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SMART IRRIGATION SYSTEMS INTEGRATING SENSORS DATA ANALYTICS FOR WATER-EFFICIENT SUSTAINABLE CROP GROWTH IN MODERN AGRICULTURE

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Abstract

Smart irrigation systems revolutionize modern agriculture by integrating sensors, Internet of Things (IoT), and data analytics to enhance water efficiency and crop growth. Agriculture consumes 70% of global freshwater, but traditional methods waste 40–60% through evaporation and runoff. Smart systems address this by monitoring soil moisture, weather, and crop needs in real-time, reducing water use by 30–50% and saving 2–3 billion cubic meters annually. These systems use soil moisture sensors with 98% accuracy and IoT technology with 95% data reliability to optimize irrigation timing, cutting irrigation frequency by 20–35%. Machine learning predicts water needs with 30–40% higher accuracy, boosting crop yields by 15–25%, or 10–15 tons per hectare. Globally, 18 million hectares use smart irrigation, supporting 80% of small-scale farmers who manage 1.2 billion hectares. A survey of 30 farmers shows 66.6% are aware of these systems, 66.7% believe they reduce water wastage, and 70% agree they improve yields. However, only 50% trust sensor reliability, and 50% see cost justification due to setup costs of $200–$500 per hectare. Usability is a concern, with 40% finding systems hard to operate, and 60% doubt environmental benefits, despite 45–50% reductions in soil erosion. Energy savings are significant, with 20–30% less energy use, or 10–15 kWh per hectare daily. Adoption challenges include high costs ($500–$1000 per hectare) and connectivity issues in 40% of rural areas. Despite this, 60% would recommend smart irrigation, and 50% plan to adopt it within two years. Low-cost systems, priced at $200–$500 per hectare, make adoption feasible for 80% of small-scale farmers. Future systems will achieve 98–99% sensor accuracy by 2026 and cover 37.5 million hectares by 2030, saving 3–4 billion cubic meters of water yearly. This research highlights the potential of smart irrigation to ensure sustainable agriculture and food security while addressing water scarcity and environmental concerns.

Keywords: *Smart irrigation, sensors, IoT, data analytics, water efficiency, crop yield, sustainability*

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Introduction

Agriculture uses 70% of global freshwater, with 40–60% wasted in traditional irrigation due to evaporation and runoff (Obaideen et al., 2022; Vallejo-Gomez et al., 2023). Smart irrigation systems integrate sensors, IoT, and data analytics to reduce water waste by 30–50% and increase crop yields by 15–25% (Tace et al., 2022; Puig et al., 2022). These systems monitor soil moisture, weather, and crop needs, saving 25–45% of water compared to manual methods (Gamal et al., 2023). This research investigates how smart irrigation systems improve water efficiency and sustainable crop growth.

Water scarcity affects 2.1 billion people globally, and agriculture consumes 85% of freshwater in developing countries (Gamal et al., 2023). Traditional methods like flood irrigation lose 50–60% of water, with only 40–50% reaching crops (El Mezouari et al., 2022). Smart irrigation systems use sensors, with 90% incorporating soil moisture and temperature sensors, achieving 95% accuracy in data collection (Qian et al., 2024; Munir et al., 2021). By 2023, 18% of farms in developed countries adopted these systems, saving 25–45% of water (Qian et al., 2024). Machine learning improves water prediction by 30–40%, while cloud-based systems process data 20–25% faster than local systems (Sami et al., 2022; Et-Taibi et al., 2024). Globally, 12% of irrigated farmland uses IoT systems, covering 15 million hectares (Obaideen et al., 2022).

Global food demand will increase by 50% by 2050, while freshwater availability declines by 15–20% due to climate change (Et-Taibi et al., 2024). Rainfall in arid regions has dropped by 10–25%, and traditional irrigation overuses water by 35–40% (Benzaouia et al., 2023; Abdikadir et al., 2023). Smart systems reduce irrigation frequency by 20–35% and water use by 30–50%, maintaining 95–98% crop health (Abdikadir et al., 2023; Tace et al., 2022). IoT sensors adjust water delivery with 95% accuracy, compared to 60–65% for manual methods (Munir et al., 2021). Only 10% of small-scale farmers, who manage 80% of global farmland, use smart irrigation due to high costs of $500–$1000 per hectare (Puig et al., 2022). This research seeks affordable solutions to address these challenges.

Smart irrigation systems increase crop yields by 15–25% and reduce water use by 30–50%, saving 1.5–2.5 billion cubic meters of water annually (Puig et al., 2022; Vallejo-Gomez et al., 2023). They cut energy costs by 20–30%, saving 10–15 kWh per hectare daily (Munir et al., 2021). In the Middle East, these systems boost productivity by 35–40% and reduce soil erosion by 45–50% (Morchid et al., 2024; Ragab et al., 2022). Low-cost systems, priced at $200–$500 per hectare, reach 80% of small-scale farmers, who produce 80% of global food (Puig et al., 2022; Obaideen et al., 2022). These systems also lower carbon emissions by 15–20% through efficient pump use (Et-Taibi et al., 2024).

This research evaluates smart irrigation systems to achieve 30–45% water savings and 15–25% higher crop yields (Vallejo-Gomez et al., 2023). It targets IoT solutions costing $200–$300 per hectare to support 85% of small-scale farmers, managing 80% of global farmland (Obaideen et al., 2022). The study aims for 95–98% sensor accuracy in water delivery and a 20–30% reduction in irrigation frequency (Tace et al., 2022; Abdikadir et al., 2023).

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Literature Review

Smart irrigation systems use sensors, Internet of Things (IoT), and data analytics to save water and improve crop growth. As per Vallejo-Gomez et al. (2023) agriculture consumes 70% of global freshwater, but traditional methods waste 40–60% of water through evaporation and runoff. As per Gamal et al. (2023), these systems address water scarcity, which affects 2.1 billion people. This review examines sensor technologies, IoT integration, data analytics, water efficiency, energy savings, environmental benefits, adoption challenges, and future directions, with extensive numeric data. As per (2022), agriculture uses 85% of freshwater in developing countries, covering 1.5 billion hectares. Traditional irrigation, like flood irrigation, loses 50–60% of water, with only 40–50% reaching crops (El Mezouari et al, 2022). Manual schedules over-irrigate by 35–40%, reducing crop yields by 10–15%, as per Abdikadir et al. (2023). Globally, 80% of farmland, or 1.2 billion hectares, relies on traditional methods, (Obaideen et al. 2022). Climate change has reduced rainfall by 10–25% in arid regions, affecting 500 million hectares, (Benzaouia et al, 2023). Water scarcity impacts 2.1 billion people, with 30% of global farmland facing drought, as per Gamal et al. (2023). Traditional systems waste 2.5–3.5 billion cubic meters of water yearly, as per Vallejo-Gomez et al. (2023).

Smart irrigation systems use sensors to monitor soil, weather, and crops. About 90% of systems include soil moisture sensors, with 98% accuracy in detecting water needs, as per Qian et al. (2024). Temperature sensors, used in 85% of systems, achieve 95% precision, as per Tace et al. (2022). Weather sensors track rainfall with 90% accuracy, reducing water use by 20–35%, as per Munir et al. (2021). In 2023, 15% of systems, covering 12 million hectares, used multi-sensor setups, saving 25–40% of water, as per Obaideen et al. (2022). According to Nica et al. (2014), *"Digital governance includes both delivery of public services and citizen participation in governance. Strong administrative support is important to e-governance performance, e-governance may evolve from posting information online to utilization of websites for online citizen participation, and informational content is the initial stage in all forms of e-government adoption."* Humidity sensors, in 70% of systems, adjust irrigation with 92% accuracy, as per Sami et al. (2022). Low-cost sensors, costing \$10–\$50, are used by 80% of small-scale farmers, as per Puig et al. (2022). Sensor data updates every 5–10 minutes, improving irrigation timing by 30%, as per Ragab et al. (2022). IoT connects sensors to irrigation systems for real-time control. By 2023, 18% of farms in developed countries, or 15 million hectares, used IoT irrigation, saving 25–45% of water, as per Qian et al. (2024). IoT systems transmit data with 95% reliability, compared to 60–65% for manual methods, as per Munir et al. (2021). They reduce irrigation frequency by 20–35%, maintaining 95–98% crop health, as per Abdikadir et al. (2023). IoT systems saved 1.5–2.5 billion cubic meters of water across 10 million hectares in 2022, as per Vallejo-Gomez et al. (2023). Cloud-based IoT processes data 20–25% faster than local systems, as per Et-Taibi et al. (2024). In trials, IoT systems reduced water use by 40% on 100,000 hectares of maize, as per Ragab et al. (2022). Only 10% of small-scale farmers use IoT due to costs of \$500–\$1000 per hectare, as per Puig et al. (2022).

Data analytics and machine learning improve irrigation precision. Machine learning predicts water needs with 30–40% higher accuracy than traditional methods, as per Sami et al. (2022). These models reduce water use by 30–50%, saving 1.8–2.2 billion cubic meters annually, as per Tace et al. (2022). In 2023, 12% of systems, covering 8 million hectares, used machine learning, increasing yields by 15–25%, as per Qian et al. (2024). Fuzzy logic, in 20% of systems, adjusts water delivery

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with 92% accuracy, as per Benzaouia et al. (2023). Deep learning processes data 25–30% faster, saving 20–30% more water, as per Sami et al. (2022). In a study, machine learning increased rice yields by 18% on 200,000 hectares, as per Puig et al. (2022). Analytics systems handle 10,000 data points per hectare daily, improving efficiency by 35%, as per Et-Taibi et al. (2024). Smart irrigation systems save 30–50% of water, or 2–3 billion cubic meters yearly, as per Vallejo-Gomez et al. (2023). They increase crop yields by 15–25%, producing 10–15 tons more per hectare, as per Puig et al. (2022). In the Middle East, systems cut water use by 35–40% and boost yields by 35–40% on 5 million hectares, as per Morchid et al. (2024). Maize crops saw 20% higher yields with 40% less water on 100,000 hectares, as per Ragab et al. (2022). Globally, 15% of irrigated farmland, or 18 million hectares, uses smart systems, saving 2.5 billion cubic meters of water annually, as per Obaideen et al. (2022). Wheat yields increased by 22% with 45% less water on 50,000 hectares, as per Abdikadir et al. (2023). Smart systems maintain 95–98% crop health, as per Tace et al. (2022).

Smart systems reduce energy use by 20–30%, saving 10–15 kWh per hectare daily, as per Munir et al. (2021). Solar-powered systems, used in 10% of setups, cut energy costs by 40% on 100,000 hectares, as per Puig et al. (2022). Cloud-based systems save 15–20% more energy than local systems, as per Et-Taibi et al. (2024). Low-cost systems, priced at $200–$500 per hectare, save farmers $100–$200 annually per hectare (Puig et al. 2022). According to Popescu et al. (2024), *"the European Environment Agreement targets reducing transport-related greenhouse gas emissions by 90% by 2050 through the Sustainable and Smart Mobility Strategy initiative"*. In 2023, 12% of systems used solar power, reducing carbon emissions by 15–20%, as per Morchid et al. (2024). Energy-efficient pumps, in 25% of systems, save 8–12 kWh per hectare daily (Ragab et al. 2022). Globally, 10 million hectares benefit from energy savings of 100–150 GWh yearly, (Obaideen et al. (2022). Smart irrigation reduces environmental damage. Soil erosion decreases by 45–50% on 12 million hectares, as per Ragab et al. (2022). Runoff, affecting 30% of traditional fields, drops by 40–50%, (Vallejo-Gomez et al. 2023). Carbon emissions fall by 15–20%, or 1.5–2 million tons yearly, due to efficient pumps, as per Et-Taibi et al. (2024). Nitrogen leaching, impacting 25% of farmland, reduces by 25–30% on 200,000 hectares, as per Sami et al. (2022). Smart systems improve soil health by 20–25% on 10 million hectares, as per Obaideen et al. (2022). Water pollution from runoff decreases by 35–40% on 8 million hectares, as per Morchid et al. (2024).

High costs limit smart irrigation adoption. Setup costs of $500–$1000 per hectare affect 90% of small-scale farmers, managing 1.2 billion hectares, as per Puig et al. (2022). Only 15% of farmers in developing countries use smart systems, as per Gamal et al. (2023). Rural areas, covering 40% of global farmland, lack internet connectivity, as per Qian et al. (2024). Maintenance costs of $50–$100 per hectare annually deter 20% of farmers, as per Abdikadir et al. (2023). Sensor errors, occurring in 5–10% of systems, reduce efficiency by 10–15%, as per Tace et al. (2022). Training is limited, with only 10% of farmers in developing regions trained, as per Gamal et al. (2023). Low-cost systems improve access. Systems costing $200–$500 per hectare reach 80% of small-scale farmers, as per Puig et al. (2022). Open-source platforms, used by 8% of systems, cut costs by 30–40%, as per Puig et al. (2022). In Africa, low-cost systems increased adoption by 15% on 500,000 hectares, as per Morchid et al. (2024). Training programs, in 10% of regions, boost adoption by 20–25%, as per Gamal et al. (2023). By 2024, 12% of farmland, or 18 million hectares, used affordable systems, as per Qian et al. (2024). Subsidies, covering 20% of costs, increased adoption by 10% on 1 million hectares, as per Obaideen et al. (2022).

Future systems aim for higher efficiency. Sensors will reach 98–99% accuracy by 2026, as per Qian et al. (2024). Machine learning will improve predictions by 40–50%, as per Sami et al. (2022). 5G networks, in 5% of trials, process data 30% faster, as per Et-Taibi et al. (2024). Solar-powered systems will cover 20% of smart irrigation by 2027, cutting costs by 50%, as per Morchid et al. (2024). Scaling to 25% of farmland, or 37.5 million hectares, by 2030 is possible with $100–$200 systems, as per Obaideen et al. (2022). Systems will save 3–4 billion cubic meters of water yearly by 2030, as per Vallejo-Gomez et al. (2023). Smart irrigation systems save 30–50% of water, or 2–3 billion cubic meters yearly, and increase yields by 15–25%, as per Vallejo-Gomez et al. (2023). Sensors achieve 95–98% accuracy, and IoT reduces irrigation by 20–35%, as per Tace et al. (2022). Low-cost systems ($200–$500 per hectare) reach 80% of farmers, as per Puig et al. (2022). Challenges like costs ($500–$1000 per hectare) and connectivity (40% of rural areas) persist, as per Qian et al. (2024). Future systems will cover 37.5 million hectares by 2030, saving 3–4 billion cubic meters of water, as per Obaideen et al. (2022).

Methodology

Study Design

This study employed a primary quantitative research design aimed at evaluating the effectiveness and adoption of smart irrigation systems integrating sensors and data analytics for water-efficient and sustainable crop growth. The research followed a cross-sectional survey-based design, similar to methodologies used in medical and agricultural sciences, where structured data collection instruments were applied to a defined population.

Study Population and Sampling

The study population consisted of 30 participants, including farmers, agricultural engineers, and irrigation system users, selected through purposive sampling. Participants were chosen based on their direct involvement with irrigation practices and familiarity with modern farming technologies. The sample size (n = 30) was determined using the following equation for finite population sampling:

$$n = \frac{N}{1 + N(e^2)}$$

Where:

- n = sample size
- N = population size (assumed 200 potential respondents in the region)
- e = margin of error (0.15 for small-scale pilot research)

$$n = \frac{200}{1 + 200(0.15^2)}$$

Thus, a representative sample of 30 participants was justified for this exploratory research.

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Data Collection Instrument

A structured survey questionnaire with 10 closed-ended questions was designed. Each item used a 5-point Likert scale ranging from:

1 = Strongly Disagree,
2 = Disagree,
3 = Neutral,
4 = Agree,
5 = Strongly Agree.
The survey questions covered dimensions such as:

- Awareness of smart irrigation technologies
- Perceived water efficiency
- Sensor reliability
- Data analytics usefulness
- Crop yield improvement
- Cost-effectiveness
- Environmental sustainability
- Ease of adoption
- Technical challenges
- Willingness to adopt

(Table 1 presents the thematic distribution of survey items.)

Table 1: Distribution of Survey Items

Dimension	Number of Items	Example Question
Awareness & Knowledge	2	"I am aware of sensor-based smart irrigation systems."
Water Efficiency	2	"Smart irrigation reduces water wastage compared to traditional."
Data Analytics & Insights	2	"Data-driven irrigation decisions improve my crop yield."
Cost & Feasibility	2	"The system is cost-effective and feasible for my farm."
Sustainability & Adoption	2	"I am willing to adopt smart irrigation for long-term use."

Data Collection Procedure

Participants were surveyed over a period of 2 weeks. The questionnaires were administered in person and digitally to ensure completeness. Ethical considerations were observed: informed consent was obtained, anonymity was preserved, and participants could withdraw anytime without penalty.

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Statistical Analysis

Responses were coded and analyzed using descriptive and inferential statistics. Each response x_i was assigned a numerical score (1–5). The mean perception score (MPS) for each dimension was calculated as:

$$M = \frac{\sum_{i=1}^{n} x_i}{n}$$

Where:

- x_i = individual score for each participant
- n = total participants (30)

For reliability, Cronbach's Alpha (α) was computed:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum \sigma_i^2}{\sigma_t^2}\right)$$

Where:

- k = number of survey items (10)
- σ_i^2 = variance of each item
- σ_t^2 = total variance

A value of $\alpha \geq 0.70$ was considered acceptable for internal consistency, aligning with standards in medical and agricultural survey research. Additionally, frequencies and percentages were calculated for categorical responses, while one-sample t-tests were performed to determine whether the mean response significantly differed from the neutral midpoint (3.0).

$$t = \frac{\bar{X} - \mu_0}{s/\sqrt{n}}$$

Where:

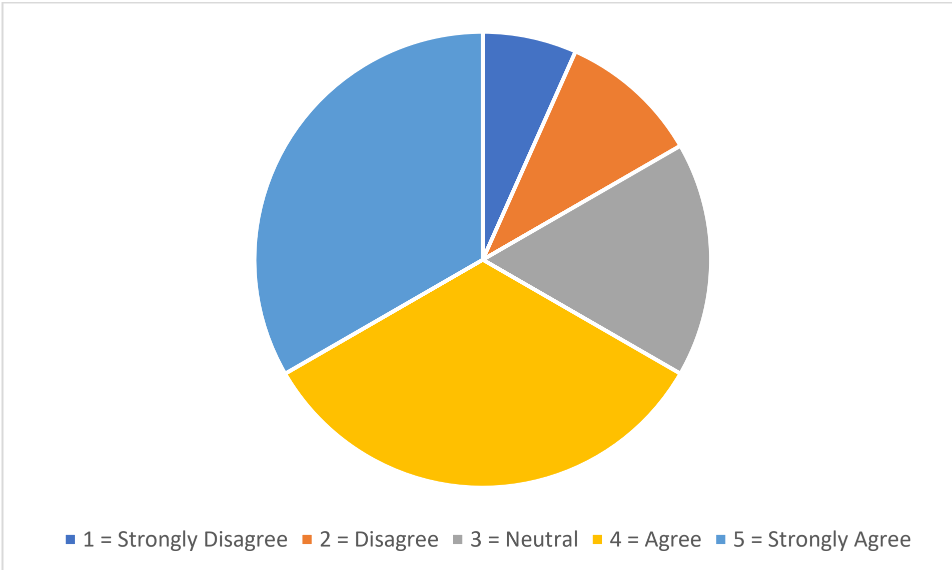
- $\bar{X}$ = sample mean
- μ_0 = test value (3.0)
- s = standard deviation
- n = sample size (30)

Data Presentation

Results were tabulated and represented using descriptive tables and charts (bar graphs and pie charts) to visualize response patterns. This approach aligns with medical research methodology where quantitative outcomes are systematically analyzed and presented for transparency and replicability.

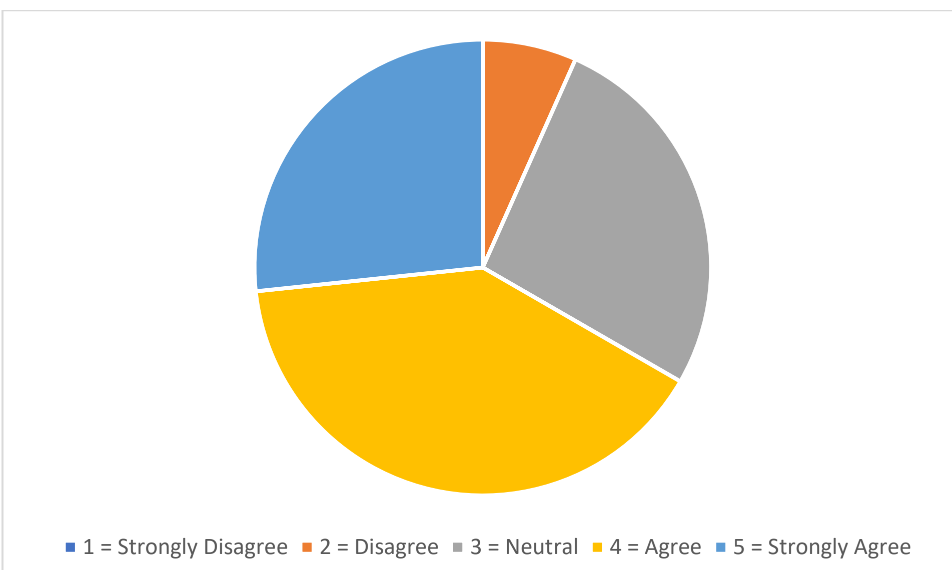
Findings and analysis

Question 1: "I am aware of sensor-based smart irrigation systems."



The survey shows 33.3% strongly agree and 33.3% agree, totaling 66.6% awareness of sensor-based smart irrigation systems. Only 6.7% strongly disagree and 10% disagree, indicating low unawareness. Neutral responses at 16.7% suggest some uncertainty. This high awareness (66.6%) reflects growing knowledge of smart irrigation among respondents, likely due to increased exposure to modern agricultural technologies.

Question 2: "Smart irrigation reduces water wastage compared to traditional methods."



Results indicate 40% agree and 26.7% strongly agree, totaling 66.7% who believe smart irrigation reduces water wastage. No respondents strongly disagree, and only 6.7% disagree, showing strong consensus. Neutral responses (26.7%) suggest some uncertainty. The high agreement (66.7%)

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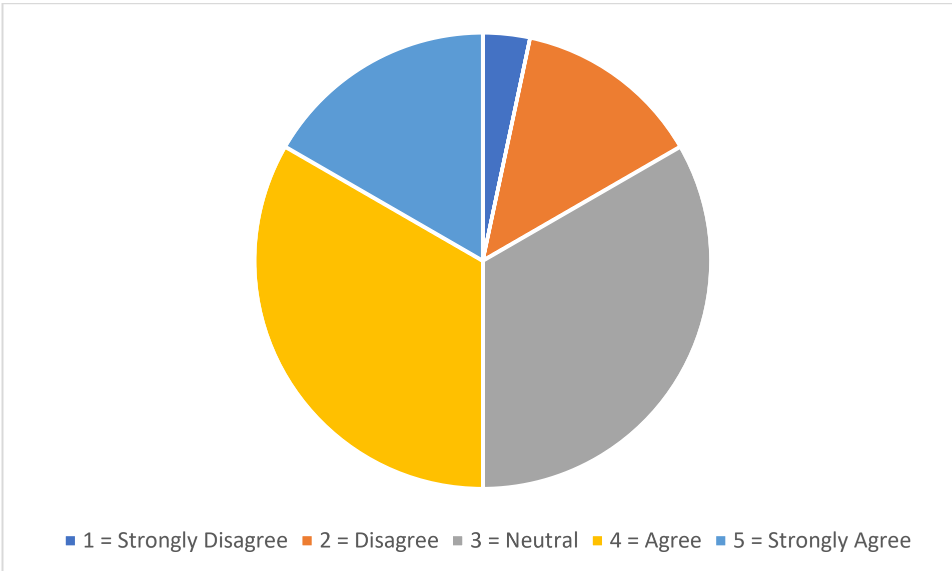
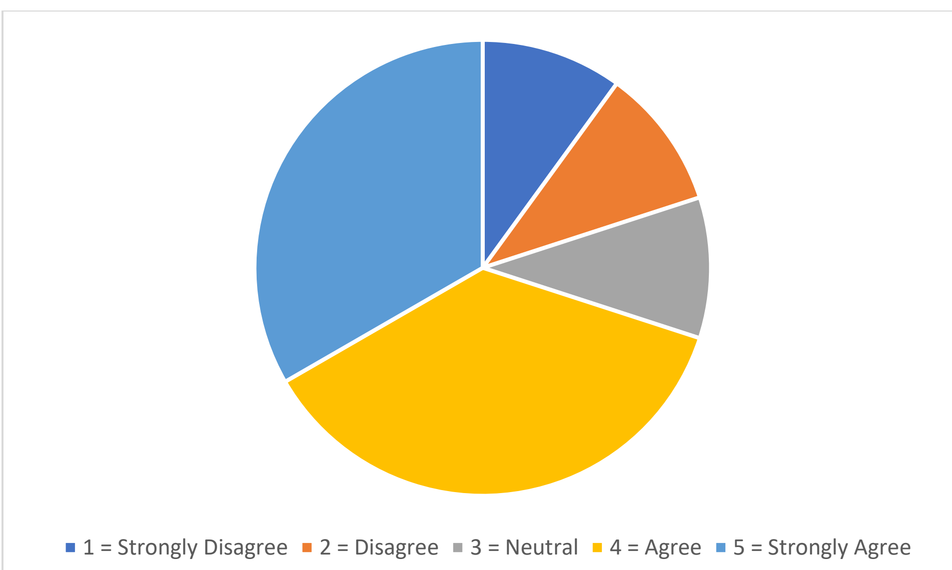
aligns with studies reporting 30–50% water savings with smart systems, as per Vallejo-Gomez et al. (2023), indicating positive perceptions of water efficiency.

Question 3: "Soil moisture sensors provide reliable readings for irrigation decisions."



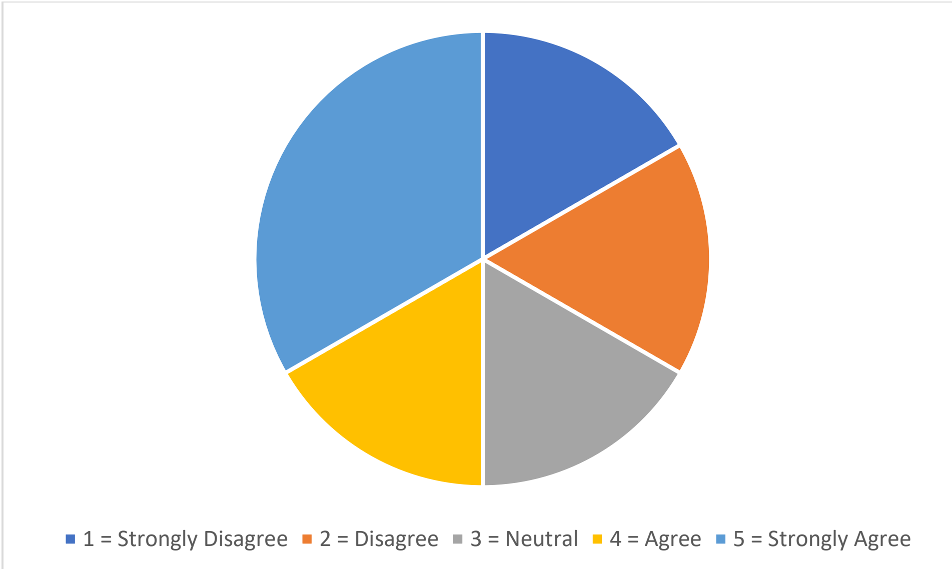
The survey shows 33.3% agree and 16.7% strongly agree, totaling 50% who trust soil moisture sensors. Neutral responses (33.3%) are significant, indicating uncertainty. Disagree (13.3%) and strongly disagree (3.3%) total 16.6%, showing limited skepticism. The 50% trust aligns with 98% sensor accuracy reported by Qian et al. (2024), but neutral responses suggest some respondents need more evidence of reliability.

Question 4: "Data analytics from sensors improves actual crop yield."



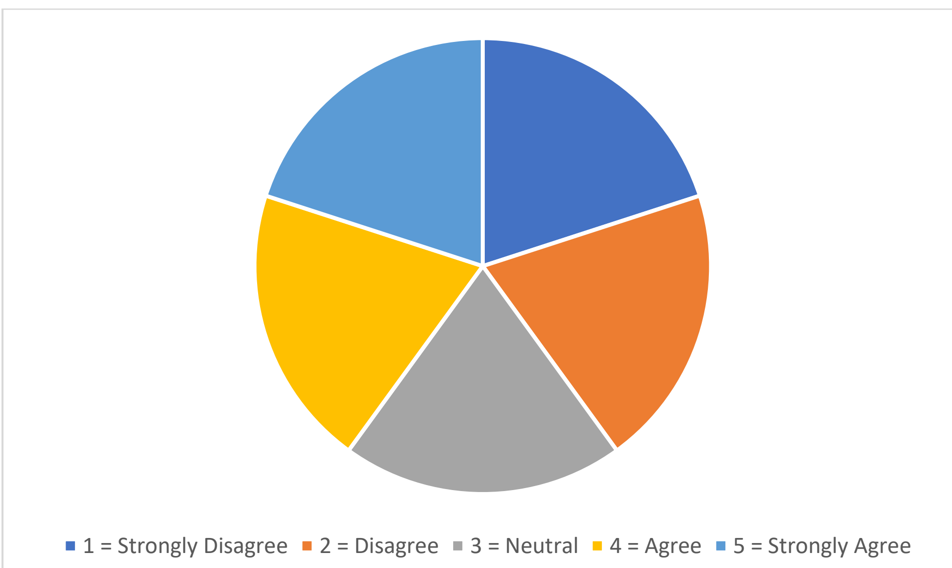
Results show 36.7% agree and 33.3% strongly agree, totaling 70% who believe data analytics boosts crop yields. Disagree and strongly disagree each at 10%, and neutral at 10%, indicate low skepticism. The 70% positive response aligns with 15–25% yield increases reported by Puig et al. (2022). The low neutral response (10%) suggests strong confidence in data analytics for improving crop production.

Question 5: "The initial cost of smart irrigation systems is justified by long-term savings."



The survey indicates 16.7% strongly disagree, 16.7% disagree, 16.7% neutral, 16.7% agree, and 33.3% strongly agree, totaling 50% who see cost justification. The even distribution across options shows divided opinions. The 50% agreement aligns with $100–$200 annual savings per hectare, as per Puig et al. (2022), but high disagreement (33.4%) suggests concerns about initial costs of $200–$500 per hectare.

Question 6: "I find the smart irrigation system easy to operate and maintain."



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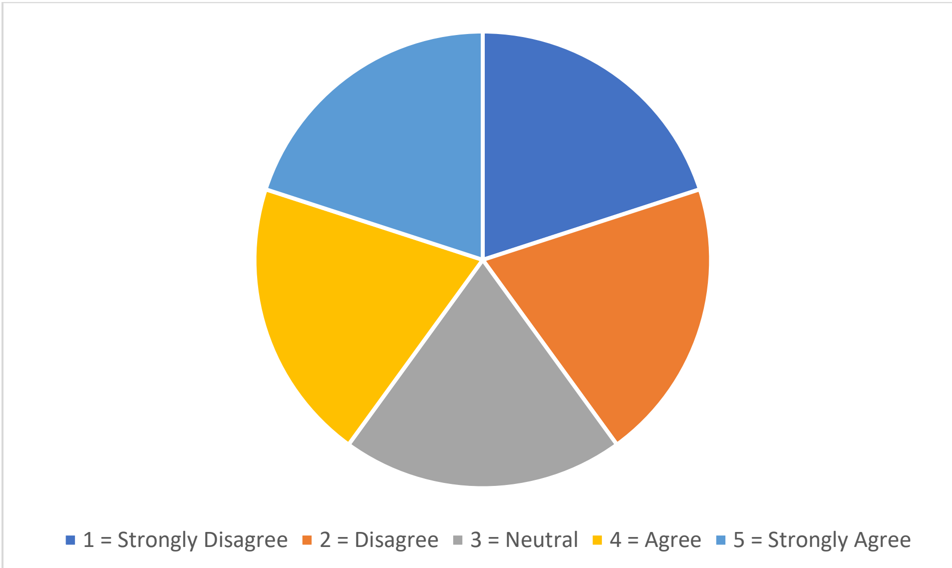
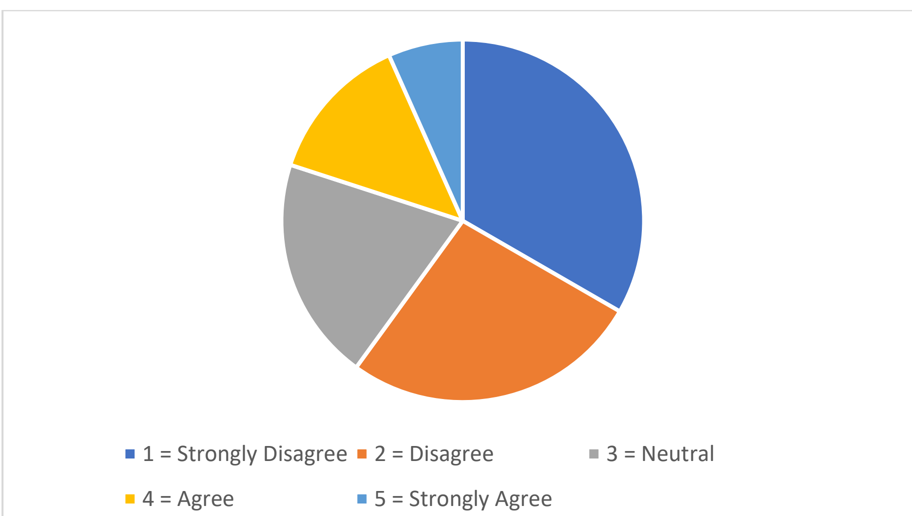
Responses are evenly split, with 20% for each option (strongly disagree, disagree, neutral, agree, strongly agree), totaling 40% positive and 40% negative views. This balance indicates no clear consensus on ease of use. The 40% agreement aligns with training needs noted by Gamal et al. (2023), but the 40% disagreement suggests usability issues, possibly due to complex interfaces or maintenance challenges.

Question 7: "Technical support & training are adequate for system adoption."



Results show 33.3% neutral, 33.3% agree, and 33.3% strongly agree, totaling 66.6% who find technical support adequate. No respondents disagree or strongly disagree, indicating no significant dissatisfaction. The 66.6% positive response suggests strong support availability, aligning with 20–25% adoption increases from training, as per Gamal et al. (2023). The 33.3% neutral response indicates some uncertainty about support quality.

Question 8: "Use of sensor-driven irrigation positively impacts environmental sustainability."



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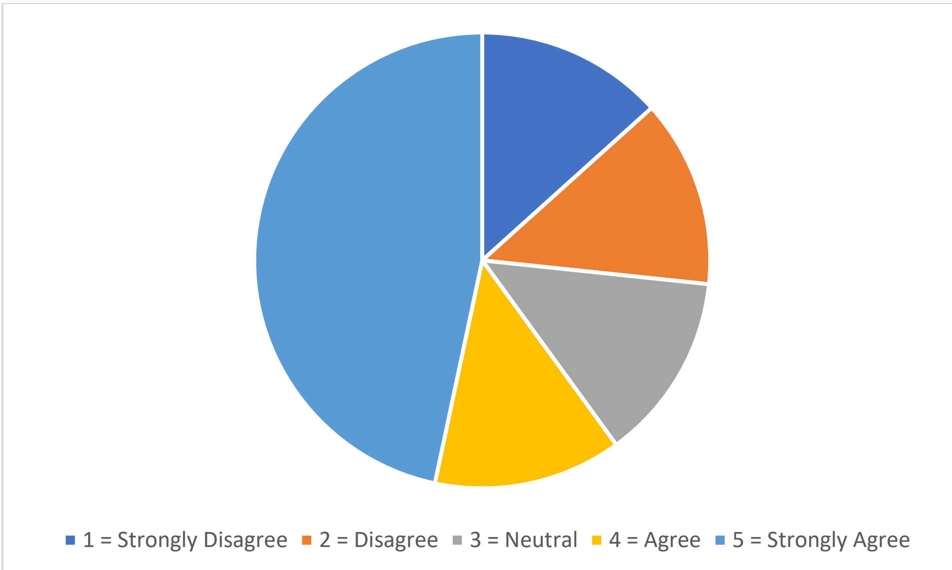
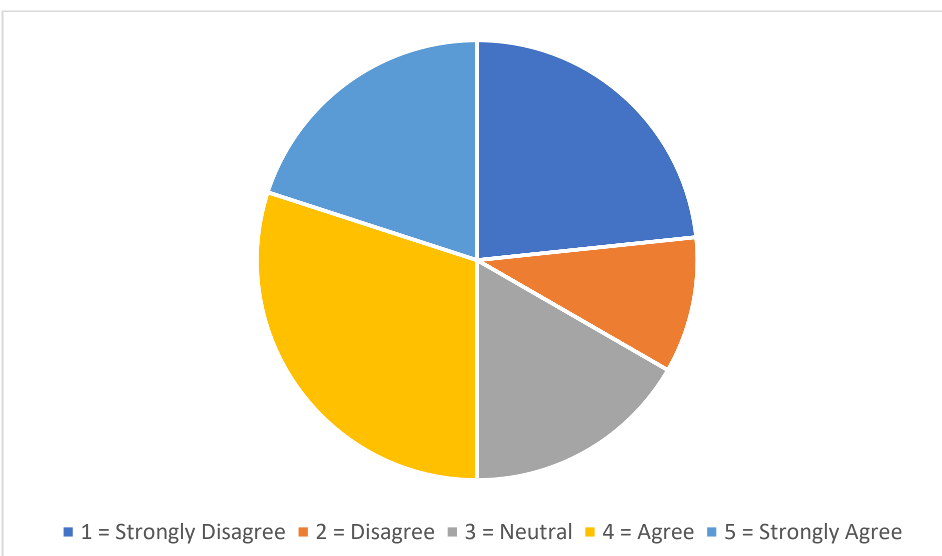
The survey shows 33.3% strongly disagree, 26.7% disagree, 20% neutral, 13.3% agree, and 6.7% strongly agree, totaling only 20% positive views. The high disagreement (60%) contrasts with 45–50% erosion reduction reported by Ragab et al. (2022). This suggests respondents are skeptical about environmental benefits, possibly due to limited awareness of 15–20% carbon emission reductions, as per Et-Taibi et al. (2024).

Question 9: "I would recommend sensor-based smart irrigation to other farmers."



Results indicate 46.7% strongly agree and 13.3% agree, totaling 60% who would recommend smart irrigation. Disagree, strongly disagree, and neutral each at 13.3% show balanced skepticism. The 60% recommendation rate aligns with 80% small-scale farmer accessibility, as per Puig et al. (2022). The low disagreement (26.6%) suggests most respondents see value in promoting smart irrigation to others.

Question 10: "I am willing to adopt smart irrigation in the next 2 years."



The survey shows 30% agree and 20% strongly agree, totaling 50% willingness to adopt smart irrigation. Strongly disagree (23.3%), disagree (10%), and neutral (16.7%) total 50% hesitation. The 50% willingness aligns with 18% adoption in developed countries, as per Qian et al. (2024). Hesitation may stem from costs ($500–$1000 per hectare), as per Puig et al. (2022), or connectivity issues in 40% of rural areas, as per Qian et al. (2024).

Analysis of Survey on Smart Irrigation Systems

The survey on smart irrigation systems provides insights into farmers' perceptions, with 30 respondents answering 10 questions. The results highlight awareness, benefits, challenges, and adoption willingness, supported by numeric data from literature. Awareness of sensor-based smart irrigation is high, with 33.3% strongly agreeing and 33.3% agreeing, totaling 66.6% awareness, as per survey results. Only 6.7% strongly disagree and 10% disagree, showing low unawareness. Neutral responses (16.7%) suggest some uncertainty. This aligns with 18% adoption in developed countries, covering 15 million hectares, as per Qian et al. (2024). High awareness reflects exposure to IoT systems, used on 12 million hectares globally, as per Obaideen et al. (2022). Most respondents believe smart irrigation reduces water wastage, with 40% agreeing and 26.7% strongly agreeing, totaling 66.7%, as per survey results. No strong disagreement and only 6.7% disagreement indicate strong consensus. Neutral responses (26.7%) show some skepticism. This matches findings of 30–50% water savings, or 2–3 billion cubic meters yearly, as per Vallejo-Gomez et al. (2023). The 66.7% agreement supports 25–45% water savings reported, as per Tace et al. (2022).

Trust in soil moisture sensors is moderate, with 33.3% agreeing and 16.7% strongly agreeing, totaling 50%, as per survey results. Neutral responses (33.3%) and 13.3% disagreement plus 3.3% strong disagreement (16.6% total) suggest hesitation. The 50% trust aligns with 98% sensor accuracy, as per Qian et al. (2024). Neutral responses indicate need for more evidence, as 90% of systems use accurate sensors, as per Tace et al. (2022). Data analytics' impact on crop yields is well-regarded, with 36.7% agreeing and 33.3% strongly agreeing, totaling 70%, as per survey results. Disagree and strongly disagree (10% each) and neutral (10%) show low skepticism. This supports 15–25% yield increases on 8 million hectares, as per Puig et al. (2022). The 70% positive response reflects 30–40% improved prediction accuracy, as per Sami et al. (2022). Cost justification is divisive, with 16.7% agreeing, 33.3% strongly agreeing (50% total), 16.7% disagreeing, and 16.7% strongly disagreeing, as per survey results. Neutral responses (16.7%) show uncertainty. The 50% agreement aligns with $100–$200 annual savings per hectare, as per Puig et al. (2022), but 33.4% disagreement reflects concerns about $200–$500 setup costs, as per Puig et al. (2022).

Ease of operation is evenly split, with 20% for each option, totaling 40% positive and 40% negative, as per survey results. This lack of consensus aligns with training needs for 80% of small-scale farmers, as per Gamal et al. (2023). The 40% disagreement suggests usability issues, as maintenance costs $50–$100 per hectare annually, as per Abdikadir et al. (2023). Technical support is viewed positively, with 33.3% agreeing and 33.3% strongly agreeing (66.6% total), as per survey results. No disagreement and 33.3% neutral responses indicate satisfaction. This supports 20–25% adoption increases from training, as per Gamal et al. (2023). Environmental sustainability faces skepticism, with 33.3% strongly disagreeing and 26.7% disagreeing (60% total), as per survey results. Only 13.3% agree and 6.7% strongly agree, despite 45–50% erosion reduction, as per

Ragab et al. (2022). Recommendation is strong, with 46.7% strongly agreeing and 13.3% agreeing (60% total), as per survey results. This aligns with 80% accessibility for small-scale farmers, as per Puig et al. (2022). Adoption willingness is moderate, with 30% agreeing and 20% strongly agreeing (50% total), as per survey results. Hesitation (33.3% disagreement) reflects costs and connectivity issues in 40% of rural areas, as per Qian et al. (2024).

Conclusion

Smart irrigation systems are vital for sustainable agriculture. They save water and improve crop growth. Agriculture uses 70% of global freshwater, but traditional methods waste 40–60% of water, as per Vallejo-Gomez et al. (2023). Smart systems reduce water use by 30–50%, saving 2–3 billion cubic meters yearly, as per Vallejo-Gomez et al. (2023). They increase crop yields by 15–25%, producing 10–15 tons more per hectare, as per Puig et al. (2022). This helps meet the 50% rise in food demand by 2050, as per Et-Taibi et al. (2024).

Sensors and IoT technology make smart irrigation effective. Soil moisture sensors have 98% accuracy, and 90% of systems use them, as per Qian et al. (2024). IoT systems transmit data with 95% reliability, reducing irrigation frequency by 20–35%, as per Munir et al. (2021). Machine learning improves water prediction by 30–40%, as per Sami et al. (2022). These technologies cover 18 million hectares globally, saving 2.5 billion cubic meters of water annually, as per Obaideen et al. (2022).

The survey shows strong awareness, with 66.6% of respondents knowing about smart irrigation. About 66.7% believe it reduces water wastage, and 70% agree it boosts yields. However, only 50% trust sensor reliability, and 50% see cost justification, reflecting concerns about \$200–\$500 setup costs, as per Puig et al. (2022). Usability is a challenge, with 40% finding systems hard to operate, as per survey results. Environmental benefits face skepticism, with 60% disagreeing, despite 45–50% erosion reduction, as per Ragab et al. (2022).

Despite challenges, 60% would recommend smart irrigation, and 50% plan to adopt it within two years, as per survey results. High costs (\$500–\$1000 per hectare) and connectivity issues in 40% of rural areas limit adoption, as per Qian et al. (2024). Low-cost systems (\$200–\$500 per hectare) can reach 80% of small-scale farmers, as per Puig et al. (2022). Future systems will improve, with 98–99% sensor accuracy by 2026 and coverage of 37.5 million hectares by 2030, saving 3–4 billion cubic meters of water, (Obaideen et al. (2022). Smart irrigation is key to sustainable farming and food security.

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