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Perceptions of South African small-scale farmers towards the adoption of smart irrigation technologies

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Background: South Africa's agricultural issues include water scarcity, unpredictable climate conditions and the degradation of soil. Considering the crucial importance of food and water as commodities, farmers must carefully conserve water while maintaining food security.

Objectives: This study aims to determine the elements that influence farmers' readiness to use smart irrigation technology and to evaluate their perception regarding their adoption.

Method: Data were gathered through semi-structured interviews with 53 South African small-scale farmers from Gauteng and North-West provinces and analysed using interpretive approaches.

Results: The findings reveal a cautious, but hopeful assessment of smart irrigation technologies, with significant perceived benefits such as water conservation, increased agricultural production and cost savings. Challenges such as high start-up costs, technological awareness, maintenance concerns and Internet connectivity prevent the adoption.

Conclusion: Financial subsidies, extensive training programmes, farming community engagement projects and collaborations with technology suppliers are all suggested as ways to encourage the adoption of smart irrigation technologies.

Contribution: The study adds to the literature on technology adoption by increasing understanding of the elements that influence farmers' readiness for adopting smart irrigation technologies and by highlighting socio-economic and technological challenges.

Keywords: smart farming; farmers' perceptions; sustainable agriculture; smart irrigation technology; water conservation; small-scale farmers.

Introduction

Given that food and water are essential commodities, agriculture must find strategies to save water while ensuring food security. Concerns over a lack of water have led conservation organisations, governments and legislators to create and support domestic water conservation policies, regulations and goods, such as water-efficient devices and smart irrigation technologies (Devanand, Vidheya & Nandan 2020). Smart irrigation technologies are innovative agricultural tools that seek to solve the interrelated concerns of drought and food security.

Although international research has proved the efficacy of smart irrigation technologies in enhancing crop yields and resource management (Bwambale, Abagale & Anornu 2022; Qazi, Khawaja & Farooq 2022), the uptake of such technologies among smallholder farmers, particularly in developing regions, remains a gap. Persistent barriers, including excessive initial costs, insufficient technical expertise, inadequate Internet connectivity and a lack of institutional backing, continue to impede adoption (Jaafar & Kharroubi 2021; Madushanki et al. 2019). South Africa's agricultural issues include water scarcity, unpredictable climate conditions and degradation of soil. These challenges necessitate innovative techniques to ensure sustainable agricultural practices (Mango et al. 2018). To address these difficulties, South African researchers and universities are developing smart irrigation technologies tailored to real-time needs. Adoption of these technologies is driven by a desire to increase water efficiency and food safety.

The objective of this study is to evaluate the perceptions of farmers towards the implementation of smart irrigation technologies. The study identifies key factors influencing the adoption of smart irrigation technologies and the challenges farmers face. It identifies key enablers and constraints to adoption. It also contributes to the digital agriculture

Note: Additional supporting information may be found in the online version of this article as Online Appendix 1 and Online Appendix 2.

discourse by showing how global innovations can be adapted to local farming contexts (Paudel et al. 2021).

Overview of smart irrigation technologies

A smart irrigation technology can enable automated, water-saving irrigation, though it is relatively complex. It typically includes monitoring, control, transmission components and a terminal platform (Obaideen et al. 2022). Different accessories work together to form an irrigation unit. The following are the available basic smart irrigation technologies:

Soil moisture sensors

A smart irrigation technology called a soil moisture sensor determines the soil's dryness directly. When the probe is implanted at the same depth as the plant's root, the measurement is typically more precise (Obaideen et al. 2022). Utilising the closest soil controller, soil sensors from various locations are used. Manage the irrigation in various areas. For soil sensors at various locations, the management platform can establish high and low alarm values. The control unit opens the water valve when the soil moisture level drops below the alert value and closes the water valve when the soil moisture level rises above it (Pivoto et al. 2018). We can select different soil moisture sensors based on the types of soil. When buying sensors, customers just need to make sure they are compatible with their irrigation system.

Evaporation sensors

Evaporation sensors is a smart irrigation technology used to measure meteorological conditions. Its value corresponds to the evaporation of the soil area (Dutta & Goswami 2020). Gathering this climate-related data can help modify irrigation duration and encourage water movement in the surrounding surface. An evaporation sensor can drastically reduce irrigation water use (Casadei et al. 2021).

Rain and snow sensors

If it starts to rain while you are watering your grass, make sure to stop right away. Rainwater collection results in unwanted runoff and wastes both money and water (Casadei et al. 2021). This is another purpose of smart irrigation. The foundation for implementing this function is the rain and snow sensor. The rain and snow sensor smart irrigation technologies have metal wires on their surface that conduct electricity when they meet rainfall drops (Obaideen et al. 2022). The management platform receives an electrical signal, processes it and then alerts the controller to promptly close the water valve.

Wind speed sensors

Irrigation on a windy day can lessen the amount of water that penetrate the soil and the regularity of the irrigation system (Dutta & Goswami 2020). Installing wind speed sensors is necessary so that, should the wind speed above a predetermined threshold, the irrigation cycle will be stopped (Obaideen et al. 2022). We strategically plan the irrigation cycle and length based on the local weather conditions, which can save a significant amount of water resources over time.

Drone irrigation system

Water can be applied with precision when employing agricultural drones for irrigation, which is one of the main advantages. Drones with advanced sensors and nozzles can water specific areas of a field. This reduces waste and ensures each plant receives the right amount of moisture (Dutta & Goswami 2020). This degree of accuracy encourages healthier plant growth and higher agricultural yields in addition to conserving water.

Internet of Things irrigation system

Internet of Things (IoT) connects hardware devices, software and people to exchange data for specific purposes. Researchers note that computers in these networks are increasingly able to make decisions without human input (Madushanki et al. 2019). Nawandar and Satpute (2019) suggest that smart irrigation technologies, like IoT in farming, can reduce crop loss. This, in turn, helps prevent revenue loss for farmers.

Related literature

The study by Jaafar and Kharroubi (2021) revealed that farmers desire to use free smart irrigation technologies that only require a basic degree of expertise and understanding. The study revealed notable findings. It focused on diverse farmers from different agroclimatic zones (semi-arid, sub-humid, and so on), with varying irrigation systems, educational backgrounds and crops. The desire to pay seemed to be significantly influenced by the expense of irrigation. Another tactic mentioned in the literature study was raising farmers' awareness of smart irrigation technologies and the significance of utilising them on their farms (Paudel et al. 2021). Improving access to technical support, advisers and consultants can encourage adoption. Allowing farmers to test smart irrigation technologies also boosts their engagement and impact within the farming community.

Bwambale et al. (2022) investigated intelligent irrigation monitoring and control strategies to improve the water use efficiency of precision agriculture. The study found that implementing IoT-based monitoring systems greatly increased agricultural yields and water use efficiency, demonstrating the promise of new technologies in optimising irrigation methods. Similarly, Madushanki et al. (2019) investigated the use of IoT in smart irrigation and agribusiness, with an emphasis on boosting urban greening. Their findings revealed that the use of IoT technologies improved resource management and aided urban greening programmes, highlighting the importance of IoT in sustainable farming practices.

In yet another investigation, Kpadonou et al. (2017) looked at the adoption of several on-farm water and soil conservation technologies in West Africa's Sahel. The study found that using these conservation methods in dryland areas greatly enhanced agricultural output and resilience, highlighting their role in enhancing productivity and sustainability in dry environments. Qazi et al. (2022) did a thorough study of next-generation smart agriculture powered by Artificial Intelligence (AI) and IoT, highlighting the key challenges and potential advances in the use of these technologies in agriculture. Their review offered a full understanding of the obstacles and opportunities for incorporating AI and IoT in smart irrigation.

Finally, Vaishali et al. (2017) created an IoT-based mobile integrated smart irrigation management and monitoring system. This unique technology increased user accessibility and control, allowing for efficient irrigation management via mobile devices. The system's capacity to promote optimal irrigation techniques demonstrated the advantages of combining IoT and mobile technology for better agriculture management.

Research methods and design

The study followed the qualitative research method. The data analysis includes farmer demographic data, the benefits and barriers of smart irrigation technology, and their implementation strategies and use in plantations. The unit of analysis was individual small-scale farmers from Gauteng and North-West provinces in South Africa. The research used semi-structured interviews to gather data from 53 farmers about their perceptions towards the implementation of smart irrigation technologies. The semi-structured interview questions were typed on Microsoft Word and shared with farmers via their group WhatsApp and email. Due to limited access to emails and WhatsApp among some farmers, face-to-face and telephone-based data collection techniques were used to interview them. The Microsoft Excel application was used to extract the interview data and analyse the demographic data in the table and graphic presentation. The interpretivism method was used to analyse the qualitative interview responses about the perceptions of farmers towards the adoption of smart irrigation technologies. Thematic analysis was used to analyse the interview data to depict a relationship diagram using the ATLAS.ti application.

Prior to data collection from research participants, the researchers obtained the ethical clearance approval certificate from the university research ethics committee. The researchers explained the purpose of the study to the participants, emphasised that participation was voluntary, and assured them of the confidentiality and integrity of the information provided.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of South Africa, College of Science, Engineering and Technology School of Engineering (No.06/05/2024).

Results

Farmer perceptions of smart irrigation technologies may offer better insights into technology adoption. This is because farmers interact directly with the technologies and may perceive them differently from researchers and extension agents. These perceptions of innovation mainly depend upon their knowledge and information about the innovation and socio-economic situation (Karunathilake et al. 2023). The level of information depends on the farmer's level of education and training that they receive about the technology. The following are the descriptive demographic and qualitative interviews results from the farmers' perceptions towards the adoption of smart irrigation technologies.

Section A: Demographic results

Gender frequency

The following findings are shown by the demographic analysis of the gender distribution among the 53 farmers surveyed:

- Female farmers: Approximately 36% of the sample is comprised of 19 female farmers.
- Male farmers: Out of the entire sample, there are 34 (64%) male farmers. With almost double number of men as compared to women, this distribution suggests that there are more male farmers participated as shown in Table 5.

Farming qualifications frequency

The frequency distribution of farming qualifications among a sample of respondents is shown in Table 1. In conclusion, of the 53 responses, 28 (53%) are qualified to farm, while the remaining 25 (47%) are not.

Computer skills frequency

The distribution of computer skills among South African farmers is displayed in Figure 10 along with their opinions regarding the adoption of smart irrigation technologies. 23% (12) of the 53 farmers that participated in the study had average computer abilities, 15% (8) had low computer skills, and the majority 62% (33) had good computer skills. Based on this distribution, it appears that most farmers have sufficient computer abilities, which may help them implement smart irrigation technologies.

Age group frequency

Figure 11 depicts the age distribution of South African farmers based on their attitudes about the deployment of smart irrigation technologies. The largest age group among the 53 farmers polled is 36–45 years, that is, 32% (17) of farmers, followed by 25–35 years and over 55

TABLE 1: Distribution of farmers' qualifications (N = 53).

Farming qualification	Frequency
Yes	28
No	25

years with 23% (12) of each category, 46–55 years with 15% (8) of participants, and below 25 years with 8% (4) participants. This distribution demonstrates a wide range of ages among the farmers, which may influence their attitudes and adoption of smart irrigation methods.

Farming experience frequency

Figure 12 shows how South African farmers' farming experience varies in relation to their attitudes towards the deployment of smart irrigation technologies. Out of 53 farmers polled, the majority 31% (16) of participants have 5–10 years of farming experience, followed by 23% (12) of participants with experience of 10–15 years. There are 19% (10) participants in each of the age groups under 5 years and 15–20 years of experience. The smallest group is 9% (5) participants with over 20 years of farming experience. This distribution demonstrates a wide variety of respondents' farming experience, which may influence their attitudes and adoption of smart irrigation systems.

Adoption rate frequency

Table 2 outlines several smart irrigation technologies that South African farmers have adopted or plan to adopt. Participants were allowed to select more than one option. Based on the results in Table 2, out of 53 farmers, most farmers, that is, 38 (72%), indicated that they have either adopted or are planning to adopt soil moisture sensors for irrigation management. Around 31 (32%) of the farmers mentioned that they have adopted or plan to adopt evaporation sensors. A notable portion (58%) of 31 farmers indicated adoption or plans to adopt rain and snow sensors. No farmers have adopted or plan to adopt wind speed sensors. Only 8 (15%) farmers have adopted or are planning to adopt drone-based irrigation systems. Twenty-one (40%) farmers indicated that they have adopted or are considering IoT-based irrigation systems. About 16 (30%) farmers stated that they have not adopted any of the listed technologies. These farmers rely on traditional water-saving practices and manual monitoring instead.

TABLE 2: Distribution of farmers' adoption behaviour or intentions to adopt.

Smart irrigation technologies	Frequence	%	Description of responses
Soil moisture sensors	38	72	Farmers indicated that they have either adopted or planning to adopt soil moisture sensors.
Evaporation sensors	17	32	Farmers indicated that they have either adopted or planning to adopt evaporation sensors.
Rain and snow sensors	31	58	Farmers indicated that they have either adopted or planning to adopt rain and snow sensors.
Wind speed sensors	0	0	Farmers indicated that they have either adopted or planning to adopt wind speed sensors.
Drone irrigation system	8	15	Farmers indicated that they have cither adopted or planning to adopt drone irrigation system.
IoT irrigation system	21	40	Farmers indicated that they have either adopted or planning to adopt IoT irrigation system.
Other	16	30	Have not adopted or not planning to adopt any of the listed technology.

IoT, Internet of Things.

Section B: Presentation of interview results

The outcomes of the interview are shown in this section. There were 10 questions in the interview. However, during the analysis, Question 7 was removed as participants' responses were repetitive of those given for Question 3. As a result, only 9 interview questions were taken into consideration, and Question 7 was eliminated from the study. Figure 1 illustrates the thematic analysis, developed using ATLAS.ti.

Question 1: Explain a little bit about yourself as a farmer and how you handle your farming operation

> 'My family has been involved in agriculture for generations. To manage our farm, we rely on help from relatives or hire workers.'
>
> 'I come from a family with a long farming history. We usually get help from relatives or hire workers during harvest. I believe in combining modern and traditional farming practices for sustainability.'

Density of 48 out of 53 sentences (90.57%) indicated that they come from families with a long agricultural history. Usually, they seek the assistance of family members or hire workers to keep track of their farming operations. Many make a strong emphasis on mixing smart irrigation method with traditional knowledge in order to achieve sustainable farming practices.

Question 2: What is the size of your farm and what do you plant?

Density: Highlighted farm sizes ranging from small 2–5 hectares to big farms with more than 10–12 hectares (Figure 2). Vegetables (including wheat, tomatoes, cabbage, spinach and soya beans, maize, and sunflower) are the main crops planted. Table 3 demonstrates the wide variety of crops growing on the farms, with the most frequent being spinach, maize and tomatoes. Some farmers indicated more than one crop, which means they plant different crops each season.

Question 3: Have you been using any smart irrigation technologies on your farm? Why?

An overview of the responses (Figure 3): Approximately half of the farmers have already deployed smart irrigation technology:

1. *Adopted smart irrigation technologies:* 27 (51%)
2. *Not adopted smart irrigation technologies:* 26 (49%)

As shown in Table 4, those who did not adopt smart irrigation technologies cited reasons such as they cannot afford to buy them, they have a lack of understanding, and they are uncertain about the benefits.

Question 4: Explain your views on farmers' adoption of smart irrigation technologies

An overview of the responses (Figure 4): The majority of farmers said adoption is slow because of the high cost and complexity of these technologies. They recognise the potential benefits in terms of productivity and resource management.

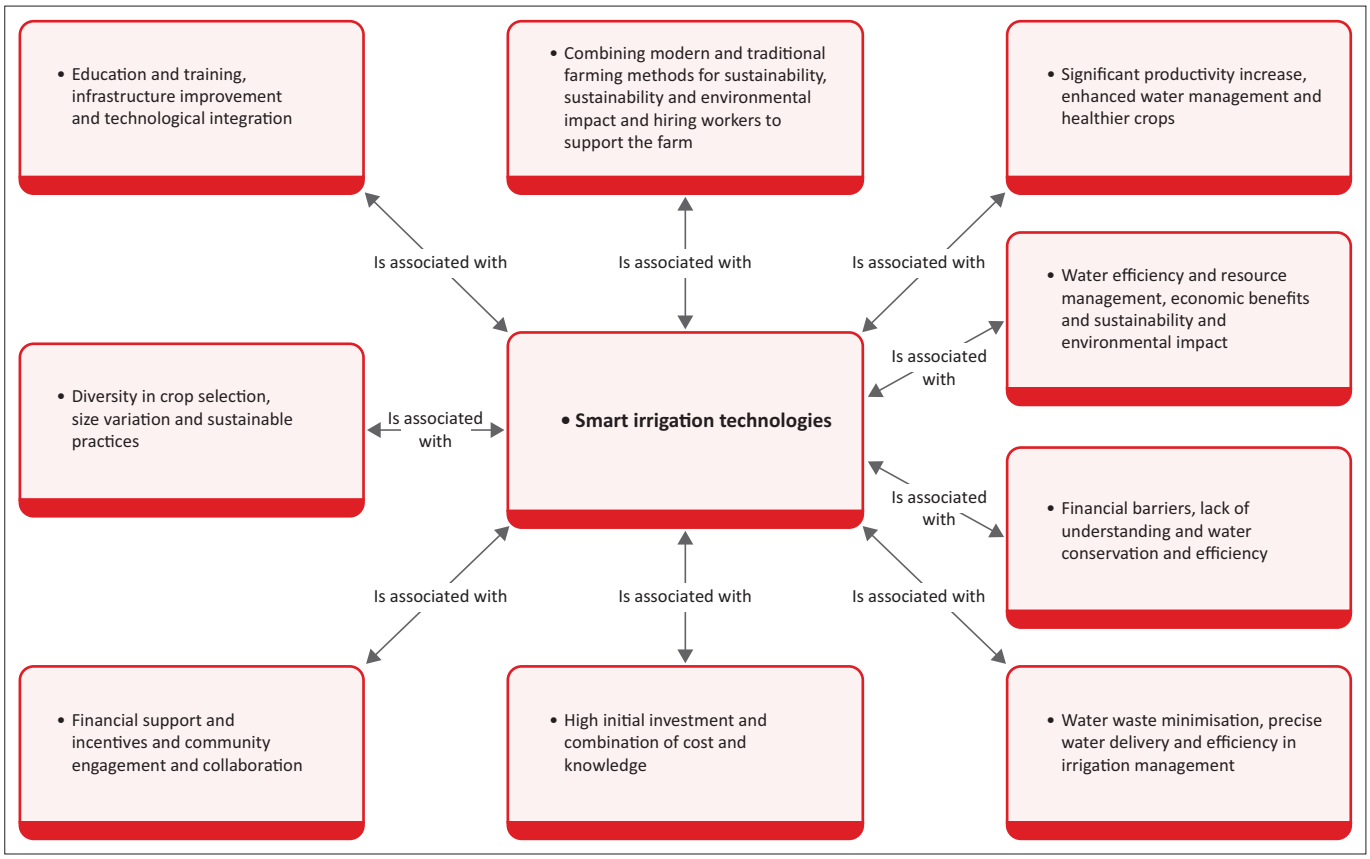


FIGURE 1: Thematic analysis diagram.

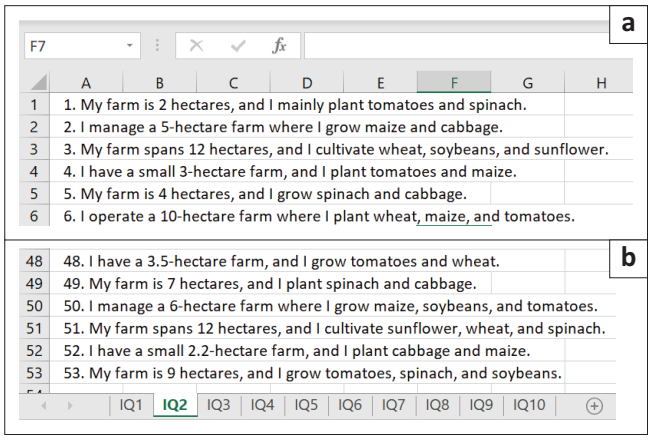


FIGURE 2: Participants' responses to question 2.

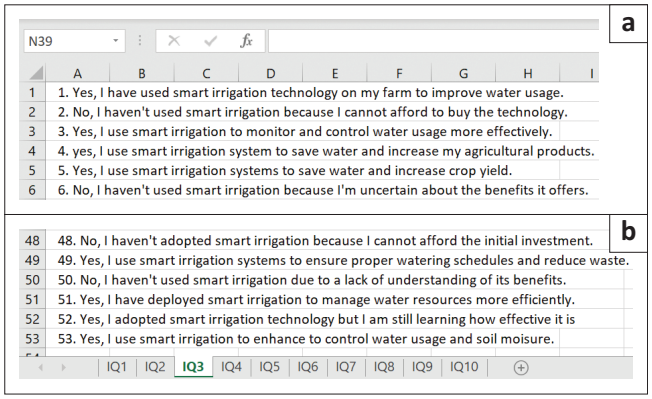


FIGURE 3: Participants' responses to question 3.

TABLE 3: Distribution of farmers' crops they planted.

Crop	Frequency	Farms (List of farmers numbers)
Maize	20	2, 4, 6, 9, 11, 14, 20, 22, 25, 30, 33, 34, 35, 38, 40, 45, 47, 52, 12, 19
Tomatoes	21	1, 4, 6, 11, 17, 21, 24, 32, 34, 35, 37, 40, 41, 43, 50, 51, 53
Spinach	20	1, 5, 8, 11, 15, 18, 21, 30, 31, 35, 41, 43, 44, 49, 51, 53
Soybeans	14	3, 7, 10, 12, 13, 23, 26, 30, 39, 42, 45, 50, 53
Cabbage	12	2, 5, 10, 12, 16, 22, 26, 33, 36, 42, 49
Wheat	14	3, 4, 12, 15, 19, 23, 31, 35, 38, 41, 46, 51, 52
Sunflower	12	3, 11, 15, 23, 27, 35, 39, 43, 47, 51, 52, 48

TABLE 4: Reasons for not adopting smart irrigation technologies.

Reason for not adopting	Frequency
Cannot afford	9
Lack of understanding of the technology	8
Uncertainty about effectiveness and benefits	9

TABLE 5: Distribution of farmers' gender ($N = 53$).

Gender	Frequency
Female	19
Male	34

Question 5: Do you think the implementation of smart irrigation technologies will reduce water usage, and why?

An overview of the responses (Figure 5): All farmers believe that smart irrigation technologies can save them a lot of water. They explained that this reduces water waste and ensures that their crops receive the appropriate amount of water.

a

7	7. Farmers are hesitant to adopt smart irrigation due to cost and complexity, but the benefits in productivity and resource management are significant.
8	8. The slow adoption of smart irrigation is due to its high cost and complexity, but it can improve productivity and resource management.
9	9. Smart irrigation adoption is slow because of cost and complexity, but the potential benefits for productivity and resource management are evident.
10	10. The high cost and complexity of smart irrigation technologies hinder adoption, though they can enhance productivity and resource management.
11	11. Adoption is slow because smart irrigation is expensive and complex, but it offers substantial benefits in productivity and resource management.
12	12. Farmers are slow to adopt smart irrigation due to the high cost and complexity, but it can greatly improve productivity and resource management.
13	13. The expense and complexity of smart irrigation slow adoption, but the benefits for productivity and resource management are clear.

b

47	47. The slow adoption of smart irrigation is due to its expense and complexity, but it can greatly enhance productivity and resource management.
48	48. Smart irrigation adoption is slow because of cost and complexity, though it offers substantial benefits in productivity and resource management.
49	49. The high cost and complexity of smart irrigation technologies slow adoption, but they can improve productivity and resource management.
50	50. Farmers are hesitant to adopt smart irrigation due to cost and complexity, but the potential benefits in productivity and resource management are significant.
51	51. Adoption is slow because smart irrigation is expensive and complex, but it offers significant benefits for productivity and resource management.
52	52. The expense and complexity of smart irrigation technologies hinder adoption, though they can greatly enhance productivity and resource management.
53	53. High cost and complexity make adoption of smart irrigation slow, but the benefits in productivity and resource management are substantial.

FIGURE 4: Participants' responses to question 4.

29	29. Yes, implementing smart irrigation will reduce water usage by optimising water application.
30	30. For sure, smart irrigation can save a lot of water by preventing unnecessary waste.
31	31. Yes, I believe smart irrigation will reduce water usage by providing precise water amounts to crops.
32	32. Absolutely, smart irrigation systems reduce water waste and ensure crops get the appropriate amount of water.
33	33. Yes, I think smart irrigation will save water by optimising irrigation schedules and amounts.
34	34. Definitely, smart irrigation helps reduce water waste and ensures crops receive the necessary water.
35	35. Yes, I believe smart irrigation will reduce water usage through efficient water management.
36	36. For sure, smart irrigation systems can save a lot of water by eliminating waste and providing the right amount for crops.
37	37. Yes, smart irrigation will cut down on water usage by ensuring precise water delivery to crops.
38	38. Absolutely, smart irrigation reduces water waste and optimises water usage for crops.
39	39. Yes, I think smart irrigation will reduce water usage by providing the exact amount of water needed for crops.
40	40. Definitely, smart irrigation systems help save water by reducing waste and ensuring proper irrigation.
41	41. Yes, implementing smart irrigation will reduce water usage by optimising water application.
42	42. For sure, smart irrigation can save a lot of water by preventing unnecessary waste.
43	43. Yes, I believe smart irrigation will reduce water usage by providing precise water amounts to crops.

FIGURE 5: Participants' responses to question 5.

	A
30	29. Based on my experience, I believe smart irrigation would greatly enhance productivity by ensuring healthier crops.
31	30. Smart irrigation could boost productivity dramatically through better water management.
32	31. From my experience, I think smart irrigation can improve production by 30%-40% through optimised water use.
33	32. I believe smart irrigation technologies would significantly boost productivity by enhancing crop health.
34	33. Smart irrigation can improve productivity dramatically by 30%-40% through better water management.
35	34. I think these technologies would greatly boost productivity through optimised water use.
36	35. Based on my farming experience, smart irrigation can significantly improve productivity by ensuring healthier crops.
37	36. Smart irrigation would dramatically improve production by 30%-40% through better water management.
38	37. From my experience, I believe smart irrigation can significantly boost productivity by optimising water use.
39	38. Smart irrigation technologies would greatly enhance productivity through improved crop health.
40	39. I think these technologies could dramatically improve productivity by 30%-40% through better water management.
41	40. Based on my experience, smart irrigation can significantly boost productivity by ensuring healthier crops.
42	41. Smart irrigation would dramatically improve production through better water management.
43	42. From my experience, I believe smart irrigation can improve productivity by 30%-40% through optimised water use.
44	43. I think smart irrigation technologies would greatly boost productivity by enhancing crop health.
45	44. Smart irrigation can improve productivity significantly, possibly by 30%-40%, through better water management.
46	45. Based on my experience, I think smart irrigation would greatly enhance productivity by optimising water use.
47	46. Smart irrigation technologies can dramatically boost productivity by ensuring healthier crops.
48	47. I believe these technologies would significantly improve productivity through better water management.
49	48. Smart irrigation can boost productivity by 30%-40% through optimised water use.
50	49. From my experience, I believe smart irrigation would greatly enhance productivity through better water management.
51	50. Smart irrigation technologies can dramatically improve production by ensuring healthier crops.
52	51. I think smart irrigation would significantly boost productivity through optimised water use.
53	52. Smart irrigation can improve productivity dramatically, possibly by 30%-40%, through better water management.
54	53. Based on my experience, I believe smart irrigation technologies would greatly enhance productivity by ensuring healthier crops.

FIGURE 6: Participants' responses to question 6.

Question 6: Based on your farming experience, to what extent do you think smart irrigation technologies could improve production?

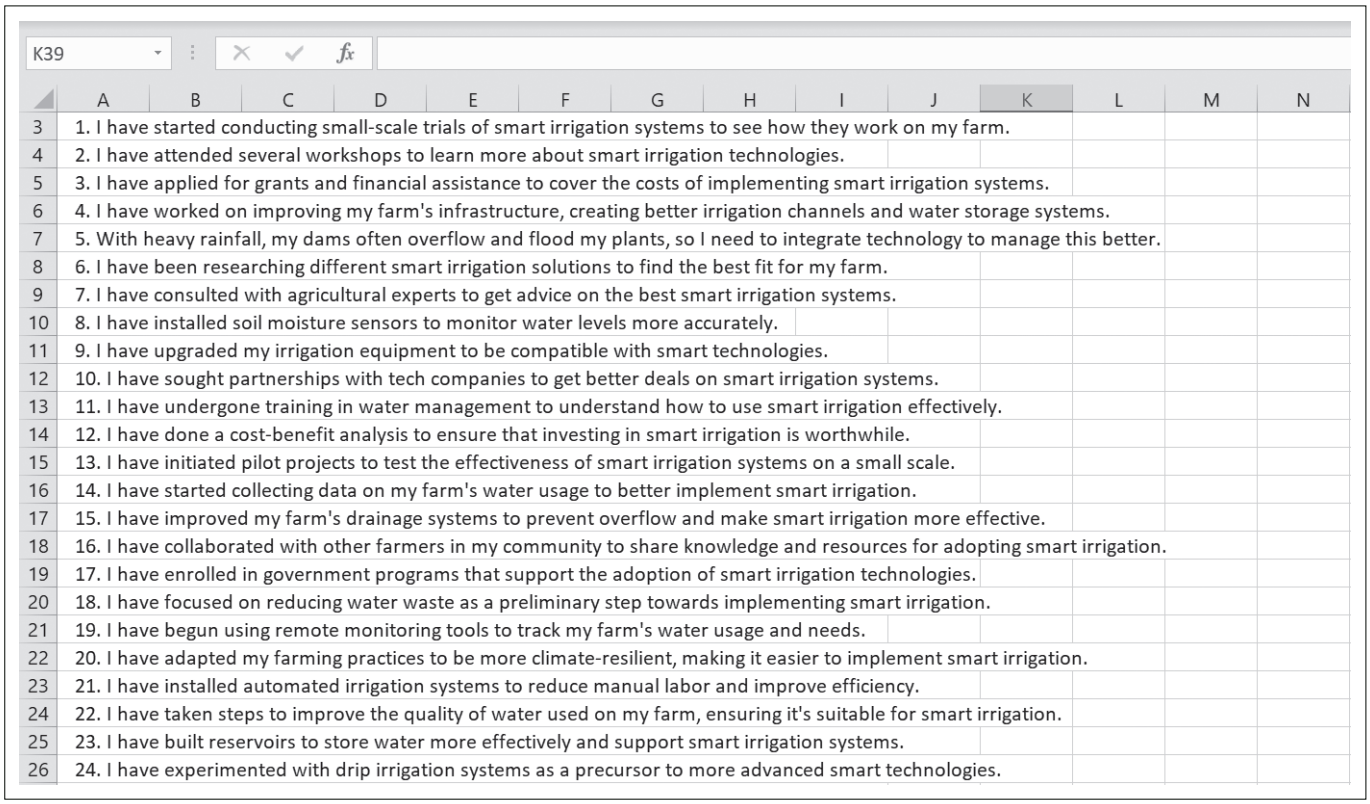
An overview of the responses (Figure 6): Farmers think that these technologies will dramatically boost productivity by improving water management, resulting in healthier crops and greater harvests. The level of improvement varies, with some predicting a 30% – 40% boost in productivity if they could be given opportunity of using those technologies.

Question 7: What changes, if any, would you make or have you made on your farm that could enhance your opportunity to adopt smart irrigation technologies?

An overview of the responses (Figure 7): Some farmers said they have begun by conducting small-scale trials of smart irrigation systems, attending workshops and applying for help or grants to cover the costs. Others have improved their infrastructure by building better irrigation channels and water storage systems. However, they have not integrated technology into these systems. As a result, during heavy rainfall, their dams overflow and flood their crops.

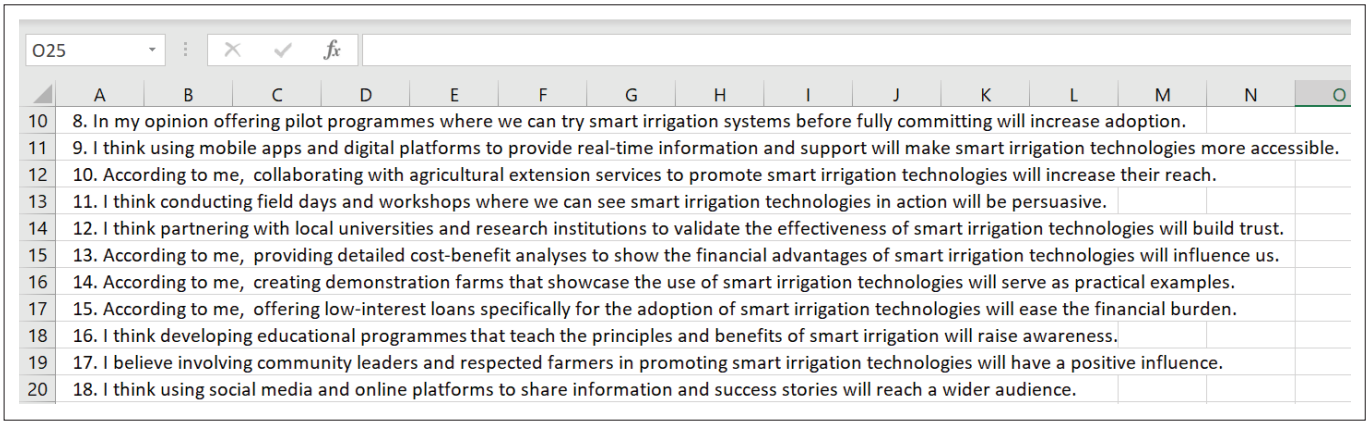
Question 8: Explain the best strategy to influence farmers to use smart irrigation technologies

An overview of the responses (Figure 8): Participants think that if the government can offer financial incentives or subsidies, providing hands-on training and demonstrations, this will help them successfully adopt smart irrigation technologies. Some mentioned that sharing other farmers' successful stories will influence the adoption rate. Organising cooperatives or farmer



	A
3	1. I have started conducting small-scale trials of smart irrigation systems to see how they work on my farm.
4	2. I have attended several workshops to learn more about smart irrigation technologies.
5	3. I have applied for grants and financial assistance to cover the costs of implementing smart irrigation systems.
6	4. I have worked on improving my farm's infrastructure, creating better irrigation channels and water storage systems.
7	5. With heavy rainfall, my dams often overflow and flood my plants, so I need to integrate technology to manage this better.
8	6. I have been researching different smart irrigation solutions to find the best fit for my farm.
9	7. I have consulted with agricultural experts to get advice on the best smart irrigation systems.
10	8. I have installed soil moisture sensors to monitor water levels more accurately.
11	9. I have upgraded my irrigation equipment to be compatible with smart technologies.
12	10. I have sought partnerships with tech companies to get better deals on smart irrigation systems.
13	11. I have undergone training in water management to understand how to use smart irrigation effectively.
14	12. I have done a cost-benefit analysis to ensure that investing in smart irrigation is worthwhile.
15	13. I have initiated pilot projects to test the effectiveness of smart irrigation systems on a small scale.
16	14. I have started collecting data on my farm's water usage to better implement smart irrigation.
17	15. I have improved my farm's drainage systems to prevent overflow and make smart irrigation more effective.
18	16. I have collaborated with other farmers in my community to share knowledge and resources for adopting smart irrigation.
19	17. I have enrolled in government programs that support the adoption of smart irrigation technologies.
20	18. I have focused on reducing water waste as a preliminary step towards implementing smart irrigation.
21	19. I have begun using remote monitoring tools to track my farm's water usage and needs.
22	20. I have adapted my farming practices to be more climate-resilient, making it easier to implement smart irrigation.
23	21. I have installed automated irrigation systems to reduce manual labor and improve efficiency.
24	22. I have taken steps to improve the quality of water used on my farm, ensuring it's suitable for smart irrigation.
25	23. I have built reservoirs to store water more effectively and support smart irrigation systems.
26	24. I have experimented with drip irrigation systems as a precursor to more advanced smart technologies.

FIGURE 7: Participants' responses to question 7.



	A
10	8. In my opinion offering pilot programmes where we can try smart irrigation systems before fully committing will increase adoption.
11	9. I think using mobile apps and digital platforms to provide real-time information and support will make smart irrigation technologies more accessible.
12	10. According to me, collaborating with agricultural extension services to promote smart irrigation technologies will increase their reach.
13	11. I think conducting field days and workshops where we can see smart irrigation technologies in action will be persuasive.
14	12. I think partnering with local universities and research institutions to validate the effectiveness of smart irrigation technologies will build trust.
15	13. According to me, providing detailed cost-benefit analyses to show the financial advantages of smart irrigation technologies will influence us.
16	14. According to me, creating demonstration farms that showcase the use of smart irrigation technologies will serve as practical examples.
17	15. According to me, offering low-interest loans specifically for the adoption of smart irrigation technologies will ease the financial burden.
18	16. I think developing educational programmes that teach the principles and benefits of smart irrigation will raise awareness.
19	17. I believe involving community leaders and respected farmers in promoting smart irrigation technologies will have a positive influence.
20	18. I think using social media and online platforms to share information and success stories will reach a wider audience.

FIGURE 8: Participants' responses to question 8.

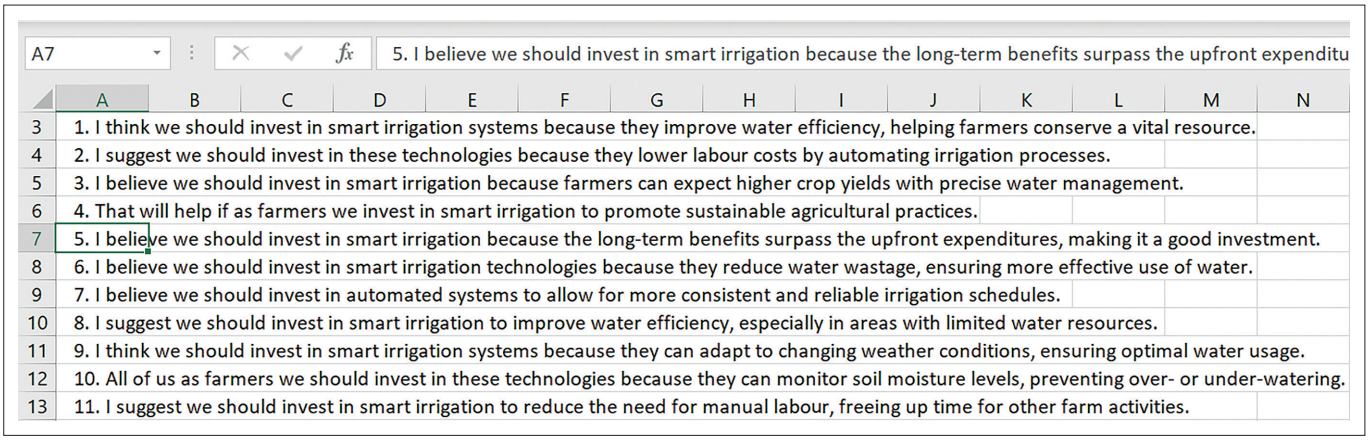


FIGURE 9: Participants' responses to question 9.

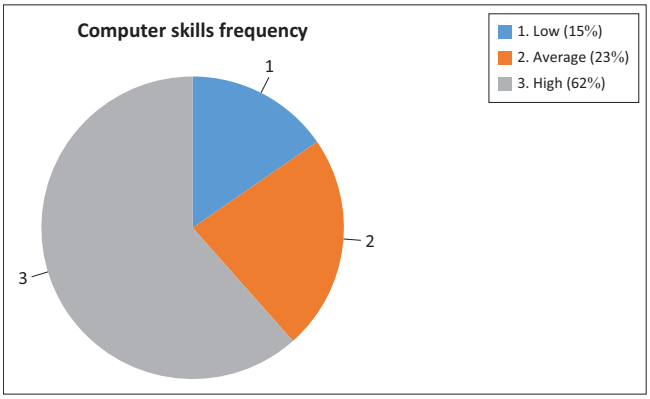


FIGURE 10: Distribution of farmers' computer skill levels.

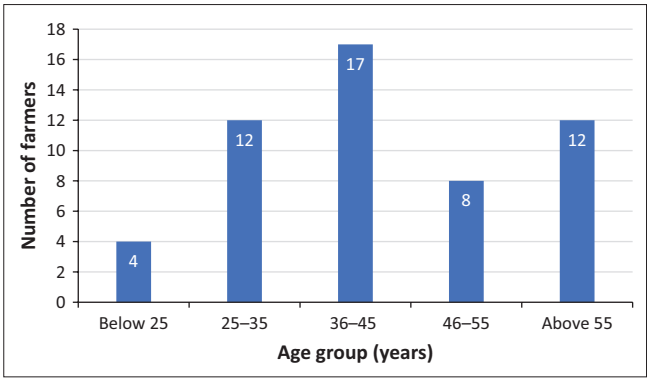


FIGURE 11: Distribution of farmers' age group.

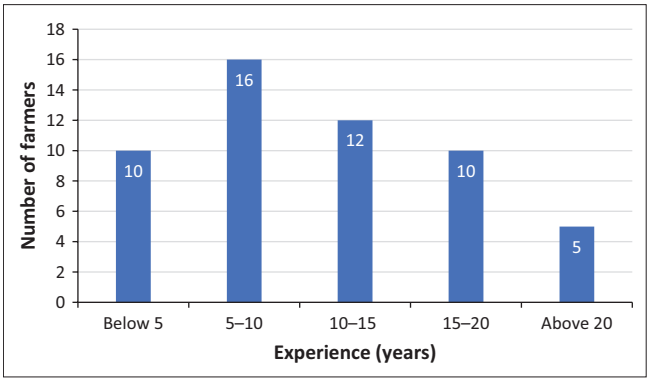


FIGURE 12: Distribution of farmers' farming experience.

organisations to share costs and information is also recommended.

Question 9: Explain why farmers should invest in smart irrigation technologies

An overview of the responses (Figure 9): Participants highlighted various opinions, such as farmers should invest in smart irrigation technologies because they improve water efficiency, lower labour costs, raise crop yields, and promote sustainable agricultural practices. One mentioned that the long-term benefits surpass the upfront expenditures, making them a good investment.

Discussion

The interviews suggest that plantation farmers are cautious about adopting smart irrigation technologies. However, they remain hopeful about the potential benefits, such as water conservation, higher production and sustainable farming. The following sections provide a full discussion of the benefits and challenges identified from the interview results.

Perceived benefits of smart irrigation technologies

Farmers reported that smart irrigation technologies help reduce costs related to water use and manual labour. Smart irrigation systems decrease the need for personal supervision and manual irrigation. Several international studies have proven the ability of smart irrigation systems to increase water efficiency, which supports what has been anticipated by the participants in this study. For example, soil moisture sensors and weather stations have been utilised to collect real-time data that is then used to make irrigation decisions (Casadei et al. 2021; Devanand et al. 2020). Furthermore, the usage of IoT systems and drones improves farm management by providing real-time data and remote monitoring capabilities, allowing for improved decision-making and more convenient control of farming operations (Dhanaraju et al. 2022; Dutta & Goswami 2020; Koech & Langat 2018).

Looking into the related literature included in this study and the results from participating farmers, both results agree that

farmers can benefit from the advantages of using smart irrigation technologies. Nawandar and Satpute (2019) have shown that IoT can enhance resource management and promote urban greening projects, implying larger environmental advantages. Kpadonou et al. (2017) demonstrated the efficiency of water and soil conservation methods in enhancing output and resilience in dryland areas, which is especially relevant to South Africa's drought regions. Collectively, these studies support South African farmers' belief that using smart irrigation technologies will enhance agricultural production, promote sustainability and improve resource management.

Challenges and limitations of smart irrigation technologies

The participating farmers highlighted that the implementation of smart irrigation technologies involves several key limitations and challenges. The related literature also highlighted that the implementation of smart irrigation technologies involves several key limitations and challenges. South African farmers should be aware of the limitations and challenges identified in the related literature. Bwambale et al. (2022) observed that, while IoT-based monitoring systems might enhance water use efficiency, their performance is dependent on stable Internet access and infrastructure, which may be missing in some rural regions. Madushanki et al. (2019) underlined that IoT adoption necessitates significant initial investments and continuing maintenance, which may be financially burdensome for small-scale farmers. Understanding such challenges is critical for South African farmers to successfully adopt and profit from smart irrigation technologies. Limited technical knowledge and connectivity challenges are also reported in global contexts such as West Africa, Italy and the USA (Kpadonou et al. 2017; Paudel et al. 2021).

Recommendations

These studies offer numerous critical measures to help with the acceptance and deployment of smart irrigation technologies. The following themes identified in this study, seek to address the financial, educational, community projects and collaboration problems that farmers confront.

Financial subsidies

Farmers request financial support and subsidies in order to cover the high initial costs of smart irrigation technologies. They believe that government subsidies or low-interest loans might greatly reduce the financial burden, making it easier for farmers to invest in these advanced technologies. By lowering the initial expenses, such financial assistance will not only encourage the use of smart irrigation technologies but also promote more sustainable and efficient agriculture practices. This strategy seeks to make the transition to smart farming more accessible, ultimately leading to increased production and resource management in agriculture.

Educational programmes

To address the issue of low technical knowledge and training, a strategy based on comprehensive educational and training initiatives is required. Farmers suggested the creation of training programmes and workshops to improve their technical abilities and confidence in using smart irrigation technologies (Dhanaraju et al. 2022). These programmes would provide farmers with direct exposure and practical knowledge, allowing them to efficiently operate and maintain the technologies. In addition to initial training, continuing education and technical assistance will be required to solve any issues that develop and keep farmers up to date on the newest developments. Younger farmers may be more likely to adopt smart irrigation technologies than elderly farmers, as indicated in our demographic results. Old farmers may be more hesitant to learn and use smart irrigation technologies. Providing young farmers with essential skills and expertise through training can support the effective adoption of smart irrigation technologies. This leads to more efficient and productive farming methods (Jaafar & Kharroubi 2021).

Farming community engagement projects

To increase the utilisation of smart irrigation technologies, community showcase programmes are an extremely effective technique. These programmes entail demonstrating the technologies' benefits and practical uses to small-scale farming populations. Setting up demonstration sites on surrounding farms allows other farmers to experience how the systems work, resulting in better knowledge and trust in the technology. Such helpful, practical instances can be significantly more persuasive than theoretical explanations since farmers can experience the tangible benefits, such as enhanced water efficiency and high production of crops (Suh et al. 2017). These demonstration initiatives can also serve as hubs for information sharing and collaboration. They allow farmers to discuss challenges, exchange ideas and learn from others who have successfully implemented smart irrigation systems. This collaborative approach not only generates interest but also creates an environment of support that promotes wider adoption and innovation in smart agricultural practices (Koech & Langat 2018).

Collaboration with technology providers

Developing collaborations with technology providers is an important strategy for ensuring the successful implementation of smart irrigation technologies. These collaborations can lead to the development and implementation of cost-effective and scalable solutions customised to farmers' needs. Working directly with smart irrigation technology providers allows farmers to receive continuing support and regular system updates, ensuring that the technologies stay effective and reliable over time (Bwambale et al. 2022). Such collaborations can also promote innovation because technology suppliers can use farmer feedback to modify and improve their products.

These collaborations can help farmers bridge the gap between themselves and innovative technical solutions. This makes it easier to adopt and integrate smart irrigation technologies into their farming practices. Farmers can have access to the most recent innovations, receive expert advice, and, as a result, improve the efficiency and productivity of their methods of farming (Mango et al. 2018).

Limitations and future studies

This study relies solely on qualitative data from 53 small-scale farmers in Gauteng and North-West provinces, which may not represent the broader South African farming population. The exclusive use of self-reported perceptions may introduce bias and lack empirical validation of technology outcomes. Future studies should explore various regions and different scales of agriculture. They should combine quantitative and qualitative methods and assess the measurable benefits of efficient irrigation systems in terms of cost reduction, water conservation, and increased agricultural productivity. Persistent research efforts could track the transformation of technology uptake over the years, while experimental approaches might bring to light useful pragmatic insights. Assessing feedback from both supporters and opponents of smart irrigation technologies can improve understanding of the factors that help or hinder their adoption.

Conclusion

The study highlights the need for collaboration among agricultural technology suppliers, public sector entities, farmers and agricultural institutions in promoting the application of smart irrigation systems. Resolving farmers' training, financial issues and infrastructural challenges may facilitate a larger rollout of these technologies, which would in turn enhance water conservation, elevate agricultural output and support sustainability efforts. Future research should focus on developing more affordable smart irrigation technologies, enhancing training and support, and improving knowledge sharing among rural farmers.

In summary, while adopting smart irrigation systems presents challenges, the potential benefits are significant. Implementing the proposed measures will help foster an environment conducive to wider adoption, ultimately leading to more efficient, productive and sustainable agricultural practices. This will not only improve food security and economic growth but will also help agriculture remain viable in the context of increased water scarcity and climate change.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

Both A.T.K. and B.B.M. contributed towards data collection and writing up the journal. A.T.K. was the main author who initiated the project.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its online appendices (Online Appendix 1 and Online Appendix 2).

Disclaimer

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