AUTOMATION OF ALTERNATE WETTING AND DRYING METHOD AND METHANE ESTIMATION FOR PADDY

BY

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TAVANUR- 679 573, MALAPPURAM

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PROJECT REPORT

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TAVANUR- 679 573, MALAPPURAM, KERALA, INDIA

2024

DECLARATION

We hereby declare that this project entitled " AUTOMATION OF ALTERNATE WETTING AND DRYING METHOD AND METHANE ESTIMATION FOR PADDY" is a bonafide record of project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another university or society.

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CERTIFICATE

Certified that the project entitled "**AUTOMATION OF ALTERNATE WETTING AND DRYING METHOD AND METHANE ESTIMATION FOR PADDY**" is a record of project work done jointly by **Ms. ANGELEENA CATHEREEN JOSEPH (2020-02-022), Ms. VARNA MURALEEDHARAN (2020-02-042), Ms. ARDRA K (2020-02-045)** and **Mr. MUSHARAF NASAR (2020-02-047)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to them.

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Dedicated to Climate Resilient Agriculture

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SYMBOLS AND ABBREVIATIONS

AAWD : - Automated Alternate Wetting and Drying
AC : - Alternating Current
ADC : - Analog Input Pins
AO : - Analog Output
AWD : - Alternate Wetting and Drying
CF : - Continuous Flooding
CI : - Conventional Irrigation
COM : - Common
CPU : - Central Processing Unit
DAC : - Analog Outputs Pins
DIO : - Digital Input/Output
DO : - Digital Output
ESP : -Expressive Systems
et al. : - And Others
FAO : - Food and Agriculture Organisation
FTIR : - Fourier Transform Infrared
GHG : - Green House Gas
GND : - Ground
GPIO : - General-Purpose Input/Output
GWP : - Global Warming Potential
HP : - Horse Power
IEEE : - Institute of Electrical and Electronics Engineers
IPCC : - Intergovernmental Panel on Climate Change
IRRI : - International Rice Research Institute
KB : - Kilobyte
LED : - Light Emitting Diode
MB : - Megabyte
MCF : - Methane Conversion Factor
MCU : - Micro Controller Unit

MHz	: - Mega Hertz
MOS	: - Metal Oxide Semiconductor
MQ	: - Methane Quality
MSD	: - Mid-Season Drainage
NC	: - Normally Closed
NO	: - Normally Open
PVC	: - Poly Vinyl Chloride
PWM	: - Pulse Width Modulation
RMSE	: - Root Mean Square Error
SPI	: - Serial Peripheral Interface
SRAM	: - Static Random Access Memory
SRI	: - System of Rice Intensification
TRIG	: - Trigger
UART	: - Universal Asynchronous Receiver/Transmitter
USB	: - Universal Serial Bus
VCC	: - Common Collector Voltage
VIN	: - Input Voltage
WSN	: - Wireless Sensor Networks
WUE	: - Water Use Efficiency

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CHAPTER 1

INTRODUCTION

"World population is expected to grow by over a third, or 2.3 billion people, between 2009 and 2050(FAO, 2009)." As temperatures escalate and weather patterns become increasingly erratic, the challenge of providing sustenance for a growing populace assumes greater complexity and urgency. Continued greenhouse gas emissions exacerbate these climatic shifts, amplifying the stress on agricultural systems and threatening crop yields worldwide. According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are major contributors to global warming (IPCC, 2021). The concentration of GHGs such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) has been increased by 150%, 40%, and 20%, respectively, since the pre-industrial time.The energy sector accounts for approximately 73% of global CO_2 emissions, with transportation contributing around 14%, and agriculture and land use making up about 18% of total emissions, with significant methane and nitrous oxide contributions (IPCC, 2019).The concentration of GHGs such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N2O) has been increased by 150%, 40%, and 20%, respectively, since the pre-industrial time (IPCC 2014).

Agriculture stands as a critical economic sector, playing a pivotal role in ensuring both food and nutritional security. However, it impacts directly or indirectly towards the global climate change by emitting greenhouse gases and contributes about 16% of the total greenhouse gas emissions in the country (Pradhanand Goswami, 2019).In the agricultural sector, livestock and rice cultivation are significant sources of methane emissions, accounting for approximately 37% and 11% of total anthropogenic methane emissions, respectively (Smith *et al.*, 2008).Apart from being dynamic GHG, CH_4 affects the oxidation of the atmosphere by controlling the concentrations of tropospheric hydroxyl radicals and N_2O contributes to the stratospheric ozone depletion (Portmann *et al.*, 2012). Carbon dioxide also largely contributes to global climate change and accounts for 60% of the total greenhouse effect (Liu *et al.*, 2018).

Rice (Oryza sativa) is major and nutritious staple food primarily in Asia and is considered the second biggest (745 Tg in 2013) cereal crop produced in the world Rice is grown in 114 countries over a total land of around 153 Mha, which covers 11% of the world's arable land (Vijayand Roy, 2013).More than 90% of the world's rice is produced in Asia, with

75% of it cultivated in irrigated lowland areas covering approximately 80 million hectares. Rice is the country's most crucial agricultural commodity, and it is grown in an area of 43.86 Mha in India and produces more than 20% of the total rice production of the world (Papademetriou, 2000). Rice cultivation spans across nearly all states in India and is intricately linked to the nation's food security. Moreover, it serves as a significant source of livelihood and employment. Nevertheless, it poses a significant concern to the scientific community and poses a notable threat to sustainable agriculture due to its substantial contribution to vital and persistent greenhouse gases such as CH_4 and N_2O.Around 30% and 11% of global agricultural CH_4 and N_2O, respectively, are emitted from rice fields (Gupta*et al*., 2021). The GWP of rice crop is 467 and 169% higher compared to that of wheat and maize, respectively (Linquist *et al*., 2012). In rice cultivation, methane is the primary greenhouse gas emitted, with a global warming potential estimated to be about 25 times higher than that of CO_2 over a 100-year period. Methane emissions from flooded rice fields are particularly significant due to anaerobic conditions promoting methanogenesis. Additionally, paddy fields emit other greenhouse gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2). Nitrous oxide emissions arise from microbial processes such as nitrification and denitrification in the soil, particularly in flooded conditions with the application of nitrogen fertilizers. Nitrous oxide has a global warming potential approximately 298 times greater than CO_2 over a 100-year period (IPCC, 1997). Although nitrous oxide concentrations are lower than methane emissions, their global warming potential is much higher, emphasizing the need to address and reduce nitrous oxide emissions.

Paddy cultivation typically requires standing water depth of 5-10cm during the growing season. This standing water level exceeds the crop water requirement of paddy, which can contribute to methane emissions from anaerobic soil conditions (Bouman *et al*., 2007).It is projected that up to 2030, emission of both the GHGs may increase by 35–60% (Smith *et al*., 2008).However, rice production needs to be increased by 40% till 2030 to meet rising demand from the ever-growing population (FAO 2009), which may raise serious environmental concerns. Excessive use of inorganic fertilizers to enhance rice production can exacerbate the emissions of CH_4 and N_2O from rice fields. Hence, future rice cropping systems must integrate higher grain yields with reduced greenhouse gas (GHG) emissions. There's an urgent necessity to quantify N_2O and CH_4 fluxes and enhance our comprehension of these gases in rice fields to formulate effective mitigation strategies, mitigating the adverse effects of impending climate change. GHG emissions from paddy fields depend on various factors like the irrigation-water level, amount of fertilizer used, rice varieties, and soil parameters. Greenhouse gas emissions from paddy fields can be mitigated through various strategies such as Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI), and intermittent wetting, which have shown significant reductions in methane emissions (Bouman *et al.*, 2007). AWD is often preferred over SRI due to its simplicity in implementation and lower labour requirements, making it more accessible and cost-effective for farmers.

The Alternating Wetting and Drying technique, utilized in rice cultivation, has its roots in ancient China, with evidence dating back over a thousand years. Today, it is widely practiced not only in China but also in various rice-growing regions across Asia, including Japan, Vietnam, and the Philippines, as well as in other parts of the world where rice is a staple crop.

Alternate Wetting and Drying (AWD) present a straightforward and cost-effective approach to reducing water usage in rice cultivation by approximately 30%. This method allows farmers to decrease production expenses without sacrificing yields. AWD involves periodically draining the field to a specified threshold, typically 15 cm below the soil surface, followed by re-flooding. By utilizing a perforated tube inserted into the soil, farmers can monitor the water level beneath the surface to determine when irrigation is necessary. Furthermore, AWD technology has demonstrated its effectiveness in mitigating greenhouse gas (GHG) emissions, particularly methane (CH_4), in rice production by 30-70% without negatively impacting yields. During the dry phases, the activity of methane-producing bacteria is suppressed, thereby creating conditions conducive to reducing GHG emissions. Additionally, AWD has been found to enhance soil health, increase rice yields, and improve farmers' resilience to water scarcity and fluctuating water availability. Moreover, studies have shown that AWD can reduce the accumulation of toxic arsenic in rice grains by up to 25%, mitigating health risks associated with arsenic consumption. This reduction in arsenic levels is attributed to the intermittent drying of soil during AWD, which helps to inhibit the transformation of inorganic arsenic into its more bioavailable form, thus reducing its uptake by rice plants (Islam *et al.*, 2016).

Farmers practicing Alternating Wetting and Drying (AWD) for paddy cultivation encounter various challenges. One significant issue is water management, as maintaining the optimal balance between wet and dry phases requires precision. Additionally, the labour-intensive nature of AWD, involving manual monitoring and adjustment of water levels, poses a challenge, especially for resource-constrained farmers. Inadequate irrigation infrastructure further complicates the implementation of AWD, hindering effective water management. Lack of access to technical knowledge and training also limits farmers' ability to adopt AWD successfully. Furthermore, variability in yield, soil health concerns, pest and disease management, and market access issues contribute to the challenges faced by farmers practicing AWD. While various methods such as chamber-based measurements, eddy covariance, remote sensing techniques, and modelling approaches are employed to estimate methane emissions from paddy fields, they come with disadvantages such as labour intensiveness, high equipment costs, and complexity, which may limit their widespread adoption, particularly among smallholder farmers. To address these challenges and improve efficiency, automated AWD systems and automated gas chambers are required. These technologies can streamline water management processes, reduce labour requirements, and provide accurate and continuous monitoring of methane emissions, thereby facilitating more sustainable and efficient paddy cultivation practices (Chaichana *et al*., 2018).

In this study, our primary objective is to address the affordability issue associated with existing automation solutions for Alternating Wetting and Drying (AWD) systems and gas chambers for methane estimation, particularly for smallholder farmers. We aim to develop a cost-friendly Automated Alternating Wetting and Drying system (AAWD) along with an Automated Gas Chamber. By leveraging innovative design principles and low-cost materials, our goal is to create automation solutions that are accessible and affordable for smallholder farmers, enabling them to adopt sustainable water management practices and accurately monitor methane emissions from paddy fields. Through this initiative, we aspire to promote the widespread adoption of AWD and contribute to the mitigation of greenhouse gas emissions in agricultural systems, ultimately enhancing the resilience and sustainability of farming communities.

The main objectives of this study are

1. To develop a cost effective automated Alternating Wetting and Drying system (AAWD) for Paddy.
2. To develop sensor based gas chamber for Methane estimation from Paddy fields.

CHAPTER 2

REVIEW OF LITERATURE

This chapter deals with the concepts and literature available on greenhouse gas emission from agricultural sector especially from rice cultivation, alternate wetting and drying method of irrigation, Automation for AWD, estimation of methane from paddy field and Automated gas chamber for methane estimation.

2.1 GREEN HOUSE GAS EMISSION FROM AGRICULTURE SECTOR

Global greenhouse gas emissions, driven primarily by human activities, have become a critical focal point in addressing climate change. These emissions, predominantly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap heat in the Earth's atmosphere, leading to rising temperatures and associated environmental impacts. Global ecosystems, economies, and cultures are all significantly impacted by these emissions, which have increased to previously unheard-of levels. As the global population continues to grow, particularly in regions with increasing demands for food production, the agricultural sector plays a dual role as both a significant producer of greenhouse gases and a crucial absorber through practices like carbon sequestration and sustainable land management.

2.1.1 Livestock Farming

Johnson and Johnson (1995) discussed how ruminant livestock, particularly cattle, produce significant amounts of methane, contributing nearly 2% to global warming over the next 50 to 100 years. Methane emissions from cattle are influenced by factors such as feed intake, carbohydrate type, feed processing, lipid or ionophore addition, and changes in ruminal microflora. Various methods exist to measure methane emissions, including enclosure techniques, isotopic and non-isotopic tracers, and prediction equations, each with specific limitations. Group measurements can be done using mass balance, micrometeorological, or tracer methods. Understanding these factors and measurement techniques can aid in developing strategies to reduce methane emissions, enhancing productivity and reducing cattle's impact on atmospheric methane.

Su *et al*. (2003) conducted a study on GHG emissions from livestock farming in Taiwan, focusing on anaerobic wastewater treatment processes at pig and dairy farms. The study found that average methane (CH4) emissions were 0.768 kg per head per year for pigs and 4.898 kg per head per year for dairy cows, while carbon dioxide (CO2) emissions were 0.714 kg and 4.200 kg, and nitrous oxide (N2O) emissions were 0.002 kg and 0.011 kg per head per year, respectively. These emission rates were lower than IPCC limits due to Taiwan's practice of diluting manure before treatment with solid/liquid separators and anaerobic systems. The findings highlight the importance of tailored manure management practices in reducing GHG emissions in livestock farming.

Wang Lizhi *et al*. (2017) conducted a study assessing the impact of changes in pig and poultry production in China from 1960 to 2010 on greenhouse gas (GHG) emissions, measured as CO2 equivalents. In 2010, GHG emissions from pigs were 17% from enteric fermentation, 62% from manure management methane, and 21% from manure management nitrous oxide. For poultry, the corresponding figures were 1%, 18%, and 81%. The total CO2 equivalents significantly increased for both pigs (from 11,582 to 55,564 Gg yr–1) and poultry (from 1,497 to 14,873 Gg yr–1) during this period. However, emissions per kilogram of pork, poultry meat, and eggs decreased markedly, indicating enhanced production efficiency. These results offer valuable insights for Chinese policymakers in devising strategies to mitigate GHG emissions from the pig and poultry sectors.

2.1.2 Crop Cultivation

Tongwane *et al*. (2016) examined GHG emissions from synthetic fertilizers, lime, and crop residues in South Africa's field crop production to establish GHG profiles. They found that in 2012, this production emitted 5.2 million tonnes of CO2 equivalent (CO2-eq), with synthetic fertilizers contributing 57%, lime addition 30%, and crop residues 13%. Cereal crops, especially maize, wheat, and sugarcane, were major contributors (68%). The study underscores the importance of mitigating emissions by focusing on sustainable soil fertility, optimal fertilizer use, and crop residue management in South Africa's field crop production.

Chataut *et al*. (2023) discuss the surge in agricultural demand driven by population growth, leading to intensified agricultural practices and increased greenhouse gas (GHG) emissions. Despite their lower emissions compared to CO2, nitrous oxide (N2O) and methane (CH4) carry higher Global Warming Potential. Understanding the factors behind GHG emissions, including inorganic (fertilizers) and organic sources (animal manure, crop residues), requires further research into their complex interactions. Additionally, non-cereal crops like legumes, oilseeds, and fruits significantly contribute to GHG emissions, suggesting the potential of precision agriculture for enhancing efficiency. The implementation of site-specific management practices emerges as crucial for mitigating emissions and promoting sustainable agriculture.

Wang *et al*. (2023) studied greenhouse gas (GHG) emissions associated with global rice production and consumption across 227 countries and three sectors from 1986 to 2017. They noted a significant rise in production-based and consumption-based emissions, alongside domestic production (without trade), driven by increased rice trade volume. Despite trade shifting from low- to high-emission intensity countries, rice emissions intensity decreased substantially, resulting in a notable reduction in global GHG emissions. The study emphasizes the need for sustainable practices in international rice trade and urges main importing countries to consider environmental impacts alongside domestic policies.

2.1.3 Agroforestry Systems

Ansari *et al*. (2023) review the impact of agricultural practices on nitrous oxide (N2O) emissions, highlighting managed agricultural soils as both sources and sinks of N2O. Forest and agroforestry systems emit the least N2O, while corn/soybean rotations emit the most. Silvopasture systems exhibit the lowest N2O emissions, followed by deciduous forests. Extensive grass and tree roots in agroforestry systems reduce N2O emissions by absorbing soil inorganic nitrogen. Factors such as tillage practices, fertilizer application, and soil saturation conditions influence N2O emissions, with no-till practices showing lower emissions than conventional tillage. Soil tillage and compaction from livestock grazing stimulate N2O emissions through increased N mineralization and denitrification. Conservation practices like agroforestry offer potential for mitigating N2O emissions from agricultural soils.

2.1.4 Manure Management

Steed Jr. and Hashimoto (1994) conducted a study to assess methane emissions from dairy manure, a significant anthropogenic source. Their research challenged previous estimates by evaluating methane conversion factors (MCFs) from various waste management systems. They found that MCFs for rangeland/pasture disposal were lower than previously assumed, while solid and liquid slurry storage methods showed higher MCFs, especially at warmer temperatures. In regions with average temperatures near 10°C, MCFs were negligible across all systems. These findings suggest that global methane emissions from manures may have been overestimated previously, highlighting the importance of accurate MCF assessments for guiding emission reduction efforts.

Wu *et al*. (2023) conducted a review focusing on methane emissions from agricultural sources and emphasized the importance of methane accounting for developing effective mitigation strategies. The review provided an overview of methane accounting methods and the current research status across various emission sources such as rice fields, animal enteric fermentation, and manure management. Through analysis of influencing factors and diverse research efforts, the review concluded with recommendations and mitigation strategies customized to specific circumstances. Its objective is to furnish essential data and references for regions with an agricultural focus to actively engage in climate action by implementing efficient methane emission reduction measures.

2.1.5 Irrigation Practices

Islam *et al*. (2020) compared methane (CH4) and nitrous oxide (N2O) emissions from rice fields under alternate wetting and drying (AWD) irrigation versus continuous flooding (CF) in Bangladesh. They found that AWD reduced cumulative CH4 emissions by 37% without impacting yields, while N2O emissions increased by 46%. Overall, AWD lowered total greenhouse gas emissions by 36% and greenhouse gas intensity by 34% compared to CF, indicating its potential for reducing emissions while conserving water in rice cultivation.

Li *et al*. (2020) investigated greenhouse gas emissions from soil in mulching-cultivated maize fields in the upper Yellow River region, China. They found that soil acted as a methane sink irrespective of irrigation and nitrogen fertilization, but the irrigation method significantly impacted CO2 emissions, with drip irrigation causing a 24.7% increase compared to border irrigation. N2O emissions correlated positively with irrigation depth but decreased by 23.5% with drip irrigation. Drip irrigation with high frequency and medium nitrogen fertilization exhibited the best economic and environmental performance, suggesting potential for greenhouse gas mitigation in semi-arid regions.

2.2 GREEN HOUSE GAS EMISSION FROM RICE CULTIVATION

Rice cultivation, a vital global staple, contributes significantly to greenhouse gas (GHG) emissions, primarily methane (CH4) and nitrous oxide (N2O), due to anaerobic conditions in flooded paddy fields. As rice sustains a large portion of the world's population, the expanding global population and extensive rice cultivation areas amplify environmental concerns regarding GHG emissions. Mitigation strategies such as Alternate Wetting and Drying (AWD) and improved fertilizer management offer promising avenues to reduce emissions while maintaining or enhancing rice yield, crucial for addressing climate change and ensuring food security on a global scale.

2.2.1 Methane Emissions from Paddy Fields: Global Perspective

Jia *et al.* (2003) conducted a comprehensive review of methane emissions from paddy fields globally. Analysing data from field studies and modelling approaches, they found that continuously flooded rice paddies are major sources of methane emissions, contributing significantly to global greenhouse gas emissions. Results indicated that methane emissions from paddy fields account for approximately 10% of anthropogenic methane emissions worldwide.

Yan *et al.* (2003) conducted a field study in China's Zhejiang province, focusing on methane emissions from rice paddies under continuous flooding. They found that methane emissions were significantly higher in continuously flooded paddies compared to intermittently flooded ones. The study emphasized the need for alternative water management strategies to mitigate methane emissions while maintaining rice yields.

Ariani *et al.* (2021) investigated methane emissions from paddy fields in Indonesia's Sumatra region, where continuous flooding is a common practice. Their research revealed that continuously flooded paddies emitted substantial amounts of methane due to prolonged anaerobic conditions. The study underscored the importance of sustainable water management practices to reduce methane emissions from rice cultivation.

Akiyama *et al.* (2024) conducted field experiments in Japan's Niigata prefecture, focusing on methane emissions from rice paddies subjected to continuous flooding. Their findings indicated that methane emissions were highest during the early stages of rice cultivation when paddies were continuously flooded. The study highlighted the role of water management in influencing methane emissions from paddy fields.

2.2.2 Methane Emissions from Paddy Fields: Indian Perspective

Khosa *et al.* (2011) conducted a study in Punjab's rice-growing regions, where continuous flooding is a prevalent irrigation practice. Their research demonstrated that continuously flooded rice paddies emitted significant amounts of methane throughout the growing season. The study emphasized the need for optimizing water management to reduce methane emissions from rice cultivation.

Their research revealed that continuously flooded rice paddies emitted substantial amounts of methane throughout the growing season. Methane flux measurements taken from the paddies consistently showed elevated emission rates, indicating the significant contribution of continuous flooding to methane emissions in rice cultivation.

The findings of the study underscore the substantial impact of continuous flooding on methane emissions from rice paddies in Punjab, India. Prolonged inundation of the paddies creates anaerobic conditions in the soil, promoting methanogenesis and resulting in increased methane production. The study highlights the need for optimizing water management practices to reduce methane emissions while maintaining rice yields. Implementing alternative irrigation strategies, such as intermittent flooding or mid-season drainage, could help create aerobic conditions in the soil, thereby suppressing methanogenesis and mitigating methane emissions from rice cultivation in the region.

Sahai *et al.* (2011) investigated methane emissions from rice paddies in Haryana, focusing on the impact of continuous flooding on emissions. Their findings revealed that methane emissions were higher in continuously flooded paddies compared to paddies subjected to intermittent flooding. The study suggested that adopting alternate wetting and drying irrigation could help mitigate methane emissions from rice cultivation.

Bhatt *et al.* (2021) investigated methane emissions from paddy fields in the Indo-Gangetic plains of India. Conducting field measurements in traditionally flooded rice paddies, they quantified methane fluxes using chamber-based techniques. Results showed high methane emissions from continuously flooded paddies, with emission rates averaging 50 kg CH4 per hectare per year. The study highlighted the need for alternative water management practices to mitigate methane emissions.

Senthilraja *et al.* (2023) conducted field measurements in Tamil Nadu's rice-growing regions to assess methane emissions from continuously flooded paddies. Their research showed that methane emissions were elevated in continuously flooded paddies, particularly during periods of high soil moisture. The study recommended exploring water-saving irrigation techniques to reduce methane emissions while ensuring crop productivity.

2.2.3 Traditional Rice Cultivation Practices and Methane Emissions

2.2.3.1 Study on Redox Potential Changes:

Minamikawa *et al.* (2005) investigated the impact of continuous flooding on the redox potential of soil in rice paddies. Their study revealed that continuous flooding creates reducing conditions in the soil, leading to a decrease in redox potential. These anaerobic conditions promote methanogenesis and result in elevated methane emissions from flooded rice paddies.

2.2.3.2 Study on Soil Chemistry:

Wang *et al.* (1993) conducted research on the effects of continuous flooding on soil chemistry in rice paddies. Their findings indicated that continuous flooding alters soil pH and nutrient availability, influencing microbial activity and methane production. Changes in soil chemistry under continuous flooding conditions contribute to increased methane emissions from rice cultivation.

2.2.3.3 Investigation on Microbial Communities:

Hester *et al.* (2022) investigated the impact of continuous flooding on microbial communities in the rice rhizosphere. Their study showed that continuous flooding alters the composition and activity of microbial communities, favouring methanogenic archaea. Changes in the rice rhizosphere under continuous flooding conditions contribute to enhanced methane production in flooded rice paddies.

2.2.3.4 Study on Methane Oxidation:

Yang *et al.* (2022) conducted research on methane oxidation in rice paddies under different water management practices. Their study demonstrated that intermittent flooding promotes methane oxidation by aerobic methanotrophic bacteria, reducing methane emissions from rice paddies. Understanding methane oxidation processes is crucial for developing strategies to mitigate methane emissions from rice cultivation.

2.2.3.5 Investigation on Methane Transport:

Nouchi *et al.* (1993) investigated methane transport mechanisms in rice paddies under continuous flooding. Their study elucidated the pathways of methane transport from the soil to the atmosphere, highlighting the role of soil structure and plant physiology in regulating methane emissions. Insights into methane transport processes are essential for designing effective mitigation strategies for greenhouse gas emissions from rice cultivation.

2.2.3.6 Study on Methane Precursors:

Dubey *et al.* (2005) conducted research on the production of methane precursors in flooded rice paddies. Their study identified organic carbon decomposition and root exudation as primary sources of methane precursors in the rice rhizosphere. Understanding the mechanisms of methane precursor production is crucial for predicting and mitigating methane emissions from rice cultivation.

2.2.3.7Investigation on Methane Production Pathways:

Yang *et al*. (2018) investigated methane production pathways in flooded rice paddies under different water management regimes. Their study elucidated the roles of acetoclastic and hydrogenotrophic methanogenesis in methane production, highlighting the importance of microbial processes in regulating methane emissions from rice cultivation.

2.2.3.8 Study on Methane Emission Factors:

Ma *et al*. (2024) conducted a meta-analysis to estimate methane emission factors from rice cultivation under various water management practices. Their study synthesized data from field measurements and modelling studies to quantify methane emissions from flooded rice paddies. The analysis provided valuable insights into methane emission factors and the effectiveness of mitigation strategies in reducing greenhouse gas emissions from rice cultivation.

2.2.4 Alternative Irrigation Patterns and Methane Mitigation

Jagannath *et al.* (2013) conducted a meta-analysis of global rice cultivation practices, focusing on irrigation methods and their implications for water use efficiency. Their synthesis included studies from major rice-producing regions such as Asia, Africa, and the Americas. They highlighted the diverse irrigation practices employed worldwide and emphasized the need for sustainable water management strategies to optimize rice yields while conserving water resources.

Naser *et al.* (2018) investigated the impact of paddy field management practices on methane emissions in Japan. The study found that intermittent irrigation combined with mid-season drainage significantly reduced methane emissions compared to continuous flooding, highlighting the potential for water management strategies to mitigate GHG emissions in rice cultivation.

Poddar *et al.* (2022) conducted field experiments in Eastern India to assess the performance of different irrigation methods in paddy cultivation under varying soil moisture conditions. Their study compared continuous flooding with intermittent irrigation and found that intermittent irrigation significantly reduced water consumption while maintaining rice yields, particularly during periods of water scarcity.

2.3 ALTERNATING WETTING AND DRYING (AWD)

Alternate Wetting and Drying (AWD) is a water-saving technique used in rice cultivation to reduce irrigation water consumption without compromising yield. In AWD, irrigation is applied a few days after ponded water disappears, alternating between flooded and non-flooded conditions. The frequency of non-flooded periods depends on factors like soil type, weather, and crop growth stage.

Implementation of AWD involves using a 'field water tube' (Pani pipe) to monitor water depth. After irrigation, water gradually decreases, and when it drops to about 15 cm below soil surface, re-flooding is done to a depth of about 5 cm. During flowering, the field should be flooded, maintaining a 5 cm depth. After flowering, water level can drop to 15 cm below soil surface before re-irrigation.

The field water tube, typically a 30 cm long plastic or bamboo pipe with a diameter of 10-15 cm, is perforated with holes for water flow. It's hammered into soil with 15 cm protruding above ground, and soil inside is removed for visibility. If water levels inside and outside the tube differ, indicating blocked holes, the tube should be re-installed. Placed in an accessible part of the field, it ensures accurate water depth monitoring.By allowing periods of soil drying between irrigation cycles, AWD helps promote aerobic conditions, which suppress methane emissions from the soil and enhance nutrient availability for plant growth. This precise management of water depth and timing offers farmers a sustainable approach to rice cultivation, contributing to increased crop yields, reduced water consumption, and lower greenhouse gas emissions.

The benefits of Alternate Wetting and Drying (AWD) include:

- **Water Conservation:** AWD conserves water by allowing the soil to dry periodically, reducing overall water consumption compared to continuous flooding.

- **Energy Savings:** AWD saves energy since water is not continuously pumped into the fields, requiring less energy for irrigation.
- **Reduced Methane Emissions:** Periodic drying reduces methane emissions, a potent greenhouse gas, compared to continuous flooding in traditional rice cultivation.
- **Improved Soil Health:** Alternating wet and dry conditions promote better soil aeration, potentially improving soil structure and nutrient availability.
- **Cost Savings:** AWD can lead to cost savings for farmers by reducing the amount of water and energy needed for irrigation (Anonymous).

Sriphirom *et al.* (2019) evaluated the efficacy of alternate wetting and drying (AWD) irrigation in rice cultivation. Their study compared AWD with continuous flooding, aiming to assess water consumption and rice yields across diverse agro-climatic regions.

The comparison results indicated that AWD irrigation led to a significant reduction in water consumption by up to 30% compared to continuous flooding. Despite the reduced water input, AWD maintained rice yields across the different agro-climatic regions studied. This finding underscores the potential of AWD as a sustainable water management practice for enhancing water use efficiency in Indian rice cultivation.

By reducing water consumption, AWD can help conserve water resources and alleviate pressure on freshwater ecosystems. Additionally, the study suggests that AWD may contribute to mitigating greenhouse gas emissions, particularly methane, due to the reduced waterlogging associated with continuous flooding.

The significant reduction in water consumption coupled with maintained rice yields highlights the potential of AWD to enhance water use efficiency and mitigate environmental impacts. The findings underscore the importance of promoting AWD as a viable strategy for achieving both water security and environmental sustainability goals in Indian agriculture.

The results of the study revealed that AWD irrigation substantially reduced water consumption by an average of 25-30% compared to continuous flooding across the different continents. Despite the reduced water input, AWD maintained or even increased rice yields in most cases, indicating its potential to optimize water use efficiency without compromising crop productivity.

Jain *et al*. (2000) investigated the impact of different water management practices on methane emissions from rice fields in North India. Their study compared continuous flooding with AWD and found that AWD reduced methane emissions by up to 50% while maintaining rice yields, underscoring the importance of water management in GHG mitigation.

Islam *et al.* (2020) performed a comprehensive meta-analysis of rice cultivation practices across Asia, aggregating studies from China, India, and Southeast Asia. Their investigation aimed to evaluate the effectiveness of various rice cultivation practices in mitigating greenhouse gas (GHG) emissions, with a focus on methane emissions reduction.

The results of the meta-analysis highlighted the significance of alternate wetting and drying (AWD) irrigation techniques in reducing methane emissions from rice paddies across the Asian continent. On average, AWD irrigation led to a substantial reduction in methane emissions compared to conventional continuous flooding practices. The analysis revealed that AWD irrigation resulted in a reduction in methane emissions by approximately 30-50%, depending on the specific conditions and management practices.

Furthermore, the meta-analysis demonstrated that despite the reduced methane emissions, rice yields were either maintained or increased under AWD irrigation compared to continuous flooding. This finding underscores the potential of AWD irrigation as a promising strategy for mitigating GHG emissions from rice cultivation without compromising crop productivity.

Bwire *et al.* (2023) conducted a comprehensive investigation into the impact of different irrigation methods on methane emissions from paddy fields across diverse agro-climatic regions. Their study included field experiments conducted in Asia, Europe, and North America, comparing continuous flooding with alternate wetting and drying (AWD) and other water-saving practices.

The study revealed that AWD irrigation significantly reduced methane emissions from paddy fields compared to continuous flooding. On average, AWD irrigation led to a reduction in methane emissions by approximately 30-50% compared to continuous flooding across the different regions studied. Despite the reduced methane emissions, AWD maintained or even increased rice yields, highlighting its potential for mitigating greenhouse gas (GHG) emissions in global rice cultivation.

The significant reduction in methane emissions associated with AWD indicates its potential to contribute to global efforts aimed at mitigating climate change. By promoting the adoption of AWD and other water-saving practices, policymakers and agricultural stakeholders can work towards achieving both environmental sustainability and food security goals in rice cultivation.

Cebi *et al.* (2023) conducted field experiments in various rice-growing regions to assess the performance of different irrigation methods under varying soil and climatic conditions. Their study compared continuous flooding with alternate wetting and drying (AWD) and other water-saving techniques, evaluating their impact on rice yields, water productivity, and environmental sustainability. They emphasized the need for integrated water management approaches to enhance water use efficiency and mitigate environmental impacts in global rice cultivation.

Zhang *et al.* (2023) delved into the potential of integrating alternate wetting and drying (AWD) and mid-season drainage (MSD) practices in rice cultivation in South India. Their study aimed to assess the impact of these water management strategies on methane emissions and rice yields.

The study revealed that AWD and MSD practices led to a substantial reduction in methane emissions compared to conventional continuous flooding practices. On average, AWD and MSD practices resulted in a reduction in methane emissions by approximately 30-50%. Despite the reduced methane emissions, rice yields were maintained at comparable levels, indicating the feasibility of implementing these water management strategies for greenhouse gas (GHG) mitigation.

2.4 AUTOMATION FOR AWD

The Alternate Wetting and Drying (AWD) method requires regular human observation to monitor water levels in the field. Farmers typically use a measuring tape or scale to gauge water levels in the AWD pipe during inspections, which can become challenging, particularly in the face of natural calamities. Precisely timing irrigation can also pose difficulties for farmers when water levels drop below a certain threshold or need to be reinitiated. To address these challenges, advanced technologies are now being integrated into the AWD system, offering potential solutions. Despite these advances in rice irrigation systems, no research has yet addressed precise irrigation systems in the context of India.

Pham *et al.* (2021) found that in Vietnam's Mekong Delta, reduced rainfall and water stress threaten rice farmers' livelihoods. Promoting water-saving practices like alternate wetting and drying (AWD) is crucial for sustaining rice production and resilience to climate change. The study hypothesized that using Internet of Things (IoT) technology for precise water measurement could facilitate AWD adoption. Farmers were divided into three groups: continuously flooded irrigation, manual AWD tubes, and tubes with sensors. The results showed that sensor-based precise water measurement maximized AWD benefits, saving an additional 13-20% water over manual AWD, reducing irrigation energy costs by 25%, and moderately increasing rice yields by 2-11%. This large-scale trial demonstrated that IoT technology can significantly enhance water use efficiency and sustain agricultural livelihoods in the Delta.

Siddiqui *et al*. (2021) Water is essential for rice production, and alternate wetting and drying (AWD) is a proven irrigation method. Large-scale AWD implementation can be automated using wide-area wireless sensor networks (WSNs). Integration of these WSNs, along with external data sources via IoT, enhances AWD system performance. Plastic pipes and pump clusters ensure efficient water distribution across vast areas. Mathematical models aid in system dimensioning, and low-power sensor nodes facilitate remote monitoring in rural areas.

Tolentino *et al*. (2021) aimed to develop an automated watering system that combines network-based irrigation monitoring with a secure alternate wetting and drying (AWD) method. This method involves alternately subsiding and immersing rice paddies, maintaining water levels between 100mm below and 150mm above ground. The system uses sensor data to assess water needs and current conditions, controlling the irrigation schedule by operating a counterweight-designed water gate valve according to a smart timetable. This innovative approach conserved approximately 20% of water over three weeks in a two-hectare area with four weirs, compared to traditional irrigation methods.

Cruz *et al*. (2022) developed a low-cost wireless sensor for real-time monitoring of water depth and surface temperature in lowland rice fields under an alternate wetting and drying (AWD) irrigation regime. Comprising an ultrasonic depth sensor, a waterproof temperature sensor, a humidity sensor, and a Wi-Fi-enabled microcontroller, the sensor exhibited accuracy and precision akin to high-end sensors. Tests demonstrated a small error range of 5.2% to 6.6% and root mean square error (RMSE) of 5.0 mm to 13.5 mm, confirming its reliability. This affordable sensor provides an efficient solution for irrigation water management in lowland crop production systems, especially valuable in water-scarce conditions influenced by climate change and variability.

Kalyan *et al*. (2022) highlights the challenges faced by the agricultural sector due to climate change, particularly global water scarcity, which threatens irrigated rice production. They discuss the role of Alternate Wetting and Drying (AWD) technology, developed by the International Rice Research Institute (IRRI), in addressing this issue. AWD enables rice to tolerate reduced water supply by up to 30-40% compared to conventional irrigation methods. Utilizing tools like the 'field water tube', AWD can save water by 20-50%, improve water use efficiency, and reduce greenhouse gas emissions by 30-50%. The authors also suggest integrating IoT-based soil moisture sensors with artificial intelligence to enhance precision farming practices, leading to further water and energy conservation while enhancing productivity and quality. They emphasize the potential of this technology in effectively managing field variability and optimizing agricultural outcomes.

Gaputra *et al*. (2023) highlighted the importance of effective irrigation systems in Indonesia for improving rice farming yields and reducing crop failures. The widely implemented wet-dry irrigation system has been beneficial. To further enhance control and monitoring, an IoT-based smart irrigation system using Arduino Uno was developed. This prototype automates irrigation based on soil moisture levels and utilizes water level sensors to manage water distribution. It enables automatic irrigation in alignment with the wet-dry system and allows for remote monitoring via the internet, thereby increasing farming efficiency and agricultural profits.

Rana *et al*. (2023) conducted a study at Bangabandhu Sheikh Mujibur Rahman Agricultural University to develop and assess an automated version of the alternate wetting and drying (AWD) irrigation system for rice cultivation in Bangladesh. This system, known as Automated Alternate Wetting and Drying (AAWD), utilized water level controllers, solenoid valves, and water level detection probes to regulate water levels in the paddy field. The experiment compared three treatments: Conventional Irrigation (CI), AWD, and AAWD, with AAWD demonstrating the highest water use efficiency (WUE) at 65.20 kg/ha/cm. Minimal variation in growth and yield-contributing factors was observed between the CI and AWD treatments, indicating the effectiveness of AAWD in maintaining crop growth while reducing water usage. The findings underscore the potential of automated AWD systems to achieve a 20% reduction in irrigation water usage and minimize labour-intensive interventions in rice cultivation, thereby promoting more efficient and sustainable farming practices in Bangladesh.

2.5 ESTIMATION OF METHANE FROM PADDY FIELD

Understanding methane emissions from rice cultivation is crucial for addressing its environmental impact and developing effective mitigation strategies. Various methods have been developed to quantify methane emissions accurately, considering factors such as soil characteristics, water management practices, and climate conditions. These methods range from direct measurements, such as static chamber techniques and eddy covariance systems, to indirect approaches like modelling based on environmental variables and agronomic practices. Among these, static chamber techniques are widely accepted and commonly used.

2.5.1 Static chamber techniques and Gas sampling

The static chamber method is a widely used technique for quantifying greenhouse gas emissions, particularly methane, from agricultural ecosystems such as rice fields. In this method, chambers are placed over the soil surface to enclose a known volume of air, creating a controlled environment for gas sampling. Over a predetermined period, gas samples are collected from within the chamber and analysed for methane concentration. The static chamber method allows for direct measurement of methane fluxes from the soil surface, providing valuable insights into emission dynamics and facilitating the development of mitigation strategies.

Gas sampling from static chambers involves manually collecting gas samples from chambers placed over the soil surface. This process typically requires repeated visits to the field site, where researchers or technicians manually extract gas samples from the chambers using syringes or gas sampling pumps. Each sampling event necessitates careful handling and processing of samples to ensure accuracy and consistency. However, the labour-intensive nature of gas sampling can present challenges, as it demands significant time and effort from field personnel. Moreover, the need for frequent sampling sessions throughout the measurement period adds to the overall workload, making it a resource-intensive task. This labour-intensive aspect of gas sampling can be a limiting factor, especially in large-scale field studies or under conditions where manpower is limited. Therefore, while static chamber methods offer valuable insights into greenhouse gas emissions, their labour-intensive nature underscores the importance of exploring alternative sampling approaches to enhance efficiency and scalability.

Minamikawa *et al*. (2012) employed static gas chambers to measure methane emissions from rice paddies, highlighting the labour-intensive process of gas sampling. Manual collection of gas samples required significant time and effort, posing challenges for researchers and small-scale farmers alike. The cumbersome nature of traditional gas analysis methods underscores the urgency for automated solutions, which can streamline data collection and enhance accessibility for agricultural stakeholders.

Sander *et al*. (2014) reported that rice cultivation contributes significantly to global methane emissions, and numerous studies have examined greenhouse gas (GHG) flux rates from rice fields using the closed chamber method for manual sampling. However, there is currently no standardized protocol for these measurements, leading to varied practices across studies. A review of 155 peer-reviewed articles highlighted some common practices, including a chamber closure duration of 30 minutes or less, 3-4 gas samples per closure, 3 replicates, 1-2 samplings per day during late morning, and intervals of 7 days or less between consecutive sampling days. These findings offer valuable insights for establishing standardized GHG measurement protocols in rice field studies.

2.6 AUTOMATED GAS CHAMBER FOR METHANE ESTIMATION

Automated gas chambers represent a significant advancement in the quantification of methane emissions from paddy fields, offering enhanced precision, efficiency, and reliability compared to manual methods. By automating the data collection process, these chambers overcome the limitations of labour-intensive manual sampling techniques and provide comprehensive insights into methane fluxes. The integration of high-resolution sensors allows for precise measurement of methane concentrations, facilitating nuanced analysis of emission patterns and trends. Automated gas chambers play a crucial role in informing climate change mitigation strategies and optimizing agricultural practices for sustainable rice cultivation.

Chatterjee *et al*. (2019) developed automated gas chambers featuring advanced ultrasonic sensors for methane estimation in rice fields. The integration of cutting-edge sensor technology enabled real-time monitoring of methane fluxes, providing detailed insights into emission dynamics. The automated system's ability to detect subtle changes in methane concentrations enhances the accuracy of emission estimates, supporting informed decision-making for sustainable rice production and climate change mitigation efforts.

Gupta *et al*. (2021) developed automated gas chambers integrated with Gasmet DX4000 Fourier Transform Infrared (FTIR) sensors for methane estimation in paddy fields. The incorporation of Gasmet FTIR sensors enabled real-time monitoring of methane dynamics, surpassing the capabilities of conventional manual methods. The automated system's ability to capture temporal variations in methane emissions offers invaluable insights for optimizing water and fertilizer management strategies in rice cultivation.

Chenchireddy (2022) deployed an automated gas chamber utilizing MQ-135 sensors to assess methane emissions from rice fields in the Jiangsu Province of China. The MQ-135 sensors, known for their sensitivity to various gases including methane, facilitated continuous monitoring of methane concentrations, enabling researchers to quantify emission rates with high accuracy. Through the integration of MQ-135 sensors, the study provided valuable data on methane emission dynamics and environmental factors influencing methane fluxes in rice cultivation.

Komarudin *et al*. (2022) utilized an automated gas chamber equipped with MQ-4 sensors to quantify methane emissions from rice paddies in the Gyeonggi Province of South Korea. The MQ-4 sensors, renowned for their high sensitivity to methane, facilitated continuous monitoring of methane concentrations, enabling researchers to capture temporal and spatial variations in emission levels. Through the integration of MQ-4 sensors, the study demonstrated the feasibility of automated methane estimation and provided valuable data for greenhouse gas management in rice cultivation.

Rajasekar *et al*. (2022) implemented an automated gas chamber incorporating MQ-7 sensors to investigate methane emissions from rice fields in the Punjab region of India. The MQ-7 sensors, designed for detecting methane concentrations, enabled precise and real-time measurement of methane fluxes in the paddy environment. By automating gas sampling and analysis with MQ-7 sensors, the study enhanced data accuracy and efficiency, offering insights into methane emission dynamics and agricultural practices' impact on greenhouse gas emissions.

CHAPTER III

MATERIALS AND METHODS

This chapter consists of materials used and methodologies adopted for the development of Automated Alternate Wetting and Drying System and sensor based gas chamber for the estimation of methane gas from paddy field.

3.1 DETAILS OF THE STUDY AREA

The study was carried out in the Instructional Farm of KCAET Campus which is situated in Tavanur village of Malappuram District. The site is situated on the cross point of 10° 51'18" N latitude and 75 °59' 11" E longitude at an altitude of 8.54 m above mean sea level. Agro climatically, the area straddles the border between the northern and central zone of Kerala. The average annual rainfall varies from 2500 mm to 2900 mm. The average maximum temperature of the study area is 35°C and the average minimum temperature is 26°C. Average relative humidity and average light intensity are 73% and 30,000 lx respectively.

Table 3.1 Description of the land

Area	42.5 m^2
Length	8.5 m
Breadth	5 m
Soil type	Laterite
A Soil texture	Sandy loam

The overall experiment period was carried out from February 2024 to May 2024.

3.2 COMPONENTS OF AUTOMATED ALTERNATE WETTING AND DRYING (AAWD) SYSTEM

Alternate wetting and drying (AWD) is a water management method used to grow irrigated lowland rice with significantly less water than the traditional approach of keeping the field continuously flooded. A secure AWD irrigation method alternates rice paddy water levels between 15 cm below ground and 5 cm above ground, with an automated system managing the water based on current and required levels.

Components of Automated AWD includes both hardware and software components.

3.2.1 Pump

A 0.5 HP centrifugal AC pump is a mechanical apparatus crafted to transfer fluids by harnessing the rotational power of an alternating current (AC) motor, typically with a 0.5 horsepower capacity, and converting it into hydrodynamic force. Its fundamental components comprise an impeller, casing or volute, motor, shaft, and inlet/outlet ports.

Table 3.2 Specifications of pump

Model	MSTD
Head range	16-21 m
Capacity	12.5 mfd
Overall efficiency	20%
KW/HP	0.37/0.5
T/Head	20 m
Size	25*25
Rated discharge	1 lps
Rated speed	2880 rpm
Maximum current	4 A

Plate 3.1 0.5 hp AC Pump

3.2.2 Ultrasonic Sensor module

For our study an ultrasonic sensor which is a type of electronic sensor that uses ultrasonic waves to determine the distance between two objects and converts the reflected sound into electrical signals was used. The working principle of an ultrasonic sensor is to measure distance using ultrasound which travels faster than sound that is audible.This sensor consists of two major components that are transmitter which generate sound waves via piezo electric crystal and receiver that detects the reflected ultrasonic waves.It operates reliably regardless of sunlight or black materials, with a detection range from 2cm to 450cm. An ultrasonic signal is propagated by a wave at an angle of 30 degree. The distance is calculated by measuring the ultrasonic sound travel time and speed:

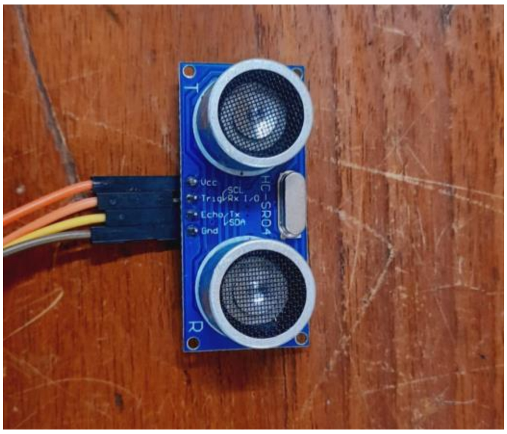


Plate 3.2 Ultrasonic sensor

Distance = Time × Speed of sound/2

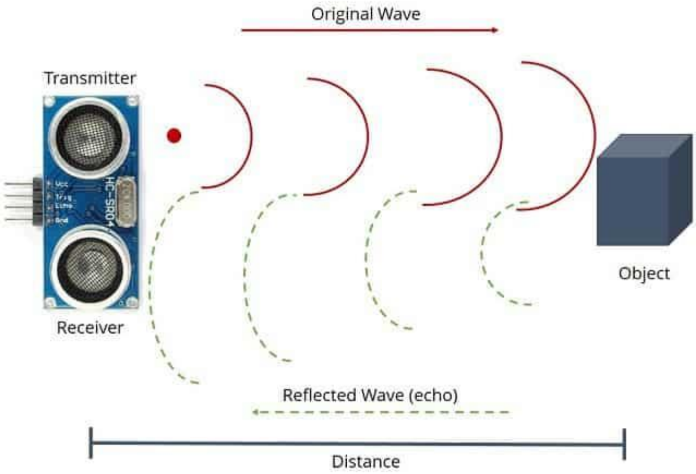


Fig. 3.1 Basic working principle of Ultrasonic sensor

Wiringare+5V (positive), Trig (control), Echo (receive), GND (negative). Applications include distance measurement, depth sensing in water, obstacle detection for robots, and parking assistance. The sensor operates on the principle of Doppler's Effect, producing square graph shapes in its readings.

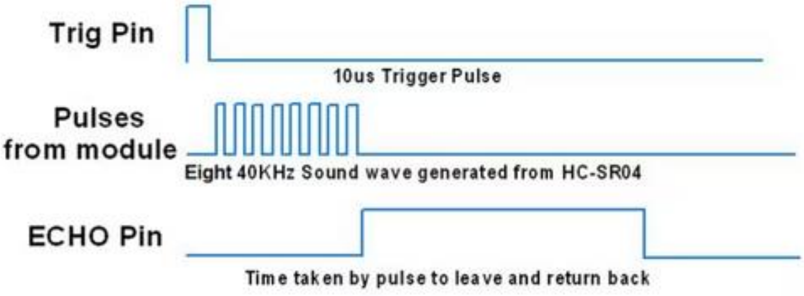


Fig. 3.2 Ultrasonic HC-SR04 Module Timing Diagram

3.2.3 5V Relay module

The 5V relay module is another component which was used in this study. It is a compact device designed to facilitate the control of high-power circuits by low-voltage signals. Operating at 5 volts DC, it typically features a contact rating of 10A at 250VAC or 30VDC, making it suitable for a variety of applications. With a trigger voltage of approximately 3.5V to 5V and an operating current ranging from 70mA to 150mA, it responds quickly to control signals, with a typical response time in the range of milliseconds. The 5V relay module operates on the principle of electromagnetism. When a control signal, typically ranging from 3.5V to 5V, is applied to the relay coil, it generates a magnetic field that activates the relay switch. This magnetic force attracts the movable contact arm, causing it to make contact with one of the stationary contact terminals. This action completes the circuit, allowing current to flow through the relay contacts and control the connected high-power device. When the control signal is removed, the magnetic field dissipates, and the spring-loaded mechanism returns the movable contact arm to its original position, opening the circuit and interrupting the currentflow.

Plate 3.3 5V Relay module

The 5V relay module typically includes several pins with specific functions:

- VCC: This pin is connected to the positive terminal of the power supply, providing 5 volts DC to power the relay module and its components.
- GND: This pin is connected to the ground or negative terminal of the power supply, completing the circuit and providing a reference voltage for the relay module.
- IN: The IN pin is used to provide the control signal to the relay module. When a high voltage (typically 3.5V to 5V) is applied to this pin, it activates the relay and switches its contacts.
- COM (Common): This is the common terminal of the relay switch. It is typically connected to one side of the circuit that needs to be switched.
- NO (Normally Open): The NO pin is the normally open terminal of the relay switch. When the relay is not activated, this pin is not connected to the COM pin. When the relay is activated, the NO pin becomes connected to the COM pin, completing the circuit.
- NC (Normally Closed): The NC pin is the normally closed terminal of the relay switch. When the relay is not activated, this pin is connected to the COM pin, completing a separate circuit. When the relay is activated, the NC pin is disconnected from the COM pin.

3.2.4 Microcontroller

A microcontroller (MCU) functions as a compact computing unit on a single chip, dedicated to managing specific tasks within electronic systems. This integrated device merges the capabilities of a central processing unit (CPU), memory, and input/output interfaces, streamlining functionality onto a solitary circuit.

At its core, a typical microcontroller comprises a processor core, both volatile and non-volatile memory, an array of input/output peripherals, and assorted communication interfaces. The processor core oversees instruction execution and coordinates the operation of other components. Memory serves the purpose of storing both data and program instructions. Meanwhile, input/output peripherals facilitate interaction with the external environment.

3.2.4.1 ESP 32 Devkit V1

ESP 32 microcontroller was used for the study purpose. It is a range of affordable microcontrollers that are energy-efficient and come with built-in Wi-Fi and Bluetooth capabilities. They feature different types of microprocessors, including dual-core and single-core variants of the Tensilica Xtensa LX6, as well as the Xtensa LX7 dual-core and a single-core RISC-V. These microcontrollers also have various integrated components such as antenna switches, RF balun, power amplifier, and power management modules.

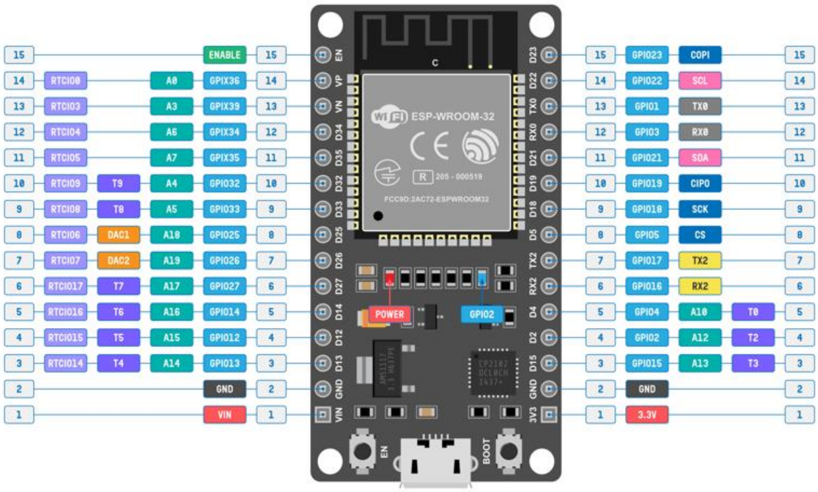


Fig. 3.3 ESP 32

Table 3.3 Features of ESP 32

Microcontroller	Tensilica 32-bit Single-/Dual-core CPU Xtensa LX6
Operating Voltage	3.3 V
Input Voltage	7-12 V
Digital I/O Pins (DIO)	25
Analog Input Pins (ADC)	6
Analog Outputs Pins (DAC)	2
UARTs	3
SPIs	2
12Cs	3
Flash Memory	4 MB
SRAM	520 KB
Clock Speed	240 Mhz
Wi-Fi	IEEE 802.11 b/g/n/e/i

Table 3.4 Ultrasonic sensor to ESP 32 Pin configuration

Ultra Sonic Sensor Pin	ESP 32 Dev Kit Pin
GND	GND
VCC	3V3
TRIG	D27
ECHO	D26

Table 3.5 Relay module to ESP 32 Pin configuration

5 V Relay Module	ESP 32 Dev Kit Pin
VCC	3V3
GND	GND
VIN	D5

3.2.5 Breadboard

A GL-12 840 Points Solderless Breadboard is an invaluable tool for experimenting with circuit designs whether in the R&D or university lab. A breadboard is used to make up temporary circuits for testing or to try out an idea. No soldering is required so it is easy to change connections and replace components.

- 840 Tie points
- 128 Groups of 5 connected terminals, 8 Bus of 25 connected terminals Reusable for fast build a prototype of an electronic circuit
- will accept transistors, diodes, LEDs, resistors, capacitors and virtually all types of components
- No soldering required
- Can modify or revise the circuits easily Fit for jumper wire of 0.8mm diameter
- Standard 2.54mm hole spacing Adhesive sheet on the back side of the board
- Multiple breadboards can be spliced together too

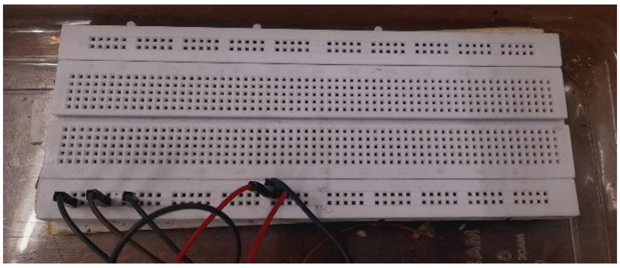


Plate 3.4 Breadboard

3.2.6 Jumper wires

Jumper wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering and also to modify a circuit or diagnose problems in a circuit. Further, they are best used to bypass a part of the circuit that does not contain a resistor and is suspected to be bad.

Fig. 3.4 Male-Male, Male-Female and Female-Female jumper wires

Jumper wires come in three versions:

- Male-to-male jumper
- Male-to-female jumper
- Female-to-female jumper

And two types of head shapes:

- Square head
- Round head

Here we have used only square head type jumper wires. The difference between each is in the endpoint of the wire. Male ends have a pin protruding and can plug into things, while female ends do not have a pin protruding but are also used for plugging. Moreover, a male connector is referred to as a plug and has a solid pin for centre conduction. Meanwhile, a female connector is referred to as a jack and has a centre conductor with a hole in it to accept the male pin. Male-to-male jumper wires are the most common and what you will likely use most often. For instance, when connecting two ports on a breadboard, a male-to-male wire is what you will need.

3.2.7 Power Supply and WiFi

The microcontroller was powered by a power bank, and WiFi was provided by an old mobile phone. A SIM card from a mobile network was inserted into the mobile phone to provide an internet connection to the microcontroller.

3.2.8 Water source

A water tank with a capacity of 500 litres was used as an alternative water source.

Plate 3.5 Cleaning of tank

Plate 3.6 Tank installed in field

3.3 METHODOLOGY FOR AAWD SYSTEM

3.3.1 Preparation of land

- The initial tillage operation was carried out by mould board plough and the land was pulverised with the help of rotavator.
- Levelling of the land was done manually and bunds were created for ponding the water.
- Cow dung and lime was applied.
- The land was irrigated and was simultaneously puddled.

Plate 3.7 Land preparation

3.3.2 Selection of rice variety

The rice variety named ‘Uma’ developed by Kerala Agricultural University, Thrissur was been considered for this study. MO 16 (Uma) is the most popular rice variety of the state. The duration of this particular variety is 120-140 days and the transplanting age was 30 days.

Plate 3.8 Collection of seedlings

3.3.3 Development of AWD Pipe

- PVC pipe with the dimensions of 110 mm diameter and 2 m length had been taken to make the AWD Pipe.
- The 2 m pipe was cut into 5 pieces each of 40 cm long.
- From the bottom of the pipe 25 cm was marked in order to make perforations.
- 0.5 cm diameter holes have been made in this entire 25 cm length with a centre-to-centre distance of 2 cm.

Plate 3.9 Different stages of making of AWD pipe

3.3.4 Installation of AWD Pipe

- After proper levelling of land 6-inch diameter holes were made at the 4 corners and at the centre of the field.
- The pipe was fixed exactly at the centre of the hole.
- Gravel pack of thickness 3 cm has been made around the pipe in order to prevent the entry of soil into pipe and clogging of holes.

Plate 3.10 Different steps for installation of AWD pipe in field

3.3.5 Transplantation

On the ninth day, after the application of cow dung and lime, transplantation was carried out.

Table 3.6 Details of transplantation

Plant to plant spacing	15 cm
Row to row spacing	20 cm
No. of plants in 1 hill	3
Total no. of hills	1417
Total no. of plants	4251

Plate 3.11 Transplantation and different stages of paddy seedlings in the field

3.3.6 Manual monitoring of AWD

- Before the installation of the automated AWD system, irrigation was done manually.
- The water level in the field was checked by going directly to the field and measuring it with a scale.
- The readings were taken daily, and irrigation was performed three times a week.
- Water for irrigation was sourced from the nearby hydrant.

3.3.7 Weed control and insecticide application

On the twenty first day after transplantation the weeds from the field has been removed manually. After the removal of weeds insecticide (15ml Malathion and 5ml Cymbush) has been applied and followed by the application of 200gm urea and 400gm potash.

Plate 3.12 Monitoring of water level in the AWD pipe installed in the paddy field

Plate 3.13 Plant protection management (Fertilizer application & weed removal)

Plate 3.14 Different growth stages of crop before and after crop protection management

3.3.8 Calibration of Ultrasonic Sensor

Calibration is the process of adjusting and verifying the accuracy of the instrument or device by comparing its readings to a known standard or reference. The calibration of the ultrasonic sensor was performed by positioning the sensor at known distances, measured using a ruler on a paper.

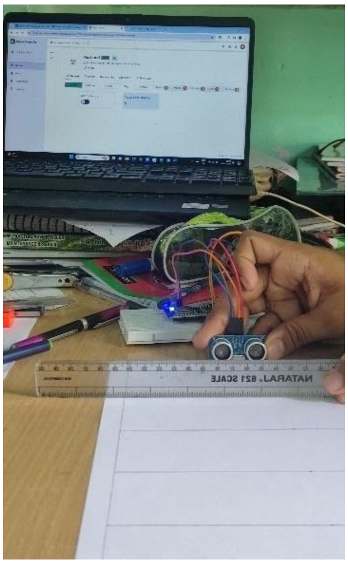


Plate 3.15 Calibration of Ultrasonic sensor

3.3.9 Schematic Diagram

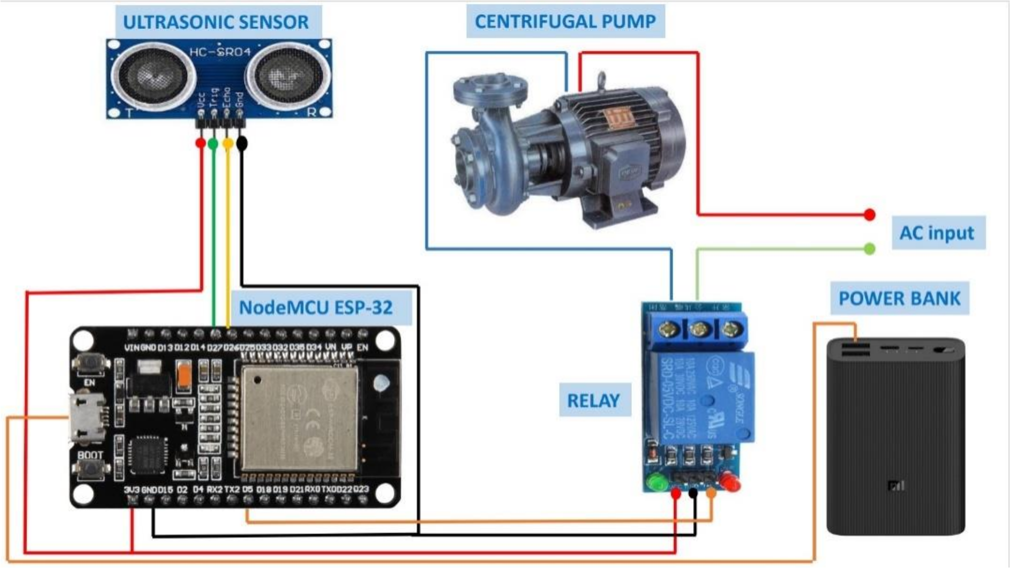
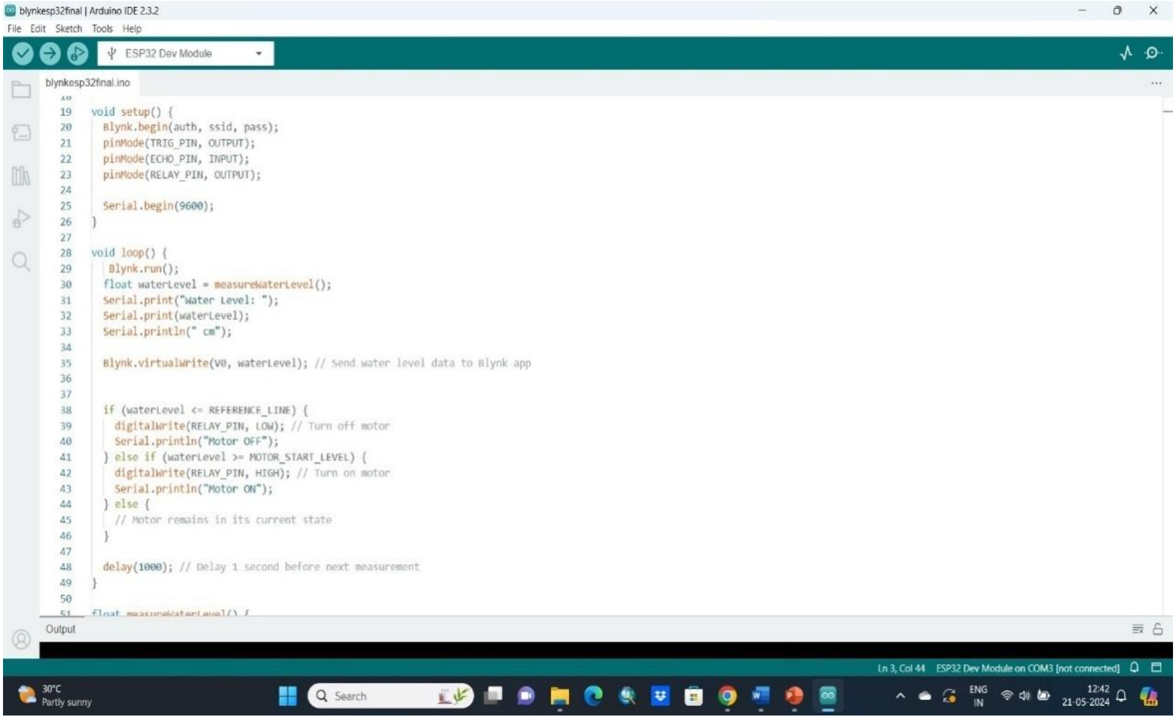


Fig. 3.5 Schematic diagram of AAWD

3.3.10 Coding

The code uploaded in the ESP32 for the working of circuit and operation of Blynk application are shown below:



```
void setup() {
  Blynk.begin(auth, ssid, pass);
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);
  pinMode(RELAY_PIN, OUTPUT);

  Serial.begin(9600);
}

void loop() {
   Blynk.run();
  float waterLevel = measureWaterLevel();
  Serial.print("Water Level: ");
  Serial.print(waterLevel);
  Serial.println(" cm");

  Blynk.virtualWrite(V0, waterLevel); // Send water level data to Blynk app


  if (waterLevel <= REFERENCE_LINE) {
    digitalWrite(RELAY_PIN, LOW); // Turn off motor
    Serial.println("Motor OFF");
  } else if (waterLevel >= MOTOR_START_LEVEL) {
    digitalWrite(RELAY_PIN, HIGH); // Turn on motor
    Serial.println("Motor ON");
  } else {
    // Motor remains in its current state
  }

  delay(1000); // Delay 1 second before next measurement
}

float measureWaterLevel() {
```

Plate 3.16 Code for AAWD

3.3.11 Installation of Setup in the field

After testing of circuit in the laboratory, it was installed in the field. Firstly, socket connection was taken from nearby pump house through service wire extension. A tank of 500L was kept to be used as a water source and the pump was placed on a stand. Finally, the circuit was installed on a raised wooden plank and the working was monitored at frequent intervals.

Plate 3.17 Installation of automated AWD system in the field

3.3.12 Working of the Automation Systems

According to the principle of AWD system setup, the field should be irrigated when the water level falls to 15 cm from the ground level and also it should stop when the water level reaches at a height of 5 cm from the ground level. Considering these parameters 10 cm and 30 cm has been given as the lower and upper threshold values of water level respectively.

Plate 3.18 Inspection of the working of Automated AWD system

3.3.13 Monitoring of Automation through Blynk

The "Automation" device features a dashboard that displays information regarding water levels sensed on an hourly, daily, and weekly basis. Additionally, it presents water level variations through charts, facilitating user comprehension of fluctuations over time.

Fig. 3.6 Dashboard view of Automation of AWD system

3.3.14 Performance evaluation of AWD

To take the biometric observations, a 1-square-meter area was measured and selected from the study area using a ruler. General information such as the number of hills per square meter, soil type, soil texture and number of leaves per hill were recorded. Crop growth parameters like plant height, number of tillers per hill, leaf height and number of panicles in 1 square meter were measured. These crop growth parameters were recorded on a weekly basis. The collected data were tabulated and compared. The data obtained are as follows:

a. Number of tillers:

Tillers are specialized offshoots growing autonomously from the main stem of a rice plant and which bear grains, were quantified in the field.

b. Plant height (cm):

The height of plants, measured from the base of the stem (at ground level) to the highest point of the canopy, was assessed by randomly selecting plants within the designated one-square-meter area.

c. Leaf height (cm):

The leaf length was determined by measuring from the tip to the base of the leaf.

d. Number of panicle:

The panicle, which constitutes the uppermost portion of a rice plant and gives rise to the rice inflorescence on each plant, was quantified within the designated one-square-meter area.

3.3.15 Determination of soil moisture content

Soil moisture when the water level drops to 15 cm was determined using the oven-dry method. Soil samples were collected from four random places in the field. First, the initial weight of each sample was taken. After measuring the initial weight, the samples were kept in oven for 24 hours. Then, the final weight was measured. The moisture content was determined using the following empirical formula:

$$\text{Moisture content} = (\text{Initial Weight} - \text{Final weight}) / \text{Final weight} \times 100$$

3.4 COMPONENTS OF SENSOR BASED GAS CHAMBER FOR METHANE ESTIMATION

3.4.1 MQ 4 Methane gas sensor

The MQ4 methane gas sensor which is a type of metal oxide semiconductor (MOS) sensor designed specifically for detecting methane gas concentrations in various settings, including residential and industrial environments was used for the sensor-based gas chamber.Its primary function is to sense the presence of methane gas within a specific range, typically from 300 parts per million (ppm) up to 10,000 ppm, which is crucial for detecting potential leaks.

Plate 3.19 MQ 4 Methane sensor

3.4.1.1 Adjustable Sensitivity:

One of its key features is its adjustable sensitivity, facilitated by a potentiometer. This allows users to fine-tune the sensor's response according to specific requirements, enhancing its versatility in different applications.

3.4.1.2 Pin Configuration:

The sensor module comprises four pins: VCC, GND, DO, and AO.

- VCC Pin: Supplies voltage to the module, usually operating at +5V.
- GND Pin: Establishes the ground connection of the system, ensuring proper electrical conductivity.
- DO Pin (Digital Out): Provides digital output based on a threshold set by the potentiometer, indicating the presence of methane gas.
- AO Pin (Analog Out): Delivers analogue voltage output proportional to the intensity of methane gas detected.

The sensor's detecting element consists of ceramic coated with tin dioxide (SnO2) and arranged within a stainless-steel mesh. This composition enhances its sensitivity and responsiveness to methane gas.

The MQ4 sensor finds widespread use in various applications, including: gas leakage, portable gas detectors and industrial combustible gas detectors in manufacturing and production environments.

3.4.1.3 Specifications:

- Load resistance of 20KΩ and detecting resistance ranging from 10KΩ to 60KΩ.
- Low heater utilization, consuming less than 750mW of power.
- Preheat time exceeding 24 hours, ensuring optimal performance.
- Operating temperature range from -10 to 50°C (14 to 122°F), suitable for diverse environmental conditions.

3.4.2 NodeMCU ESP8266

The ESP8266 NodeMCU is a versatile microcontroller board based on the ESP8266 WiFi module. It's widely used for IoT (Internet of Things) projects due to its low cost, ease of use, and built-in WiFi connectivity. Here's a detailed description of its key features and components:

- ESP8266 Module: At the heart of the NodeMCU is the ESP8266 WiFi module. This module integrates a powerful 32-bit Tensilica L106 microcontroller along with a WiFi stack, allowing it to connect to WiFi networks and communicate over the internet.
- Microcontroller: The ESP8266 module includes a 32-bit Tensilica microcontroller with clock speeds up to 80 MHz. It offers sufficient processing power and memory for many IoT applications.
- Flash Memory: Most NodeMCU boards come with onboard flash memory, typically ranging from 4MB to 16MB. This flash memory is used to store the program code, web pages, and other data required by the application.
- USB-to-Serial Converter: NodeMCU boards often feature a USB interface for programming and serial communication. It typically includes a USB-to-Serial converter chip (such as CH340 or CP2102) to facilitate communication between the microcontroller and the computer.

- GPIO Pins: The NodeMCU board provides several General-Purpose Input/Output (GPIO) pins, which can be used to interface with various sensors, actuators, and other electronic components. These pins support digital input/output, analog input (in some versions), PWM (Pulse Width Modulation) output, and more.
- Analog Input: Some variants of the NodeMCU include analog input pins (often labelled A0) that can be used to measure analog voltage levels. These pins typically have a resolution of 10 bits, allowing for measurements between 0 and 3.3 volts.
- WiFi Connectivity: One of the key features of the NodeMCU is its built-in WiFi connectivity, which enables it to connect to local WiFi networks and communicate with other devices or servers over the internet. It supports both infrastructure mode (connecting to an existing WiFi network) and soft-AP mode (acting as a WiFi access point).
- Programming Interface: The NodeMCU board can be programmed using the Arduino IDE or using Lua scripting language. Additionally, there are various other development environments and programming languages that support the ESP8266, including MicroPython and ESP-IDF (Espressif IoT Development Framework).
- Power Supply: NodeMCU boards typically operate at 3.3 volts and require a stable power supply. They can be powered via the USB interface or an external power source connected to the VIN pin.
- Form Factor: The NodeMCU board is usually designed in a compact form factor, making it easy to integrate into various projects. It's often equipped with standard pin headers for easy connection to external components and breadboards.

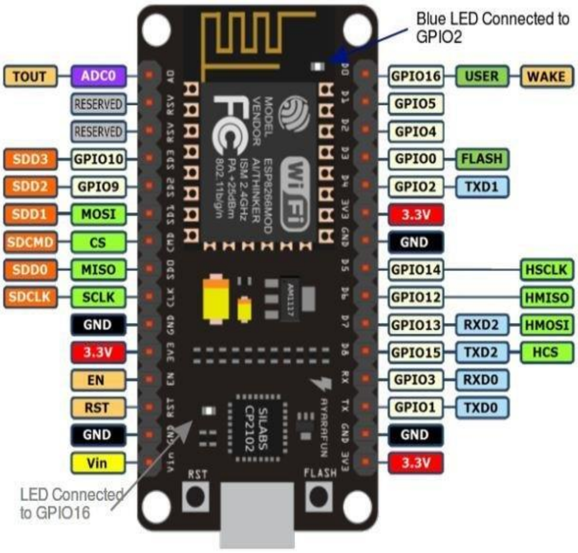


Fig. 3.7 Pin configuration ESP8266

Table 3.7 Features of ESP8266NodeMCU

Microcontroller	ESP-8266 32-bit
Clock Speed	80 MHz
USB to Serial	CP2102
USB Connector	Micro USB
Operating Voltage	3.3V
Flash Memory	4 MB
Digital I/O Pins	11
Analog In Pins	1
Communicators	Serial, SPI, I2C and 1-Wire via software libraries
Wi-Fi	Built-in 802.110b/g/n

Important pins of NodeMCU are:

3.4.2.1 Power Pins:

There are four power pins. VIN pin and three 3.3V pins.

- VIN can be used to directly supply the NodeMCU/ESP8266 and its peripherals. Power delivered on VIN is regulated through the onboard regulator on the NodeMCU module – you can also supply 5V regulated to the VIN pin.
- 3.3V pins are the output of the onboard voltage regulator and can be used to supply power to external components.

3.4.2.2 GND:

GND are the ground pins of NodeMCU/ESP8266

3.4.2.3 I2C (Inter- Integrated Circuit) Pins:

They are used to connect I2C sensors and peripherals. Both I2C Master and I2C Slave are supported. I2C interface functionality can be realized programmatically, and the clock frequency is 100 kHz at a maximum. It should be noted that I2C clock frequency should be higher than the slowest clock frequency of the slave device.

3.4.2.4 GPIO (General Purpose Input and Output) Pins:

NodeMCU/ESP8266 has 17 GPIO pins which can be assigned to functions such as I2C, I2S, UART, PWM, IR Remote Control, LED Light and Button programmatically. Each digital enabled GPIO can be configured to internal pull-up or pull-down, or set to high impedance. When configured as an input, it can also be set to edge-trigger or level-trigger to generate CPU interrupts.

3.4.2.5 ADC (Analog to Digital Converter) Channel:

The NodeMCU is embedded with a 10-bit precision SAR ADC. The two functions can be implemented using ADC. Testing power supply voltage of VDD3P3 pin and testing input voltage of TOUT pin. However, they cannot be implemented at the same time.

3.4.2.6 UART (Universal Asynchronous Receiver Transmitter) Pins:

NodeMCU/ESP8266 has 2 UART interfaces (UART0 and UART1) which provide asynchronous communication (RS232 and RS485), and can communicate at up to 4.5 Mbps. UART0 (TXD0, RXD0, RST0 & CTS0 pins) can be used for communication. However, UART1 (TXD1 pin) features only data transmit signal so, it is usually used for printing log.

3.4.2.7 SPI (Serial Peripheral Interface) Pins:

NodeMCU/ESP8266 features two SPIs (SPI and HSPI) in slave and master modes. These SPIs also support the following general-purpose SPI features:

- 4 timing modes of the SPI format transfer
- Up to 80 MHz and the divided clocks of 80 MHz
- Up to 64-Byte FIFO

3.4.2.8 SDIO (Secure Digital Input/Output Interface) Pins:

It is used to directly interface SD cards. 4-bit 25 MHz SDIO v1.1 and 4-bit 50 MHz SDIO v2.0 are supported.

3.4.2.9 PWM (Pulse Width Modulation) Pins:

The board has 4 channels of (PWM). The PWM output can be implemented programmatically and used for driving digital motors and LEDs. PWM frequency range is adjustable from 1000 μs to 10000 μs (100 Hz and 1 kHz).

3.4.2.10 Control Pins:

These are used to control the NodeMCU/ESP8266. These pins include Chip Enable pin (EN), Reset pin (RST) and WAKE pin.

- EN: The ESP8266 chip is enabled when EN pin is pulled HIGH. When pulled LOW the chip works at minimum power.
- RST: RST pin is used to reset the ESP8266 chip.
- WAKE: Wake pin is used to wake the chip from deep-sleep.

3.4.2.11 Tiny Sine Wave Control Pins:

These are used to control the NodeMCU/ESP8266. These pins include Chip Enable pin (EN), Reset pin (RST) and WAKE pin.

- EN: The ESP8266 chip is enabled when EN pin is pulled HIGH. When pulled LOW the chip works at minimum power.
- RST: RST pin is used to reset the ESP8266 chip.
- WAKE: Wake pin is used to wake the chip from deep-sleep.

Plate 3.20 ESP8266

Table 3.8 MQ 4 Sensor to ESP 8266 Pin configuration

MQ 4 Sensor pin	**ESP 8266 Pin**
GND	GND
VCC	3V3
AO	AO

3.4.3 Acrylic sheet

Acrylic sheets are widely used in gas collection applications due to their excellent clarity, high impact resistance, and chemical stability. These sheets provide a robust barrier that can withstand various gases without degrading, ensuring accurate and reliable containment. Additionally, their lightweight nature and ease of fabrication make acrylic sheets a versatile and practical choice for constructing custom gas collection systems.Acrylic sheets are simple to fabricate, adhere well with adhesives and solvents, and are easy to thermoform.Here, we used a clear transparent acrylic sheet with a thickness of 2 mm.

Plate 3.21 Acrylic sheet of different thickness

3.5 METHODOLOGY FOR SENSOR BASED GAS CHAMBER FOR METHANE ESTIMATION

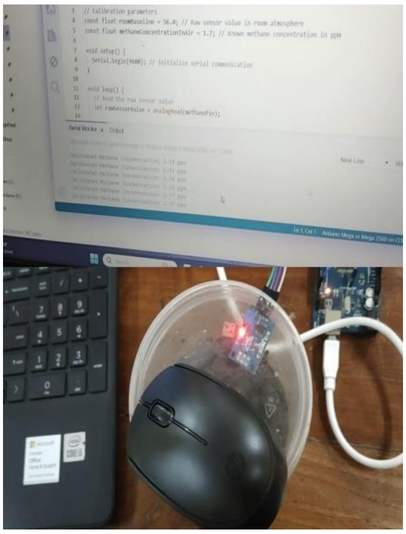
3.5.1 Fabrication of gas chamber

- In order to make the gas chamber for methane collection square GI Pipe of 1 cm and acrylic sheet of thickness 2mm has been taken.
- At first a cuboid frame was constructed using the GI Pipe with a length, breadth and height of 100 cm, 50 cm and 50 cm respectively. An additional 10 cm was added in height to act as legs for insertion into the soil.
- Then the acrylic sheet was attached into the frame using self-screw and made the chamber air tight using silicone glue and m seal.

Plate 3.22 Fabrication of gas chamber

3.5.2 Calibration of MQ4 Sensor

The MQ-4 sensor was calibrated by taking atmospheric methane concentration (ppm) as the standard. Since this value cannot be relied globally, further calibration was done by using different locally available methane sources such as cattle manure and continuous flooding paddy field



```
// Calibration parameters
const float roomBaseline = 56.0; // Raw sensor value in room atmosphere
const float methaneConcentrationInAir = 1.7; // Known methane concentration in ppm

void setup() {
  Serial.begin(9600); // Initialize serial communication
}

void loop() {
  // Read the raw sensor value
  int rawSensorValue = analogRead(methanePin);
```

Plate 3.23 Calibration of MQ-4 sensor

3.5.3 Connection Diagram of Automated Gas Chamber

Figure 3.8 shows the connection diagram of Automated Gas Chamber for methane estimation from paddy field.

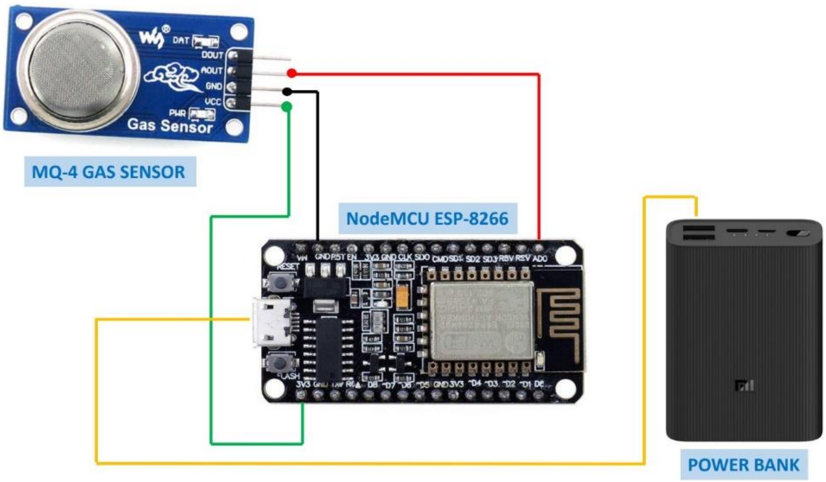
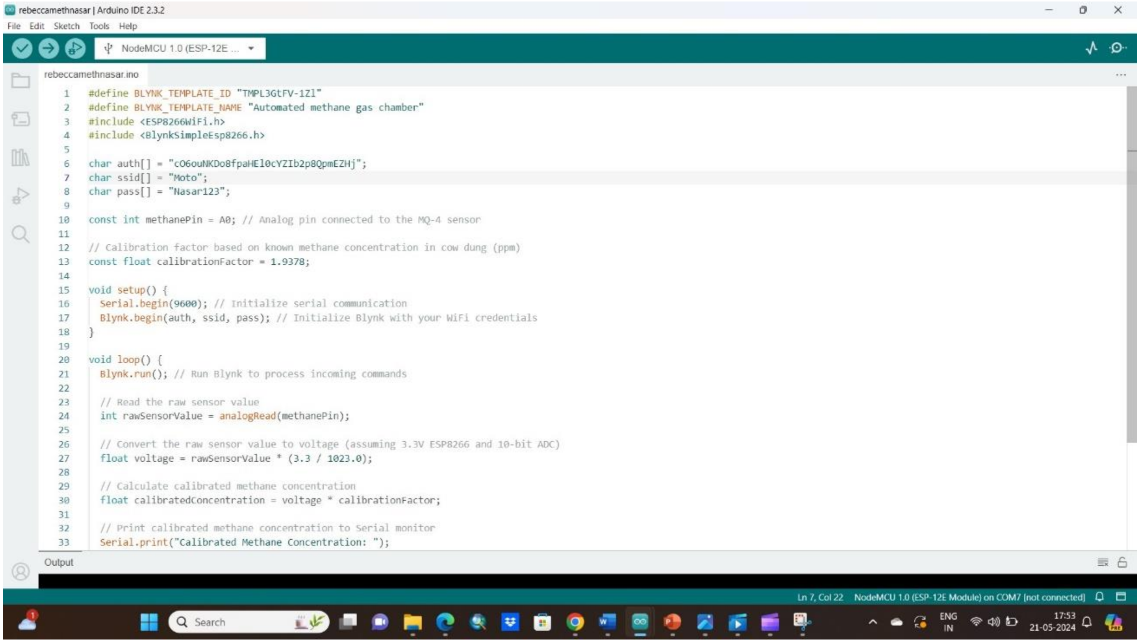


Fig. 3.8 Connection diagram of automated gas chamber

3.5.4 Coding

The code uploaded in theESP8266 for the working of circuit and operation of Blynk application is shown below:



```
#define BLYNK_TEMPLATE_ID "TMPL3GtFV-1Z1"
#define BLYNK_TEMPLATE_NAME "Automated methane gas chamber"
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>

char auth[] = "cO6ouNKDo8fpaHEl0cYZIb2p8QpmEZHj";
char ssid[] = "Moto";
char pass[] = "Nasar123";

const int methanePin = A0; // Analog pin connected to the MQ-4 sensor

// Calibration factor based on known methane concentration in cow dung (ppm)
const float calibrationFactor = 1.9378;

void setup() {
  Serial.begin(9600); // Initialize serial communication
  Blynk.begin(auth, ssid, pass); // Initialize Blynk with your WiFi credentials
}

void loop() {
  Blynk.run(); // Run Blynk to process incoming commands

  // Read the raw sensor value
  int rawSensorValue = analogRead(methanePin);

  // Convert the raw sensor value to voltage (assuming 3.3V ESP8266 and 10-bit ADC)
  float voltage = rawSensorValue * (3.3 / 1023.0);

  // Calculate calibrated methane concentration
  float calibratedConcentration = voltage * calibrationFactor;

  // Print calibrated methane concentration to Serial monitor
  Serial.print("Calibrated Methane Concentration: ");
```

Plate 3.24 Code for gas chamber

3.5.5 Installation of Automated Gas Chamber Setup in the field

The circuit was placed on a raised wooden plank, and the gas chamber was positioned to encompass the maximum number of rice saplings inside it, in order to capture the gas.

(c)

Plate 3.25 Installation of Sensor based gas chamber in field

3.5.6 Working of the Automation Systems

The gases generated from the field was accumulated in the sensor base gas chamber installed in the field. The MQ4 sensor inside the gas chamber detects the gas, and its concentration value is displayed on the Blynk interface.

3.5.7 Monitoring of Automation through Blynk

The "Automated Methane Gas Chamber" device features a dashboard that displays information regarding methane level sensed on an hourly, daily, and weekly basis. Additionally, it presents variation in the readings through charts, facilitating user comprehension of fluctuations over time.

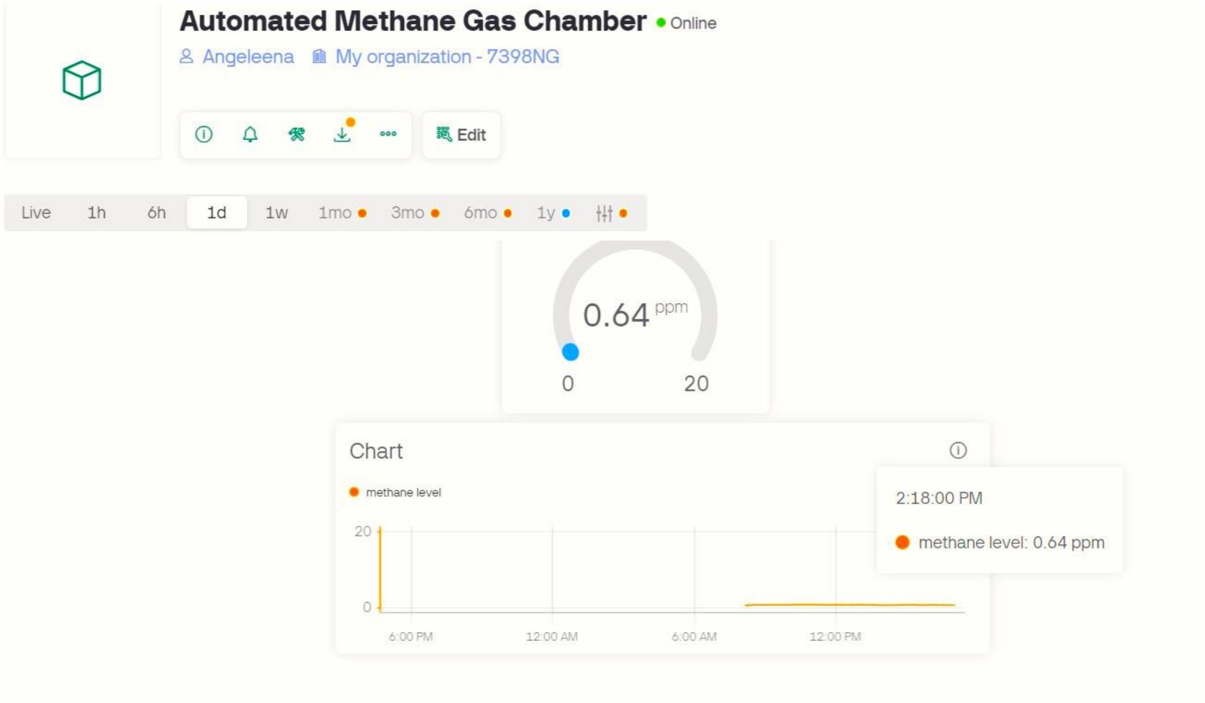


Fig 3.9 Dashboard view of working of automated gas chamber

3.6 POWER SUPPLY AND WIFI

The microcontroller was powered by a power bank, and WiFi was provided by an old mobile phone. A SIM card from a mobile network was inserted into the mobile phone to provide an internet connection to the microcontroller.

3.7 BLYNK INTERFACE

Blynk is an Internet of Things (IoT) platform that simplifies the process of controlling hardware remotely and visualizing its data. Using the free Blynk App, users can create custom interfaces to interact with their IoT devices. Blynk supports connectivity with various types of devices including those using Wi-Fi, Bluetooth/BLE, Ethernet, and Serial connections. Devices can connect to the Blynk cloud or a locally hosted server.

3.7.1 Prerequisites

- Arduino IDE: Version 1.8.5 or newer is required.
- Wi-Fi Connection:

3.7.2 Include ESP8266 Core and ESP 32 to Arduino IDE

- Go to 'Preferences' in the Arduino IDE and add the following URL to the Additional Board Manager.

URLs: http://arduino.esp8266.com/stable/package_esp8266com_index.json (For ESP 8266)

https://espressif.github.io/arduino-esp32/package_esp32_index.json(For ESP 32)

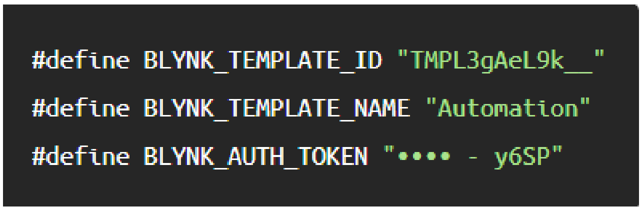
- Open the Boards Manager (Tools > Board Menu).
- Search for "esp8266" and “esp32” and install the latest version.
- Select your ESP8266 board under Tools > Board and define parameters like Baud Rate for gas chamber experiment and same for ESP 32 for AWD experiment.

3.7.3 Install Blynk libraries:

- Install the latest release of the Blynk libraries from GitHub.
- Unpack the downloaded files.
- Move the libraries to the Arduino libraries directory (typically located at C:/User//Documents/Arduino/libraries).

3.7.4 Install Blynk App:

- Download the Blynk App from the App Store or Google Play Store for iOS or Android, respectively.
- Creating a Blynk Project:Sign in or create an account on the Blynk App.
- Click 'Create New Project'.
- Choose your device and connection type (e.g., NodeMCU and Wi-Fi).
- Receive and note down your 'Auth Token', which is a unique identifier for your project.
- Open the 'Widget Box' by clicking on the '+' button.
- Add a button widget to your project.
- Name the button and select the switch mode to define its functionality.



```
#define BLYNK_TEMPLATE_ID "TMPL3gAeL9k__"
#define BLYNK_TEMPLATE_NAME "Automation"
#define BLYNK_AUTH_TOKEN "•••• - y6SP"
```

Fig. 3.10 Firmware Configuration

Fig. 3.11 Selected Widgets for AWD

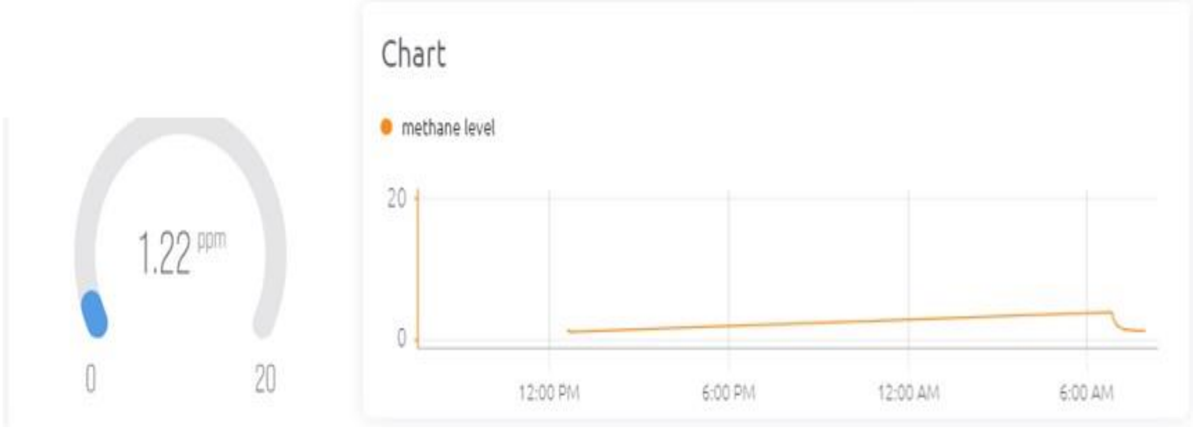


Fig. 3.12 Selected Widgets for Automated Gas chamber

3.7.5 Connecting Arduino to Blynk

Open the Arduino IDE

- Go to Examples > Blynk > Boards WiFi and select your dev board
- Enter your 'Auth Token' (char auth [])
- Enter your WiFi credentials (char ssid[], char pass[])
- Compile and Upload

CHAPTER 4

RESULTS AND DISCUSSIONS

An automated alternate wetting and drying system for paddy cultivation, along with an automated gas chamber for estimating methane emissions from paddy fields, was developed and tested. In this chapter, the observations and results recorded during our study are presented and discussed under the following subheads.

4.1 RESULTS OF CALIBRATION OF SENSORS

4.1.1 Ultrasonic Sensor

The ultrasonic sensor used in this study has a speed of sound (i.e. 340 m/s). Based on this speed, the distance of sound travelled is calculated by using the formula:

Distance = Speed×Time

Speed of sound: $v = 340$ m/s = 0.034 cm/µs

The sound wave must travel in forward and reverse direction and so that the amount produced from the echo pin would be two times of the actual distance. As a result, distance from sensor to obstacle is calculated as:

Distance from sensor to obstacle:

Distance = (Time taken * Speed of sound)/2 = (Time taken * 0.034)/2

Table 4.1 Calibration chart of ultrasonic sensor

Sl. No.	Known Distance (cm)	Sensed Distance (cm)
1.	5	5
2.	10	10
3.	15	15
4.	20	20

The known and sensed values are same; hence it is indicated that the sensor was calibrated correctly. This is confirmed that the sensor was working properly.

4.1.2 MQ-4 Sensor

1) The readings obtained from the sensor when exposed to open air conditions over a period of 10 secondswere observed (Table no. 4.2).

Table 4.2 Readings of open-air conditions

Observations	Readings (ppm)
First	1.70
Second	1.70
Third	1.68
Fourth	1.70
Fifth	1.72

Average concentration of methane in open air = (1.70 + 1.70 + 1.68 + 1.70 + 1.72) / 5

= 1.70 ppm

The result is justified with the current atmospheric concentration of methane (1.7 ppm) by Neue and Heinz-Ulrich (1993).

2) The readings obtained from the sensor when exposed to fresh cattle manure (cow dung) over a period of 10 seconds were observed (Table 4.3).

Table 4.3 Readings of fresh cattle manure

Observations	Readings (ppm)
First	2.40
Second	2.50
Third	2.60
Fourth	2.30
Fifth	2.15

Average concentration of methane in fresh cattle manure = (2.40 + 2.50 + 2.60 +2.30 + 2.15) / 5

= 2.39 ppm

Generally, methane emissions from fresh cattle manure range from 1 to 10 ppm in well-ventilated environments where oxygen inhibits anaerobic methanogenic activity.

3) The readings obtained from sensor when kept in continuous flooding field over a period of 10 seconds were observed (Table 4.4).

Table 4.4 Readings of continuous flooding field

Observations	Readings (ppm)
First	1.65
Second	1.70
Third	2.20
Fourth	2.50
Fifth	1.66

Average concentration of methane from continuous flooding field = (1.65 + 1.70 + 2.20 + 2.50 + 1.66) / 5 = 1.942 ppm

The result is justified with the continuous flooded paddy cultivation of methane i.e. 1.65 to 2.85 ppm by Pazhanivelan*et al*. (2024).

4) The readings obtained when Sensor was kept in AWD field over a period of 10 seconds were observed.

Table 4.5 Readings of AWD field

Observations	Readings (ppm)
First	0.56
Second	0.55
Third	0.54
Fourth	0.53
Fifth	0.52

Average concentration of methane from AWD field = (0.56 + 0.55 + 0.54 + 0.53 + 0.52) / 5

= 0.54 ppm

According to Loaiza *et al.* (2024) AWD can reduce methane emission around (72-100) % compared to continuous flooded fields.

72 % of 1.942 ppm = 1.40 ppm

- Theoretical concentration of methane from AWD field = 1.942 – 1.40 = 0.54 ppm

Since, the theoretical average methane concentration and the practical average methane concentration from the AWD field were the same, calibration of the device was done by matching theoretical and practical methane concentration.

4.2 EVALUATION OF AUTOMATED ALTERNATE WETTING AND DRYING (AAWD) SYSTEM

The evaluation of the AAWD system encompasses several critical components to ensure its efficacy and reliability in real-world applications. This section focuses on three key areas of evaluation: the ON/OFF functionality of the pump at threshold values sensed by the sensor and the continuous monitoring of water levels. Each aspect plays a vital role in the overall performance and utility of the AAWD system.

4.2.1 Evaluation of automation (ON / OFF) of pump at the threshold values sensed by sensor

The system was able to correctly sense the upper and lower threshold limits of 30 cm and 10 cm, respectively, and took the appropriate action without any delay. When the distance between the sensor and the surface of the water level to 30 cm, the pump was activated and irrigation starts. It was also observed that the pump automatically stopped when the water level reached the lower threshold of 10 cm. The red colour on the dashboard indicated that the pump was "ON," and the green colour indicated that the pump was "OFF."

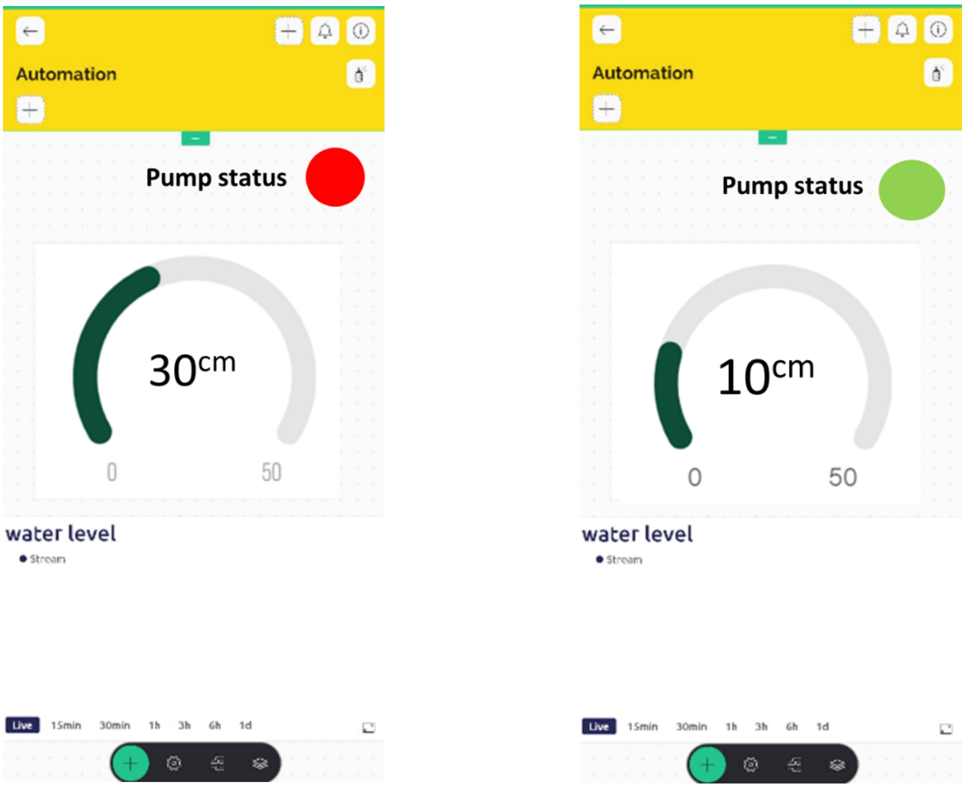


Fig. 4.1 Dashboard view of working status of pump (‘ON’ and ‘OFF’)

4.2.2 Evaluation of continuous monitoring of water level

The system was able to continuously monitor the water level without any lag. It provided continuous data for 48 hours, i.e., one irrigation cycle. Table 4.6 presents data of continuous monitoring of water level over a period from April 23, 2024, to April 25, 2024. The water level, measured in centimetres, was recorded at various times throughout the day. The data demonstrated that the irrigation interval in manually controlled AWD and AAWD was equal, i.e., 48 hours. Hence, the system was working properly.

Table 4.6 Water level fluctuation, 6-hour basis

Date	Time	Distance(cm)
23-04-2024	07:00	10.01
23-04-2024	13:00	13.8
23-04-2024	19:00	14.88
24-04-2024	01:00	16.99

24-04-2024	**07:00**	**20.59**
24-04-2024	**13:00**	**23.59**
24-04-2024	**19:00**	**25.02**
25-04-2024	**01:00**	**28.63**
25-04-2024	**07:00**	**30.02**

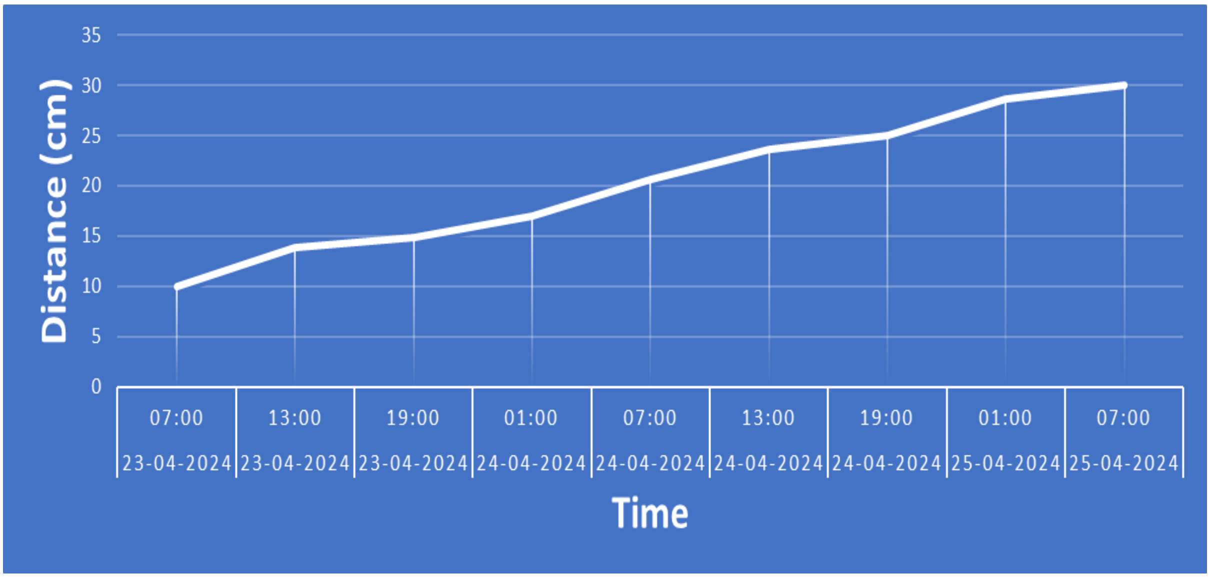


Fig 4.2 Water Level Monitoring on 6-hour basis

4.2 EVALUATION OF SENSOR BASED GAS CHAMBER FOR METHANE ESTIMATION

The evaluation of the sensor-based system for methane estimation was crucial in understanding its effectiveness in real-time environmental monitoring. This system was designed to provide continuous, accurate methane concentration data from the field, ensuring that measurements were unaffected by external factors such as rainfall and wind. A key feature of the system was its airtight gas chamber, which guaranteed efficient methane collection and precise readings.

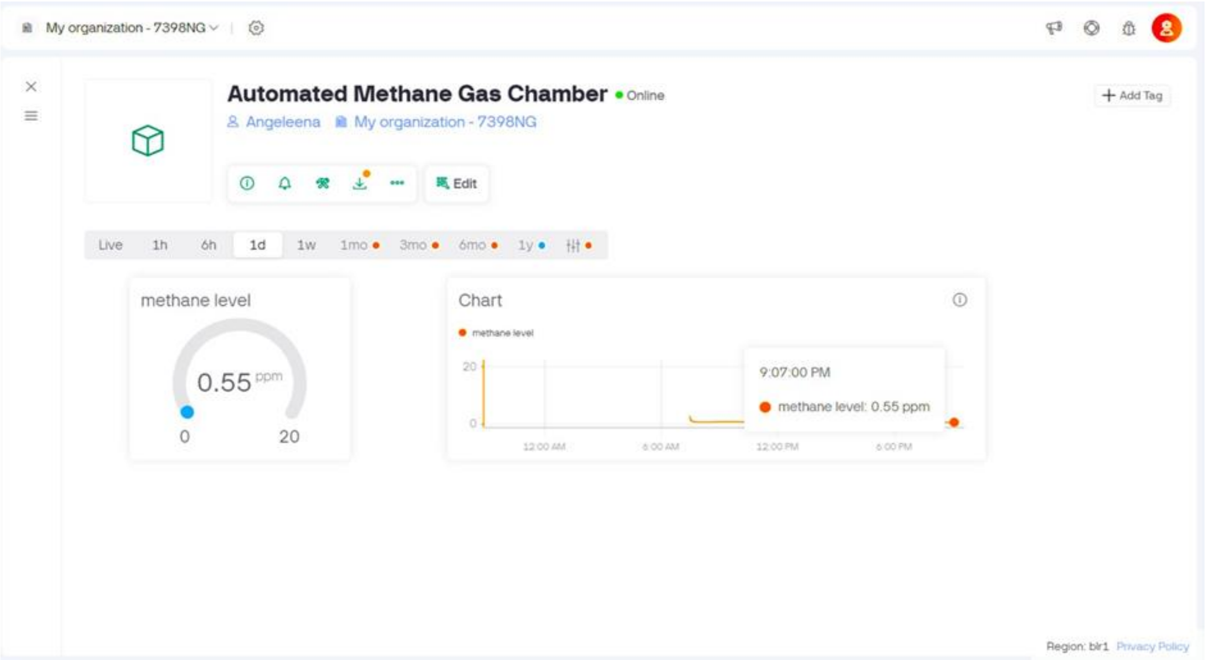


Fig 4.3 Dashboard display of Sensor based gas chamber for methane estimation

The table 4.2 represents methane concentration data recorded at 4-hours interval over a 24-hour period.

Table 4.7 Concentration of methane in 4-hour interval

Time	CH_4 Concentration (ppm)
06:00	0.540
10:00	0.544
14:00	0.548
18:00	0.553
22:00	0.549
02:00	0.549
06:00	0.551

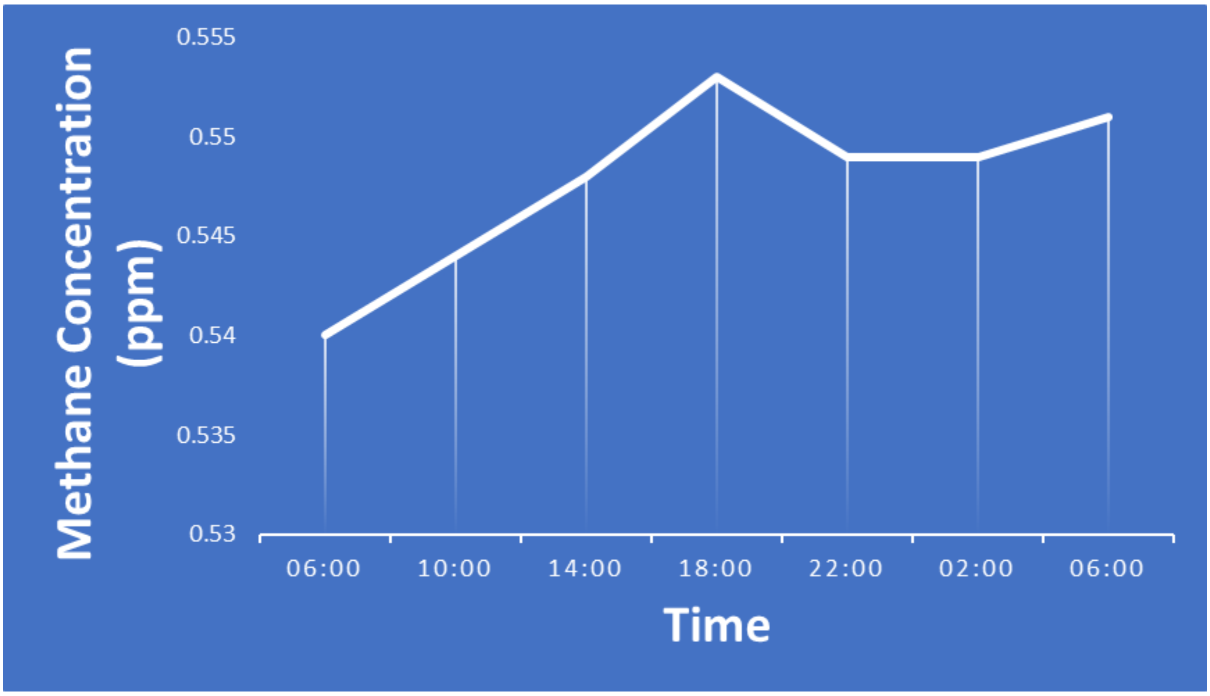


Fig 4.4 Methane concentration in 4-hour interval

The graph showed the methane concentration over a 24-hour period at 4-hour intervals. The concentration levels displayed a gradual increase from 0.540 ppm at 06:00 to a peak of 0.553 ppm at 18:00, followed by a slight decrease and stabilization around 0.549 ppm. This indicated a pattern of methane emission changes throughout the day, likely influenced by environmental factors such as temperature and paddy field activities. The slight increase at 06:00 the next day suggested a continuing dynamic pattern in methane emissions.

4.3 IMPACT OF AAWD ON PLANT GROWTH PARAMETERS

Table4.8 shows a consistent increase in plant height, leaf height, and the number of tillers per hill over the observation period. Plant height reached up to 91 cm and leaf height up to 82 cm by mid-April, indicating robust vegetative growth under traditional AWD practices. The number of tillers per hill also increased steadily, reaching 33 by 13 April 2024. The number of panicles per square meter, an important yield component, increased significantly from 216 to 1080 over the six weeks, demonstrating strong reproductive development and yield potential under AWD conditions.

Table 4.8 Weekly Progression of Plant Growth Parameters under AAWD Irrigation method (March - April 2024)

Date	Number of hills/m^2	Number of tillers/ hills	Plant Height (cm)	Leaf Height (cm)	Number of panicles/ m^2
09 March 2024	36	9	30	26	216
16 March 2024	36	12	46	40	300
23 March 2024	36	18	61	50	520
30 March 2024	36	21	72	59	640
06 April 2024	36	27	80	71	820
13 April 2024	36	33	91	82	1080

Table 4.9 represents the plant growth parameters under different irrigation practices (Continuous flooding, AWD, AAWD) (Rana *et al*., 2023). While the field utilized manually controlled AWD, we can compare its growth parameters with those of AWD from Table 4.8. However, since our field is currently in the reproductive stage, a full comparison with Table 4.9 is not feasible. Nonetheless, relative growth patterns suggest that once our field reaches the harvesting period, its growth parameters may align with those observed in Table 4.9.

Table 4.9 Impact of Irrigation Treatments on Plant Growth and Yield Contribution

Treatments	**Plant Height (cm)**	**No. of Tillers/Hill**	**Panicle Length (cm)**	**1000 Grain Weight (g)**	**Grain Yield (t/ha)**	**Straw Yield (t/ha)**	**Biological Yield (t/ha)**	**Harvesting Index (%)**
T1	115.45	15.47	30.05	21.67	6.57	10.96	17.53	37.48
T2	115.46	15.42	30.12	21.71	6.46	10.91	17.37	37.19
T3	113.96	15.47	30.13	21.95	6.52	10.85	17.51	37.51
CV (%)	0.61	0.15	0.12	0.57	0.69	0.41	0.40	0.39
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

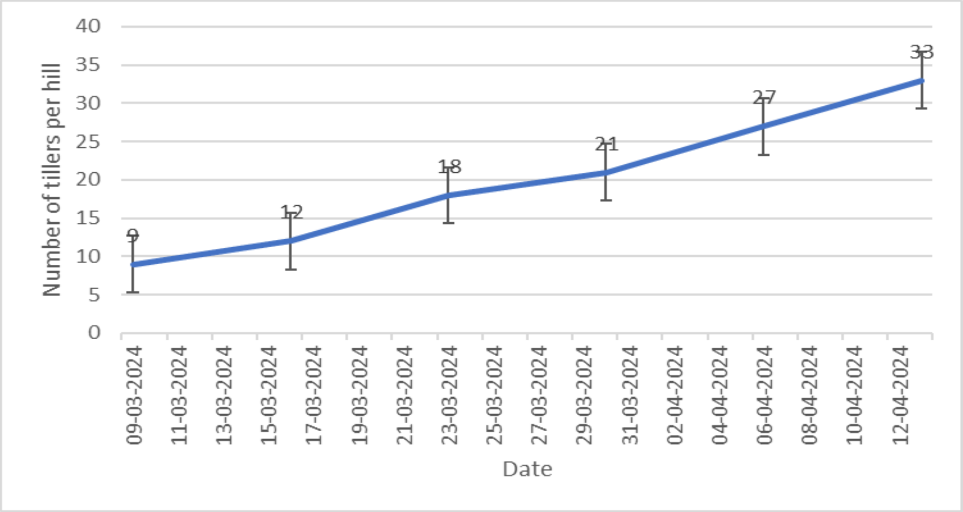


Fig. 4.5 Number of Tillers per hill

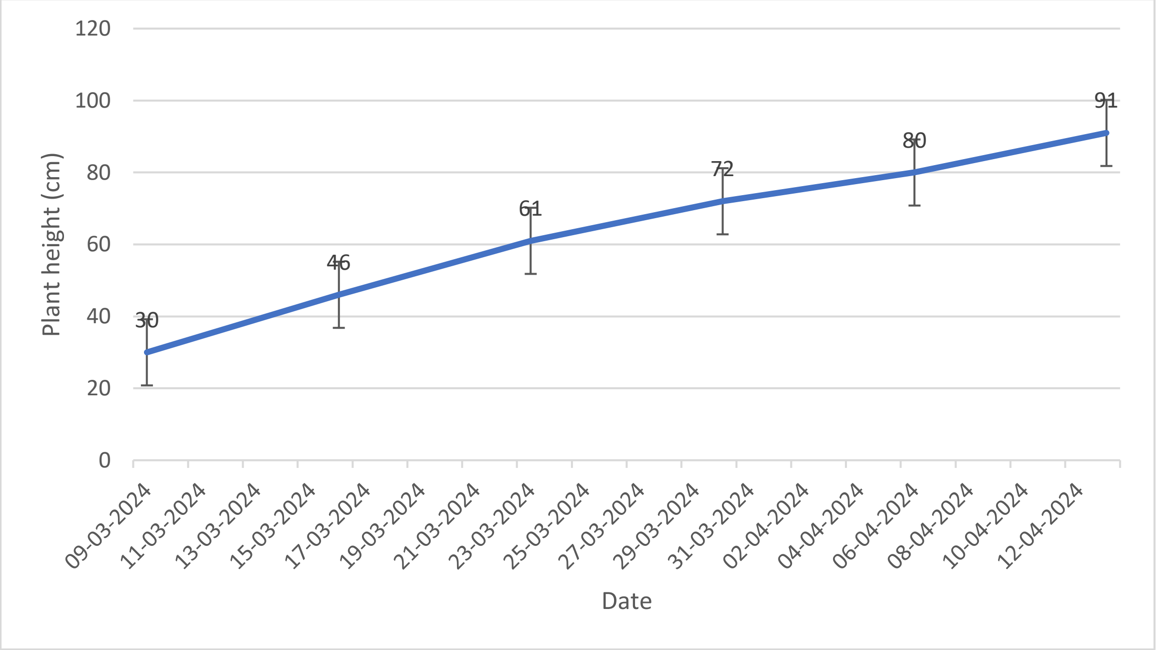


Fig4.6 Plant Height

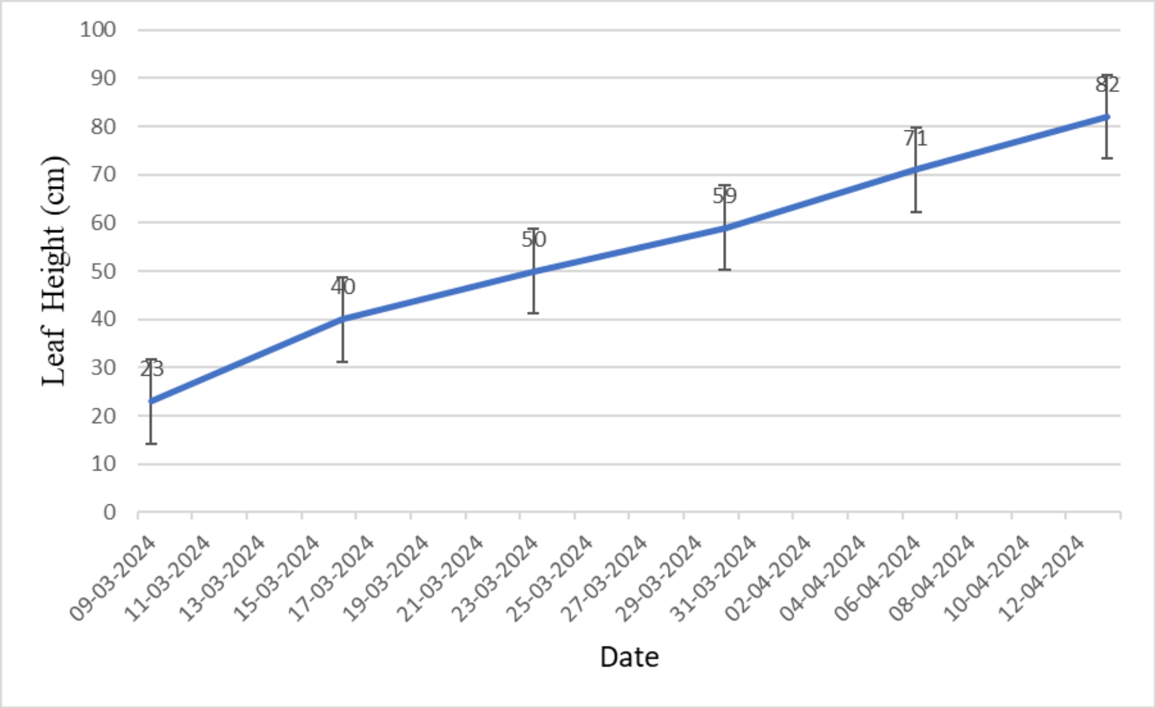


Fig. 4.7 Leaf Height

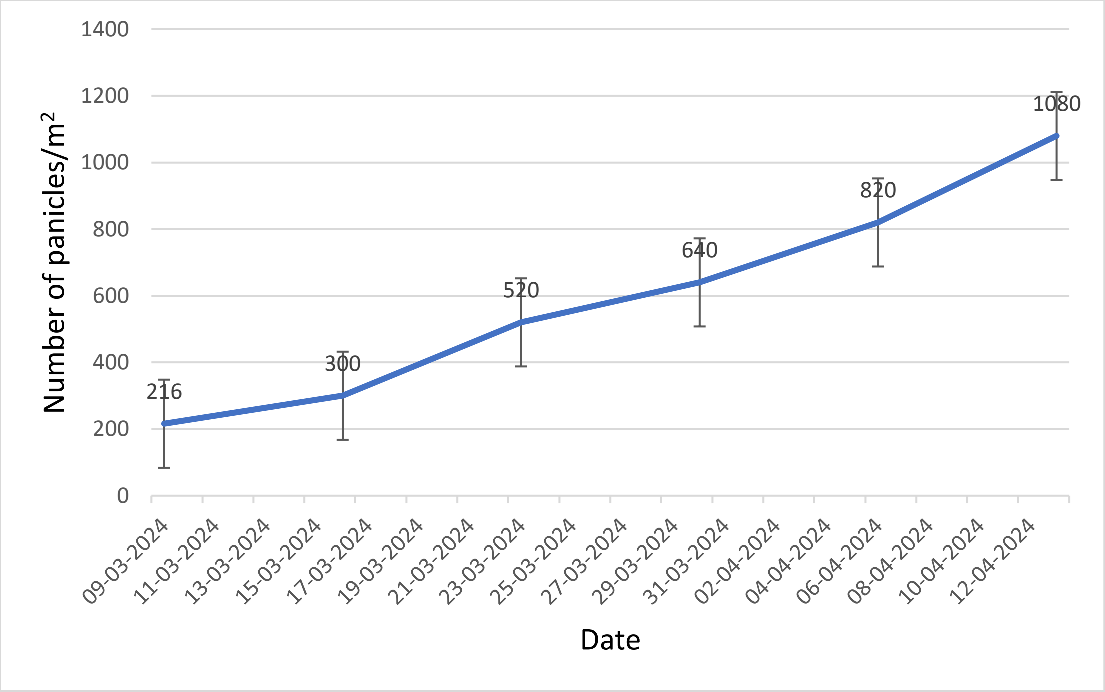


Fig. 4.8 Number of panicles per meter square

4.4 SOIL MOISTURE CONTENT

Soil samples were collected from four random locations in the field when the water level in the AWD tube fell down by 15 cm below the ground level, and soil moisture was calculated by gravitational method.

Table 4.10 Moisture Content collected from random locations of the field

Sl. No.	Weight of container(g)	Weight of wet soil(g)	Wet of oven dried soil + Weight of container(g)	Weight of dry soil(g)	Moisture Content (%)
A1	35.63	50	74.79	39.16	27.68
A2	13.80	50	52.82	39.02	28.13
A3	15.36	50	51.28	35.92	39.19
A4	14.41	50	52.42	38.01	31.54

Average soil moisture when the water level falls 15 cm below the ground level in the AWD tube = 31.63 %

4.5 COST OF AAWD SYSTEM AND AUTOMATED GAS CHAMBER

The table 4.11 and table 4.12 demonstrates that setting up an AAWD system and sensor-based gas chamber is affordable and provides a clear cost distribution, aiding in budgeting and resource allocation.

Table 4.11 Cost of AAWD system

Sl. No.	Components	Qty	Rate (Rupees/unit)	Cost
1	Esp 32 Devkit V1	1	550.00	550.00
2	Ultrasonic sensor	1	195.00	195.00
3	Jumper wires	3 set	24.00	72.00
4	Breadboard	1	70.00	70.00
5	5V relay	1	90.00	90.00
6	Service wire	60 meters	18.64	1118.40
7	Open box,6V switch,6V socket	1	50.00	50.00
8	PVC pipe	2 meters	158.00	316.00
				Total = Rs 2461.40/-

Total amount for AAWD system = Rs. 2461.40/-

Table 4.12 Cost of sensor-based gas chamber for methane estimation

Sl. No.	Components	Qty	Rate (Rupees/unit)	Cost
1	Acrylic sheet	1 (2.25 m^2)	4661.00	4661.00
2	Self-screw	180	1.20	216.00
3	Esp 8266 Node MCU	1	416.00	416.00
4	MQ-4	1	155.00	155.00
5	Jumper wires	1 set	24.000	24.00
				Total = Rs 5472.00

Total amount for sensor-based gas chamber for methane estimation = Rs. 5472/-

4.6 ADVANTAGES

There are several advantages to the AAWD and sensor-based gas chamber systems, some of which are listed below:

4.3.1 Automated AWD

- Reduced labour requirement
- Water conservation
- High yield
- Reduces greenhouse gas emission
- Accurate cut-off of water
- Farmer's involvement is not required in operating the pump
- Easy to take the water level reading despite the increased plant height

4.3.2 Gas chamber

- Higher methane capture rates with quick reading times
- Precise monitoring of methane levels in real-time

CHAPTER 5

SUMMARY AND CONCLUSION

This study addresses the critical challenges in modern paddy cultivation by developing an innovative Automated Alternating Wetting and Drying (AAWD) system, complemented by a sensor-based gas chamber for methane emission monitoring. The study was conducted at the instructional farm of KCAET Tavanur, providing a practical and controlled environment for testing and implementation. The AAWD system utilized an ultrasonic sensor for automated water management, enabling precise monitoring of water levels in the paddy fields. This system efficiently maintained optimal water levels by activating water pumps based on set thresholds, resulting in a remarkable 50-70% reduction in water usage compared to conventional continuous flooding methods. This significant water saving is crucial for regions facing water scarcity, supporting sustainable water resource management.

In addition to water management, the study employed a sensor-based gas chamber equipped with an MQ4 sensor to accurately measure methane concentrations under various conditions, including open air, cattle manure application, continuously flooded fields, and AAWD-managed fields. The results showed that the AAWD system significantly reduced methane emissions, with levels dropping to 0.55 ppm, a 71% decrease compared to continuously flooded fields. This reduction not only enhances the sustainability of paddy cultivation but also contributes to global efforts in reducing greenhouse gas emissions. The AAWD system also promoted continuous and healthy crop growth, indicating a strong potential for high grain yields at harvest stage. Economically, the system proved viable, with setup and operational costs of Rs. 2461/- and Rs. 5472/- for Automated Alternate Wetting and Drying system and Automated Gas Chamber respectively, suggesting long-term savings in water and energy expenses. By integrating automated water management and environmental monitoring, the study fosters a shift towards more sustainable and eco-friendly agricultural practices.

This study presents a comprehensive solution to key challenges in water management in paddy cultivation. It is concluded that, this study effectively integrates an ultrasonic sensor for water management and an MQ4 sensor for methane measurement. The AAWD system effectively conserves water, which significantly reduces methane emissions and is economically feasible, making it a practical and sustainable approach for modern agriculture.

The system's ability to reduce water usage by 50-70% and minimise methane emissions by 71% compared to traditional methods marks a significant advancement in agricultural technology. The findings indicate that the AAWD system not only addresses immediate agricultural challenges but also aligns with broader environmental conservation goals, supporting the transition to more sustainable farming practices. The study sets a strong precedent for future research and development in automated agricultural systems, highlighting the need for further testing across diverse regions and long-term impact studies to fully realize its benefits. By integrating such technologies with other smart farming innovations, the project lays the groundwork for a holistic approach to precision agriculture, promoting food security and environmental sustainability.

REFERENCES

Abid, A.A., Zhang, Q., Adil, M.F., Batool, I., Abbas, M., Hassan, Z., Khan, A.A., Castellano-Hinojosa, A., Zaidi, S.H.R., Di, H. and Abdeslsalam, N.R., 2022. Nitrogen optimization coupled with alternate wetting and drying practice enhances rhizospheric nitrifier and denitrifier abundance and rice productivity. *Frontiers Plant Sci.*, *13*, p.927229.

Adopted, I.P.C.C., 2014. Climate change 2014 synthesis report. IPCC: Geneva, Switzerland, pp.1059-1072.

Akiyama, H., 2024. Methane and nitrous oxide emissions from agricultural fields in Japan and mitigation options: a review. Soil Science and Plant Nutrition, pp.1-9.

Alam, M.S., Islam, M.S., Salam, M.A. and Islam, M.A., 2009. Economics of alternate wetting and drying method of irrigation: evidences from farm level study. *Agric*., 7(1&2), pp.82-89.

Alauddin, M., Sarker, M.A.R., Islam, Z. and Tisdell, C., 2020. Adoption of alternate wetting and drying (AWD) irrigation as a water-saving technology in Bangladesh: Economic and environmental considerations. *Land use policy*, *91*, p.104430.

Ansari, J., Udawatta, R.P. and Anderson, S.H., 2023. Soil nitrous oxide emission from agroforestry, rowcrop, grassland and forests in North America: a review. *Agrofor. Syst.*, *97*(8), pp.1465-1479.

Ariani, M., Hanudin, E. and Haryono, E., 2021. Greenhouse Gas Emissions from Rice Fields in Indonesia: Challenges for Future Research and Development. *Indonesian J.Geogr.*, 53(1).

Bank, R.K., Saving Water with Alternate Wetting Drying (AWD). Truycậptừ http://www. knowledgebank. irri. org/training/fact-sheets/water-management/saving-water-alternate-wetting-drying-awd.

Bhatt, R., Singh, P., Hossain, A. and Timsina, J., 2021. Rice–wheat system in the northwest Indo-Gangetic plains of South Asia: issues and technological interventions for increasing productivity and sustainability. *Paddy Water Environ.*, 19(3), pp.345-365.

Bouman, B.A., Barker, R., Humphreys, E., Tuong, T.P., Atlin, G., Bennett, J., Dawe, D., Dittert, K., Dobermann, A., Facon, T. and Fujimoto, N., 2007. *Rice: feeding the billions*.

Bwire, D., Saito, H., Sidle, R.C. and Nishiwaki, J., 2023. Water Management and Hydrological Characteristics of Rice-Paddy Catchments Under AWD Irrigation Practice: Asia and Sub-Saharan Africa.

Carrijo, D.R., Akbar, N., Reis, A.F., Li, C., Gaudin, A.C., Parikh, S.J., Green, P.G. and Linquist, B.A., 2018. Impacts of variable soil drying in alternate wetting and drying rice systems on yields, grain arsenic concentration and soil moisture dynamics. *Field Crops Res.*, 222, pp.101-110.

Cebi, U., Özer, S., Öztürk, O., Aydın, B. and Çakır, R., 2023. Yield and water productivity of rice grown under different irrigation methods. *J. Agric. Sci.*, 161(3), pp.387-397.

Chaichana, N., Bellingrath-Kimura, S.D., Komiya, S., Fujii, Y., Noborio, K., Dietrich, O. and Pakoktom, T., 2018. Comparison of closed chamber and eddy covariance methods to improve the understanding of methane fluxes from rice paddy fields in Japan. *Atmosphere*, 9(9), p.356.

Chataut, G., Bhatta, B., Joshi, D., Subedi, K. and Kafle, K., 2023. Greenhouse gases emission from agricultural soil: A review. *J. Agric. Food Res.*, 11, p.100533.

Chatterjee, D., Nayak, A. K., Das, S. R., Nayak, B. K., Shahid, M., Khanam, R., Tripathi, R., Pradhan, A., Kumar, U., Kaviraj, M., Kumar, A., 2024. Current and emerging method of estimating greenhouse gas emission from agriculture. Research Bulletin No. 43; ICAR-National Rice Research Institute, Cuttack, Odisha, 753006, India. pp. 44

Chenchireddy, Kalagotla. (2022). Air Quality Monitoring and Alert System Using MQ135 Gas Sensor with Arduino Controller, *Int. J. Res. Publ. Rev.*

Cheng, H., Shu, K., Zhu, T., Wang, L., Liu, X., Cai, W., Qi, Z. and Feng, S., 2022. Effects of alternate wetting and drying irrigation on yield, water and nitrogen use, and greenhouse gas emissions in rice paddy fields. *J. Cleaner Prod.*, 349, p.131487.

Cruz, K.M.S.D., Ella, V.B., Suministrado, D.C., Pereira, G.S. and Agulto, E.S., 2022. A low-cost wireless sensor for real-time monitoring of water level in lowland rice field under alternate wetting and drying irrigation. *Water*, 14(24), p.4128.

Dahlgreen, J. and Parr, A., 2024. Exploring the Impact of Alternate Wetting and Drying and the System of Rice Intensification on Greenhouse Gas Emissions: A Review of Rice Cultivation Practices. *Agron.*, 14(2), p.378.

Dossou-Yovo, E.R. and Saito, K., 2021. Impact of management practices on weed infestation, water productivity, rice yield and grain quality in irrigated systems in Côte d'Ivoire. *Field Crops Res.*, 270, p.108209.

Dubey, S.K., 2005. Microbial ecology of methane emission in rice agroecosystem: a review. Applied ecology and environmental research, 3(2), pp.1-27.

Food and Agriculture Organization of the United Nations (FAO), 2009. High Level Expert Forum—How to Feed the World in 2050.

Gaputra, I., Fryonanda, H., Arsyah, U.I. and Atma, Y.A., 2023. Smart irrigation system prototype for rice plants using the awd method. JurnalIpteksTerapan, 17(1), pp.146-153.

Gupta, K., Kumar, R., Baruah, K.K., Hazarika, S., Karmakar, S. and Bordoloi, N., 2021. Greenhouse gas emission from rice fields: a review from Indian context. *Environ. Sci. Pollution Res.*, 28(24), pp.30551-30572.

Hester, E.R., Vaksmaa, A., Valè, G., Monaco, S., Jetten, M.S. and Lüke, C., 2022. Effect of water management on microbial diversity and composition in an Italian rice field system. *FEMS Microbiol. Ecol.*, 98(3), p. fiac018.

IPCC (Intergovernmental Panel on Climate Change), 1997. Revised 1996 IPCC guidelines for national greenhouse gas inventories.

Ishfaq, M., Akbar, N., Anjum, S.A. and Anwar-Ijl-Haq, M., 2020. Growth, yield and water productivity of dry direct seeded rice and transplanted aromatic rice under different irrigation management regimes. *J. Integrative Agric.*, 19(11), pp.2656-2673.

Ishfaq, M., Farooq, M., Zulfiqar, U., Hussain, S., Akbar, N., Nawaz, A. and Anjum, S.A., 2020. Alternate wetting and drying: A water-saving and ecofriendly rice production system. *Agric. Water Manag.*, 241, p.106363.

Islam, S., Rahman, M.M., Islam, M.R. and Naidu, R., 2016. Arsenic accumulation in rice: consequences of rice genotypes and management practices to reduce human health risk. *Environ. Int.*, 96, pp.139-155.

Islam, S.M., Gaihre, Y.K., Islam, M.R., Akter, M., Al Mahmud, A., Singh, U. and Sander, B.O., 2020. Effects of water management on greenhouse gas emissions from farmers' rice fields in Bangladesh. *Sci. Total Environ.*, 734, p.139382.

Jagannath, P., Pullabhotla, H. and Uphoff, N., 2013. Meta-analysis evaluating water use, water saving, and water productivity in irrigated production of rice with SRI vs. standard management methods.

Jain, M.C., Kumar, S., Wassmann, R., Mitra, S., Singh, S.D., Singh, J.P., Singh, R., Yadav, A.K. and Gupta, S., 2000. Methane emissions from irrigated rice fields in northern India (New Delhi). *Nutr. Cycling Agroecosystems*, 58, pp.75-83.

Jia, Z. and Cai, Z., 2003. Effects of rice plants on methane emission from paddy fields. Ying yong sheng tai xue bao=*J. Appl. Ecol*., 14(11), pp.2049-2053.

Johnson, K.A. and Johnson, D.E., 1995. Methane emissions from cattle. *J. Anim.Sci.*, 73(8), pp.2483-2492.

Kalyan, G.P., Bingipalli, M. and Patil, N.B., 2022. Alternate wet drying method in paddy cultivation in India by using soil moisture sensors: a review. *Pharma Innovation J.*, 11(5), pp.292-296.

Katti, G. and Ch, P., 2022 Impact of Rice Cultivation Methods on Insect Pest Incidence and Their Management, *J. Rice Res.*

Khosa, M.K., Sidhu, B.S. and Benbi, D.K., 2011. Methane emission from rice fields in relation to management of irrigation water. *J. Environ. Biol.*, 32(2), pp.169-172.

Kikstra, J.S., Nicholls, Z.R., Smith, C.J., Lewis, J., Lamboll, R.D., Byers, E., Sandstad, M., Meinshausen, M., Gidden, M.J., Rogelj, J. and Kriegler, E., 2022. The IPCC Sixth Assessment Report WGIII climate assessment of mitigation pathways: from emissions to global temperatures. *Geoscientific Model Dev.*, *15*(24), pp.9075-9109.

Komarudin, M., Septama, H.D. and Yulianti, T., 2022, March. Autonomous Cyber Physical Systems for Monitoring of Methane Gas in Rice Field. In *2nd Int. Conf. Smart Innovative Agric. (ICoSIA 2021)* (pp. 138-143). Atlantis Press.

Lampayan, R.M., Rejesus, R.M., Singleton, G.R. and Bouman, B.A., 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Res.*, 170, pp.95-108.

Le, L.T., 2021. Alternate wetting and drying technique in paddy production in the Mekong Delta, Vietnam: economic evaluation and adoption determinants. *J. Agribusiness Developing Emerging Economies*, 11(1), pp.42-59.

Li, C., Xiong, Y., Huang, Q., Xu, X. and Huang, G., 2020. Impact of irrigation and fertilization regimes on greenhouse gas emissions from soil of mulching cultivated maize (Zea mays L.) field in the upper reaches of Yellow River, China. *J.Cleaner Prod.*, 259, p.120873.

Linquist, B.A., Adviento-Borbe, M.A., Pittelkow, C.M., van Kessel, C. and van Groenigen, K.J., 2012. Fertilizer management practices and greenhouse gas emissions from rice systems: a quantitative review and analysis. *Field Crops Res.*, 135, pp.10-21. *Sci. Pollution Res.*, 28(24), pp.30551-30572.

Loaiza, S., Verchot, L., Valencia, D., Guzmán, P., Amezquita, N., Garcés, G., Puentes, O., Trujillo, C., Chirinda, N. and Pittelkow, C.M., 2024. Evaluating greenhouse gas mitigation through alternate wetting and drying irrigation in Colombian rice production. *Agric., Ecosyst. Environ.*, 360, p.108787.

Ma, N., Liu, X., Wang, L. and Liu, G., 2024. A meta-analysis on the mitigation measures of methane emissions in Chinese rice paddy. *Resour., Conserv. Recycling*, 202, p.107379.

Majumdar, A., Upadhyay, M.K., Dubey, P.K., Giri, B., Srivastava, A.K. and Srivastava, S., 2022. Effect of combined dry-wet irrigation and microbial dynamics on soil nutrient bioavailability.

Minamikawa, K. and Sakai, N., 2005. The effect of water management based on soil redox potential on methane emission from two kinds of paddy soils in Japan. *Agric., Ecosyst.Environ.*, 107(4), pp.397-407.

Minamikawa, K., Yagi, K., Tokida, T., Sander, B.O. and Wassmann, R., 2012. Appropriate frequency and time of day to measure methane emissions from an irrigated rice paddy in Japan using the manual closed chamber method. *Greenhouse Gas Measurement Manag., 2*(2-3), pp.118-128.

Naser, H.M., Nagata, O., Sultana, S. and Hatano, R., 2018. Impact of management practices on methane emissions from paddy grown on mineral soil over peat in Central Hokkaido, Japan. *Atmosphere*, 9(6), p.212.

Norton, G.J., Shafaei, M., Travis, A.J., Deacon, C.M., Danku, J., Pond, D., Cochrane, N., Lockhart, K., Salt, D., Zhang, H. and Dodd, I.C., 2017. Impact of alternate wetting and drying on rice physiology, grain production, and grain quality. *Field Crops Res.*,205, pp.1-13.

Nouchi, I. and Mariko, S., 1993. Mechanism of methane transport by rice plants. In Biogeochemistry of Global Change: Radiatively Active Trace Gases Selected Papers from the Tenth International Symposium on Environmental Biogeochemistry, San Francisco, August 19–24, 1991 (pp. 336-352).

Orasen, G., De Nisi, P., Lucchini, G., Abruzzese, A., Pesenti, M., Maghrebi, M., Kumar, A., Nocito, F.F., Baldoni, E., Morgutti, S. and Negrini, N., 2019. Continuous flooding or alternate wetting and drying differently affect the accumulation of health-promoting phytochemicals and minerals in rice brown grain. *Agron.*, *9*(10), p.628.

Papademetriou, M.K., 2000. Rice production in the Asia-Pacific region: issues and perspectives. Bridging the rice yield gap in the Asia-Pacific region, 220, pp.4-25.

Pham, V.B., Diep, T.T., Fock, K. and Nguyen, T.S., 2021. Using the Internet of Things to promote alternate wetting and drying irrigation for rice in Vietnam’s Mekong Delta. *Agron. Sustain. Dev*., 41(3), p.43.

Poddar, R., Acharjee, P.U., Bhattacharyya, K. and Patra, S.K., 2022. Effect of irrigation regime and varietal selection on the yield, water productivity, energy indices and economics of rice production in the lower Gangetic Plains of Eastern India. *Agric. Water Manag.*, 262, p.107327.

Portmann, R.W., Daniel, J.S. and Ravishankara, A.R., 2012. Stratospheric ozone depletion due to nitrous oxide: influences of other gases. *Philosophical Transactions Royal Society B:Biol. Sci.*, 367(1593), pp.1256-1264.

Pradhan, S. and Goswami, G., 2019. India’s second Biennial Update Report. *Curr. Sci.*, 117(12), pp.1944-1946.

Rajasekar, P. and Selvi, J.A.V., 2022. Sensing and analysis of greenhouse gas emissions from rice fields to the near field atmosphere. *Sensors*, *22*(11), p.4141.

Rana, M.M., Rahman, M.M., Oliver, M.M.H. and Miah, M.Y., 2023. Development and evaluation of the first automated irrigation system for alternate wetting and drying technique in rice cultivation in Bangladesh. *Smart Agric. Technol.*, 6, p.100348.

Sahai, S., Sharma, C., Singh, S.K. and Gupta, P.K., 2011. Assessment of trace gases, carbon and nitrogen emissions from field burning of agricultural residues in India. *Nutr. Cycling Agroecosystems*, 89, pp.143-157.

Sander, B.O. and Wassmann, R., 2014. Common practices for manual greenhouse gas sampling in rice production: a literature study on sampling modalities of the closed chamber method. *Greenhouse Gas Measurement Manag.*, 4(1), pp.1-13.

Senthilraja, K., Venkatesan, S., Udhaya Nandhini, D., Dhasarathan, M., Prabha, B., Boomiraj, K., Mohan Kumar, S., Bhuvaneswari, K., Raveendran, M. and Geethalakshmi, V., 2023. Mitigating Methane Emission from the Rice Ecosystem through Organic Amendments. *Agric.*, 13(5), p.1037.

Setyanto, P., Pramono, A., Adriany, T.A., Susilawati, H.L., Tokida, T., Padre, A.T. and Minamikawa, K., 2018. Alternate wetting and drying reduces methane emission from a rice paddy in Central Java, Indonesia without yield loss. *Soil Sci. Plant Nutr.*, 64(1), pp.23-30.

Shafi, S., Shafi, I., Zaffar, A., Zargar, S.M., Shikari, A.B., Ranjan, A., Prasad, P.V. and Sofi, P.A., 2023. The resilience of rice under water stress will be driven by better roots: evidence from root phenotyping, physiological, and yield experiments. *Plant Stress*, p.100211.

Siddiqui, M., Akther, F., Rahman, G.M., Elahi, M.M., Mostafa, R. and Wahid, K.A., 2021. Dimensioning of wide-area alternate wetting and drying (Awd) system for iot-based automation. Sensors, 21(18), p.6040.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C. and Scholes, B., 2008. Greenhouse gas mitigation in agriculture. *Philosophical transactions Royal Society B: Biol. Sci.*, *363*(1492), pp.789-813.

Sriphirom, P., Chidthaisong, A. and Towprayoon, S., 2019. Effect of alternate wetting and drying water management on rice cultivation with low emissions and low water used during wet and dry season. *J. Cleaner Prod.*, 223, pp.980-988.

Steed Jr, J. and Hashimoto, A.G., 1994. Methane emissions from typical manure management systems. *Bioresource Technol.*, 50(2), pp.123-130.

Su, J.J., Liu, B.Y. and Chang, Y.C., 2003. Emission of greenhouse gas from livestock waste and wastewater treatment in Taiwan. Agriculture, ecosystems & environment, 95(1), pp.253-263.Dubeux, J.C., Garcia, L., Queiroz, L.M., Santos, E.R., Oduor, K.T. and Bretas, I.L., 2023. Carbon footprint of beef cattle systems in the Southeast United States.

Tolentino, L.K.S., Bacaltos, P.C., Cruz, R.M.V., Cruz, N.J.S.D., Medina, L.R.S., Panergalin, J.V., Padilla, M.V.C. and Velasco, J.S., 2021. Autogation: An alternate wetting and drying-based automatic irrigation and paddy water level control system through Internet of Things. AGRIVITA, *J. Agric. Sci.*, 43(3), pp.479-494.

Tongwane, M., Mdlambuzi, T., Moeletsi, M., Tsubo, M., Mliswa, V. and Grootboom, L., 2016. Greenhouse gas emissions from different crop production and management practices in South Africa. *Environ. Dev.*, 19, pp.23-35.

Vijay, D. and Roy, B., 2013. Chapter-4 Rice (Oryza Sativa L.). Breeding, Biotechnology and Seed Production of Field Crops (December), pp.71-122.

Wang LiZhi, W.L., Xue Bai, X.B. and Yan TianHai, Y.T., 2017. Greenhouse gas emissions from pig and poultry production sectors in China from 1960 to 2010.

Wang, X., Chang, X., Ma, L., Bai, J., Liang, M. and Yan, S., 2023. Global and regional trends in greenhouse gas emissions from rice production, trade, and consumption. *Environ. Impact Assess. Rev.*, 101, p.107141.

Wang, Z.P., Delaune, R.D., Patrick Jr, W.H. and Masscheleyn, P.H., 1993. Soil redox and pH effects on methane production in a flooded rice soil. *Soil Sci. Soc. America J.*, 57(2), pp.382-385.

Wu, X., Zhang, Y., Han, Y., Zhang, Y., Zhang, Y., Cheng, X., Zhong, P., Yuan, X., Zhang, Y. and Li, Z., 2023. Advances in methane emissions from agricultural sources: Part I. Accounting and mitigation. *J.Environ.Sci.*

Xi-Liu, Y.U.E. and Qing-Xian, G.A.O., 2018. Contributions of natural systems and human activity to greenhouse gas emissions. *Adv. Clim. Change Res.*, 9(4), pp.243-252.

Yadav, G.S., Datta, M., Babu, S., Singh, R., Devi, H.L., Debnath, C., Singh, V. and Saha, P., 2015. Climate resilient rice production systems. *Popular Kheti*, *3*(3), pp.14-19.

Yan, X., Cai, Z., Ohara, T. and Akimoto, H., 2003. Methane emission from rice fields in mainland China: Amount and seasonal and spatial distribution. *J. Geophys. Res.: Atmospheres*, 108(D16).

Yang, W.T., Wang, W.Q., Shen, L.D., Bai, Y.N., Liu, X., Tian, M.H., Wang, C., Feng, Y.F., Liu, Y., Yang, Y.L. and Liu, J.Q., 2022. Potential role of nitrite-dependent anaerobic methane oxidation in methane consumption and nitrogen removal in Chinese paddy fields. *Sci. Total Environ.*, 838, p.156534.

Zhang, Y., Wang, W., Li, S., Zhu, K., Hua, X., Harrison, M.T., Liu, K., Yang, J., Liu, L. and Chen, Y., 2023. Integrated management approaches enabling sustainable rice production under alternate wetting and drying irrigation. *Agric. Water Manag.*, 281, p.108265.

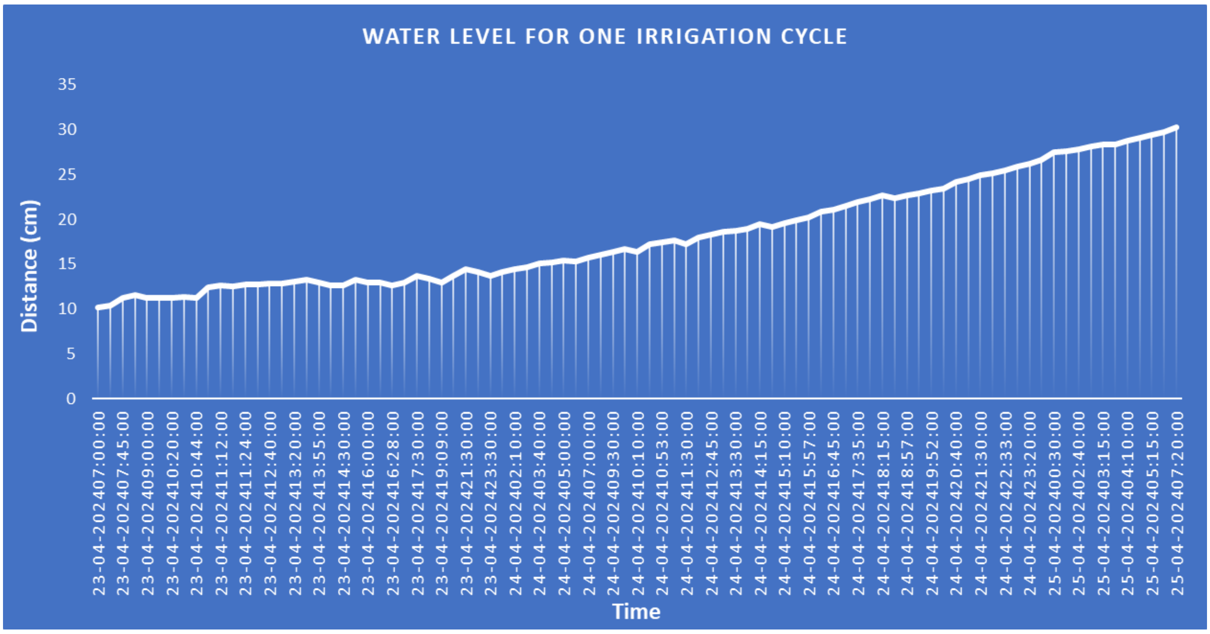
Appendix I

Continuous Monitoring of Water Level by AAWD system

Date	Time	Distance (cm)
23-04-2024	07:00:00	10.2
23-04-2024	07:15:00	10.4
23-04-2024	07:45:00	11.3
23-04-2024	08:30:00	11.6
23-04-2024	09:00:00	11.2
23-04-2024	10:00:00	11.2
23-04-2024	10:20:00	11.2
23-04-2024	10:30:00	11.4
23-04-2024	10:44:00	11.3
23-04-2024	11:00:00	12.4
23-04-2024	11:12:00	12.6
23-04-2024	11:20:00	12.5
23-04-2024	11:24:00	12.7
23-04-2024	12:00:00	12.75
23-04-2024	12:40:00	12.85
23-04-2024	13:00:00	12.85
23-04-2024	13:20:00	13.08
23-04-2024	13:40:00	13.33
23-04-2024	13:55:00	13
23-04-2024	14:00:00	12.61
23-04-2024	14:30:00	12.62
23-04-2024	15:00:00	13.33
23-04-2024	16:00:00	12.97
23-04-2024	16:23:00	12.99
23-04-2024	16:28:00	12.63
23-04-2024	17:00:00	13
23-04-2024	17:30:00	13.69
23-04-2024	18:08:00	13.35
23-04-2024	19:09:00	13.01
23-04-2024	20:20:00	13.7
23-04-2024	21:30:00	14.42
23-04-2024	22:30:00	14.14
23-04-2024	23:30:00	13.72
24-04-2024	01:30:00	14.1
24-04-2024	02:10:00	14.42
24-04-2024	03:15:00	14.63
24-04-2024	03:40:00	15.1
24-04-2024	04:30:00	15.18
24-04-2024	05:00:00	15.45
24-04-2024	06:15:00	15.3
24-04-2024	07:00:00	15.7

24-04-2024	08:00:00	16.01
24-04-2024	09:30:00	16.39
24-04-2024	09:45:00	16.7
24-04-2024	10:10:00	16.4
24-04-2024	10:35:00	17.2
24-04-2024	10:53:00	17.43
24-04-2024	11:00:00	17.6
24-04-2024	11:30:00	17.2
24-04-2024	12:10:00	18
24-04-2024	12:45:00	18.34
24-04-2024	13:05:00	18.56
24-04-2024	13:30:00	18.67
24-04-2024	14:00:00	18.88
24-04-2024	14:15:00	19.44
24-04-2024	14:25:00	19.17
24-04-2024	15:10:00	19.58
24-04-2024	15:27:00	19.94
24-04-2024	15:57:00	20.24
24-04-2024	16:24:00	20.81
24-04-2024	16:45:00	21.04
24-04-2024	17:10:00	21.46
24-04-2024	17:35:00	21.89
24-04-2024	17:55:00	22.24
24-04-2024	18:15:00	22.65
24-04-2024	18:40:00	22.32
24-04-2024	18:57:00	22.65
24-04-2024	19:10:00	22.87
24-04-2024	19:52:00	23.23
24-04-2024	20:10:00	23.45
24-04-2024	20:40:00	24.11
24-04-2024	20:55:00	24.47
24-04-2024	21:30:00	24.95
24-04-2024	22:10:00	25.17
24-04-2024	22:33:00	25.42
24-04-2024	22:47:00	25.84
24-04-2024	23:20:00	26.15
24-04-2024	23:45:00	26.66
25-04-2024	00:30:00	27.45
25-04-2024	01:45:00	27.55
25-04-2024	02:40:00	27.75
25-04-2024	02:55:00	28.11
25-04-2024	03:15:00	28.31
25-04-2024	03:45:00	28.36
25-04-2024	04:10:00	28.74
25-04-2024	04:20:00	29.11
25-04-2024	05:15:00	29.42

25-04-2024	06:25:00	29.67
25-04-2024	07:20:00	30.21



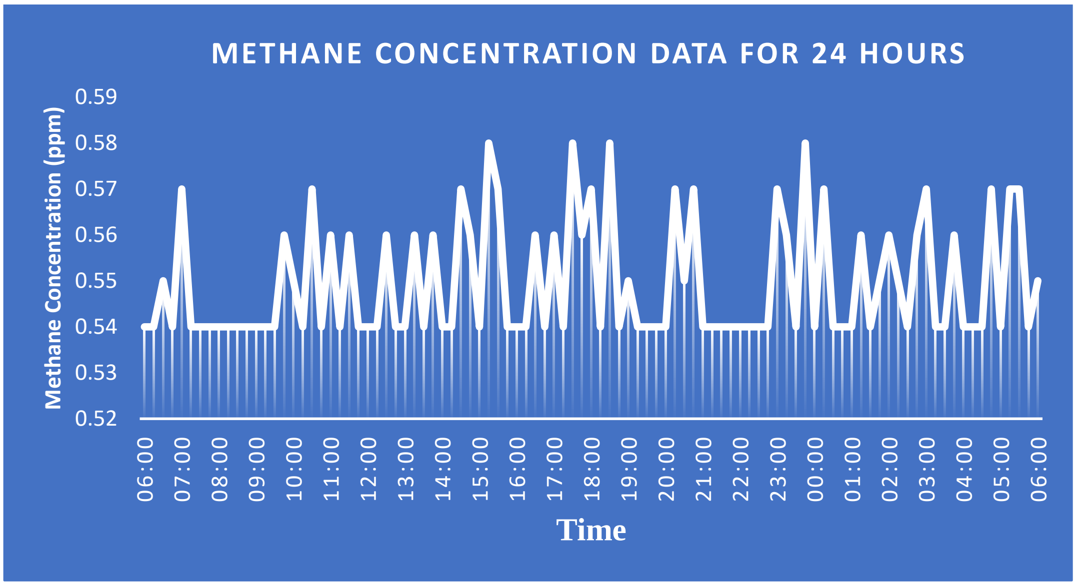
Appendix II

Methane Concentration Data Recorded at 15-Minute Intervals Over a 24 - Hour Period

Time	CH_4 Concentration (ppm)
06:00	0.54
06:15	0.54
06:30	0.55
06:45	0.54
07:00	0.57
07:15	0.54
07:30	0.54
07:45	0.54
08:00	0.54
08:15	0.54
08:30	0.54
08:45	0.54
09:00	0.54
09:15	0.54
09:30	0.54
09:45	0.56
10:00	0.55
10:15	0.54
10:30	0.57
10:45	0.54
11:00	0.56
11:15	0.54
11:30	0.56
11:45	0.54
12:00	0.54
12:15	0.54
12:30	0.56
12:45	0.54
13:00	0.54
13:15	0.56
13:30	0.54
13:45	0.56
14:00	0.54
14:15	0.54
14:30	0.57
14:45	0.56
15:00	0.54
15:15	0.58
15:30	0.57
15:45	0.54
16:00	0.54

16:15	0.54
16:30	0.56
16:45	0.54
17:00	0.56
17:15	0.54
17:30	0.58
17:45	0.56
18:00	0.57
18:15	0.54
18:30	0.58
18:45	0.54
19:00	0.55
19:15	0.54
19:30	0.54
19:45	0.54
20:00	0.54
20:15	0.57
20:30	0.55
20:45	0.57
21:00	0.54
21:15	0.54
21:30	0.54
21:45	0.54
22:00	0.54
22:15	0.54
22:30	0.54
22:45	0.54
23:00	0.57
23:15	0.56
23:30	0.54
23:45	0.58
00:00	0.54
00:15	0.57
00:30	0.54
00:45	0.54
01:00	0.54
01:15	0.56
01:30	0.54
01:45	0.55
02:00	0.56
02:15	0.55
02:30	0.54
02:45	0.56
03:00	0.57
03:15	0.54
03:30	0.54

03:45	0.56
04:00	0.54
04:15	0.54
04:30	0.54
04:45	0.57
05:00	0.54
05:15	0.57
05:30	0.57
05:45	0.54
06:00	0.55



AUTOMATION OF ALTERNATE WETTING AND DRYING METHOD AND METHANE ESTIMATION FOR PADDY

BY

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ABSTRACT OF THESIS

Submitted in partial fulfilment of the requirement for the degree

Bachelor of Technology

In

Agricultural Engineering

Faculty of Agricultural Engineering and Technology

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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ABSTRACT

Rice farming, reliant on paddy cultivation, is vital for providing a staple food to many worldwide. This intricate process involves various steps, starting from preparing the fields and ending with the harvest. Today, key issues revolve around conserving water, addressing climate change, and managing environmental impacts. This study focuses on the development and evaluation of an Automated Alternate Wetting and Drying (AAWD) system and a sensor based gas chamber to enhance paddy cultivation efficiency and reduce methane emissions. The AAWD system automates water management using the HC-SR04 ultrasonic sensor to monitor water levels and activate a pump when water levels fall below a threshold, reducing water usage by 50-70% compared to conventional methods. The system successfully maintained water levels between set thresholds, ensuring continuous and healthy crop growth, thus showing promise for higher yields.

The sensor-based gas chamber, equipped with the MQ-4 methane sensor, provided accurate, real-time monitoring of methane emissions. Methane measurements indicated a significant reduction in emissions, with AAWD fields showing a 71% lower methane concentration (0.55 ppm) compared to continuously flooded fields (1.942 ppm). The calibration of the ultrasonic and MQ-4 sensors ensured precise measurements, validating the system's reliability.

Cost of these systems used in this study confirmed the affordability of the systems, with the AAWD system costing Rs. 2461/- and the gas chamber costing Rs. 5472/-. This project highlights the potential for widespread adoption of automated systems in sustainable agriculture, promoting water conservation and reducing greenhouse gas emissions.