Design and Fabrication of an Automated Mini Portable Sprinkler System

Aqib Ali[1], Mashooque Ali Talpur[2], Zaheer Ahmed Khan[3], Irfan Hussain Bhutto[1], Mian Noor Hussain Asghar Ali[3]*, Mir Muhammad Khan Talpur[1], Tasbeeha[1], Abdul Khalique Jatoi[1], Jazib Hussain Jakhrani[2].

[1]Faculty of Agricultural Engineering & Technology, Sindh Agriculture University, Tandojam, Sindh, Pakistan.

[2]Department of Land & Water Management, Faculty of Agricultural Engineering and Technology, Sindh Agriculture University, Tandojam, Sindh Pakistan.

[3]Department of Farm Structures and Postharvest Engineering, Faculty of Agricultural Engineering and Technology, Sindh Agriculture University, Tandojam, Sindh Pakistan.

Corresponding author: noorhussain@sau.edu.pk

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This research addresses critical limitations in Pakistan's agricultural sector, where irrigation is essential to sustain productivity for major crops like wheat, cotton, sugarcane, and rice. Current irrigation systems are often inefficient, lack automation, fail to accurately gauge adequate water application, and require significant user input, manual operation, and technical expertise. To overcome these challenges, a novel automated and portable pivotal sprinkler irrigation system is presented. The system's core is controlled by an Arduino Nano microcontroller, enabling fully automated operation. A key feature is the integration of a Bluetooth module, allowing a user to wirelessly control the system's movement right, left, forward, and backward-via a mobile device, effectively eliminating the need for complex, manual water supply connections. The water application depth is made adjustable through interchangeable sprinkler nozzles. Designed to be portable and easily managed, the framework features a fixed central point and a long rotating arm that pivots with the assistance of a sham wheel. This work successfully develops a compact and automated center-pivot system, proving the concept using Arduino Nano. Beyond new installations, the customizable design of this automated system offers a viable solution to upgrade and retrofit existing spraying, drip, and traditional sprinkler irrigation machinery, enhancing efficiency and resolving existing operational constraints across diverse field environments.

Keywords: Sprinkler System, Ardino Nano, Variation in Discharge, Area to be Covered by Nozzles, Application Rate, Gross Application Depth.

Introduction:

Water scarcity is a pervasive global crisis exacerbated by climatic fluctuations and the rapidly growing demand for limited freshwater, currently affecting an estimated 700 million people across 43 countries. This scarcity directly threatens food security, making the effective management of water resources crucial, especially in developing nations where over a billion people live in areas demanding highly efficient water use due to economic constraints [1]. Consequently, developing and deploying advanced irrigation systems is essential not only to boost agricultural productivity and meet the projected 50% surge in agricultural water demand by 2025 (as estimated by the International Water Management Institute) but also to ensure long-term food security and sustainable production worldwide, particularly in arid and semi-arid regions like Pakistan and India [2], [3].

This challenge is particularly acute in Pakistan, which falls within an arid to semi-arid climate zone. Here, the annual precipitation (ranging from below 100 mm to 1,050 mm) is drastically insufficient. The constant agricultural water requirement is approximately 1,778 mm. Historically; this shortfall has been managed through surface irrigation. However, rapid population growth has severely strained these inadequate resources. The population skyrocketed from 32.4 million in 1948 to an estimated 221 million by 2025 [4]. This exponential increase in demand makes the shift toward highly efficient, modern irrigation technologies an absolute necessity to avert a profound water crisis.

In response to increasing water scarcity and population pressures, the Government of Pakistan has prioritized the efficient use of water in agricultural production. For over a hundred years, Pakistani farmers have largely relied on conventional surface irrigation practices. This reliance has been profoundly detrimental. It has led not only to widespread waterlogging across the country but also to an exceptionally low yield per unit of water compared to global standards [4]. Consequently, there is an urgent need to transition from these outdated practices to modern, efficient irrigation systems. This transition is vital to conserve water, improve land health, and boost national agricultural output.

Recognizing the urgent need to enhance water use efficiency, Micro-irrigation (MI), also known as the High-Efficiency Irrigation System (HEIS), has been introduced as a vital strategy in Pakistan. HEIS primarily involves pressurized techniques like sprinkler and drip/trickle irrigation. These methods offer significantly greater efficiency compared to traditional practices. Flood or basin irrigation typically offers the lowest efficiency, between 40 and 50%. Overhead sprinklers can reach around 75%. Drip irrigation systems may achieve efficiencies of up to 90% [5].

These systems work by precisely delivering water directly onto or beneath the soil surface, right to the plant's root zone. This minimizes water loss and greatly reduces soil erosion. Furthermore, HEIS facilitates the precise application of both irrigation water and agrochemicals according to specific crop needs. Unlike basin and furrow methods, it also allows for the efficient irrigation of irregularly shaped fields without extensive land leveling [5].

Pakistan faces severe water scarcity, necessitating critical improvements in water management, particularly within the agricultural sector, to combat food insecurity and poverty. Formally classified as water-scarce, the nation relies primarily on the Indus River system and its tributaries, which supply an average of 138 million acre-feet (MAF) of water annually; however, this resource is unevenly distributed, with the Indus River contributing 65% of the supply, followed by the Chenab (19%) and the Jhelum (17%) [6]. Experts advocate for the adoption of improved water management techniques, such as monitoring soil moisture to enhance crop water productivity [7]. This urgency is amplified by a rapidly growing population, which is projected to increase from 165 million to a range of 234 to 357 million by 2025–2050, further aggravating the critical challenges related to per capita land and water availability and agricultural output [8].

In addition to scarcity, issues such as groundwater contamination pose significant challenges. This highlights the need to expand land use and increase cropping intensity to satisfy future food demands. However, adopting advanced methods remains a barrier. Sabbagh & Gutierrez [9] noted that a lack of knowledge prevents the acceptance of efficient irrigation. Although the pressurized pipe system, introduced via extension services, can minimize distribution losses, the farming community has resisted this shift. They prefer to maintain traditional sowing and flood irrigation methods due to required changes in their cropping patterns and supply systems.

Novelty Statement:

This study presents a mobile, Arduino-based pivotal sprinkler system with Bluetooth control, offering automated irrigation with adjustable discharge and application depth. Its portability and low-cost design differentiate it from traditional fixed systems, making it suitable for diverse agricultural settings, especially in arid regions.

Materials and Methods:

Methodology:

The present research, a compact mechanical structure was developed, featuring a wooden base that supports a small water tank connected to the sprinkler mechanism via a pipe, terminating in a controllable nozzle. The robot is fully controlled by an Arduino Nano microcontroller, programmed to receive and process data transmitted wirelessly from a mobile phone. This wireless command system controls essential tasks, including the rotation of the sprinkler pipe (the long rotating arm) and the starting and stopping of the water flow. Importantly, the system enables precise, site-specific irrigation: when the soil attains the target moisture level, the Arduino-controlled rotating arm automatically halts within its designated circular coverage area. This integration ensures that the required irrigation, optimized according to specific crop and soil needs, is delivered efficiently and at an optimal cost.

Channel Relay Module:

This 5V, 4-channel relay module requires 15–20 mA of current per channel and can control a variety of high-current appliances and devices. It provides a standard interface that allows direct control by a microcontroller, as depicted in Figure 1 [10].

Arduino Nano:

Arduino nano is important component that was used to control various parts of the sprinkler system, like rotating wheels and the speed of PVC pipes, with the help of programming, as shown in Figure 2 [11].

HC05 Bluetooth Module:

In the project, a Bluetooth module was used to control the movements of a Bluetooth-enabled car, allowing it to move forward, backward, left, and right. The Bluetooth module was controlled with the help of a mobile whose complete control was set up with a pre-coded program with the help of Arduino Nano, as shown in Figure 3 [12].

XL4015 Buck Converter:

The XL4015 5A is the DC-DC Step-down buck converter module. XL4015 works as a 180KHz fixed frequency PWM buck (step-down) DC/DC module. XL4015 can drive a 5A load with high efficiency, low ripples, and excellent line and load regulation, as shown in Figure 4 [13].

Spray Nozzles:

Spray nozzle or atomizer is a device that facilitates the dispersion of a liquid by the formation of a spray. Total four (4) nozzles were fixed in the sprinkler system, and the speed of the nozzles was easily adjustable, as shown in Figure 5 [14].

Figure 1. Channel relay module

Figure 2. Arduino nano

Figure 3. HC05 Bluetooth module

Figure 4. XL4015 buck converter

Figure 5. Spray Nozzles

Figure 6. DC motor water pump

Figure 7. DC rover speed motor

DC-Motor Water-Pump:

The proposed irrigation system employs a DC water pump [15], chosen for its low power consumption and quiet operation, making it well-suited for portable, battery- or solar-powered agricultural use. These small pumps were fundamentally designed for circulating, pressurizing, and emulsifying water within a closed system. Critically, when integrating this component, care must be taken to match the pump's power demands-as it draws up to 8.5 amps-with the chosen power source (battery, DC supply, or solar panel) to ensure stable and reliable performance in the field, as illustrated in Figure 6.

DC Rover Speed Motor: In the present project we used total 4 motors, which helped the wheel rotate to the right, left, forward and backward. We were using a 24-volt motor in our project, as shown in Figure 7 [16].

Location of Experiment:

The experiment was performed after the fabrication of the sprinkler system near the Department of Land & Water Management, Faculty of Agricultural Engineering and Technology, Sindh Agriculture University, Tandojam, Sindh, Pakistan, in December 2023. During this exercise, four parameters were measured, such as discharge, area to be irrigated, application rate and gross application depth from each nozzle.

Parameters:

After the design and fabrication of the automated sprinkler system, its performance was assessed, as it consists of three sprinklers. Initially, one sprinkler was kept open, and the rest were closed, and its discharge, diameter of water thrown, velocity of water and discharge were measured; these observations were repeated with two, three and four sprinklers, respectively.

Methods of Sprinkler System Discharge:

The discharge to nozzles by volume method was a way to determine the amount of water delivered by a sprinkler system based on the volume of water passing through the nozzles [17].

$$Q = V/t$$

Where, Q = Discharge of nozzles, V = Volume of water, (liter) & T = Time, (sec)

A pot of the same size was placed near the nozzle of each sprinkler, and time was noted. These readings were repeated 05 times, and average reading was considered as final. When the volume of the container was divided by the tithe, the flow rate was observed.

Precipitation or Application Rate:

The precipitation rate (or application rate) of sprinkler nozzles was measured by the amount of water applied to a specific area over a given time. The application rate depends on the size of sprinkler nozzles, the operating pressure and the distance between sprinklers [18].

$$I = (0.042 \times Qs)/(D \times SB)$$

Where, I = Precipitation or application rate, (inch/min), Qs = Discharge from individual nozzles, (LPS), D = Diameter of nozzles, (inch), & SB = Spacing of nozzles, (inch)

The same procedure of discharge measurement was repeated, and then the area of the nozzle was calculated from the diameter of the nozzle. Finally, by discharge was divided by the area velocity.

Gross Application Depth:

The gross application depth of a sprinkler system refers to the total amount of water applied to a given area by sprinklers. It was expressed in inches.

$$D = Qs/ (0.189\times 〚V\times S〛 SB)$$

Where, D = Application depth, (inches), V = Velocity of rotational speed of individual sprinkler (m/sec), Qs = Discharge from individual nozzles, (LPS), and SB = Spacing of nozzles (meters).

Results:

Figure 8 illustrates the relationship between the number of open nozzles and the resulting discharge in cubic centi-meters per second (cu.cm/s), demonstrating a positive correlation between the two variables. The x-axis represents the experimental control variable, the 'No. of open nozzles,' systematically varied from 1 to 4. The y-axis plots the measured 'Discharge (cu.cm)' (likely cu.cm/s). The data clearly shows that as the number of open nozzles increases, the total discharge dramatically rises from approximately 6.17cu.cm/s for one nozzle to 8.16 cu.cm/s for two, 11.98cu.cm/s for three, and a final value of approximately 24.39cu.cm/s for four open nozzles. This trend confirms that increasing the total effective flow area by opening more nozzles leads to a significant increase in the overall system discharge.

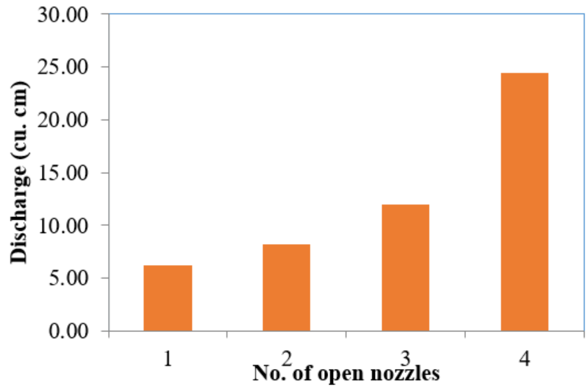

Figure 8. Discharge of different nozzles

The results showed that when one nozzle was opened, it delivered less discharge compared to configurations with two, three, or four nozzles individually. It was observed that opening two nozzles increased the discharge by approximately 32.24%, three nozzles by about 94%, and four nozzles resulted in a 294% increase in discharge. As the number of nozzles increased, overall discharge also rose. However, when examining the discharge per individual nozzle, it was observed that with two nozzles open, each nozzle's discharge dropped to about 66%. With three nozzles open, the discharge per nozzle further decreased to 64.8%, whereas with all four nozzles operating, each nozzle delivered approximately 98.88% of its capacity, as presented in Table 1. The result further revealed that when the area covered by nozzles was measured, it was observed that when more nozzles were opened it was observed that the area coverage increased. It was observed that with one nozzle open, the coverage area was about 81% smaller compared to four nozzles. With two nozzles open, the area was approximately 61% smaller, and with three nozzles open, it was about 47% smaller than the coverage achieved with all four nozzles, as shown in Figure 9. The relationship is mathematically represented by the linear regression equation y = 2.9662x - 1.3353, which fits the data well, as indicated by the high coefficient of determination, R2 = 0.9303. It is also observed that area coverage increases as a greater number of nozzles were kept open, which shows a direct relation. The setup of measured discharge and area coverage shown in Figure 10.

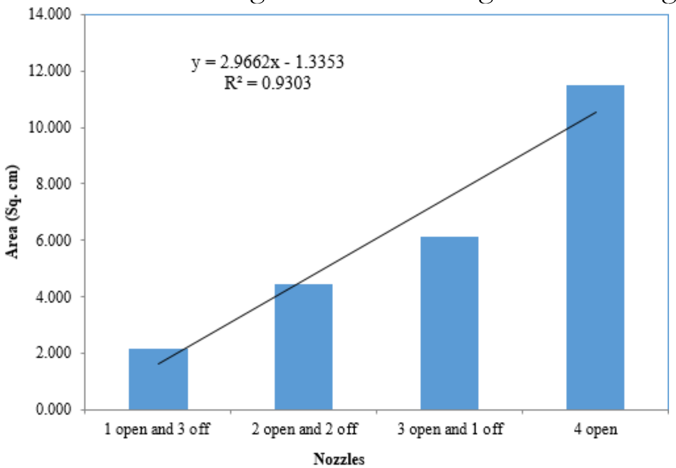

Figure 9. Area to be irrigated by different numbers of nozzles (sq. cm)

Figure 10. Measuring the discharge, inner and outer area covered

Table 1. Discharge parameters and velocity as a function of open nozzles

No. of open nozzles	Dia of nozzle (cm)	Volume of tank (cm^3)	Time taken to empty tank (sec)	Total area of nozzles (cm^2)	Velocity (cm/s)	Variation of discharge of individual nozzle %
1	1.397	2000	324	1.533	4.027	100
2	1.397	2000	245	3.066	2.663	33.88
3	1.397	2000	167	4.598	2.604	35.33
4	1.397	2000	82	6.131	3.978	1.22

Figure 11 comparing the measured discharge values in cm3/sec with their corresponding percentage variations, illustrating the experimental results within the study. The x-axis displays the four distinct discharge values (6.173, 8.163, 11.976, and 24.39 cm3/sec), while the y-axis represents the calculated discharge variations in percentage (%). The initial discharge of 6.173 cm3/sec serves as the baseline, corresponding to a 100% variation (or reference point). Subsequent discharge values show variations of 32.24%, 94.01%, and a substantial increase to 295.12% for the final discharge of 24.39 cm3/sec. The figure effectively visualizes the non-linear trend where increasing discharge magnitude leads to a marked increase in the percentage variation relative to the initial baseline, highlighted by the dotted trend line connecting the tops of the bars.

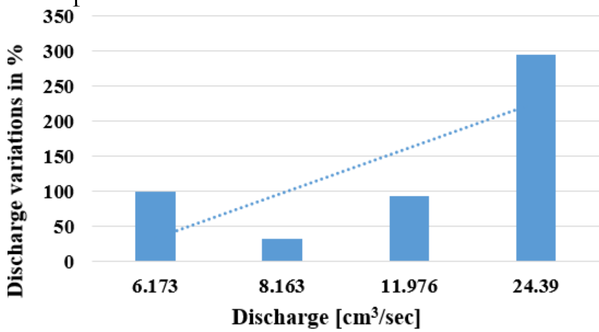

Figure 11. Comparison between Discharge (cm3/sec) and Discharge Variation (%).

Figure-12 comparing the required area coverage for sprinklers in m2 with the corresponding percentage of less area needed if nozzles were used instead, illustrating a key efficiency metric for different irrigation or fire suppression system designs. The x-axis displays four distinct area requirements (2.186, 4.472, 6.148, and 11.515m2), and the y-axis shows the percentage of area reduction (% of less area to be covered by Nozzles). The data suggests that for a required coverage area of 2.186 m2, using nozzles reduces the area by 81.1%, followed by reductions of 60.9% and 46.2% for the middle areas. Notably, the largest required sprinkler coverage area of 11.515 m2 yields the maximum area reduction of 100% when using nozzles, implying that nozzles are significantly more efficient for covering larger areas, as suggested by the generally increasing trend line connecting the bars.

Table 1, the present data collected from a fluid dynamics test investigating the effect of varying the number of open nozzles on flow characteristics. The experiment maintained a constant nozzle diameter (1.397 cm) and a constant tank volume (2000 cm3) across all four test runs. The key manipulated variable, the 'No. of open nozzles,' was systematically increased from one to four. The measured output, 'Time taken to empty tank (sec),' decreased significantly from 324 to 82 seconds as the number of nozzles increased. Calculated parameters are also presented: the 'Total area of nozzles (cm2)' increased proportionally from 1.533 to 6.131 cm2. The 'Velocity (cm/s)' showed a non-linear trend, decreasing initially from 4.027 to 2.604 cm/s before increasing again to 3.978 cm/s for four nozzles. Finally, the 'Variation of discharge of individual nozzle %' establishes the single-nozzle run as the 100% reference, with subsequent runs showing a significant drop in the individual nozzle's discharge percentage, indicating a negative correlation between the number of open nozzles and the efficiency (or discharge rate) of each single nozzle.

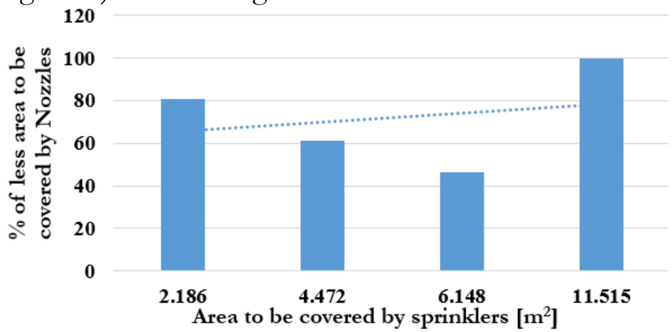

Figure 12. Comparison between Area to be covered bysprinklers (m^2) and % of less area to be covered byNozzles

This table 2 quantifies the changes in water coverage geometry based on the operating configuration of a four-nozzle system. The experiment systematically varied the 'On/Off Nozzles' from one open nozzle to four open nozzles. For each configuration, the 'Internal diameter of water throw (m)' and 'Area of internal sprinkler (m2)' demonstrated a strong inverse relationship with the number of open nozzles, decreasing from 0.92m and 0.664m2 to 0.204m and 0.033m2, respectively. Conversely, both the 'External diameter of water Throw (m)' and the 'Area of external sprinkler (m2)' showed a direct proportional relationship, increasing consistently from 1.905m and 2.85m2 to maximum values of 3.834m and 11.547m2 when all four nozzles were active. These results indicate that increasing the number of active nozzles significantly expands the overall area of water coverage while simultaneously creating a smaller, more concentrated void or core area at the center of the spray pattern.

Table 2. Effect of nozzle configuration on water throw diameters and coverage areas

On/Off Nozzles	Internal diameter of water throw (m)	External diameter of water Throw (m)	Area of internal sprinkler (m^2)	Area of external sprinkler (m^2)
1 open and 3 off	0.92	1.905	0.664	2.85
2 open and 2 off	0.61	2.463	0.292	4.764
3 open and 1 off	0.509	2.844	0.203	6.352
4 open	0.204	3.834	0.033	11.547

Discussion:

The results indicate that when only one nozzle was opened, it produced less discharge compared to scenarios where two, three, or four nozzles were opened individually. The data reveals a progressive increase in discharge as the number of open nozzles rises [19]. Specifically, opening two nozzles resulted in a significant 32.24% increase in discharge. This trend continues with even greater improvements: three open nozzles result in a significant 94% increase, and four open nozzles lead to an impressive 294% more discharge. These findings demonstrate a positive correlation between the number of active nozzles and the total discharge, indicating a cumulative effect [20]. Interestingly, when examining the discharge of individual nozzles in these scenarios, a different pattern emerges. For example, when two nozzles were open, the discharge of each nozzle decreased to approximately 66%. This reduction became more pronounced with three nozzles open, where individual discharge further declined to 64.8%. However, in the case of all four nozzles being open simultaneously, each nozzle showcases a notably high discharge, reaching about 98.88% [21].

Results further shed light on the relationship between the number of opened nozzles and the area coverage they achieve. The results indicate a notable increase in the area covered as more nozzles are opened, suggesting a direct correlation between the two variables. Specifically, when only one nozzle is open, it covers about 81% less area compared to the scenario where four nozzles are simultaneously opened. This substantial reduction in coverage with a single open nozzle suggests limited effectiveness in spreading the discharge over a wider surface [22].

A clear trend emerges as the number of open nozzles increases. With two nozzles open, the coverage area improves but remains about 61% smaller than that achieved with four nozzles open. The pattern continues with three open nozzles, providing even greater coverage but still resulting in approximately 47% less coverage compared to the four-nozzle configuration. These findings underscore the positive relationship between the number of active nozzles and the extent of area coverage. The progressive improvement in coverage with each additional open nozzle implies that multiple nozzles working concurrently contribute synergistically to a more efficient distribution of the discharge [23], [24].

Conclusion:

This research successfully demonstrated the functionality of a novel, low-cost automated pivotal sprinkler irrigation system controlled by a Bluetooth-enabled car across various field and environmental conditions. The framework not only allows for the limited and precise application of water required by specific crops but also provides a viable solution for agricultural condition monitoring. Furthermore, the system is designed for easy modification: it can be adapted to detect tank water levels and automatically trigger a sound alarm and switch on the water motor when the supply runs low. By implementing effective control drives and communication protocols, we met the energy requirements for site-specific water management using a portable sprinkler setup. While current implementation utilizes Bluetooth for portability and ease of handling-making it highly effective for areas facing acute water shortages-the foundational architecture can readily incorporate other wireless communication techniques to control motion over significantly larger irrigation areas, offering a flexible and scalable solution for modern, water-efficient agriculture.

Author Contribution:

Aqib Ali performed the research work and wrote the manuscript, Mashooque Ali Talpur & Zaheer Ahmed Khan proposed, designed and supervised the whole research, Mian Noor Hussain Asghar Ali reviewed and finalized the manuscript, Irfan Hussain Bhutto and Mir Muhammad Khan collected the data, Jazib Hussain Jakhrani, Abdul Khalique Jatoi and Tasbeeha analyzed the data.

Conflict of Interest:

The Authors declare that there is no conflict of interest regarding the publication of the article.

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