factors, including socioeconomic, financial, farmers' perception, agroecological, and institutional considerations [86–89]. Understanding these factors is crucial for promoting widespread adoption and usage of irrigation technologies.

It is worth noting that determining the exact adoption rate of irrigation technologies in each country represented in our benchmark can be challenging. Factors such as cultural norms, educational levels, land characteristics, energy costs, and perception about sustainability can vary widely and impact adoption rates differently in different regions [90,91].

Statistics indicate that developed countries tend to have higher adoption rates of precision agriculture technologies compared to developing nations. For instance, the US, Australia, Canada, and some European Union countries are among the leaders in adopting precision agriculture technologies due to factors like larger farm sizes and greater financial resources [92]. On the other hand, developing countries face challenges such as limited access to technology and resources, which can hinder adoption [93,94].

While the significance of new agricultural methods in alleviating poverty in developing nations is widely acknowledged, their adoption has frequently been sluggish, with numerous challenges remaining incompletely understood [20]. This underscores the complexity inherent in defining technology adoption, as it hinges on individual acceptance and adoption of the technology [20].

Although smartphone apps and internet connectivity have the potential to facilitate access to agricultural information and decision support tools, challenges such as poor internet coverage and financial barriers can impede their widespread adoption [95,96].

5.2. Services

The studied irrigation advisory platforms offer a diverse range of services aimed at optimizing water usage in agriculture. Among these, Sowit stands out for its use of satellite imagery and meteorological data to provide farmers with precise irrigation recommendations, along with a six-day watering schedule [79]. AgriEdge takes a comprehensive operational and technical approach, starting with on-site visits to install IoT sensors and satellite imaging systems, before providing simple communication tools tailored to farmers' needs [60,61]. Irrismart distinguishes itself with its intuitive application, connected to updated satellite climate data every 15 min, and supported by a multilingual voice guide for user-friendly operation [72,73].

On the other hand, Supplant utilizes an AI-powered system with advanced algorithms to analyze real-time data from plant, soil, and meteorology sensors, providing irrigation recommendations based on plant stress, growth patterns, weather conditions, and soil moisture content [82]. Netirrig offers personalized support in managing irrigators' water needs, with features such as parcel tracing, adjustable phenological stages, and irrigation recommendations based on satellite imagery and historical data [75,76]. AgSat and Eo4Water provide crop water requirement estimations based on vegetation indices and soil moisture content, respectively [59,67].

Finally, IrriSat distinguishes itself by using thermal infrared spatial observation to calculate indicators of irrigation water consumption and needs, with advanced prediction of the irrigation date and quantity, thus offering precise agricultural activity planning [71].

These examples illustrate the diversity of services offered by some irrigation advisory platforms, showcasing their ability to leverage different data sources to provide accurate recommendations to farmers. It is worth noting that other studied platforms also offer similar services, employing varied approaches based on a combination of meteorological data, satellite imagery, IoT sensors, and artificial intelligence. This variety of approaches demonstrates the sector's widespread commitment to meeting farmers' varied needs in water management and maximizing agricultural yields.

5.3. Crops

It is also prudent to acknowledge the considerable potential within arboriculture, notably in the citrus sector, for exports, particularly in various regions globally. Given its strategic significance to economies, employment generation, and the significant water demands inherent in citrus cultivation, irrigation advisory platforms with a specific focus on arboriculture assume added importance in enhancing productivity and sustainability (Figure 5).
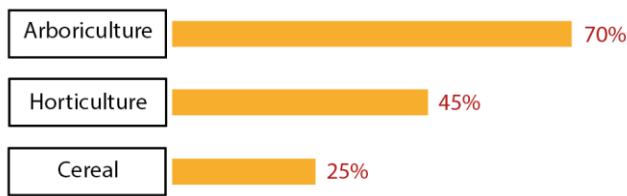

Figure 5. The percentage of crop types within the evaluated platforms.

In the context of this comparative study of irrigation advisory platforms, a detailed analysis of the supported crops reveals significant trends. Among the 20 examined platforms, it was observed that 10 of them are dedicated to a single type of crop, while 6 platforms cater to two distinct types of crops. Specifically, two platforms were identified to concurrently cover all three types of crops considered in this study, Weenat and Netirrig.

However, for Hydrawise and Irrisat, no precise information was available regarding the crop type addressed. Delving further into this distribution, it is noteworthy that arboriculture predominates, accounting for 7 out of 20 platforms, while horticulture alone is specified in 3 platforms. Furthermore, an association between arboriculture and cereals is mentioned in 2 out of 20 cases, whereas the combination of horticulture and arboriculture is the most frequently encountered, covering 6 out of the 20 analyzed platforms. These findings suggest a diverse agricultural coverage within irrigation advisory platforms, highlighting specific preferences and orientations of service providers and potentially addressing the specific needs of farmers in certain regions or agricultural practices.

5.4. Target Users and Ease of Use

A nuanced understanding of the diverse target audience emerges in dissecting the user landscape across 20 irrigation advisory platforms. This investigation reveals the platforms' adaptability to cater to a spectrum of stakeholders crucial to the agricultural ecosystem. Research and development projects are now more frequently using multi-stakeholder platforms to gather various types of knowledge together [97].

The primary beneficiaries, undoubtedly, are the farmers. Several platforms (19/20 = 95%) explicitly target this key demographic, acknowledging the pivotal role they play in the agricultural chain. By providing tailored irrigation solutions, these platforms empower farmers to make informed decisions regarding water and resource management. Beyond farmers, a significant portion of platforms extends their services to advisors, agricultural technicians, and engineers. Insurance companies and cooperatives are represented as well. The platforms also extend their reach to researchers and specialists affiliated with chambers of agriculture.

Water resource managers, irrigation managers, and specialists in water supply further delineate the broad scope of impact. By engaging with professionals responsible for the oversight and distribution of water resources, these platforms contribute to the sustainable and equitable use of this critical agricultural input. Local association technicians, farm managers, and agriculture experts represent the grassroots involvement of community-level stakeholders. By addressing the needs and challenges faced at the local level.

Moreover, an analysis of specific agricultural advisory platforms, such as AgriEdge and NetIrrig, underscores the requirement for farmers to commit to an annual subscription for the installation of sensors to facilitate monitoring. AgriEdge provides customers with two types of offers: an annual rental of sensors installed in their agricultural parcels or outright purchase [60,61]. Similarly, Netirrig offers its solution to farmers through subscriptions starting from €250 per year [75,76]. However, it is important to note that, even with these subscriptions, access to all the promised services is not always guaranteed. For example, the satellite imagery service is priced based on the number of image packs and their resolution. In our study, we decided not to select the cost criteria because the cost can vary significantly depending on the context of use, the services available and the user requirements. Aligning with the principle of providing more accessible platforms, it is suggested that platforms offer trial simulations instead of mandating subscriptions, enabling users and researchers to gain hands-on experience with the tools. This approach would prove particularly valuable, especially considering that the step-by-step descriptions provided on their websites may occasionally be insufficient.

In the realm of accessibility and ease of use in irrigation advisory platforms, several solutions offer user-friendly features. AgriEdge, for instance, stands out for its proactive communication with farmers. By developing simple and effective tools such as mobile applications, web platforms, and SMS, the AgriEdge team is committed to addressing specific client needs. Moreover, they pay special attention to farmer training, explaining to them in clear and concise terms how to use these tools, while incorporating their visions and constraints [60,61].

Similarly, Irrismart distinguishes itself with its intuitive user interface and guided assistance. The application provides clear explanations for each parameter, with a voice guide available in French, Arabic, and Moroccan dialects. [72].

Likewise, Netirrig stands out for its simple and intuitive interface, making data input and retrieval easily accessible from anywhere. Additionally, a mobile application is in development, which will further enhance users' experience with more convenient and portable access to the platform's features [75,76].

Lastly, AgSat offers a multilingual experience, with an application available in both English and Arabic. This language availability facilitates user accessibility, allowing them to choose the language that best suits their interaction with the platform [59].

Overall, these solutions highlight the importance of ease of use and accessibility for users, offering user-friendly interfaces, clear user guides, and multilingual availability, thereby maximizing adoption and effectiveness of irrigation advisory platforms.

5.5. Data Sources

The analysis of deployed data sources reveals specific trends among the 20 examined platforms (Figure 6). Most platforms (10 out of 20) rely on two distinct data sources to fuel their services, utilizing combinations such as weather stations and satellite imagery or IoT sensors and weather stations. An equivalent proportion (5 out of 20) limits itself to a single data source, while an equal number of platforms (5 out of 20) utilize three different data sources (IoT, sensors, weather station). These findings suggest diversity in the platforms' approaches to data sources, with some preferring a combination of two sources for their services, while others opt for a single or multiple sources. These observations underscore the importance of the variety and quality of data used in developing and providing irrigation advisory services. Thoughtful selection of data sources could contribute to enhancing the relevance and effectiveness of irrigation solutions offered to end-users.
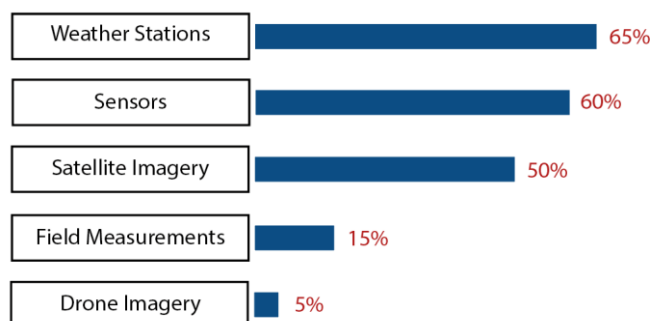

Figure 6. The percentage of deployed data sources within the evaluated platforms.

5.6. Challenges and Future Perspectives

The agricultural sector remains an important income source for people's livelihoods. The implementation of digital transformation holds promising advantages for small-scale farmers. However, its transition to digitalization is conditioned by the level of digital literacy, a crucial aspect for the efficient adoption of digital technologies. Individuals lacking technical skills risk marginalization in societies where digitalization is increasingly significant, especially in nations where state policies and institutional frameworks play a pivotal role in driving digital transformation. These countries foster an environment conducive to establishing competitive online services. It is common for states themselves to initiate online services (such as e-government services), primarily in areas like healthcare, education, the environment, and employment. Tailoring affordable services and products specifically for small-scale producers becomes imperative. Thus, developing seamless, user-friendly tools and solutions becomes essential. Additionally, ensuring the durability and resilience of smart farming solutions becomes crucial, requiring robustness to withstand harsh conditions while demanding minimal support for repair and maintenance. Long-term business models underpinning digital solutions are pivotal for sustainability and

ensuring a reasonable return on investment for small-scale farm entrepreneurs and actors within agricultural value chains. Aligning digital solutions with the needs and objectives of small-scale farmers remains fundamental, emphasizing reliability and relevance in addressing their requirements.

Consequently, the success of a digitalization program heavily depends on the respective sector, especially its users. In the case of the agricultural sector, its users are generally farmers with limited digital skills.

As mentioned in [28], favorable elements facilitating the digital transformation of agriculture include three aspects: the use of the Internet, mobile, and social networks by farmers and agricultural extension specialists; IT skills within rural populations; and a culture fostering digital agricultural entrepreneurship and innovation.

While most developing countries, do not meet these conditions, technology is evolving exponentially, while economic and social systems progress gradually. In this context, rural areas, generally exhibit the lowest rates of education and literacy. This poses a barrier to the introduction of digital agricultural applications, which require more advanced IT skills. These disparities in access to digital technologies and services risk further widening the digital gap in the future. Farmers face the risk of lagging not only in digital literacy but also in productivity and social and economic integration.

6. Conclusions

This benchmarking article on irrigation advisory platforms represents a significant contribution in the field of technology applied to agriculture. By presenting a range of both national and international platforms, we have been able to showcase the latest developments and solutions available to support farmers, policymakers, and researchers in their endeavors towards optimal water resource management in agriculture.

The diversity of irrigation advisory platforms presented offers users a spectrum of choices tailored to their specific needs. Whether it is through smart soil sensors, real-time meteorological data-based irrigation algorithms, or advanced analytics systems, these technological solutions provide valuable insights for well-informed decision-making.

Through the use of these platforms, farmers can optimize water usage according to their crops' actual requirements, resulting in increased efficiency, cost reduction, and the preservation of water resources. Policymakers can also leverage these platforms to formulate data-driven agricultural policies, thereby promoting the sustainability and resilience of agricultural systems.

Furthermore, researchers benefit from these technological advances in terms of digital agriculture by having precise and reliable tools for data collection and analysis, enabling them to conduct in-depth studies and develop new knowledge in the field of digitalization agricultural irrigation. This progress holds promise for delivering economic, environmental, social, and cultural benefits. From an economic standpoint, it enhances agricultural productivity through data-driven decision-making, potentially augmenting farmers' income and alleviating poverty by broadening market access. In terms of the environmental benefits, digital agriculture optimizes resource utilization and offers enhanced prediction and monitoring of natural hazards. Socially and culturally, it fosters inclusivity and equity in rural governance, human capital development, education, healthcare, and housing.

The success of digitizing the agricultural sector heavily relies on its continuous adoption by farmers, particularly smallholders, predominant in the sector. Therefore, entrepreneurs and companies aiming to develop irrigation advisory systems should devise a technological solution reflecting an ecosystem, providing a conducive environment not only for farmers but also for other stakeholders, such as advisors and decision-makers. In this regard, these organizations could benefit from the expertise of youth, who play a vital role in this process due to their digital literacy and capacity to propose innovative solutions.

Despite progress made in digitizing agriculture and rural areas, numerous challenges persist. Among these, the lack of systematic and official data on the subject hampers the understanding of this evolution. Information, such as the level of digital literacy, is

generally available only at the national level, without breakdown between rural and urban areas. Additionally, data on networks only provide details on coverage, neglecting the quality or cost of services. Information on government support for digital transformation is limited, often indirectly inferred from existing online public services and regulations on connectivity and data protection. Secondly, significant disparities in the adoption of digital agricultural technologies exist between developed and developing countries as well as between large international enterprises and small local structures, often influenced by financial and educational factors. Rural smallholder farmers are disadvantaged by a lack of infrastructure, access to networks, and technological resources. Lastly, economies of scale play a major role in the adoption of digital agricultural technologies, favoring users planning large-scale implementations. This creates a disadvantage for small farmers compared to large agri-food sector enterprises, leading to disparities between small- and large-scale farmers as well as between developed and developing countries, where digital innovations are often not designed to meet the needs of small-scale farming.

In order to keep up with the rapid evolution of informatization and digitalization, farmers and rural stakeholders must acquire new skill sets and profiles. This involves understanding the fundamental aspects of agrifood value chains, mastering advanced concepts in digital agriculture, evaluating risks and returns, embracing digital resources in their work, and fostering a mindset inclined towards innovation and utilizing proven digital products and services.

In 2018, Zhejiang University, in collaboration with China's Ministry of Agriculture and Rural Affairs' Agricultural Management Institute and Yunji Sharing Technology Co., Ltd., initiated the Rural Revitalization Thousand Talents Plan. This ambitious project aims to identify, train, and empower 1000 new farmers and rural talents within a three-year period. Those selected for the program undergo intensive training, acquiring advanced knowledge and skills in digital and innovative agricultural practices, such as utilizing real-time climate information networks, AI-controlled fertilization, and engaging in livestreaming and community e-commerce. These initiatives can serve as models for enhancing digital literacy and innovation among farmers, enabling them to harness the benefits of digital agriculture and contribute to rural development.

In summary, this article underscores the crucial role of irrigation advisory platforms in the technological advancement of agriculture. By providing accurate information, personalized recommendations, and advanced analytical tools, these platforms contribute to a more efficient and sustainable use of water in agriculture. Through these advancements, we are able to promote optimal water resource management, preserve the environment, and ensure food security for both present and future generations.

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