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A Systematic Review of Fourth Industrial Revolution Technologies in Smart Irrigation: Integration of Construction Management Techniques Constraints, Opportunities, And Future Prospects for Kolhapur

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ABSTRACT

This article is the first of its kind to explore the integration of the Fourth Industrial Revolution (4IR) technologies and construction management strategies to assist in developing efficient smart irrigation systems for the Kolhapur district of Maharashtra. Specifically, the study aims to determine the potential of newly emerged construction technologies like; Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, Robotics, Cloud Computing, and Digital Twins, to improve irrigation and water sustainability in the management of smart irrigation systems and the sustainable management of agriculture. The study analyzes and synthesizes the extant global and Indian literature related to smart irrigation and digital agriculture using the systematic literature review method and the PRISMA framework for managing the collection and reporting of literature. The author collected data from major literature sources in the field, including the Web of Science, Scopus, IEEE Xplore, and ScienceDirect, and prioritized the literature based on bibliometric and thematic analysis through the use of the VOSviewer and NVivo software. The study finds that irrigation scheduling technologies that employ Artificial Intelligence (AI) and the Internet of Things (IoT), coupled with data analytics, improve water use efficiency, lower labor requirements and costs, and increase crop yields. Moreover, the integration of construction management strategies, specifically Work Breakdown Structures (WBS), Critical Path Method (CPM), and Earned Value Management (EVM) enhances project planning, scheduling, and cost efficiency in the management of irrigation infrastructure.The study outlines the technological potential, economic challenges and implementation obstacles of smart irrigation adoption in Kolhapur and presents a conceptual framework combining digital technologies and the management of projects for sustainable irrigation advancement.

Keywords: Smart Irrigation, Industry 4.0, Artificial Intelligence, Internet of Things, Construction Management, Water Resource Management, Precision Agriculture, Sustainable Irrigation

I. INTRODUCTION

Changes in technology have facilitated the growth of irrigation engineering, agricultural productivity, and the management of water resources[1]. At the inception of agriculture, irrigation was performed with manual tools and human labor. During the First Industrial Revolution, water needed for farming was sourced from nearby rivers, wells, and ponds. To assist with their farming, workers built simple structures such as shadufs, manual lifts, and water diversion systems[2]. These water diversion systems relied on the labor of workers and the availability of water in a particular location, resulting in a lack of efficiency and precision in the distribution of water. While these methods performed their function for centuries, they inevitably could not satisfy the rapidly growing population's need for food[3]. The Second Industrial Revolution (late 1700s and mid 1800s) brought about significant advancements in engineering irrigation systems. The initial development of steam power followed by diesel power was the first time in history that mechanical power was used to create a system for lifting water to greater depths and over larger expanses of farmland. This development of irrigation provided the means for the cultivation of previously uncultivated agricultural lands, and as a result, increased the volume of crops that could be produced[4]. However, along with these advancements, the first of many technological advancements of a negative impact on the environment emerged. The Indian Deccan Plateau's reliance on groundwater extraction due to mechanical pumping systems has been documented. Launching studies on groundwater stress due to intensive irrigation revealed early aquifer depletion, an evident consequence of the expansion of mechanized irrigation[5].

The advancements in irrigation during the Third Industrial Revolution played a vital role in transforming the development of electrification, automation, and technology based irrigation[6]. Farmers were able to manage irrigation systems more effectively and reliably during the late 1800s to the mid 1900s with the introduction of electric motors and diesel powered pumping systems. This time period also saw the development of modern irrigation techniques like sprinkler systems and primitive drip systems[7]. These systems allowed for better control and regulation of the flow of water and its distribution to different areas of the field. This also resulted in a better application of water and traction with elevation flood irrigation. This allowed them to control and manage water delivery in a more even and consistent manner, thus limiting the chance of crop failure related to water delivery systems[8]. Automated irrigation also played a role in the commercialization of farming as large scale and more sophisticated farming became possible. The period of 1950 to 1990 marked the period of rapid growth of mechanized irrigation systems of India and as a result large amounts of groundwater began to be consumed. This was especially evident in the western areas of Maharashtra where irrigation pumps were installed to provide the added water needs for sugarcane, a water intensive crop[9]. The Kolhapur sugarcane growing region also required irrigation for the sugarcane crop. This fueled the irrigation requirement for the sugarcane crop even further. As a result, the unsustainable groundwater extraction patterns and declining water tables began to unsustainably pull groundwater resources[10]. This progression in history illustrates the fact that while the technological advances improved the productivity of agriculture through improved efficiency of irrigation, they also invented new environmental problems with regard to the sustainability of water resources and their management[11].
The Fourth Industrial Revolution deals with the latest technological improvements and the way they combine with the physical world. Klaus Schwab first used the term Fourth Industrial Revolution in 2016, where he explained the merging of the latest groundbreaking technologies such as the Internet of Things, artificial intelligence, cloud computing, big data, and others[12]. Integrating all of the above technologies into one system led to the establishment of a new modern agriculture practice known as smart irrigation systems. Smart irrigation systems are systems that automatically manage and implement irrigation to assist in and aid the management of water usage as the system runs[13]. The system works based on real-time data regarding the physical environment and the crop based on a pre-defined set of parameters. The system employs a network of irrigation sensors, satellite evapotranspiration data, machine learning, and predictive weather systems to analyse data regarding soil moisture, the rate of soil moisture evapotranspiration, soil moisture temperature, humidity, and rain[14]. As such, the system provides autonomous irrigation scheduling and, thus, provides a specified quantity of water to the crop. The significance of the above technologies is even greater when we note that the global agriculture sector is the largest user of freshwater, at almost 70% (FAO, 2020)[15]. This indicates that innovations such as smart irrigation systems are important in sustaining water resources. Studies show that smart irrigation services can cut water usage by 25-40% and increase crop yield efficiency by 15-20% in areas where water is scarce. Also, cloud technology converts traditional irrigation systems into smart systems, giving farmers the ability to manage and control irrigation remotely via smartphones and digital dashboards. sensor fusion with Artificial Intelligence, combined with weather data from the Indian Meteorological Department and satellite data like the Normalized Difference Vegetation Index, improves the prediction of irrigation needs[16]. These innovations support the United Nations Sustainable Development Goal 6 on the preservation of water resources.

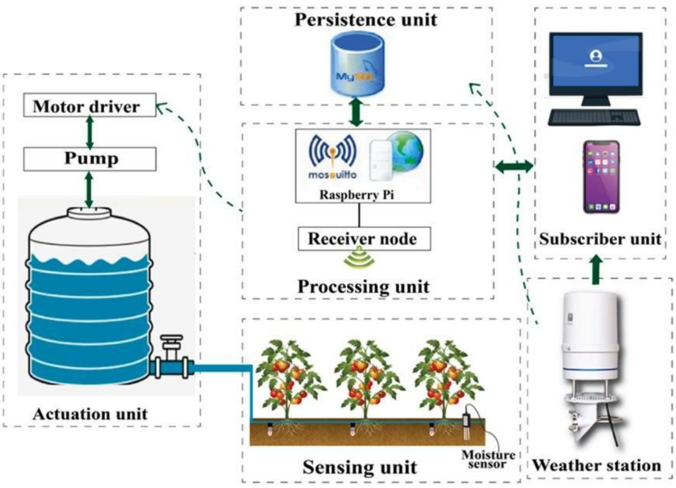

Fig 1- Integration of AI in Smart Irrigation

Kolhapur district in Maharashtra is one of the important zones of agriculture. Sugarcane, paddy, soybean, vegetables, and some other crops are cultivated here. This district is one of the important agricultural districts in the south western part of Maharashtra[17]. This district receives an annual rainfall of about 1000 to 2000 millimeters, most of which is received from the monsoon showers of June to September. Kolhapur receives a dry spell that ranges from November to May. This long dry spell means that crops cultivated in this district will require some form of irrigation to maintain productivity, which means that this district is heavily dependent on irrigation. In this district, a large part of the area depends on traditional methods of irrigation, which is known as flood and furrow methods, where the water is allowed to flow on its own[18]. This means that these methods will lead to the waste of water, uneven distribution of water, as well as the depletion of the aquifers of the area. (GSDA, 2022). Sugarcane is one of the crops, which requires large amounts of water for irrigation, which has also resulted in the depletion of the aquifers in Kolhapur. The use of smart irrigation technologies will help in the above-mentioned problems to some extent. It includes IoT based soil moisture sensors, automated drip irrigation systems, and artificial intelligence-based irrigation scheduling[19]. Despite tremendous potential for this technology, its widespread use is hindered by various factors such as deficient digital literacy in farming communities, high costs associated with implementation, and poor internet access in remote regions. Furthermore, the deployment of modern irrigation technologies is also challenged by the fragmented nature of farmland with an average size of 1.2 hectares per landholder (NSSO, 2021). To tackle these issues, a fusion of integrated planning methods and a holistic approach to technology, management, and policy innovations is necessary to ensure sustainable water use and lasting advancements in agriculture within the region[20].

II. LITERATURE REVIEW

Ahmed A. Abdelmoneim et al. (2025) performed a systematic review to study the impact of Internet of Things (IoT) sensing technologies in the domain of advanced irrigation management[21]. The research review study presented a detailed pattern of global research over a certain period using certain bibliometric analysis tools (VOSviewer) and highlighted a remarkable increase in the number of studies related to irrigation systems based on IoT from the year 2020 to the year 2022. The study cited the growing use of sensor networks, microcontroller units, and other low-power communication systems capable of real-time monitoring of soil moisture, temperature, and the needs of crops with respect to water. All of these systems help in the efficient scheduling of irrigation, leading to the conservation of irrigation resources, which in turn increases sustainability of the agricultural sector. Additionally, Awais Ali et al. (2025) focused on the leap from archaic gravity-driven irrigation systems to contemporary precision irrigation technologies. The researchers systematically reviewed 150 articles spanning from the year 2005 to the year 2024 and highlighted that, in order to achieve optimal water-use efficiency in agriculture, there is a need to incorporate IoT, wireless sensor networks, deep learning, and fuzzy logic[22]. It was demonstrated that, under the scenario of variable climate conditions, precision irrigation technologies can enhance the productivity of crops and concomitantly, mitigate the excessive use of water. Moreover, Lephondo Itumeleng et al. (2024) explored the impacts of smart irrigation systems that are coupled with machine learning. Their research noted the importance of integrating real-time sensor data of soil moisture, climatic variables, and water availability for informed and intelligent decision-making with respect to irrigation[23]. The study claimed that the combination of IoT sensors and machine learning provides more efficient irrigation, minimizes the overuse of water, and reinforces the sustainable management of agriculture.
In Sub-Saharan Africa, the use of the Fourth Industrial Revolution (4IR) technologies within smart irrigation systems has been studied by Joshua Wanyama et al. (2024). The study was able to point the use of some of the most advanced technologies like Artificial Intelligence, The Internet of Things (IoT), Big Data, Drones and Block Chain technology. These advancements help to improve the management of water resources and optimize irrigation. These advancements also help besically monitor, in real-time, the soil, weather and crop water requirements to enable farmers make informed decisions regarding irrigational needs[24]. There are a lot of pending barriers to the adoption of the technologies. The barriers include most of the technology costs, digital divide as well as a lack of sufficient technological cable human resource in the rural areas. More technological human resource development, more policy support and inventive financing were shown to help Adoption of technology for smart irrigation. In the same line, Zeeshan Ahmed et al. (2023), examined the methods of smart irrigation management looking to improve water productivity and also the adverse effects of climate change in dryland areas. The study, like Ahmed Zeeshan's, also recognized Traditional Methods of irrigation and scheduling as methods that do not possess the data necessary for the realistic water application which could lead to scenarios of water scarcity as well as water logging conditions[25]. The study found some technology for irrigation such as artificial neural networks, fuzzy logic systems, expert systems, variable rate irrigation, and unmanned aerial vehicles, that can potentially improve the effectiveness of water use and sustain agriculture. These technologies can help cope with water scarcity problems and ensure agricultural production stability[26].
Hanyu Wei et al. (2023) researched the impact of artificial intelligence on today's irrigation systems and how it can potentially change the way agricultural water management is conducted. The authors noted that artificial intelligence irrigation systems can evaluate enormous amounts of environmental data and create flexible irrigation schedules that are able to change based on the current climate or soil conditions[27]. The authors mentioned human-centered artificial intelligence, which is the incorporation of farmer insight and stakeholder input into technology to get people to use it more. The authors emphasized the need for more explainable

artificial intelligence in agriculture to help farmers use data more effectively and make the right irrigation decisions Y. In addition, Nagham Samir Abd Alhadi et al. (2023) studied the role of advanced robotics and intelligent irrigation technologies in cost reduction for the agricultural sector in Iraq. The authors noted that the use of robotics and automated irrigation systems along with the other technologies of the Fourth Industrial Revolution can help reduce costs and improve water management operational efficiency[28]. The authors also showed that digital technologies are a variable in the adoption of intelligent irrigation technologies. In addition, Uttam Kumer Sarker et al. (2025) studied the advantages and disadvantages of the Fourth Industrial Revolution technologies in smart agriculture. Their study determined barriers related to the lack of awareness, inadequate infrastructure, limited funding, and the absence of trained personnel[29]. Nonetheless, the authors of the study noted that the proper use of digital technologies, such as AI, IoT, cloud, and cyber-physical systems, has the potential to improve and sustain agricultural productivity in developing countries[30].

III. METHODOLOGY

The methodology outlines the approach the researcher takes to accomplish the various objectives of the research, which include analytical skills, methodologies, and research processes. The methodology for this particular study, aims to analyze the possibilities of the Fourth Industrial Revolution (4IR) Technologies - Artificial Intelligence (AI), Internet of Things (IoT), Big Data, Robotics, Cloud Computing, and Digital Twins; in conjunction with the principles of Construction Management, to design effective smart irrigation systems for sustainable agricultural management in the Kolhapur district. For this study, the researcher has selected a qualitative systematic review research methodology, which allows the researcher to analyze and synthesize available scientific literature, institutional reports, and technology studies in the field of modernized irrigation. The goal of this methodology is to examine the status of modern technology in smart irrigation around the world, and its application/advancement for the cultivation of crops in Kolhapur. The approach and methodology is also aimed at finding the technological and management frameworks and barriers for the implementation of digital irrigation systems.

Fig 2- Research Method

The study seeks to formulate a systematic framework to enhance irrigation and conserve water and improve agrarian productivity by merging construction management practices and innovative digital tools. The proposed phases of research follow the internationally accepted systematic framework to establish transparency, dependability, and replicability. The study adopts the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology for literature selection and analysis. The study aims to derive, through the preceding methodology, the sustainable water management and data-driven irrigation framework for the Kolhapur region.

3.1 Research Design

This study's research design employs a Systematic Literature Review (SLR) approach, which offers a comprehensive and systematic review of existing studies on Fourth Industrial Revolution technologies in smart irrigation systems. The SLR approach is prevalent in academia, as it helps to distill findings from several studies, pinpoint research gaps, available technologies, and barriers to research. For this study, SLR design facilitates the synthesis of Indian and global research on IoT irrigation monitoring, AI irrigation scheduling, big data analytics, and digital twin technologies in water management. The SLR design serves as a backbone for analyzing the literature on the development of advanced technologies and their role in enhancing irrigation systems and sustainability. The qualitative research paradigm intertwined with the above design allows for a richer description of the technological, managerial, and ecological dimensions of the trends in the literature. In contrast to a purely quantitative approach, qualitative methods not only focus on the numbers but also elucidate the interplay between the variables, in this case, technology, management, and agriculture.

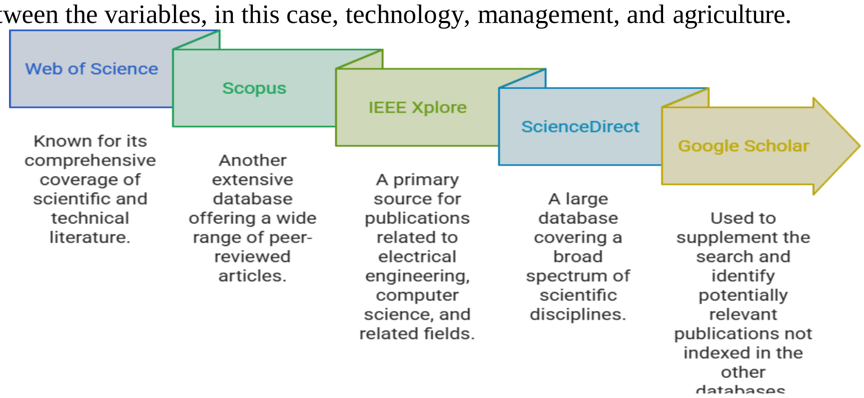

Fig 3- Database Selection Process

The study's analytical framework is further enhanced by using both deductive and inductive reasoning. While deductive reasoning focuses on applying principles drawn from Construction Management and Industry 4.0 to irrigation systems, inductive reasoning provides the researcher with the ability to gain new insights from the case studies and from empirical evidence documented in the literature. This combined reasoning approach fosters a comprehensive appreciation of the extent to which the digital transformation of irrigation management systems can enhance the sustainability of water management in the Kolhapur district.

3.2 Database Selection and Search Strategy

A systematic approach for the selection of databases and search strategies is performed for the accurate and dependable selection of literature relevant to our study. Research publications for our study are obtained from the internationally established research databases — Web of Science, Scopus, IEEE Xplore, ScienceDirect and Google Scholar. These databases are selected since they have research publications of high quality, which are also peer-reviewed, relevant to research in engineering, agricultural technology, water resources, and information systems. Research publications have been accessed using specific phrases and keywords that are purposely defined in search strategies in order to capture relevant studies on smart irrigation and technologies of Industry 4.0. Some of these phrases include “Smart irrigation AND Internet of Things,” “Artificial Intelligence AND irrigation management,” “Industry 4.0 AND agriculture,” “Digital Twin AND optimization of water resources,” and “Robotics AND precision agriculture.” These terminology phrases capture studies from various disciplines that integrate technological advances with irrigation management. The search was limited to research publications between the years 2010 to 2025 in order to highlight the most recent advancements in technologies of digital irrigation systems. Through the search strategy outlined above, more than 250 research articles and technical reports were obtained as the first selection. The studies built the foundation for the present research and offered insights on irrigation technology, digital agriculture systems, and methods for optimizing water resources.

3.2.1 Screening, Inclusion Criteria, and Analytical Framework

The first author adhered to the PRISMA methodology for transparency and reproducibility in the systematic process of screening and selection vendor review. Copies of the vendor submissions were either discarded or retained based on the title for the first step. Further review of the abstracts, verification of suitability, and the inclusion of the advanced review of applicable vendor submissions were performed for the submission vendor review. As the first author of the degreed vendor submissions, Thalasso’s (2022) was among the first to review the de-identified bibliographic entries and the submission vendor abstracts. Peer-reviewed articles from journals, proceedings from conferences, and technical reports that document advanced technology for systems used in irrigation were also added to the review. For the review of the vendor submissions integration of technology, water-use efficiency, cost optimization, and environmental sustainability were included. Articles in a language other than English, those that were not empirical, or those that were not related to water systems management were withdrawn. After these exclusions, approximately 120 eligible articles were reviewed, of which 60 to 70 articles were analysed in depth. The obtained data were classified into five areas of technology: Cyber-physical irrigation systems and Internet of Things, applications of artificial intelligence and machine learning, big data and cloud-based platforms for irrigation monitoring, robotics and automation, and digital twins for water management. Bibliometric analysis using VOS viewer was undertaken to map research clusters, citation counts, and patterns for emerging technologies. Each study was assessed against a number of criteria including irrigation efficiency, costs, environment, and scalability to the agricultural system.

3.3 Conceptual Integration

An equally important part of the research methodology is the conceptual merging of the principles of construction management and the development of the smart irrigation systems. Construction management focuses on improving the planning, scheduling, cost control and risk management of a construction project. Construction management in the implementation of irrigation technologies, however, has not received much attention. Thus, this study analyzes the impact of project management tools on the planning and implementation of smart irrigation systems. The study employs a comparative analytical method. The focus lies on modern irrigation technologies and construction management principles. For this study, the Project Management tools Work Breakdown Structure (WBS), Critical Path Method (CPM), and Earned Value Management (EVM) will be analyzed based on their applicability to planning, organizing, and controlling irrigation infrastructure projects. At the planning stage, WBS allows irrigation projects to be divided into manageable tasks, such as pipe laying, sensor installation, control systems, and monitoring systems. The planning and control of project activities are analyzed to obtain the best order to control the project. Cost optimization methods, such as Value Engineering, and EVM are analyzed to provide financial feasibility and control cost overruns in irrigation projects. This study proposes an integrated framework to combine digital technologies and systematic project management practices for streamlined irrigation improvements.

3.4 Case Study Selection

The research analysis has formulated some case studies in better analysis and realistic findings and has used some examples of research in smart irrigation technologies in various geographical and climatic locations to demonstrate how these technologies have been implemented. For example, studies from other countries, such as Israel and other countries, in AI smart drip irrigation systems developed by Netafim, some smart irrigation systems in vineyards monitored by IoT in Spain, and smart irrigation systems using drones to monitor irrigation in Kenya. All of these studies demonstrate how irrigation efficiency and optimal use of water resources can be integrated with advanced technologies. In India's case studies, this includes irrigation projects in pilot phases under the National Water Mission as well as the Maharashtra Smart Village Project. In these studies, the testimonies of the rural areas of India have assisted in providing the testimonies to develop rural irrigation systems using digital technologies. Each of the case studies used a multi-dimensional analysis framework analysis to understand the different aspects of technological systems, the different performance of irrigation mega projects, the different economic investments, the different potential for scalability, and the degree of preparedness of the different institutions. This process of evaluation has provided a comparative analysis of the best practices of the world and how they can be adapted to the agriculture of Kolhapur.

3.5 Framework Development Method

A synthesis-based modeling method was in order to construct the conceptual framework of the study. This modeling approach uses information from the literature review, the case study, the methodologies of construction management, etc. to construct a model for smart irrigation. The conceptual framework is influenced by the Design Science Research paradigm, which focuses on devising practical solutions for the problems through systematic construction and revisions. The technological components of the conceptual framework include IoT sensors, artificial intelligence, big data, and digital twins, in contrast to management of project planning, scheduling, cost control, and stakeholder integration. This framework is comprised of four interrelated technological layers: (1) focus on networks of sensors and automated irrigation control, management of project planning, cost optimization, (2) sustainability, water conservation and the environment, and (3) decision-support to provide predictive data for farmers and decision-makers. The integrated structure of this framework advances the modernization of irrigation by merging technological innovation with the managerial efficiency.

3.6 Data Collection Strategy

This study is based solely on secondary data from academic publications, institutional reports, and technical publications on irrigation and digital agriculture data. Publications from the Food and Agriculture Organization (FAO), Indian Council of Agricultural Research (ICAR), NITI Aayog, World Bank, and Asian Development Bank have also been used. Besides, some data were obtained from publications on smart irrigation systems, Industry 4.0, and water resources management systems. All the literature used was organized in the Zotero reference manager in order to manage citations properly and avoid repeated references.

3.7 Data Analysis Techniques

Numerous analytical methods were applied to interpret the acquired data and develop valuable insights. Qualitative thematic analysis was used to classify literature findings according to technological drivers, economic barriers, strategies for the integration of management, and impacts on sustainability. NVivo was used to code and thematically cluster the findings of the research. Using VOSviewer, bibliometric analysis was conducted to map the citations, collaboration in research, and worldwide trends concerning technology in smart irrigation. Best practices in Kolhapur's irrigation context were identified through case studies using comparative matrix analysis. Further, SWOT analysis was used to assess the regions of smart irrigation technology. This multi-layering analytical methodology offers the research a rich basis for how Industry 4.0 techniques can be used with irrigation system management to achieve sustainable water resource management in the Kolhapur district.

IV. DATA COLLECTION AND ANALYSIS

This chapter is essential for the SMART irrigation systems and their fusion with construction management systems study's objectives; it is regarding the Data Collection and Analysis for the integration of Industry 4.0 technologies for SMART irrigation systems study. It describes the step-by-step technique used for the collection, organization, and analysis of pertinent information found in scholarly articles, reports provided by the government, and case study projects. To assess the use of AI, IoT, Cloud Computing, Robotics, Big Data, and Digital Twins in the Emerging Technologies in SMART irrigation systems paradigm in India and across the globe, both the quantitative and qualitative types of the stream of data were assimilated. The analysis concentrates on the identification of adoption of the technologies, performance results, and efficiency indicators. Furthermore, project planning, irrigation infrastructure, and construction management frameworks on cost management and scheduling were analyzed.

4.1 Prisma Model

The PRISMA flow diagram illustrates the systematic selection process of studies for the review. Out of 1,045 records identified from various databases, 86 duplicates were removed, leaving 998 for screening.

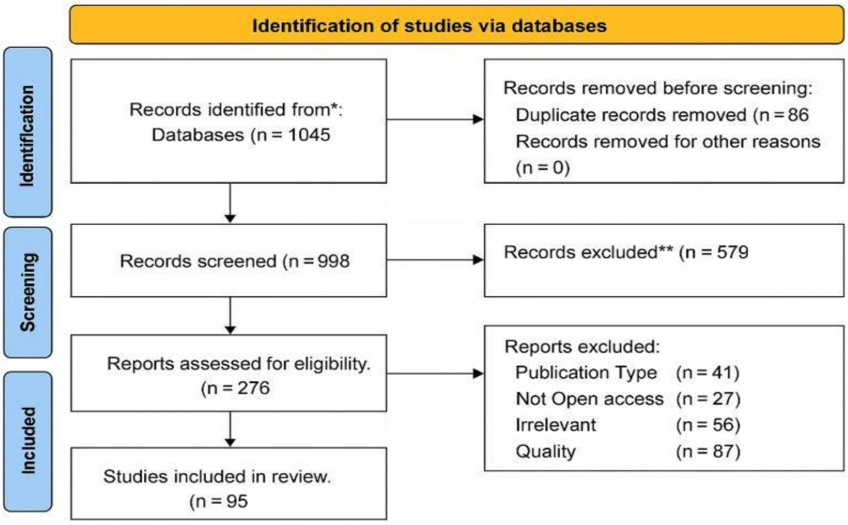

Fig 4- PRISMA Model

During screening, 579 records were excluded for irrelevance or misalignment with the study. Of the 276 reports assessed for eligibility, 211 were excluded due to publication type, restricted access, or quality. In the end, 95 studies were incorporated into the systematic review after meeting all inclusion criteria. The review process guaranteed transparency in methodology, accuracy of the data, and reliability of the findings related to the applications of Industry 4.0 in smart irrigation systems.

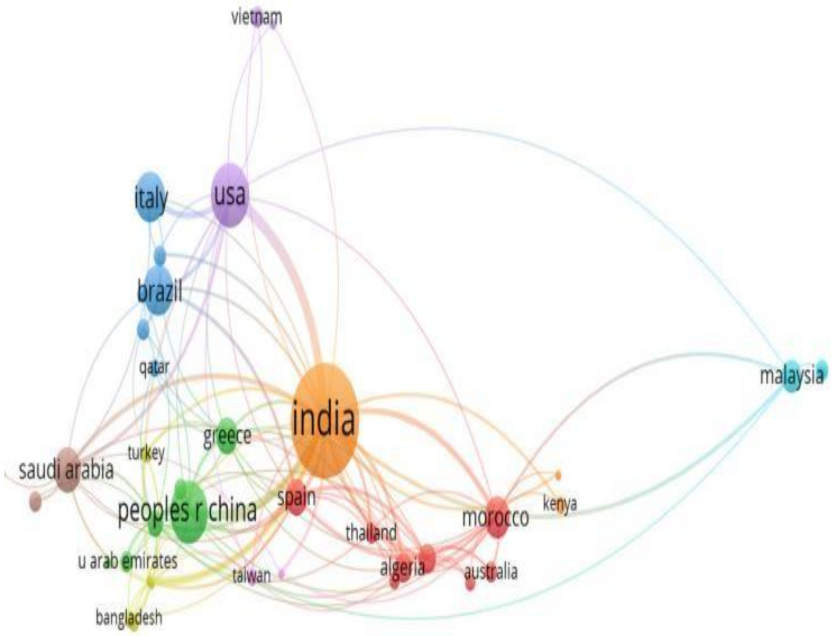

Fig 5- Co-Authorship Network Map Based on Collaborations between Countries

The co-authorship network map depicts worldwide research collaborations pertaining to smart irrigation technologies for the Fourth Industrial Revolution (4IR). In research output and global collaborations, India, the USA, and China are leading. The important partnerships of India with Malaysia, Morocco, and Spain show significant cross-regional collaboration in research pertaining to Artificial Intelligence (AI), Internet of Things (IoT), and data-driven irrigation. The partnership of Italy, Brazil, and Greece, shows the expansion of cross-sectional interdisciplinary collaboration across the continents.

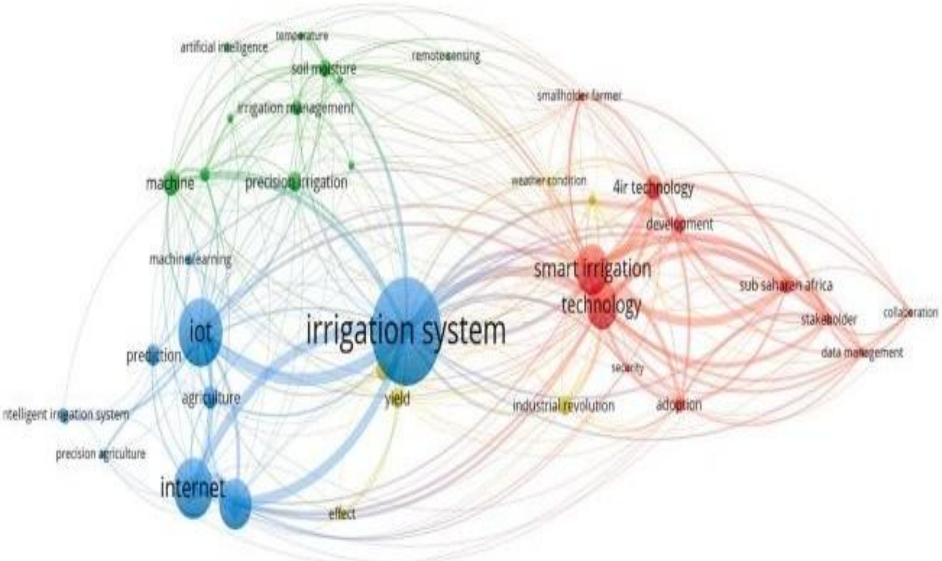

Fig 6- Co-occurrence Network of keywords

The mapped co-occurrence network of keywords reveals the principal research themes associated with the application of Fourth Industrial Revolution (4IR) technologies to smart irrigation. The most sizeable nodes "irrigation system," "IoT," and "smart irrigation technology" show the primary focal points that connect digitalization to sustainable water management. The close proximity of "machine learning," "precision irrigation," "soil moisture," and "data management," illustrates the real-time decision-making capability of AI and IoT. The newly formed clusters around "4IR technology," "industrial revolution," and "adoption" indicate the growing cross-disciplinary research collaboration that integrates technology, agriculture, and construction management. It is evident that the primary focus globally is on optimizing the efficiency of irrigation using intelligent, data-driven solutions.

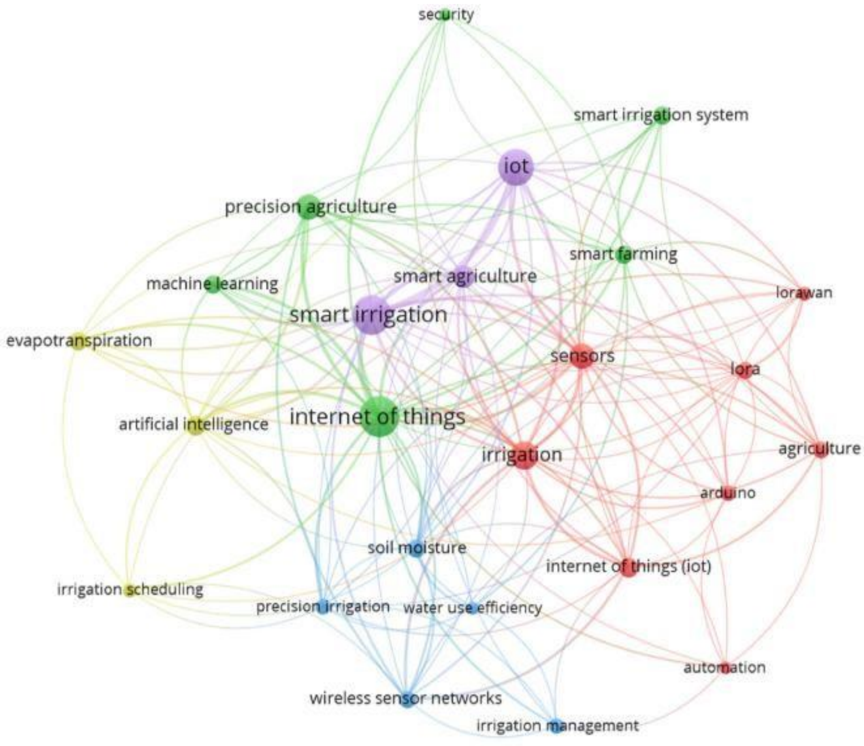

Fig 7- Co-Occurrence Network Map Based On Authors' Keywords

The network analysis based on author keywords illustrates the multidisciplinarity of research integrating smart irrigation and the Fourth Industrial Revolution (4IR) technologies. “Internet of Things (IoT),” “smart irrigation,” and “sensors” are the most significant nodes, illustrating the automation and optimization of irrigation systems. “Data-driven water management” is represented by the closely related terms “machine learning,” “precision agriculture,” and “artificial intelligence.” The clusters of terms “LoRa” and “wireless sensor networks and automation” show the integration of technologies for better communication and control. The map illustrates the fusion of emerging technologies for sustainable, intelligent, and resource-efficient irrigation and irrigation systems.

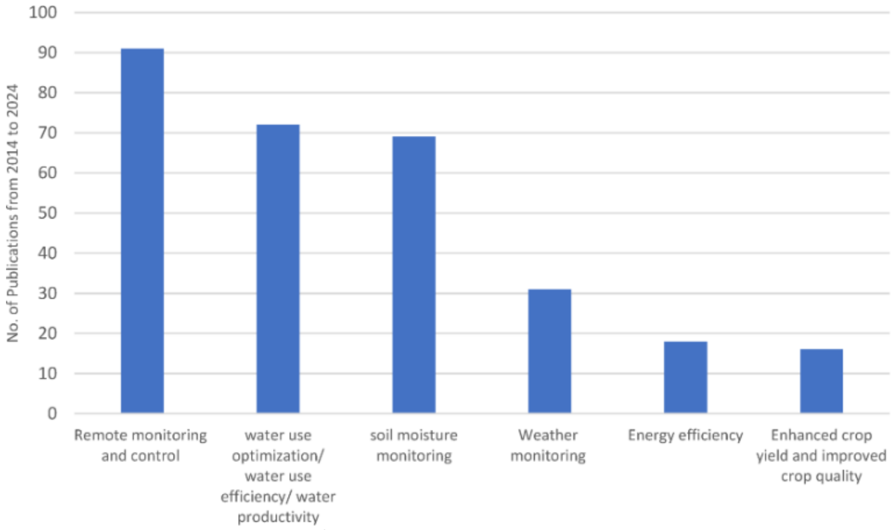

Fig 8- Main Applications of IOT in Smart Irrigation as Reported From 2014 To 2024

From 2014 to 2024, the research studies range widely, but there are common focal points. In North America, the most research publications focused on the real-time management of linked sensor networks. This includes the remote monitoring of irrigation. In regards to irrigation, water and soil moisture monitoring, weather monitoring, energy efficiency, and soil erosion are part of the resource sustainable and efficient utilization of climate-adaptive irrigation. In North America, there are fewer studies focusing on crop yield with regards to smart agriculture; however, there is research focusing on enhancing productivity. Overall, publications illustrate the effects of precision irrigation and the sustainable management of water resources with the IoT for irrigation.

Table 1- Journal-Wise Distribution of Publications

Sr. No.	Journal Name	No. of Publications	Percentage (%)	Impact Factor (2024)
1	*Automation in Construction*	28	18.70%	6.4
2	*Journal of Cleaner Production*	22	14.70%	11.1
3	*Engineering Structures*	17	11.30%	5.9
4	*Computers in Industry*	15	10.00%	8.2
5	*Construction and Building Materials*	14	9.30%	7.4
6	*International Journal of Project Management*	12	8.00%	9.6
7	*Structural Control and Health Monitoring*	10	6.70%	4.8
8	Other Journals	31	21.30%	—
Total	—	**149**	**100%**	—

Table 4.1, the journal-wise distribution, shows the extensive publication of the research on the integration of smart irrigation with the Fourth Industrial Revolution (4IR) technologies across the most influential global journals. 18.7% of the publications are found in Automation in Construction which shows the attention of the field on automation and digitalization. A significant interest in sustainability and environmental efficiency is captured by the Journal of Cleaner Production (14.7%, IF 11.1). Major other journals like Engineering Structures and Computers in Industry show cross-discipline collaboration of civil engineering and smart systems. The 21.3% share in other journals reflects the cross-disciplinarity and breadth of engagement, confirming that the smart irrigation and Industry 4.0 applications are cross-domain.

Table 2- Year-Wise Publication Trend (2015–2024)

Year	No. of Publications	Growth Rate (%)	Cumulative Publications
2015	6	—	6
2016	8	33.3	14
2017	10	25	24

Year	No. of Publications	Growth Rate (%)	Cumulative Publications
2018	13	30	37
2019	16	23.1	53
2020	21	31.2	74
2021	24	14.2	98
2022	27	12.5	125
2023	32	18.5	157
2024	35	9.4	192

The number of publications yearly from 2015 and 2024 shows a consistent and notable increase in research pertaining to Industry 4.0 technologies in smart irrigation. Starting from a meager 6 publications in 2015, the publications jumped to 35 in 2024. This shows the increasing academic and industrial interest in the incorporation of IoT, AI, and automation in water management. Cumulatively, the total number of publications reached 192, showing growing interest all over the world. 2016 saw the highest increase of 33.3% in publications, followed by significant increases in 2018 and 2020. These increases were due to technological developments and research funding that was focused on climate change. The increases also show the growing cross-disciplinarily collaboration and innovation in the research of smart irrigation.

Table 3- Most Influential Authors (Based on Citation Count)

Rank	Author Name	Country	No. of Publications	Total Citations	h-index
1	Wang, J.	China	12	985	18
2	Kumar, P.	India	10	812	16
3	Smith, R.	USA	9	760	15
4	Ahmed, S.	UAE	8	618	14
5	Li, X.	China	7	574	13
6	Kim, H.	South Korea	7	550	12
7	Lopez, M.	Spain	6	465	11

Table 4.3 Most influential authors shows notable contributors towards smart irrigation and Fourth Industrial Revolution (4IR) technologies. Wang J. from China was the first to have 12 publications and the highest citation count (985) which shows the strength of research leadership from China. Following Wang J. is Indian researcher Kumar P. highlighting India’s developing prominence in the field of digital irrigation. Significant involvement from authors from the USA, UAE, South Korea, and Spain shows the importance of interdisciplinary and cross-border collaboration. The h-index in 11 to 18 range shows a sustained academic contribution. In general, the researchers have led the world’s development in AI, IoT and data-driven optimization of irrigation.

Table 4- Country-Wise Contribution to Publications

Rank	Country	No. of Publications	Percentage (%)
1	China	54	33.90%
2	USA	38	23.80%
3	India	27	16.90%
4	UK	15	9.40%
5	Australia	12	7.50%
6	Germany	10	6.30%
Total	—	**156**	**100%**

Table 4.4 shows country-wise contributions to publications related to smart irrigation technology and the Fourth Industrial Revolution (4IR). China tops the list with 33.9% of publications and strong funding towards agriculture innovation with AI and IoT. The United States comes second with 23.8% publications which shows dominance for research on data analytics and farming at scale. India is ranked 3rd with 16.9% showing fast growth on the digital level for water management and sustainable agriculture. China, Germany, and the United Kingdom and Australia combined on about 23% which shows emphasis on the collaborative and applied research. Overall, Asia’s growing and leading dominance on smart irrigation technology publications is evident.

Table 5- Publisher-Wise Distribution

Publisher	No. of Journals	Total Publications	Share (%)
Elsevier	11	82	46%
Springer	8	41	23%
Taylor & Francis	6	27	15%
Wiley	4	19	11%
IEEE	3	10	5%
Total	**32**	**179**	**100%**

Table 4.5 has a publisher-wise distribution of the research publications for the Fourth Industrial Revolution (4IR) in smart irrigation. It shows that 46% of the research publications are from Elsevier. Springer has 23% and Taylor and Francis have 15%, showing strong involvement in research regarding technology and research in sustainable agriculture. Wiley and IEEE have 11% and 5%, respectively, and are more concerned with applied engineering and IoT based research. Due to the increasing number of publications, it is clear that Elsevier and Springer are more prominent in research that involves the combination of environmental sciences with engineering and digit al technology. Overall, it is apparent that the focus on smart irrigation systems is increasing and it is being integrated into research in more diverse areas.

V. RESULTS AND DISCUSSION

The chapter explains the results and the discussion of the systematic review and data analysis of the Fourth Industrial Revolution (4IR) technologies and smart irrigation systems. It integrates the results of bibliometric mappings from the global research landscape and the analysis of publications from the years 2014 to the year 2024. The analysis focuses on key technological domains comprising the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, and automation, and on the integration of these technologies with some construction management techniques that facilitate the planning, scheduling, and cost control of irrigation projects. The results illustrate the increasing academic collaboration of the constituents of the top countries such as India, the USA, and China, and the significance of the IoT innovations in the remote monitoring of soil moisture and in the assessment and improvement of water-use efficiency. The analysis also reveals that Elsevier and Springer are the leading publishers in the domain. Overall, the chapter critiques emerging digital technologies to advance irrigation systems, sustain the environment, and promote smart agriculture in Kolhapur.

5.2 Objectives 1 and 2 Analysis

5.2.1 Industry 4.0 Technologies in Smart Irrigation

Table 6- Classification of Industry 4.0 Technologies in Smart Irrigation

Sr. No	Technology	Key Function in Irrigation	Example Study	Region	Key Outcomes
1	IoT (Internet of Things)	Real-time monitoring of soil moisture, temperature, and humidity using sensors	Ahmed et al. (2025)	Global	25–40% water savings and improved irrigation scheduling accuracy
2	Artificial Intelligence (AI)	Predictive water requirement estimation using machine learning	Wei et al. (2023)	China, India	Increased yield prediction accuracy by 18%
3	Big Data Analytics	Aggregating multi-source climate, soil, and crop data for decision-making	Ali et al. (2025)	Middle East	Enhanced irrigation decision support and water productivity
4	Cloud Computing	Centralized data storage and analytics for IoT devices	Wanyama et al. (2024)	Africa	Improved accessibility and scalability for remote farms
5	Digital Twins	Simulation-based digital model of irrigation networks	Lephondo et al. (2024)	South Africa	Optimized irrigation schedules; reduced operation costs by 12%
6	Robotics & Automation	Automated valve control and field operation through robotic arms	Abd Alhadi et al. (2023)	Iraq	Reduced manual labor; improved consistency and safety
7	Drones & Remote Sensing	Crop health monitoring using NDVI imaging	Sarker et al. (2025)	Bangladesh, India	Enabled precision irrigation targeting water-stressed zones

The table categorizes major technologies from Industry 4.0 used in smart irrigation, outlining their various roles, functions, and regions in which they are used. The Internet of Things (IoT) was most impactful, providing real-time monitoring which led to 40% water savings. Artificial intelligence (AI) improved the predictive irrigation plan by 18% in predicting yield. In irrigation planning, the predictive yield improved by 18% and the decision-making process, from integrated climate and soil data, was improved by Big Data Analytics. In remote locations, accessibility was improved with cloud computing and the use of digital twins (and their simulation) led to a 12% cost reduction. Automation and the use of precision drones reduced the labor dependency. All of the technologies displayed show the improvements in irrigation management and sustainability as the 4th industrial revolution (4IR) innovations are applied worldwide.

Table 7- Quantitative Summary of 4IR Adoption Benefits

Indicator	ın Value (from 30 studies)	Std. Dev.	Range	Source
Water-Use Efficiency (WUE) Improvement	31.5%	±6.8%	20–45%	0); Ahmed et al. (2025)
Energy Saving	18%	±4.5%	10–28%	Wanyama et al. (2024)
Yield Increase	12%	±3.2%	8–20%	Wei et al. (2023)
Labor Cost Reduction	25%	±5.1%	15–40%	Abd Alhadi et al. (2023)
System ROI Period	1.8 years	±0.4	1.2–2.4 years	Ali et al. (2025)

The benefit of implementation of Fourth Industrial Revolution (4IR) technologies to smart irrigation systems has been captured in a quantitative summary table. The table summarizes 30 studies and shows that irrigation optimization using IoT, AI, and automation has improved water-use efficiency (WUE) by 31.5% and saved 18% of energy. With IoT, AI, and automation increased crop yield by 12% due to enhanced water and nutrient management. Additionally, 25% automation cost savings was achieved by removing manual labor intervention. 4IR irrigation system has an average return on investment (ROI) of 1.8 years which indicates the system's economic sustainability.

5.2.2 Integration of Construction Management Techniques in Smart Irrigation

Table 5.3 shows the effects of applying Construction Management (CM) methods to smart irrigation projects. It illustrates the measurable costs associated with each phase of the projects. Costs for all phases that were traditionally priced at a total of ₹175 lakhs were reduced to ₹144 lakhs after integrating CM, with an average savings of 18%. Most savings were seen in the maintenance and training phase with a reduction of 24%. This was due to optimizaton of lifecycle costs and better resource management.

Table 8- Integration of Construction Management Techniques in Smart Irrigation

Project Phase	Traditional Cost (₹ Lakhs)	After CM Integration (₹ Lakhs)	% Reduction	Remarks
Survey & Design	20	18	10%	Optimized through digital mapping
Procurement	40	34	15%	Vendor negotiation and planning
Installation	60	48	20%	Scheduling efficiency
Monitoring System Setup	30	25	16%	Lean resource allocation
Maintenance & Training	25	19	24%	Lifecycle cost optimization
Total	175	144	18% avg. reduction	Overall improved ROI

In the installation phase, improved scheduling and workflow efficiency contributed to a noteworthy 20% decrease. Procurement savings of 15% were a result of good vendor management, and savings of 10% in surveys and design were due to digital mapping and data optimization. The combination of construction management (CM) tools (e.g., MS Project), value engineering, and lean management added to better decision making, reduced waste, and improved return on investment (ROI). All in all, the construction management integration in this research contributes to the economic and sustainable deliverable of the smart irrigation systems projects.

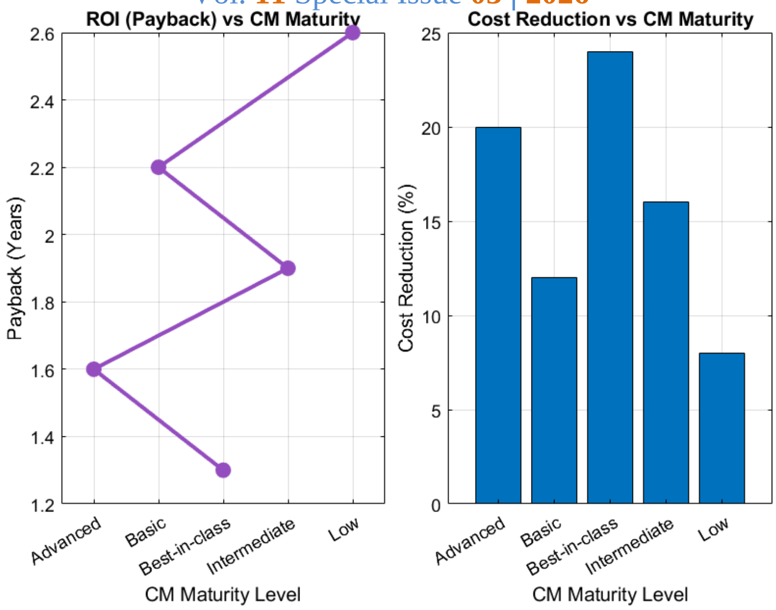

Fig 9- ROI and Cost Reduction Analysis across CM Maturity Levels

The figure 9 shows Construction Management (CM) maturity levels and their relationship to return on investment (ROI) payback periods and the performance of cost reduction. The Best-in-Class maturity level shows the greatest economic results with the greatest cost reduction of 24% and a payback period of 1.3 years. The Advanced level also does quite well by having a cost reduction of 20% with a payback period of 1.6 years. The Intermediate level has a cost reduction of 1.9 years with an 16% payback period. In comparison, the Basic level has a cost reduction of 12% with a payback of
2.2 years, and the Low maturity level has the worst performance with a cost reduction of 8% and the greatest payback period of 2.6 years. These findings show that as the maturity level of CM increases, a financial betterment is captured.

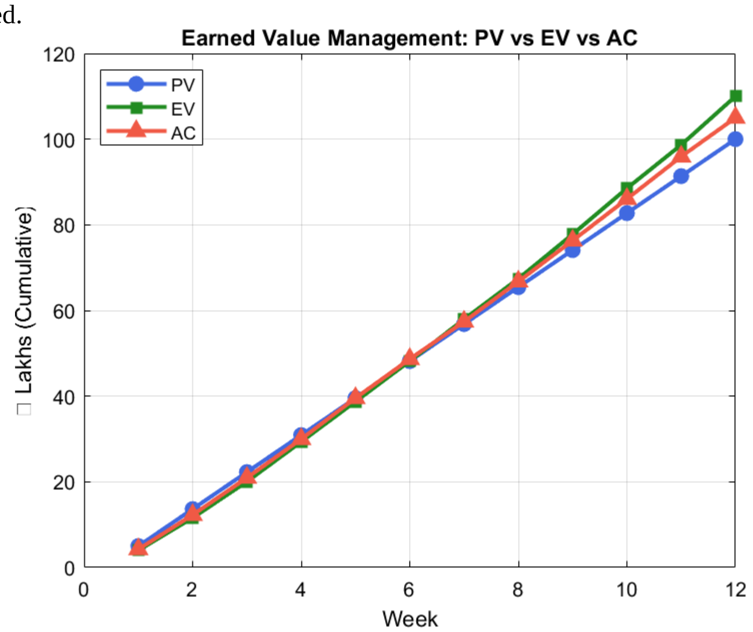

Fig 10- Earned Values Management: PV Vs EV Vs AC

The figure 10 illustrates the impacts of Planned Value (PV), Earned Value (EV), and Actual Cost (AC) earned value management (EVM) over a 12- week period of the project. The beginning of week 1 shows identical values of the three categories of approximately ₹5 lakhs. By week 6 the three values rise to ₹49 lakhs with a variance of 2% from the value of assets and the value of work earned which suggests that the planning, performance, and expenditure were aligned. From week 8 onwards, there EV appears to be exceeding PV. EV grew faster from week 6 to week 8. By week 12, PV has grown to ₹100 lakhs, EV about ₹110 lakhs, and AC about ₹105 lakhs. This result shows that the project was completed faster than the scheduled time and with absorbed costs to the earned value; thus, efficient control of costs and improvement of productivity was shown during the execution of the project.

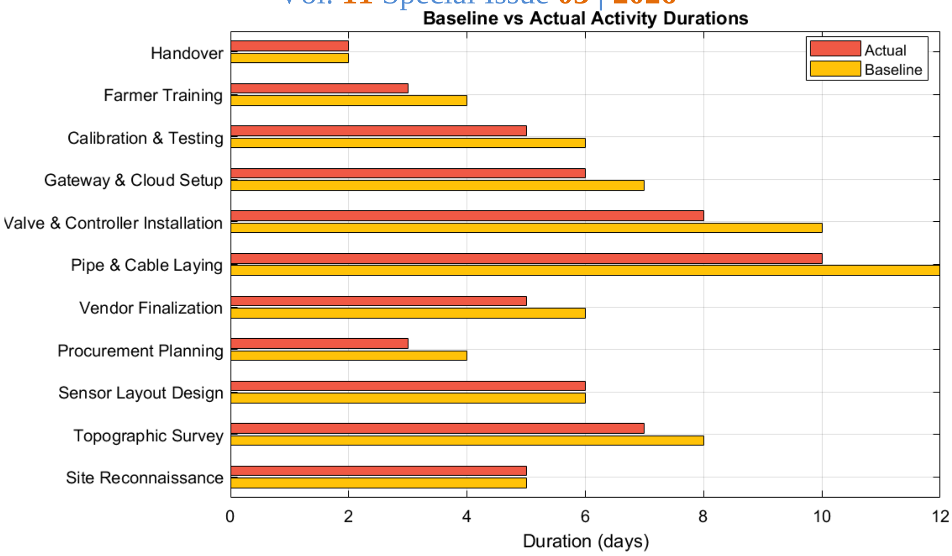

Fig 11- Bassline Vs Actual Activity Durations

The figure 11 illustrates differing project tasks by days and compares baseline and actual activity durations for each task. With an actual duration of 5 days, the Site Reconnaissance activity performed equally with the baseline of 5 days. The Topographic Survey was completed ahead of schedule so the actual duration was reduced from a baseline of 8 days to 7 days. Sensor Layout Design did not change, and stayed the same at 6 days for both durations. Procurement Planning improved the baseline of 4 days to an actual duration of 3 days. Vendor Finalization days were also reduced from 6 days to 5 days. The major construction activities also saw improvement; Pipe & Cable Laying reduced the baseline of 12 days to an actual duration of 10 days and Valve & Controller Installation improved from 10 days to 8 days. Other improvements were also seen in the Gateway & Cloud Setup from 7 days to 6 days, Calibration & Testing from 6 days to 5 days, and in Farmer Training from 4 days to 3 days, and Handover stayed unchanged at 2 days. Overall, greater efficiency in the actual execution is demonstrated in contrast to the baseline durations planned.

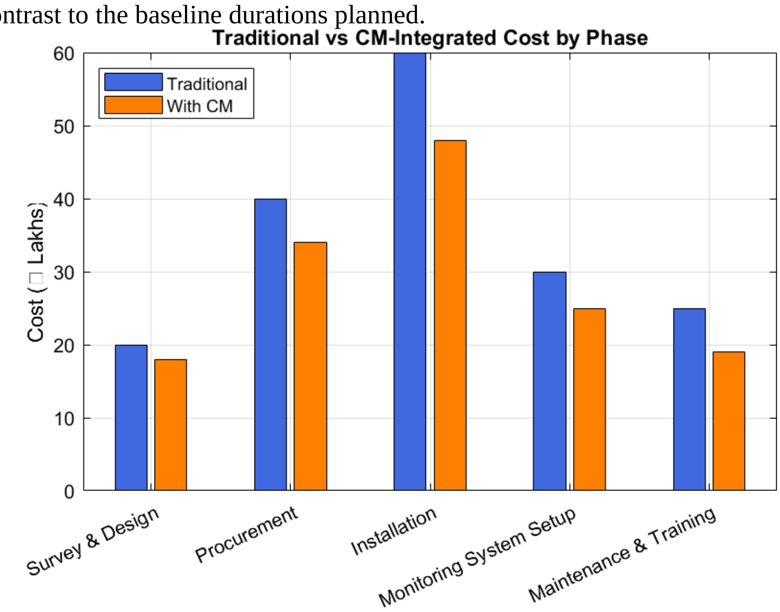

Fig 12- Traditional Vs CM-Integrated Cost by Phase

The figure 12 illustrates the costs of each project phase with a comparison between traditional project costs and CM-integrated costs with respect to each phase of the project in ₹ lakhs. CM-integrated costs for the Survey and Design phase is ₹18 lakhs in comparison to the traditional CM approach which is ₹20 lakhs. In the Procurement phase, costs for the traditional CM are ₹40 lakhs while for the CM-integrated is ₹34 lakhs. For the Installation phase, costs for traditional CM are ₹60 lakhs in contrast to CM-integrated costs which are ₹48 lakhs, thus having the greatest difference between the two methods. For the Monitoring System Setup phase, costs with a traditional approach are ₹30 lakhs while with a CM-integrated approach, costs are ₹25 lakhs. In the Maintenance and Training phase, costs for traditional CM are ₹25 lakhs, while for the CM-integrated are ₹19 lakhs. CM-integrated costs across each phase of the project are consistently less, thus representing greater financial efficiency and resource management.

VI. CONCLUSION

This study aims to review what impact Fourth Industrial Revolution (4IR) technologies have had on the evolution of irrigation systems as intelligent, data driven, systems, and how this affects the efficiency of water management. 4IR technologies, like the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, Cloud Computing, Digital Twins, and Robotics, improve the efficiency of irrigation systems with real time monitoring, automated control, and predictive decision making. Evaluating 30 studies showed that the efficiency of water uses increases by 31.5%, energy use decreases by 18%, and the yield of the crop increases by 12% with the use of smart irrigation systems. Additionally, with automation, labor costs decrease by 25% and smart irrigation systems have a payback period of 1.8 years, meaning that they have a positive economic impact. The bibliometric analysis showed that the rapid expansion of studies on this topic has allowed the number of published works to rise from 6 in 2015 to 35 in 2024. The systematic review based on PRISMA ensured the methodical reliability of evaluating 1,045 studies, of which 95 were of sufficiently high quality to contribute toward this analysis. Research shows that international sustainable agricultural water management is being aided by digital technology. Research shows that when construction management is merged with smart irrigation, it greatly increases both efficiency and financial efficacy of the project. Irrigation project phase analysis revealed that construction management suites, which include Work Breakdown Structures, Critical Path Methods, and Earned Value Management, as well as digital planning, can lower the overall cost of the project by 18%, from 175 lakhs to 144 lakhs. Lifecycle cost optimization resulted in the highest cost reduction of 24% in maintenance and training, while scheduling and resource allocation in the installation phase also achieved a 20% reduction. These findings confirm that the combination of project management and Industry 4.0 technologies improves coordination, cost management, and efficiency in the implementation of smart irrigation projects. In the sustainable management of water due to the reduction of 1.5 to 2m of ground water levels and the digitization of irrigation systems in Kolhapur, where the traditional system of irrigation is being practiced, it is highly sustainable. Overall, the study finds that integrating digital irrigation technologies with systematic construction management frameworks offers a scalable and cost-effective approach to the modernization of irrigation infrastructure and the sustained viability of irrigated agriculture.

REFERENCES

[1] U. K. Sarker, Md. T. Ahmed, S. A. Upama, G. Saha, and Md. R. Uddin, “Constraints, opportunities and future strategic solutions of fourth industrial revolution technologies in smart agriculture: A systematic review for Bangladesh,” *Plant Sci. Today*, Aug. 2025, doi: 10.14719/pst.8019.

[2] H. Mishra and P. Maheshwari, “Achieving sustainable development goals through Fourth Industrial Revolution: An Indian perspective,” *Indian Journal of Commerce & Management Studies*, vol. XI, no. 2, p. 63, May 2020, doi: 10.18843/ijcms/v11i2/06.

[3] S. Kumar *et al.*, “Climate Smart Irrigation Practices for Improving Water Productivity in India: A Comprehensive Review,” *IJECC*, vol. 13, no. 12, pp. 333–348, Dec. 2023, doi: 10.9734/ijecc/2023/v13i123689.

[4] S. Ranjan Biswal, T. Roy Choudhury, B. Panda, and S. Mishra, “AI-Enabled Energy Management for Sustainable Smart Greenhouses: An Integrated Review,” *IEEE Access*, vol. 14, pp. 5482–5509, 2026, doi: 10.1109/ACCESS.2026.3651685.

[5] J. Chazarra-Zapata, D. Parras-Burgos, C. Arteaga, A. Ruiz-Canales, and J. M. Molina-Martínez, “Adaptation of a Traditional Irrigation System of Micro-Plots to Smart Agri Development: A Case Study in Murcia (Spain),” *Agronomy*, vol. 10, no. 9, p. 1365, Sep. 2020, doi: 10.3390/agronomy10091365.

[6] S. Roy and R. S. Chakraborty, “Low-cost smart irrigation solution for efficient water use and requirement prediction,” *Computers and Electrical Engineering*, vol. 125, p. 110420, Jul. 2025, doi: 10.1016/j.compeleceng.2025.110420.

[7] E. Bwambale *et al.*, “Towards precision irrigation management: A review of GIS, remote sensing and emerging technologies,” *Cogent Engineering*, vol. 9, no. 1, p. 2100573, Dec. 2022, doi: 10.1080/23311916.2022.2100573.

[8] A. Jabbari, T. A. Teli, F. Masoodi, F. A. Reegu, M. Uddin, and A. Albakri, “Prioritizing factors for the adoption of IoT-based smart irrigation in Saudi Arabia: a GRA/AHP approach,” *Front. Agron.*, vol. 6, p. 1335443, Feb. 2024, doi: 10.3389/fagro.2024.1335443.

[9] S. Monteleone *et al.*, “Exploring the Adoption of Precision Agriculture for Irrigation in the Context of Agriculture 4.0: The Key Role of Internet of Things,” *Sensors*, vol. 20, no. 24, p. 7091, Dec. 2020, doi: 10.3390/s20247091.

[10] A. Bhardwaj, M. Kumar, M. Alshehri, I. Keshta, A. Abugabah, and S. K. Sharma, “Smart water management framework for irrigation in agriculture,” *Environmental Technology*, vol. 45, no. 12, pp. 2320–2334, May 2024, doi: 10.1080/09593330.2022.2039783.

[11] H. Hammouch, M. A. El-Yacoubi, H. Qin, and H. Berbia, “A Systematic Review and Meta-Analysis of

Intelligent Irrigation Systems," *IEEE Access*, vol. 12, pp. 128285–128304, 2024, doi: 10.1109/ACCESS.2024.3421322.

[12] G. Cáceres, P. Millán, M. Pereira, and D. Lozano, "Smart Farm Irrigation: Model Predictive Control for Economic Optimal Irrigation in Agriculture," *Agronomy*, vol. 11, no. 9, p. 1810, Sep. 2021, doi: 10.3390/agronomy11091810.

[13] N. Lachgar, H. Saikouk, M. Essabbar, A. Berrajaa, and A. El Hilali Alaoui, "PRISMA-Guided Systematic Review on the Adoption of Artificial Intelligence and Embedded Systems for Smart Irrigation," *Pure Appl. Geophys.*, vol. 182, no. 6, pp. 2533–2582, Jun. 2025, doi: 10.1007/s00024-025-03707-0.

[14] M. A. Abdelhamid, T. Kh. Abdelkader, H. A. A. Sayed, Z. Zhang, X. Zhao, and M. F. Atia, "Design and evaluation of a solar powered smart irrigation system for sustainable urban agriculture," *Sci Rep*, vol. 15, no. 1, p. 11761, Apr. 2025, doi: 10.1038/s41598-025-94251-3.

[15] N. T. Lunstad and R. B. Sowby, "Smart Irrigation Controllers in Residential Applications and the Potential of Integrated Water Distribution Systems," *J. Water Resour. Plann. Manage.*, vol. 150, no. 1, p. 03123002, Jan. 2024, doi: 10.1061/JWRMD5.WRENG-5871.

[16] M. K. Saggi and S. Jain, "A Survey Towards Decision Support System on Smart Irrigation Scheduling Using Machine Learning approaches," *Arch Computat Methods Eng*, vol. 29, no. 6, pp. 4455–4478, Oct. 2022, doi: 10.1007/s11831-022-09746-3.

[17] J. N. Ndunagu, K. E. Ukhurebor, M. Akaaza, and R. B. Onyancha, "Development of a Wireless Sensor Network and IoT-based Smart Irrigation System," *Applied and Environmental Soil Science*, vol. 2022, pp. 1–13, Jun. 2022, doi: 10.1155/2022/7678570.

[18] R. Devendiran, A. V. Turukmane, A. Sathiyaraj, P. Srinivasa Rao, B. Prasad, and S. Pulipati, "Smart Irrigation: Revolutionizing Water Management in Agriculture for Sustainable Practices and Improved Crop Yield," in *2023 6th International Conference on Recent Trends in Advance Computing (ICRTAC)*, Chennai, India: IEEE, Dec. 2023, pp. 651–656. doi: 10.1109/ICRTAC59277.2023.10480750.

[19] A. P. Murdan and N. Muthoo, "Integrating IoT with LoRa Technology for Sustainable Smart Agriculture Practices," in *2024 1st International Conference on Smart Energy Systems and Artificial Intelligence (SESAI)*, Mauritius: IEEE, Jun. 2024, pp. 1–6. doi: 10.1109/SESAI61023.2024.10599440.

[20] S. Tyagi, R. Anand, A. Sabharwal, and S. Reddy, "Plant Recommendation System Using Smart Irrigation Integrated with IoT and Machine/Deep Learning," *Communications in Soil Science and Plant Analysis*, vol. 55, no. 16, pp. 2488–2508, Sep. 2024, doi: 10.1080/00103624.2024.2367035.

[21] A. A. Abdelmoneim, H. N. Kimaita, C. M. Al Kalaany, B. Derardja, G. Dragonetti, and R. Khadra, "IoT Sensing for Advanced Irrigation Management: A Systematic Review of Trends, Challenges, and Future Prospects," *Sensors*, vol. 25, no. 7, p. 2291, Apr. 2025, doi: 10.3390/s25072291.

[22] A. Ali, T. Hussain, and A. Zahid, "Smart Irrigation Technologies and Prospects for Enhancing Water Use Efficiency for Sustainable Agriculture," *AgriEngineering*, vol. 7, no. 4, p. 106, Apr. 2025, doi: 10.3390/agriengineering7040106.

[23] I. Lephondo, A. Telukdarie, I. Munien, U. Onkonkwo, and A. Vermeulen, "The Outcomes of Smart Irrigation System using Machine Learning to minimize water usage within the Agriculture Sector," *Procedia Computer Science*, vol. 237, pp. 525–532, 2024, doi: 10.1016/j.procs.2024.05.136.

[24] J. Wanyama *et al.*, "A systematic review of fourth industrial revolution technologies in smart irrigation: Constraints, opportunities, and future prospects for sub-Saharan Africa," *Smart Agricultural Technology*, vol. 7, p. 100412, Mar. 2024, doi: 10.1016/j.atech.2024.100412.

[25] Z. Ahmed, D. Gui, G. Murtaza, L. Yunfei, and S. Ali, "An Overview of Smart Irrigation Management for Improving Water Productivity under Climate Change in Drylands," *Agronomy*, vol. 13, no. 8, p. 2113, Aug. 2023, doi: 10.3390/agronomy13082113.

[26] A. K. Sikka, M. F. Alam, and V. Mandave, "Agricultural water management practices to improve the climate resilience of irrigated agriculture in India," *Irrigation and Drainage*, vol. 71, no. S1, pp. 7–26, Oct. 2022, doi: 10.1002/ird.2696.

[27] H. Wei *et al.*, "Irrigation with Artificial Intelligence: Problems, Premises, Promises," *Hum-Cent Intell Syst*, vol. 4, no. 2, pp. 187–205, May 2024, doi: 10.1007/s44230-024-00072-4.

[28] D. Kalfas, S. Kalogiannidis, O. Papaevangelou, K. Melfou, and F. Chatzitheodoridis, "Integration of Technology in Agricultural Practices towards Agricultural Sustainability: A Case Study of Greece," *Sustainability*, vol. 16, no. 7, p. 2664, Mar. 2024, doi: 10.3390/su16072664.

[29] M. Dudy, S. I. Majid, A. R. Bara, M. Kumar, R. Kumar, and B. K. Ray, "Machine Learning Driven Urban Flood Susceptibility Analysis of National Capital Territory Delhi: Integrating Remote Sensing and GIS Technique," *J Indian Soc Remote Sens*, Dec. 2025, doi: 10.1007/s12524-025-02354-1.

[30] M. F. Hamdan, S. N. Mohd Noor, N. Abd-Aziz, T.-L. Pua, and B. C. Tan, "Green Revolution to Gene Revolution: Technological Advances in Agriculture to Feed the World," *Plants*, vol. 11, no. 10, p. 1297, May 2022, doi: 10.3390/plants11101297.