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A Comprehensive Review of Automated Deep-well Irrigation System for Remote and Non-Irrigated Agricultural Areas

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Abstract: This paper will be a review of automated deep-well irrigation systems that can be applied in remote and non-irrigated fields. Inadequate to central irrigation system may regularly compel farmers in such areas to use rainfall or manually powered deep-well pumps which may result in inefficient utilization of water, excessive labor force, and unreliable crop yields. The review comprises an analysis of available studies on the techniques of automation that have been adopted in the irrigation systems that comprise of soil moisture sensors, microcontrollers, wireless communication, and automated pump control mechanism. It also determines the reliability and the long term performance of the components of the system including sensors, pump and controllers as the applied in extreme environment condition. The paper also examines the energy needs of the groundw ter pumping and discusses incorporation of renewable energy source, especially solar photovoltaic system to enhance energy efficiency and sustainability of off grid farming regions. Result of the obtained literature review shows that automated irrigation system aid considerably to the efficiency of water use, labor saving needs, and more efficient growth of the irrigation schedules. But issues to do with energy use, system service life, and sustainable use of groundwater are also important. The analysis of the research reveals the current research gaps and reveals the necessity to exploit integrated strategies that would unite automation, renewable energy, and effective ground water extraction. The findings of this eview can be used by researchers, engineers, and policy makers to come up with dependable and sustainable automated systems to be used by remote agricultural communities.

Index Terms - Automated irrigation system, deep-well irrigation, soil moisture sensors, renewable energy, solar-powered pumping, water-use efficiency, remote agriculture, irrigation automation.

I. INTRODUCTION

Agriculture accounts for approximately 70% of global freshwater withdrawals, making efficient irrigation systems essential for sustainable food production [1]. In remote and upland farming areas, access to centralized irrigation infrastructure is often limited, forcing farmers to rely on rainfall or manually operated deep-well systems. These traditional methods frequently result in inefficient water use, increased labor demand, and inconsistent crop yield.

Recent advances in automation and sensor technologies have enabled the development of smart irrigation systems that regulate water delivery based on soil moisture conditions. Automated irrigation systems can improve water-use efficiency and reduce wastage compared to conventional methods [2]. Automation can provide a variable solution to the farmers that are remote to the irrigation networks when it is combined with deep-well water sources.

Nevertheless, issues of long term reliability and excessive energy consumption, especially during ground water pumping, are also still a cause of concern. Renewable energy integration, including solar-powered pumping systems, has been identified as a sustainable approach for improving irrigation efficiency in off-grid agricultural areas [4]. Therefore, this review examines existing studies on automated deep-well irrigation systems, focusing on automation strategies, reliability, and power consumption considerations.

II. STATEMENT OF THE PROBLEM

In non irrigated and remote agricultural regions, a number of farmers are not connected to centralized irrigation system and many have to use manually operated deep-well pumps or rainfall-based approaches. Such practice have caused wasteful allocation of water, high labor demands, unequal crop production as well as high water wastage. There are no automated control mechanisms, and hence, it is hard to control the irrigation basing on the real soil moisture conditions increasing the total water use efficiency and the

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agricultural productivity.

That is why the automated irrigation technologies have been presented to enhance precision and efficiency and their establishment with the deep-well water systems is accompanied by the challenges associated with the long term reliability and energy consumption. Pumping of ground water consumes a lot of electrical energy that cannot be easily accessible or cost effective in isolated locations.

In addition to that, system components like sensors, pumps, and controllers are also required to endure exposure to the severe environmental conditions. So, the existing automated deep-well irrigation systems should be thoroughly reviewed to investigate the automation, durability, and the use of power.

III. RESEA OBJECTIVES

General Objective

We intended to review existing automated deep-well irrigation systems and evaluate their applicability for remote and non-irrigated agricultural areas.

Specific Objectives

- To examine different automation strategies used in deep-well irrigation systems.
- To assess the reliability and long-term performance of automated irrigation components, including pumps, sensors, and controllers.
- To analyze power consumption and energy efficiency considerations in automated deep-well irrigation systems.
- To identify research gaps and challenges in implementing sustainable automated irrigation in remote farming areas.

IV. RESEARCH QUESTION

- What automation strategies have been applied in deep-well irrigation systems for remote agricultural areas?
- How reliable are the components of automated irrigation systems over long-term use?
- What are the energy and power consumption implications of automated deep-well irrigation systems?
- What are the existing challenges and research gaps in the development and implementation of these systems?

V. SIGNIFICANCE OF THE STU

The study focuses on reviewing existing literature related to automated deep-well irrigation systems used in remote and non irrigated agricultural areas. The review covers automation technologies such as soil moisture sensor, microcontrollers, pump control systems, and energy sources, including the conventional electricity and solar power. It also examines issues related to system reliability, long term performance, and power consumption.

Furthermore, this study benefits farmers, policymakers, and technology developers by identifying reliability concerns and energy consumption issues associated with automated groundwater pumping systems. By highlighting sustainable approaches, such as energy-efficient pump operation and renewable energy integration, the review may guide future innovations and support the development of cost-effective irrigation systems suitable for rural and off-grid communities.

VI. SCOPE AND DELIMITATION

The study focuses on reviewing existing literature related to automated deep-well irrigation systems used in remote and non-irrigated agricultural areas. The review covers automation technologies such as soil moisture sensors, microcontrollers, pump control systems, and energy sources, including conventional electricity and solar power. It also examines issues related to system reliability, long-term performance, and power consumption.

But this study is only limited to secondary data obtained from published journals, reports, and technical articles. It does not involve experimental testing, prototype development, or field validation of irrigation systems. Additionally, economic analysis, detailed hydraulic design computations, and site-specific geological assessments are beyond the scope of this review.

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Review of Related Literatures

The development of automated irrigation systems has gained significant attention due to the need for efficient water management in agriculture, particularly in remote and non-irrigated areas. Because water management remains a critical concern in the modern agriculture, particularly in regions where access to centralized irrigation infrastructure is limited. Agriculture account for significant portion of global fresh water use, emphasizing the need of improved irrigation technologies [2]. In response automated irrigation system and ground water-based solution have been widely studied to enhance water use efficiency and agricultural productivity [6][7].

Deep-well irrigation systems, particularly when combined with renewable energy sources like solar photovoltaic pumping have been found to be able to be used as a solution to remote and off-grid agricultural regions [8], [9]. Nevertheless, although past research examined the automation and solar powered pumping separately, few studies have examined comprehensive studies on automation strategies, longevity reliability, and energy use in integrated in deep-well irrigation. Consequently, the section will evaluate the available literature on these interrelated subject to provide a basis on the current research.

2.1 Irrigation Water Use and the Need for Automation

The agriculture is the greatest user of fresh water in the world in almost 70% of the total water abstractions [2], [6]. The lack of water, as well as climate change the rising food demand, has brought to the fore the need to practice irrigation more efficiently [1][3]. Conventional manual irrigation tends to overwater, lack productivity and agricultural yields [6][7]. These inefficiencies are more extreme in the remote where the farmers do not have the access to organized irrigation infrastructures.

According to FAO [1], inefficient irrigation wastage does not only lead to degradation of soil, loss soil nutrients, and less quality of crops. According to Evans and Sadler [6], the use of better scheduling techniques such as scheduling based on sensor will help decrease the amount of water used by up to 30% without reducing the crop yields, or even improving them. This fact highlights the need to incorporate automation in irrigation systems particularly off-grid and remote farms [7].

Alternative irrigation approach with fix timer are not studied thoroughly as some plant-based approaches such as soil moisture and crop water stress indexes. According to Jones [7], these approaches offer real-time information on the water requirements of crop, hence irrigation can only be done when required. Evett et al. [10] also show that the soil water sensing technologies enhance the estimation of evapotranspiration and schedules of irrigation optimization. When put together, these studies support the adoption of automated system of irrigation over manual system in order to ensure better management and conservation of water as resources [2] [6] [7] [10].

Feature	Manual Irrigation (Traditional)	Automated Irrigation (Smart/IoT)	Impact of Automation
Water Savings (%)	40%-60% Water Use Efficiency	85%-95% Water Use Efficiency	**20% - 55%** reduction in water consumption
Labor Reduction (%)	High (100% manual effort)	Minimal (System handles schedules)	**60% - 90%** reduction in labor hours
Precision	Variable; prone to over/under-watering	High; uses soil/weather sensors	**10% - 20%** reduction in crop loss from watering errors
Crop Yield	Standard baseline	Often higher due to consistent moisture	**15% - 30%** increase in yield for high-value crops
Initial Investment	Low (Hoses, basic tools)	High (Sensors, Controllers, setup)	Payback period typically **1 - 7 years**

Table 2.1: Comparison of Manual vs. Automated Irrigation Efficiency (Water Savings %, Labor Reduction %).

2.2 Automated and Sensor-Based Irrigation Systems

Sensor network microcontrollers and wireless communication systems creation. Gutierez et al. [8] created an automated system with soil moisture sensors and GPRS module, which permitted to maintain irrigation in real-time and save a lot of water. On the same note, O'Shaughnessy and Evett [9] adopted a canopy temperature-based system, which revealed enhanced control to the irrigation process in different environmental conditions.

Systems, which are based on soil moisture sensor, have continued to be found to optimize irrigation schedules, where water is applied only when soil moisture drops below critical level. [7] [10]. These systems prevent the need to waste water to unneeded irrigation and ensure that crops are healthy. In addition, remote monitoring, data logging, and automated decision-making are possible with the help of the loT – enabled platform and can specially helpful to farmers in remote areas [8] [10].

The recent studies also address the recent development of advanced computing application which could help better the irrigation process decision-making, e.g. artificial intelligence, fuzzy logic. As Mellit and Kalogirou [18] note that AI controlled system can adapt the irrigation activity to various environmental factors and enhance responsiveness and efficiency of the system. All these studies indicate that automation does not only make the water use more economical, but labor requirements are also minimized as well as there is enhanced stability in the operations [8][9][10][18].

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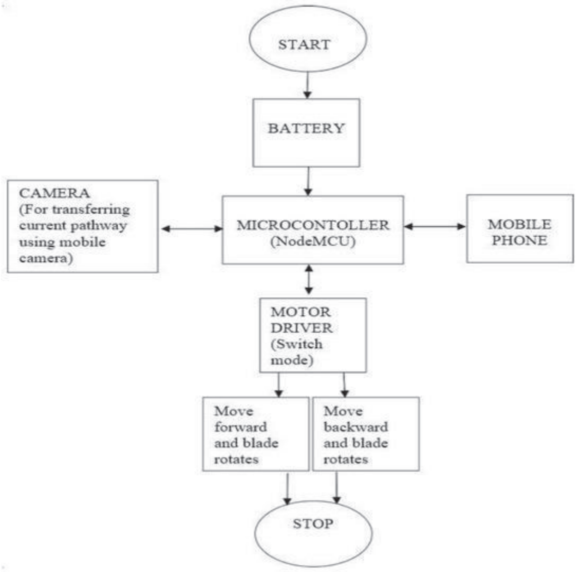

Figure 2.1: Conceptual diagram of IoT-based automated irrigation system.

2.3 Groundwater and Deep-Well Irrigation Systems

Ground water that is tapped in deep wells is very important source of water in areas that are distant to the conventional irrigation systems. According to Shah [11], deep well irrigation as well as rural livelihoods of the developing nations. Burney et al. [12] also highlights that ground water based distributed irrigation enhances resilience of farms and minimize the reliance of surface water sources.

However, even with these advantages there are risks of unregulated ground water extraction that may lead to depletion of aquifers, decline in quality of water and consumption of more energy [11][13]. Mukherji et al. [13] examined the application of solar power pumps in India and emphasized the need the balance to rate of extraction of water and the working of pumps to control the water availability versus the energy consumption. These works propose that a combination of deep well irrigation automation, and pumping plans that are efficient in terms of energy is a key to sustainability in the long term.

Pump Type	Typical Depth Range	Common Flow Rates (GPM / m³/h)	Ideal Use
Submersible	25 to 1,000+ feet	25 GPM (standard 1HP)	Deep wells, high demand
Deep-Well Jet	25 to 120 feet	5 to 15 GPM	Medium depth, lower demand
Vertical Turbine	Varies (Large scale)	High-capacity industrial	Municipal, large agriculture

Table 2.2: Types of Deep-Well Pumps, Capacity, and Energy Requirements.

2.4 Solar Pumping and Energy Efficiency

The consumption of energy is one of the significant limitation of deep well irrigation because it needs a great amount of water to pump. Diesel pumps are prevalent but cost a lot to operate and cause greenhouse gases emission [15][19]. Sustainable solutions to the off grid farming communities have been renewable energy alternatives, especially in solar photovoltaic(PV) pumping system [14][15].

Chandel et al. [15] made an extensive review on solar-powered irrigation pumps and discovered that solar system cut down the operation cost, and offer environmental advantages as well. Kumar and Kandpal [16] emphasized the PV based pumping systems are technically viable and used more frequently in rural regions. Also the ideal dimension of PV arrays and pump systems enhance the general efficiency and dependability.

Automated control with solar pumping can be used to schedule irrigation to only when water is required and when power is available to use, providing a better water and energy efficiency [14][15][16][17]. Mellit and Kalogirou [18] also prove that the AI based control will be able to optimize the use of the PV energy making the pump schedules depending on the level of the solar availability and soil moisture. The over all implication of this study is that automation and renewable energy have the potential to optimize the performance of a system in isolated rural farms.

Features	Solar Water Pump	Diesel Water Pump
Initial Cost	High (Primary barrier)	Low
Running Cost	Near Zero (Free energy)	High (Fluctuating fuel prices)
Maintenance	Minimal (Cleaning/pumps)	High (Frequent engine service)
Lifespan	20–25+ Years	7-15 Years (Engine wear)
Emissions	Zero	High(CO_2, NO_X, Smog)
Availability	Daytime only (without batteries)	Anytime (with fuel)

Table 2.3: Comparison of Diesel vs. Solar Pumps (Operational Cost, Efficiency, Emissions).

2.5 Reliability and System Sustainability

In remote automated irrigation systems, maintenance is restricted and thus the reliability has to be high. The most important factors determine the long term performance of the system is sensor accuracy, pump durability, and control stability [10][17]. Experiencing in the

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field demonstrate the effective calibration, protective casing and regular maintenance prolongs the life of the components and eliminate system breakdown [10][17][19].

Another factor that is very important is energy-water interdependence. The International Energy Agency [19] had noted the efficient management of energy is essential towards sustainable ground water pumping. Making the system reliable, minimizing downtimes, and improving their long term sustainability is achieved through combination of the durable elements, correct sizing and intelligent control measures [14][17][19].

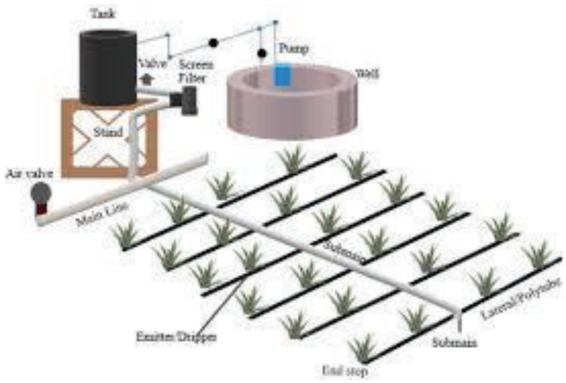

Figure 2.2: Reliability factors for automated deep-well irrigation systems.

Research Gap

The literature available has gone a long way automation of irrigation [8][10], ground water based system [11][12], solar powered pumping and energy efficiency optimization [17][18]. Nevertheless the majority of research addresses single element as opposed to combining automation, deep-well production, reliability and renewable energy into one system.

The existing body literature in the area of automated deep well irrigation system does not conduct comprehensive research on the performance of the combination of the system in remote agriculture. This gap can be filled to inform the creation of the resilient, energy efficient, and sustainable irrigation technologies to serve farmers, who are remote to conventional water infrastructure [8][11][14][17].

Conclusion

The literature review indicates the irrigation efficiency is one of the urgent issues in contemporary agriculture since water shortage is growing is growing and the energy needs is escalating. It always proves that labor intensive and manual irrigation methods leads to inefficient use of water, dependence of labor, and unreliable crop yields [2][6][7]. These technologies save unwarranted use of water and ensure crop productivity and hence automation is viable solution in enhancing agricultural activities.

Deep well system are important in the extraction of ground water, which is utilized in agricultural productivity in region that do not have surface irrigation system [7][8]. Nonetheless, there are issues related to the depletion of aquifer and the high rate of energy consumption that emphasize the necessity of developing sustainable methods of managing ground water [7][9]. The literature also suggest that the solar photovoltaic driven pumping system can also provide an economically feasible, yet environmentally sustainable alternative to diesel driven irrigation pumps [10][11][12]. Intelligent control strategies and optimization method can improve water and energy efficiency, which leads to reliability in the long run of the system [13][14][15].

However, even with the immense progress of automation technologies integration of ground water utilization as well as renewable energy, the current literature tends to analyze this aspects separately. Scarcity in the researchers give a significant evaluation of automation deep well irrigation system that have combination to consider water efficiency, power use and extended durability in distant agricultural regions. Hence, the study needs to be advanced to examine the quality and viability of the integrated automated deep well irrigation systems. Such as gap in the literature justifiers the existence of the current research.

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