Assessment of LoRa Technology in Enhancing Agricultural Productivity in Rural Malaysia

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ABSTRACT

This systematic review evaluates the effectiveness of Long Range (LoRa) technology in enhancing agricultural productivity in rural Malaysia. By conducting a comprehensive literature search across seven digital databases, 2,909 papers published between January 2019 and December 2023 were initially collected. Utilizing the PRISMA process, the review narrowed down to 47 primary studies, focusing on smart connectivity methods, verification techniques, challenges, and future directions in smart agriculture. The analysis revealed that LoRa technology, a subset of IoT, plays a significant role in agricultural advancements, offering insights into connectivity methods, validation practices, and emerging challenges. The review underscores the increasing application of smart technologies in agriculture, highlighting LoRa's impact on productivity and suggesting future research directions.

ARTICLE INFORMATION

Method Name: Systematic Literature Review

Keywords: Systematic Literature Review, LoRa Technology, Agricultural Productivity, Rural Malaysia, IoT (Internet of Things), Smart Agriculture, Precision Farming, Wireless Communication, Sensor Networks, Farming Technology, Agricultural Innovation, Rural Development, Sustainable Agriculture, Crop Management, AgriTech, Data-Driven Agriculture

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1 Introduction

The rapid advancement of technology has transformed agriculture, leveraging IoT, big data, artificial intelligence, and wireless communication protocols to enhance productivity and sustainability in what is now termed Agriculture 4.0. LoRa (Long Range), a low-power, wide-area network (LPWAN) technology, has emerged as a key player due to its suitability for long-range communication and low power consumption, making it ideal for rural and remote areas. Various studies, such as those by Ahmed et al. (2022) and Almalki et al. (2021), have demonstrated the effectiveness of LoRa-based platforms for remote monitoring and environmental oversight in agriculture. Despite its promise, challenges like connectivity, network coverage, scalability, and cost-effectiveness persist, as noted by Paul et al. (2022) and Boursianis et al. (2022).

This study systematically reviews the literature on LoRa technology's impact on agricultural productivity in rural Malaysia, aiming to provide insights into the methods for smart/IoT connectivity, verification approaches, and the evolving challenges and future directions in this field. The main contributions of this systematic review can be summarised as follows:

1 A comprehensive literature search and investigation were conducted, focusing on smart technology in the agricultural field. A total of 2,909 papers were collected using specified keyword search strategies from seven databases (Science Direct: 869; Scopus: 373; Google Scholar: 1,200; IEEE Xplore: 22; Emerald Insight: 37; Springer Link: 200; Web of Science: 208). These papers were published between January 2019 and December 2023.

2 An extensive literature review was carried out using the methodology based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process. This study addressed three research questions. The process involved formulating research questions and motivations, collecting relevant studies, defining inclusion and exclusion criteria, and identifying primary studies with acceptable quality scores. Data items for each research question were extracted for intensive data analysis, providing answers and discussions related to the proposed research questions.

3 An in-depth explanation and discussion were implemented in the primary studies. Each paper was reviewed based on the extracted data items to answer the proposed research questions, covering methods used for smart connectivity, smart technology validation methods, limitations, challenges, and future directions. The aim was to offer insights to researchers and practitioners interested in pursuing research on using smart technologies in the agricultural field, particularly in rural areas.

The structure of this study is as follows: Table 1 lists all acronyms used in the paper. Section 2 outlines the research methodology, including research protocols such as PRISMA and research questions. Section 3 presents the literature review results, including discussions and answers to the research questions. Section 4 discusses the limitations of this study. Finally, Section 5 provides the conclusions.

Table 1 Acronyms and their explanations

Acronym	Explanation
AI	Artificial Intelligence
IoT	Internet of Things
DOI	Digital Object Identifier
LoRa	Long Range
LoRaWAN	Long Range Wide Area Networks
LPWAN	Low-Power Wide-Area Networks
ML	Machine Learning
PLC	Programmable Logic Controller
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QA	Quality Assessment
RQ	Research Questions
SLR	Systematic Literature Review
UAVs	Unmanned Aerial Vehicles
UTM	University Technology Malaysia (English) or Universiti Teknologi Malaysia (Malay)
WoS	Web of Science
WSN	Wireless Sensor Networks

2 Methodology

This methodology involves two main phases: "Planning" which is detailed in Section 2, and "Conducting" described in Section 3 as proposed by Carrera-Rivera et al. (2022). In the planning phase, researchers establish the SLR procedure by defining the topics, research questions, and article search criteria. The conducting phase entails searching for relevant articles and filtering them according to inclusion and exclusion criteria.

2.1 Planning Phase

In the initial planning step of the study, broad area of interest “smart village” is proposed. The focus is narrowed down to more specific topic which include these keywords: “smart connectivity”, “rural development”, “agricultural productivity” and outcome a more specific title which focus “LoRa technology in enhancing agricultural productivity in rural Malaysia.”

In the next step, three research questions have been defined as shown in Table 2.

Table 2 Defining Research Questions

No.	Research Questions
RQ1	What are the methods used for smart / IoT connectivity in rural areas?
RQ2	What are the verification methods to evaluate the effectiveness of proposed methods for smart / IoT connectivity in rural areas?
RQ3	What are the challenges and future directions using the proposed methods for smart / IoT connectivity in rural areas?

Based on the specific topic and research questions defined, relevant keywords and search terms as shown in Table 3 are used to extract the relevant articles from the digital database.

Table 3 Defining Article Search Criteria

Digital Database	Search Strings	Searched Quantity
Science Direct	("smart" OR "connectivity") + ("lora" OR "lorawan") +agriculture	869
Scopus	("smart" OR "connectivity") + ("lora" OR "lorawan") +agriculture	373
Google Scholar	("smart" OR "connectivity") + ("lora" OR "lorawan") +agriculture	1200
IEEE Xplore	smart AND lora AND agriculture	22
Emerald Insight	("smart" OR "connectivity") + ("lora" OR "lorawan") +agriculture	37
Springer Link	("smart" OR "connectivity") + ("lora" OR "lorawan") +agriculture	200
WoS	"smart connectivity"	208

Three Quality assessments in Table 4 was conducted to evaluate how effectively the authors addressed the research questions posed in the SLR. This process facilitated the accurate extraction of relevant data and the elimination of irrelevant studies by using the scoring criteria outlined in Table 5.

Table 4 Defining Quality Assessment

No.	Quality Assessment Questions	Relevant to Research Question
QA1	How does the author(s) present the implementation of methods in the studies?	RQ1
QA2	How does the author(s) conduct comprehensive validation for the proposed research method?	RQ2
QA3	How does the author(s) present the study findings, limitations and future direction?	RQ3

Table 5 Quality Assessment Scoring Criteria

No.	Quality Assessment Scoring Criteria	Score
1	The author(s) have presented a comprehensive, clear, and unambiguous explanation of the answers to the specific RQ.	High = H = 1
2	The author(s) have provided some explanation, but it is not specific, detailed, or clear enough to the specific RQ.	Medium = M = 0.5
3	The author(s) have given little or no technical information in response to the specific RQ.	Low = L = 0

Table 6 is the title relevancy scoring metrix to identify the relevancy of the primary studies to the research title.

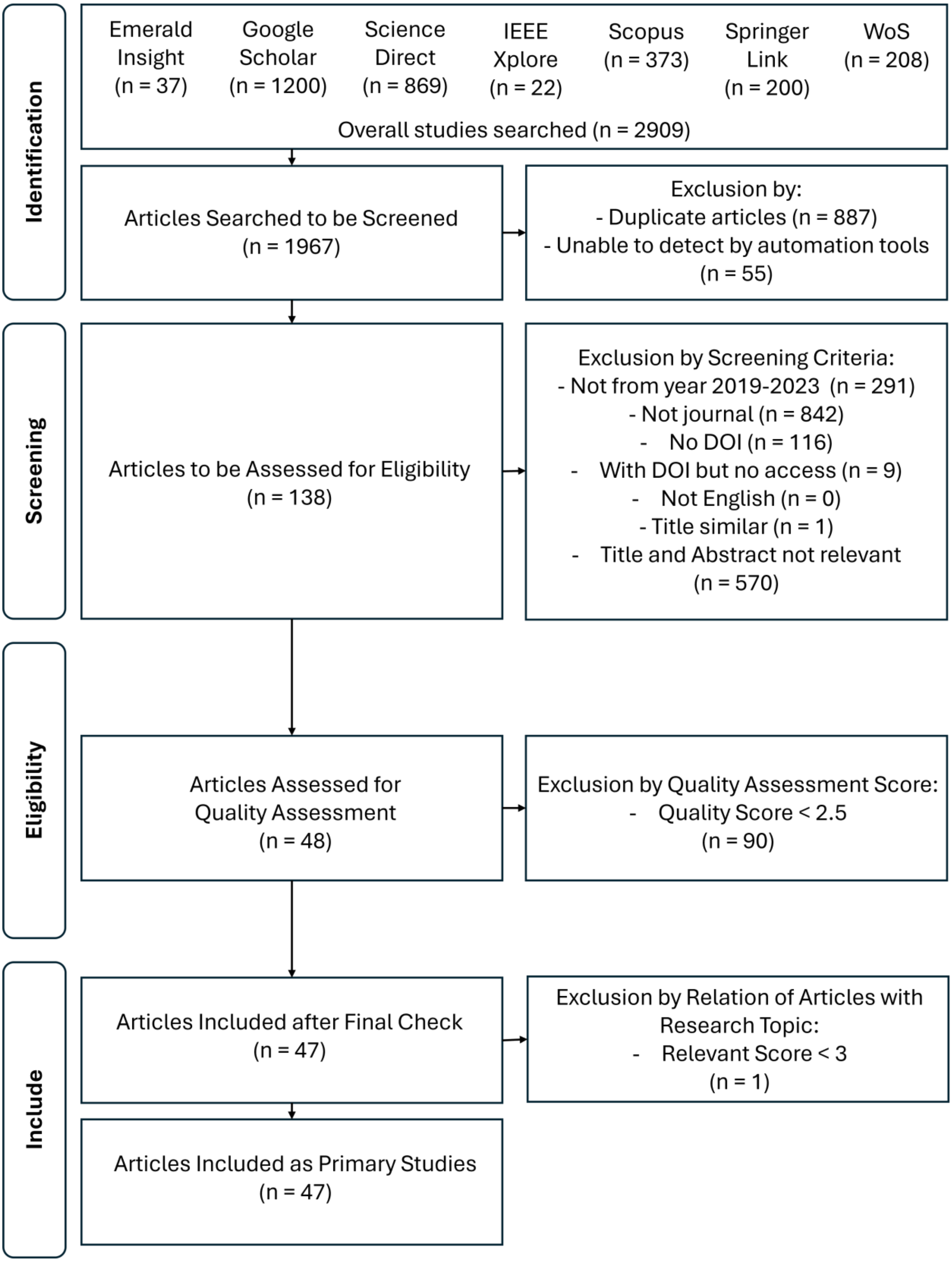
Table 6 Title Relevancy Scoring Criteria

No.	Title Relevancy Scoring Criteria	Score
1	Specifically addresses LoRa technology in enhancing agricultural productivity in rural Malaysia.	Directly relevant = 5
2	Focuses on LoRa technology in agriculture, but not specific to rural Malaysia.	Highly relevant = 4
3	Discusses IoT and agriculture with some mention of LoRa technology.	Moderately relevant = 3
4	Mentions IoT or agriculture but not specific to LoRa or rural Malaysia.	Slightly relevant = 2
5	Does not mention technology, agricultural, or rural.	Not relevant = 1

2.2 Conducting Phase

In this phase, the PRISMA guidelines is used to provide comprehensive details about the number of articles assessed in this study as in Figure 1.

Figure 1 PRISMA diagram



By using the PRISMA diagram, the selection of the papers is done based on 4 sessions which covered identification, screening, eligibility, and include sessions. In identification process, overall studies of total 2909 are searched through digital database which include Emerald Insight, Google Scholar, Science Direct, IEEE Xplore, Scopus, Springer Link and Web of

Science (WoS). Initial exclusion for duplicate papers and undetectable papers are done during this phase. Total of 942 papers had been excluded and 1967 papers is included for screening phase. In the next phase, the papers are screened based on exclusion criteria such as year not within year 2019 and year 2023, not journal articles, no Digital Object Identifier (DOI) found, with DOI but unable to access the papers, not in English language, similar title, and not relevant title and abstract. Total of 1829 papers had been excluded and 138 papers are included to proceed to the next phase to check for the eligibility. In the process of checking the eligibility, the quality assessment (Table 4) and the quality assessment scoring criteria (Table 5) are used. Appropriate scores are given to all 138 papers. From this process, 48 papers with the total QA score equal or greater than 2.5 have been chosen. Last but not least, during the inclusion process, the relevancy of the papers' title to this research's title is determined based on the title relevancy scoring metrix (Table 6). As a result, 47 papers have been included after 1 paper had been excluded as the relevancy score are less than 3. In conclusion, through the 4 phases in PRISMA, the papers have been narrowed down from total of 2909 papers to 51 papers that are relevant to the research questions proposed. These 51 papers are the primary study papers in this research.

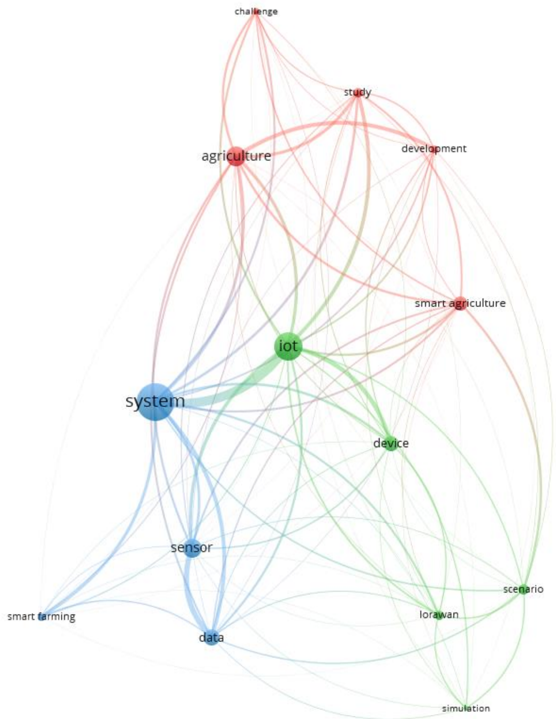
3 Results and analysis

Analysis such as background analysis, research questions analysis and other analysis have been done for the primary studies' articles after the articles has been finalised to be included in the study.

3.1 Background Analysis

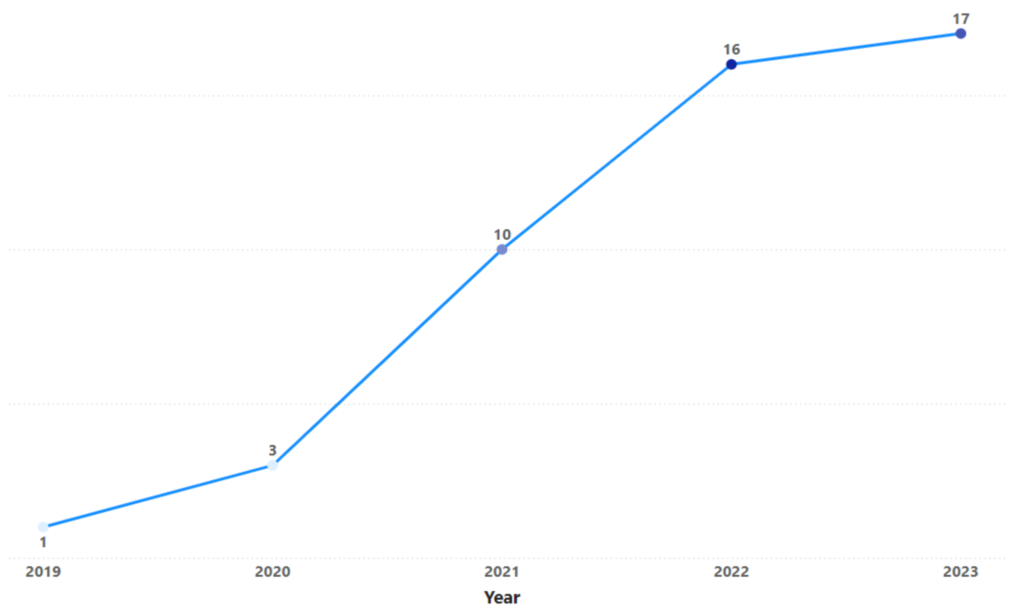
Based on the keywords visualisation in Figure 2 which generated from VOSviewer, "IoT" in green cluster act as the central hub which connected "system" and "agriculture" in blue cluster and red cluster respectively. Green cluster showing the technological backbone of IoT applications such as "lorawan". Blue cluster included the technological components and data management within system. While Red cluster emphasize the research and application aspects of agriculture. Overall, it can be concluded that the methodology used to determine the primary studies is valid as the results from Figure 2 showed that the primary studies are topic focused which include keywords "lorawan" and "agriculture".

Figure 2 Keywords Clustering and Network Visualisation of primary studies by VOSviewer



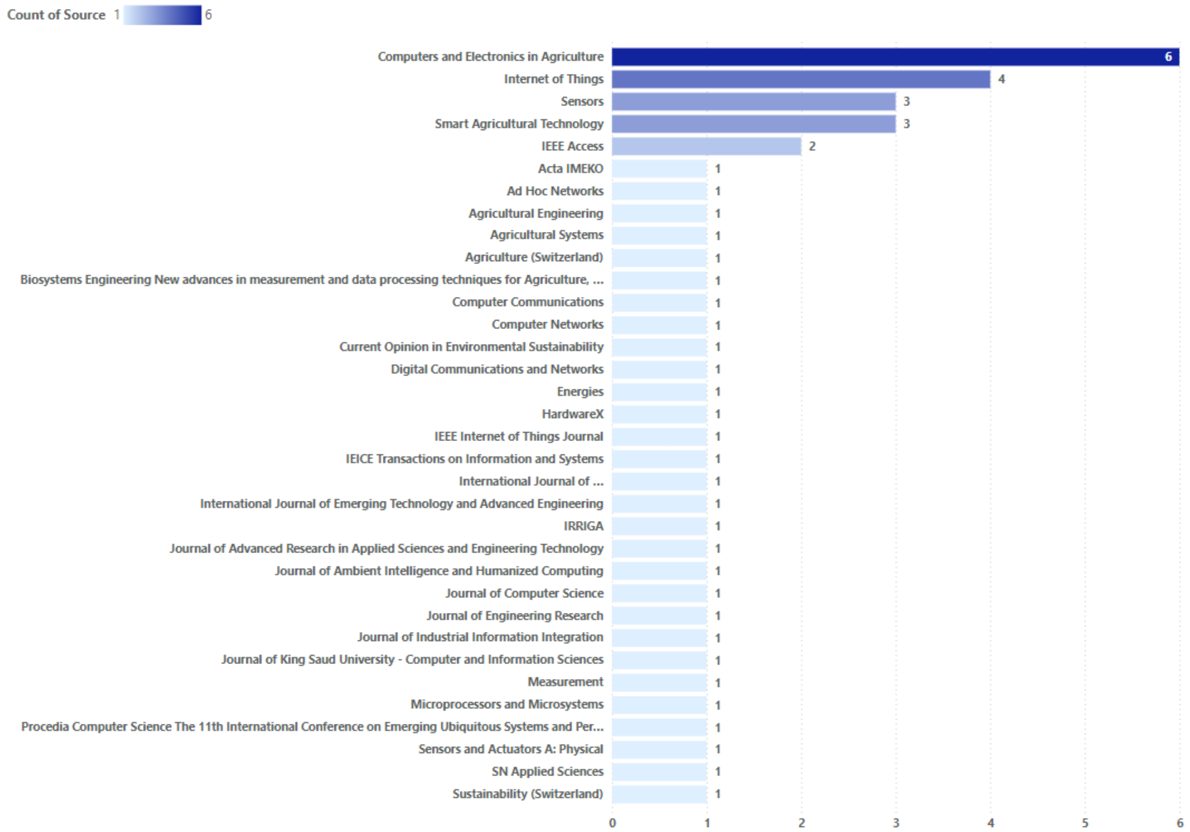
According to Figure 3, there is a significant increment of smart technology applied in agriculture field from year 2019 to year 2023 where the number increases from 1 to 17 respectively.

Figure 3 The Trend of Smart Technology Applied in Agricultural Field



Based on the analysis in Figure 4, most of the relevant studies is obtained from "Computers and Electronics in Agricultural" source followed by "IoT" source. The "Computers and Electronics in Agricultural" source accounted for 12.77% of total sources in this study.

Figure 4 The Number of Journals from Published Source



3.2 Research Questions Analysis

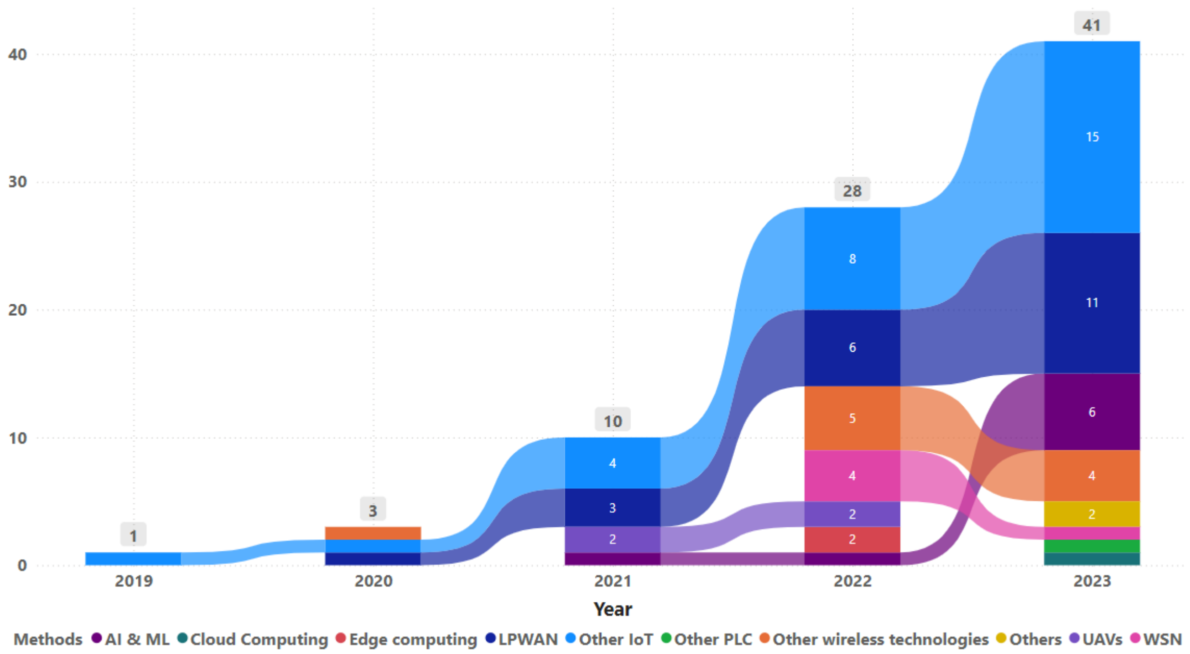
RQ1 What are the methods used for smart / IoT connectivity in rural areas?

From the analysis result in Table 7, other IoT is the methods proposed by most of the researchers followed by LPWAN. Based on Figure 5, the implementation of other IoT and LPWAN increases over years since 2019. Although the implementation of LPWAN which included LoRaWAN started later than other IoT, but it seconded the trend in year 2023. The AI & ML method start to implement in year 2021 and ranked 3rd in year 2023.

Table 7 Count of Methods/Technologies Used for Smart/IoT Connectivity by Recent 5 Years

Methods	2019	2020	2021	2022	2023	Total
Other IoT	1	1	4	8	15	**29**
LPWAN		1	3	6	11	**21**
Other wireless technologies		1		5	4	**10**
AI & ML			1	1	6	**8**
WSN				4	1	**5**
UAVs			2	2		**4**
Edge computing				2		**2**
Others					2	**2**
Cloud Computing					1	**1**
Other PLC					1	**1**
Total	**1**	**3**	**10**	**28**	**41**	**83**

Figure 5 Count of Methods/Technologies Used for Smart/IoT Connectivity by Recent 5 Years Trend



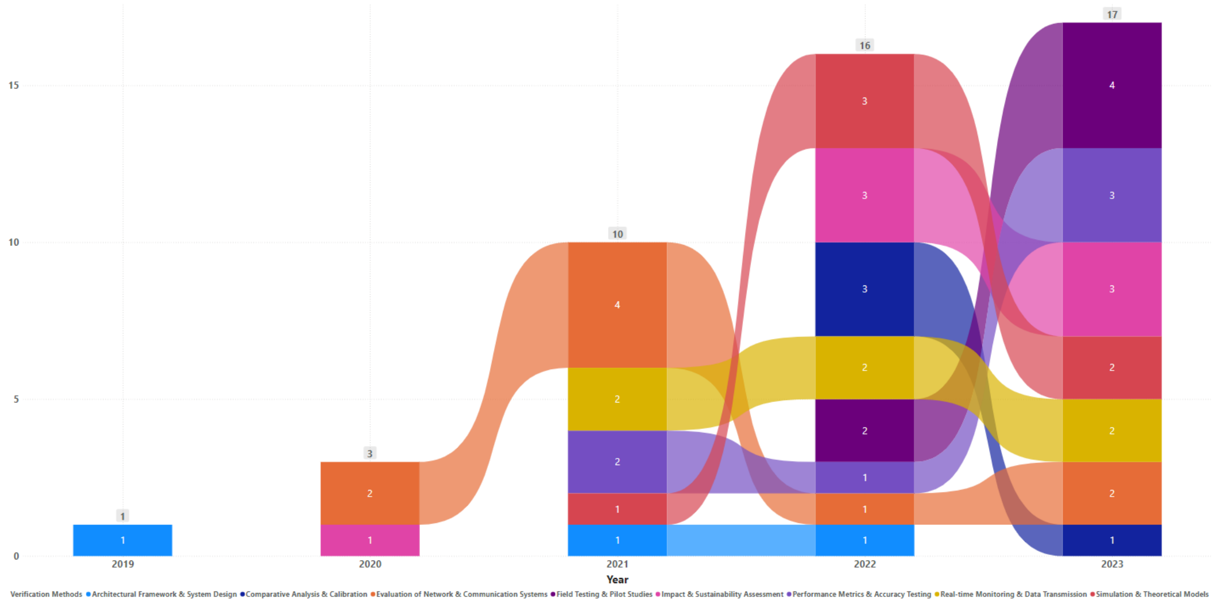
RQ2 What are the verification methods to evaluate the effectiveness of proposed methods for smart / IoT connectivity in rural areas?

Refer to the analysis in Table 8, the most common verification methods to evaluate effectiveness of the methods/technologies used for Smart/IoT connectivity in agricultural field is by doing evaluation of network and communication system as the occurrence of this verification methods is 9 which topped among other methods. However, referred to Figure 6's trend, this verification method is replaced by other methods since year 2022. The most common verification method used in year 2022 is simulation and theoretical models. While this method also had been replaced by another method: field testing and pilot study in year 2023.

Table 8 Count of Verification Methods Used by Recent 5 Years

Verification Methods	2019	2020	2021	2022	2023	Total
Evaluation of Network & Communication Systems		2	4	1	2	9
Impact & Sustainability Assessment		1		3	3	7
Field Testing & Pilot Studies				2	4	6
Performance Metrics & Accuracy Testing			2	1	3	6
Real-time Monitoring & Data Transmission			2	2	2	6
Simulation & Theoretical Models			1	3	2	6
Comparative Analysis & Calibration				3	1	4
Architectural Framework & System Design	1		1	1		3
Total	**1**	**3**	**10**	**16**	**17**	**47**

Figure 6 Count of Verification Methods Used by Recent 5 Years Trend



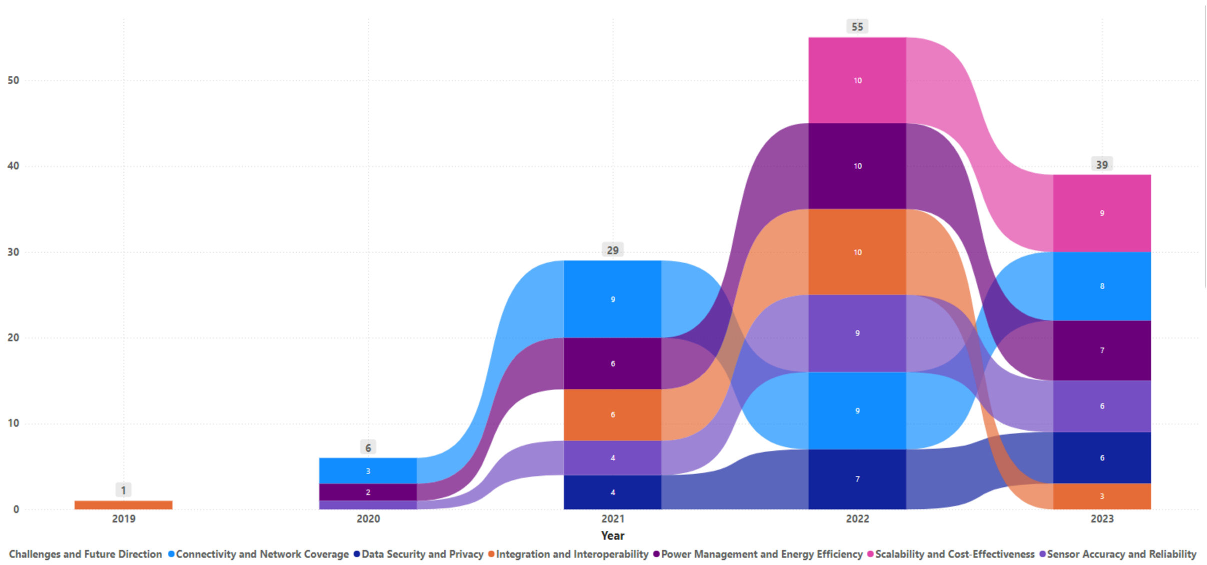
RQ3 What are the challenges and future directions using the proposed methods for smart / IoT connectivity in rural areas?

According to the analysis in Table 9, the most challenged field when implementing the smart technology in agricultural field is connectivity and network coverage. However, when compare with Figure 7, this issue became less concerned starting year 2022. Since year 2022, scalability and cost-effectiveness issue became the main concern. Although power management and energy efficiency show increasing trend since year 2019 and seconded in year 2022 it still remains as third major issue whereby the first issue is scalability and cost-effectiveness issue and the second is connectivity and network coverage in year 2023. These issues have been proposed as the future direction of the studies.

Table 9 Count of Challenges and Future Direction by Recent 5 Years

Challenges and Future Direction	2019	2020	2021	2022	2023	Total
Connectivity and Network Coverage		3	9	9	8	**29**
Power Management and Energy Efficiency		2	6	10	7	**25**
Integration and Interoperability	1		6	10	3	**20**
Sensor Accuracy and Reliability		1	4	9	6	**20**
Scalability and Cost-Effectiveness				10	9	**19**
Data Security and Privacy			4	7	6	**17**
Total	**1**	**6**	**29**	**55**	**39**	**130**

Figure 7 Count of Challenges and Future Direction by Recent 5 Years Trend



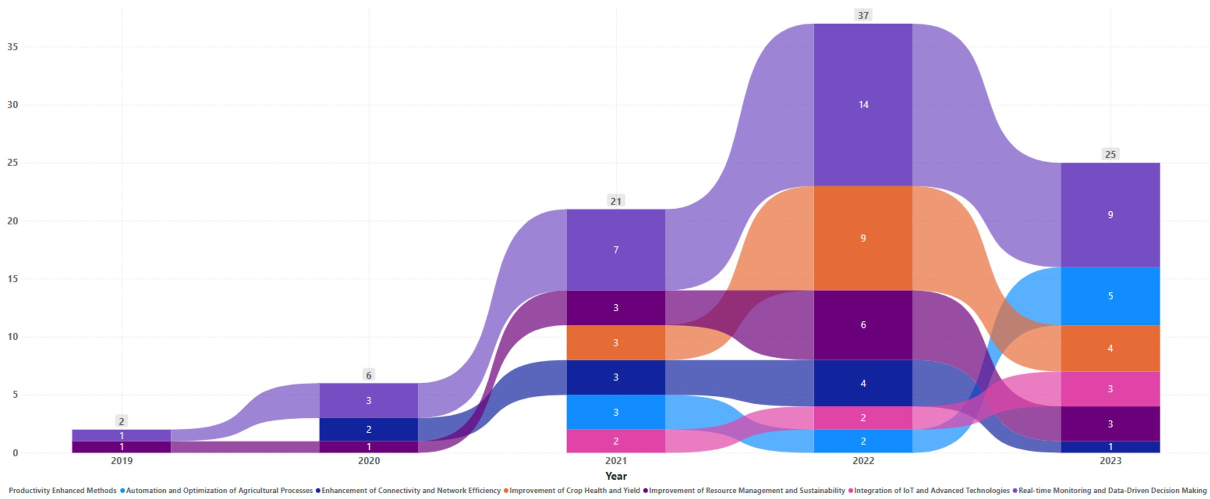
3.3 Other Analysis

Based on the analysis in Table 10, the most widely used method in enhancing the productivity in agriculture is through real-time monitoring and data-driven decision making. This method always ranked top since year 2019 until 2023 (Figure 8). The method such as improvement of crop health and yield ranked second while improvement of resource management and sustainability ranked third. However, these two method had been replaced by another method: automation and optimization of agricultural process in year 2023 (Figure 8).

Table 10 Methods in Enhancing Productivity in Agricultural by Recent 5 Years

Productivity Enhancement Methods	2019	2020	2021	2022	2023	Total
Real-time Monitoring and Data-Driven Decision Making	1	3	7	14	9	34
Improvement of Crop Health and Yield			3	9	4	16
Improvement of Resource Management and Sustainability	1	1	3	6	3	14
Automation and Optimization of Agricultural Processes			3	2	5	10
Enhancement of Connectivity and Network Efficiency		2	3	4	1	10
Integration of IoT and Advanced Technologies			2	2	3	7
Total	2	6	21	37	25	91

Figure 8 Methods in Enhancing Productivity in Agricultural by Recent 5 Years Trend



In conclusion, the analysis of the "Assessment of LoRa Technology in Enhancing Agricultural Productivity in Rural Malaysia" reveals several key insights. IoT acts as a central hub, connecting technological components and data management within agricultural systems, with LoRaWAN being a critical technology. From 2019 to 2023, there was a significant increase in smart technology applications in agriculture. Most relevant studies were sourced from "Computers and Electronics in Agriculture," and the most proposed methods were various IoT technologies and LPWAN, including LoRaWAN. Verification methods evolved over time, with field testing and pilot studies becoming the most prevalent by 2023. Initially, connectivity and network coverage were major challenges, but scalability and cost-effectiveness became the primary concerns by 2022. Real-time monitoring and data-driven decision-making were consistently the top methods for enhancing productivity, with automation and optimization of agricultural processes gaining prominence in 2023. Overall, the primary studies were topic-focused and validated through evolving verification methods, addressing key challenges and demonstrating the impact of LoRa technology on agricultural productivity.

4 Limitation of the study

This study conducted a Systematic Literature Review (SLR) to assess the impact of LoRa technology on enhancing productivity in rural Malaysia, based on 47 primary studies from 2019 to 2023. The results of this SLR may have been influenced by the search strategy coverage, researcher bias, and potential inaccuracies in data extraction. These issues are discussed and addressed below.

The search strategy coverage was determined by a limited set of keywords aimed at providing an overview of the application of smart connectivity technology, such as LoRa, in the agricultural field from selected academic databases. Consequently, related studies using different keywords or from other databases might not have been included in the search results.

Additionally, the criteria for quality assessment and title relevancy could introduce bias in evaluating the quality of primary studies. The quality score was based on expected findings related to smart technology use in agriculture, derived from the title, abstract, keywords, and full text, rather than the general quality of the academic study.

Finally, there is a possibility of inaccuracy in extracting data items based on the research questions, such as methods used for smart/IoT connectivity, validation methods, methods for enhancing productivity, and challenges and future directions. However, data items were extracted based on a comprehensive understanding of the studies, and the accuracy of this study is ensured by providing detailed search coverage, data items, and criteria for research question findings.

5 Conclusion

In conclusion, LoRa technology has demonstrated significant potential in enhancing agricultural productivity in rural Malaysia by providing efficient, low-power, long-range communication solutions. Despite various challenges such as connectivity, scalability, and cost-effectiveness, its application in environmental monitoring, data collection, and smart agriculture practices has shown promising results. Future research should focus on overcoming these challenges, improving network coverage, and integrating advanced data analytics to further optimize agricultural processes. By addressing these issues, LoRa technology can play a pivotal role in the advancement of Agriculture 4.0, contributing to sustainable and productive agricultural practices in remote and rural areas.

Credit Author Statement

Grace Ling Kian Hwai : Conceptualization, Methodology, Analysis, Writing-Original

Bakunga Bronson : Conceptualization

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