IJOER
ENGINEERING JOURNAL

# Engineering Journal IJOER

# VOLUME-11, ISSUE-12, DECEMBER 2025

DOWNLOAD NOW

Contact us +91-7665235235 www.ijoer.com info@ijoer.com

# Preface

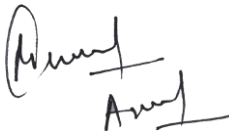
We would like to present, with great pleasure, the volume-11, Issue-12, December 2025, of a scholarly journal, *International Journal of Engineering Research & Science*. This journal is part of the AD Publications series *in the field of Engineering, Mathematics, Physics, Chemistry and science Research Development*, and is devoted to the gamut of Engineering and Science issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Engineering and Science as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Engineering and Science community, addressing researchers and practitioners in below areas:

| **Chemical Engineering** | |
|---|---|
| Biomolecular Engineering | Materials Engineering |
| Molecular Engineering | Process Engineering |
| Corrosion Engineering | |
| **Civil Engineering** | |
| Environmental Engineering | Geotechnical Engineering |
| Structural Engineering | Mining Engineering |
| Transport Engineering | Water resources Engineering |
| **Electrical Engineering** | |
| Power System Engineering | Optical Engineering |
| **Mechanical Engineering** | |
| Acoustical Engineering | Manufacturing Engineering |
| Optomechanical Engineering | Thermal Engineering |
| Power plant Engineering | Energy Engineering |
| Sports Engineering | Vehicle Engineering |
| **Software Engineering** | |
| Computer-aided Engineering | Cryptographic Engineering |
| Teletraffic Engineering | Web Engineering |
| **System Engineering** | |
| **Mathematics** | |
| Arithmetic | Algebra |
| Number theory | Field theory and polynomials |
| Analysis | Combinatorics |
| Geometry and topology | Topology |
| Probability and Statistics | Computational Science |
| Physical Science | Operational Research |
| **Physics** | |
| Nuclear and particle physics | Atomic, molecular, and optical physics |
| Condensed matter physics | Astrophysics |
| Applied Physics | Modern physics |
| Philosophy | Core theories |

| Chemistry | |
|---|---|
| Analytical chemistry | Biochemistry |
| Inorganic chemistry | Materials chemistry |
| Neurochemistry | Nuclear chemistry |
| Organic chemistry | Physical chemistry |
| **Other Engineering Areas** | |
| Aerospace Engineering | Agricultural Engineering |
| Applied Engineering | Biomedical Engineering |
| Biological Engineering | Building services Engineering |
| Energy Engineering | Railway Engineering |
| Industrial Engineering | Mechatronics Engineering |
| Management Engineering | Military Engineering |
| Petroleum Engineering | Nuclear Engineering |
| Textile Engineering | Nano Engineering |
| Algorithm and Computational Complexity | Artificial Intelligence |
| Electronics & Communication Engineering | Image Processing |
| Information Retrieval | Low Power VLSI Design |
| Neural Networks | Plastic Engineering |

Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with IJOER. We are certain that this issue will be followed by many others, reporting new developments in the Engineering and Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOER* readers and will stimulate further research into the vibrant area of Engineering and Science Research.



Mukesh Arora

(Chief Editor)

# Board Members


## Mr. Mukesh Arora (Editor-in-Chief)

BE (Electronics & Communication), M.Tech (Digital Communication), currently serving as Assistant Professor in the Department of ECE.

## Prof. Dr. Fabricio Moraes de Almeida

Professor of Doctoral and Master of Regional Development and Environment - Federal University of Rondonia.

## Dr. Parveen Sharma

Dr Parveen Sharma is working as an Assistant Professor in the School of Mechanical Engineering at Lovely Professional University, Phagwara, Punjab.

## Prof. S. Balamurugan

Department of Information Technology, Kalaignar Karunanidhi Institute of Technology, Coimbatore, Tamilnadu, India.

## Dr. Omar Abed Elkareem Abu Arqub

Department of Mathematics, Faculty of Science, Al Balqa Applied University, Salt Campus, Salt, Jordan, He received PhD and Msc. in Applied Mathematics, The University of Jordan, Jordan.

## Dr. AKPOJARO Jackson

Associate Professor/HOD, Department of Mathematical and Physical Sciences, Samuel Adegboyega University, Ogwa, Edo State.

## Dr. Ajoy Chakraborty

Ph.D.(IIT Kharagpur) working as Professor in the department of Electronics & Electrical Communication Engineering in IIT Kharagpur since 1977.

## Dr. Ukar W. Soelistijo

Ph D, Mineral and Energy Resource Economics, West Virginia State University, USA, 1984, retired from the post of Senior Researcher, Mineral and Coal Technology R&D Center, Agency for Energy and Mineral Research, Ministry of Energy and Mineral Resources, Indonesia.

## Dr. Samy Khalaf Allah Ibrahim

PhD of Irrigation &Hydraulics Engineering, 01/2012 under the title of: "Groundwater Management under Different Development Plans in Farafra Oasis, Western Desert, Egypt".

## Dr. Ahmet ÇİFCİ

Ph.D. in Electrical Engineering, Currently Serving as Head of Department, Burdur Mehmet Akif Ersoy University, Faculty of Engineering and Architecture, Department of Electrical Engineering.

## Dr. M. Varatha Vijayan

Annauniversity Rank Holder, Commissioned Officer Indian Navy, Ncc Navy Officer (Ex-Serviceman Navy), Best Researcher Awardee, Best Publication Awardee, Tamilnadu Best Innovation & Social Service Awardee From Lions Club.

## Dr. Mohamed Abdel Fatah Ashabrawy Moustafa

PhD. in Computer Science - Faculty of Science - Suez Canal University University, 2010, Egypt.

Assistant Professor Computer Science, Prince Sattam bin AbdulAziz University ALkharj, KSA.

## Prof.S.Balamurugan

Dr S. Balamurugan is the Head of Research and Development, Quants IS & CS, India. He has authored/co-authored 35 books, 200+ publications in various international journals and conferences and 6 patents to his credit. He was awarded with Three Post-Doctoral Degrees - Doctor of Science (D.Sc.) degree and Two Doctor of Letters (D.Litt) degrees for his significant contribution to research and development in Engineering.

## Dr. Mahdi Hosseini

Dr. Mahdi did his Pre-University ($12^{th}$) in Mathematical Science. Later he received his Bachelor of Engineering with Distinction in Civil Engineering and later he Received both M.Tech. and Ph.D. Degree in Structural Engineering with Grade "A" First Class with Distinction.

## Dr. Anil Lamba

Practice Head – Cyber Security, EXL Services Inc., New Jersey USA.

Dr. Anil Lamba is a researcher, an innovator, and an influencer with proven success in spearheading Strategic Information Security Initiatives and Large-scale IT Infrastructure projects across industry verticals. He has helped bring about a profound shift in cybersecurity defense. Throughout his career, he has parlayed his extensive background in security and a deep knowledge to help organizations build and implement strategic cybersecurity solutions. His published researches and conference papers has led to many thought provoking examples for augmenting better security.

## Dr. Ali İhsan KAYA

Currently working as Associate Professor in Mehmet Akif Ersoy University, Turkey.

**Research Area:** Civil Engineering - Building Material - Insulation Materials Applications, Chemistry - Physical Chemistry – Composites.

## Dr. Parsa Heydarpour

Ph.D. in Structural Engineering from George Washington University (Jan 2018), GPA=4.00.

## Dr. Heba Mahmoud Mohamed Afify

Ph.D degree of philosophy in Biomedical Engineering, Cairo University, Egypt worked as Assistant Professor at MTI University.

## Dr. Kalpesh Sunil Kamble (Ph.D., P.Eng., M.Tech, B.E. (Mechanical))

A distinguished academic with a Ph.D. in Mechanical Engineering and 13 Years of extensive teaching and research experience. He is currently a Assistant professor at the SSPM's COE, Kankavli and contributes to several undergraduate and masters programs across Mahrashtra, India.

## Dr. Aurora Angela Pisano

Ph.D. in Civil Engineering, Currently Serving as Associate Professor of Solid and Structural Mechanics (scientific discipline area nationally denoted as ICAR/08"–"Scienza delle Costruzioni"), University Mediterranea of Reggio Calabria, Italy.

## Dr. Faizullah Mahar

Associate Professor in Department of Electrical Engineering, Balochistan University Engineering & Technology Khuzdar. He is PhD (Electronic Engineering) from IQRA University, Defense View, Karachi, Pakistan.

## Prof. Viviane Barrozo da Silva

Graduated in Physics from the Federal University of Paraná (1997), graduated in Electrical Engineering from the Federal University of Rio Grande do Sul - UFRGS (2008), and master's degree in Physics from the Federal University of Rio Grande do Sul (2001).

## Dr. S. Kannadhasan

Ph.D (Smart Antennas), M.E (Communication Systems), M.B.A (Human Resources).

## Dr. Christo Ananth

Ph.D. Co-operative Networks, M.E. Applied Electronics, B.E Electronics & Communication Engineering Working as Associate Professor, Lecturer and Faculty Advisor/ Department of Electronics & Communication Engineering in Francis Xavier Engineering College, Tirunelveli.

## Dr. S.R.Boselin Prabhu

Ph.D, Wireless Sensor Networks, M.E. Network Engineering, Excellent Professional Achievement Award Winner from Society of Professional Engineers Biography Included in Marquis Who's Who in the World (Academic Year 2015 and 2016). Currently Serving as Assistant Professor in the department of ECE in SVS College of Engineering, Coimbatore.

## Dr. Balasubramanyam, N

Dr.Balasubramanyam, N working as Faculty in the Department of Mechanical Engineering at S.V.University College of Engineering Tirupati, Andhra Pradesh.

## Dr. PAUL P MATHAI

Dr. Paul P Mathai received his Bachelor's degree in Computer Science and Engineering from University of Madras, India. Then he obtained his Master's degree in Computer and Information Technology from Manonmanium Sundaranar University, India. In 2018, he received his Doctor of Philosophy in Computer Science and Engineering from Noorul Islam Centre for Higher Education, Kanyakumari, India.

## Dr. M. Ramesh Kumar

Ph.D (Computer Science and Engineering), M.E (Computer Science and Engineering).

Currently working as Associate Professor in VSB College of Engineering Technical Campus, Coimbatore.

## Dr. Maheshwar Shrestha

Postdoctoral Research Fellow in DEPT. OF ELE ENGG & COMP SCI, SDSU, Brookings, SD Ph.D, M.Sc. in Electrical Engineering from SOUTH DAKOTA STATE UNIVERSITY, Brookings, SD.

## Dr. D. Amaranatha Reddy

Ph.D. (Postdocteral Fellow, Pusan National University, South Korea), M.Sc., B.Sc. : Physics.

## Dr. Dibya Prakash Rai

Post Doctoral Fellow (PDF), M.Sc., B.Sc., Working as Assistant Professor in Department of Physics in Pachhuncga University College, Mizoram, India.

## Dr. Pankaj Kumar Pal

Ph.D R/S, ECE Deptt., IIT-Roorkee.

## Dr. P. Thangam

PhD in Information & Communication Engineering, ME (CSE), BE (Computer Hardware & Software), currently serving as Associate Professor in the Department of Computer Science and Engineering of Coimbatore Institute of Engineering and Technology.

## Dr. Pradeep K. Sharma

PhD., M.Phil, M.Sc, B.Sc, in Physics, MBA in System Management, Presently working as Provost and Associate Professor & Head of Department for Physics in University of Engineering & Management, Jaipur.

## Dr. R. Devi Priya

Ph.D (CSE), Anna University Chennai in 2013, M.E, B.E (CSE) from Kongu Engineering College, currently working in the Department of Computer Science and Engineering in Kongu Engineering College, Tamil Nadu, India.

## Dr. Sandeep

Post-doctoral fellow, Principal Investigator, Young Scientist Scheme Project (DST-SERB), Department of Physics, Mizoram University, Aizawl Mizoram, India- 796001.

## Dr. Roberto Volpe

Faculty of Engineering and Architecture, Università degli Studi di Enna "Kore", Cittadella Universitaria, 94100 – Enna (IT).

## Dr. S. Kannadhasan

Ph.D (Smart Antennas), M.E (Communication Systems), M.B.A (Human Resources).

**Research Area:** Engineering Physics, Electromagnetic Field Theory, Electronic Material and Processes, Wireless Communications.

## Mr. Bhavinbhai G. Lakhani

An expert in Environmental Technology and Sustainability, with an M.S. from NYIT. Their specialization includes Construction Project Management and Green Building. Currently a Project Controls Specialist Lead at DACK Consulting Solutions, they manage project schedules, resolve delays, and handle claim negotiations. Prior roles as Senior Project Manager at FCS Group and Senior Project Engineer at KUNJ Construction Corp highlight their extensive experience in project estimation, resource management, and on-site supervision.

## Mr. Omar Muhammed Neda

Department of Electrical Power Engineering, Sunni Diwan Endowment, Iraq.

## Mr. Amit Kumar

Amit Kumar is associated as a Researcher with the Department of Computer Science, College of Information Science and Technology, Nanjing Forestry University, Nanjing, China since 2009. He is working as a State Representative (HP), Spoken Tutorial Project, IIT Bombay promoting and integrating ICT in Literacy through Free and Open Source Software under National Mission on Education through ICT (NMEICT) of MHRD, Govt. of India; in the state of Himachal Pradesh, India.

## Mr. Tanvir Singh

Tanvir Singh is acting as Outreach Officer (Punjab and J&K) for MHRD Govt. of India Project: Spoken Tutorial - IIT Bombay fostering IT Literacy through Open Source Technology under National Mission on Education through ICT (NMEICT). He is also acting as Research Associate since 2010 with Nanjing Forestry University, Nanjing, Jiangsu, China in the field of Social and Environmental Sustainability.

## Mr. Abilash

MTech in VLSI, BTech in Electronics & Telecommunication engineering through A.M.I.E.T.E from Central Electronics Engineering Research Institute (C.E.E.R.I) Pilani, Industrial Electronics from ATI-EPI Hyderabad, IEEE course in Mechatronics, CSHAM from Birla Institute Of Professional Studies.

## Mr. Varun Shukla

M.Tech in ECE from RGPV (Awarded with silver Medal By President of India), Assistant Professor, Dept. of ECE, PSIT, Kanpur.

## Mr. Shrikant Harle

Presently working as a Assistant Professor in Civil Engineering field of Prof. Ram Meghe College of Engineering and Management, Amravati. He was Senior Design Engineer (Larsen & Toubro Limited, India).

## Mr. Zairi Ismael Rizman

Senior Lecturer, Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM) (Terengganu) Malaysia Master (Science) in Microelectronics (2005), Universiti Kebangsaan Malaysia (UKM), Malaysia. Bachelor (Hons.) and Diploma in Electrical Engineering (Communication) (2002), UiTM Shah Alam, Malaysia.

## Mr. Ronak

**Qualification:** M.Tech. in Mechanical Engineering (CAD/CAM), B.E.

Presently working as a Assistant Professor in Mechanical Engineering in ITM Vocational University, Vadodara. Mr. Ronak also worked as Design Engineer at Finstern Engineering Private Limited, Makarpura, Vadodara.

# Table of Contents

**Volume-11, Issue-12, December 2025**


| S. No | Title | Page No. |
|---|---|---|
| 1 | **Researching the satisfaction and needs of public transport users, Case study - Line 14, Bitola**<br>**Authors:** Nikola Krstanoski; Vaska Atanasova; Marija Stojanoska<br>**DOI:** https://dx.doi.org/10.5281/zenodo.18080332<br>**Digital Identification Number:** IJOER-DEC-2025-1 | 01-07 |
| 2 | **Urgent Installation of Micro Hydropower Plants in Unelectrified Villages and Territories of the Democratic Republic of Congo to Drive Industrialization**<br>**Authors:** MOKE NGAMEY Trésor<br>**DOI:** https://dx.doi.org/10.5281/zenodo.18080347<br>**Digital Identification Number:** IJOER-DEC-2025-2 | 08-11 |
| 3 | **Research on the Impact of Digital Economy Participation on the Financial Asset Allocation of the Elderly**<br>**Authors:** Zhong Xiu Luo<br>**DOI:** https://dx.doi.org/10.5281/zenodo.18080361<br>**Digital Identification Number:** IJOER-DEC-2025-3 | 12-27 |
| 4 | **Thermodynamic Equations of Nonequilibrium System for Measuring Odors by Gas Analyzers. Practical Example of a Microcontroller Calculation for Digital Odor Detection by Gas Analyzers**<br>**Authors:** Vlastopulo V.I<br>**DOI:** https://dx.doi.org/10.5281/zenodo.18086993<br>**Digital Identification Number:** IJOER-DEC-2025-6 | 28-32 |
| 5 | **Dietary Diversity and Anthropometric Shifts in School-Going Adolescents: A Pre-Post Intervention Study in Urban India**<br>**Authors:** Danika Manocha; Priya Singla<br>**DOI:** https://dx.doi.org/10.5281/zenodo.21261424<br>**Digital Identification Number:** IJOER-DEC-2025-8 | 33-40 |

# Researching the satisfaction and needs of public transport users, Case study - Line 14, Bitola

Nikola Krstanoski[1]; Vaska Atanasova[2]; Marija Stojanoska[3*]

[1,2]Ph.D., Faculty of Technical Sciences, University "St. Kliment Ohridski", Bitola, Macedonia
[*3]Ph.D candidate, Faculty of Technical Sciences, University "St. Kliment Ohridski", Bitola, Macedonia
*Corresponding Author

Received: 01 December 2025/ Revised: 08 December 2025/ Accepted: 13 December 2025/ Published: 31-12-2025
Copyright @ 2025 International Journal of Engineering Research and Science
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Mobility is an essential prerequisite for social and economic connectivity, especially for residents of rural environments who depend on public transport to access services in the city. Urban public transport plays a key role in ensuring equal mobility opportunities, allowing rural communities regular access to jobs, education, healthcare and shopping centers. This work analyzes the mobility and satisfaction of public transport users in Bitola, with special emphasis on line no. 14 connecting Scheherazade, Bistrica and Kravari with the city. Public transport in Bitola is operated by the Public Transportation Enterprise, which serves multiple urban and suburban lines providing basic connectivity between rural and urban areas. Line 14 is a significant transportation link for residents of the suburbs, especially those traveling for work, education, health services and shopping. Through a survey conducted among the users, key problems such as irregularity of buses, technical malfunction, insufficient informativity and poor road infrastructure were identified. Respondents suggested improvements such as vehicle modernization, increased frequency, timely arrival, real-time information, and infrastructure improvements. Research indicates that quality public transport is key to good mobility of rural residents and their integration with the city of Bitola.*

***Keywords— Mobility, Rural areas, Public transport, Survey.***

## I. INTRODUCTION

Public transport in Bitola is the main transport network connecting the urban and suburban areas to the city center. The system of public bus lines operated by private carriers allows mobility for a large part of the residents, without the need for their own vehicle. In Bitola there are several bus carriers, namely: Luka EXPRESS, Transkop AD, Gopesh TRANS, Boby TURS, Gem TURS [1].

To improve accessibility and practicality, in 2025 the Bitola City Bus application was introduced which allows checking the schedule, map of lines and real-time tracking of buses [2]. Among the main bus lines in the network is line number 14, which connects the suburbs/villages to the city center. Line 14 is crucial for residents of the periphery, as it provides access to services, jobs and education that are not available in their place of residence. According to the announced train schedules, this line is included as part of the municipal transport. Among the main bus lines in the network is line number 14 which connects the suburbs/villages with the city center. Line 14 is crucial for residents of the periphery, as it provides access to services, jobs and education that are not available in their place of residence. According to the announced train schedules, this line is included as part of the municipal transport [3].

The village of Kravari is in the municipality of Bitola, about 5-6 kilometers from the center of Bitola. The village of Kravari (Bitola municipality) according to the 2021 census has 819 inhabitants.

- Of these, 423 are men and 396 are women;
- Structure by age: 106 children (0 - 14), 556 adults (15 - 64) and 157 elderly people (65+) [4];
- Ethnically predominant Macedonians.

- For comparison, according to the 2002 census, Kravari had 880 inhabitants, showing a decrease in population over time.

The village of Kravari is located in the southwestern part of Bitola and is one of the larger suburban settlements in the municipality of Bitola. Its strategic position allows good connectivity with Bitola and surrounding villages. Through Kravari passes the local road Bitola - Kravari - Bistrica, which connects with the regional road to: Bistrica and the villages to Pelister, the eastern part of the municipality of Bitola, and on to the villages that lead to Demir Hisar through the mountain passes. This local road serves as a key junction for public transport (line 14) and for automobile traffic [5]. Figure 1 shows the location and distance of Kravari village from Bitola.

**FIGURE 1: The location and distance of Kravari village from Bitola**

## II. MATERIALS AND METHODS

For the purposes of this research, a quantitative method was applied by conducting a survey with the inhabitants of the village of Kravari, who use or need line 14 of the public urban transport in Bitola. The methodology was designed to obtain relevant and valid data on their daily movement, satisfaction with the service and the factors affecting their mobility. The main tool was a survey composed of closed and open questions, divided into several thematic groups:

- demographic data (age, education, occupation, number of family members),
- motor vehicles (whether they own a car),
- travel habits (how often they travel, for what purposes, by what means of transport),
- use and perception of line 14, level of satisfaction with public transport,
- identifying problems and proposing solutions.

This provided both numerical and descriptive data.

The target group were residents of Kravari. The survey was conducted with a random selection of respondents, providing a representative sample by gender and age, to obtain real data on travel habits.

The survey was carried out: on the ground, with direct face-to-face questioning, one-day, at multiple locations in the village (by households, around shops, bus stops, etc.). Such an approach allowed for greater openness and honesty of the respondents.

First, we collected data on the rural environment of Kravari, whether they have a public urban transport service, which line it crosses and in what time period.

Line 14 has 28 stations. It starts from Scheherazade, makes a full circle from Pedagogical Faculty, Hospital, City Park, goes first to the village of Bistrica, then to the village of Kravari where it stops at three stops and then returns back through the stop at the Railway Station, Karposh 4 to Bela Ceshma. The first public transport vehicle starts from the Scheherazade station at 6 a.m. and the last departure is at 7:30 p.m. The first vehicle in the rural area of Kravari, at the Kravari 1 stop is at 6:35 minutes, the same vehicle is at an interval of 1 hour, i.e. at the same stop will be at 7:35 minutes.

At the same Kravari 1 stop, the public transport vehicle stops at 6:35 and 7:35 minutes, then the next stop is at 11:35 to 15 hours. The vehicles are transported at 1 hour distance, at 15 hours does not appear at the stop, also at 18 and 19 hours. This analysis shows that the vehicles traffic with irregular frequency of movement, late or do not appear at all in the parking lot, which makes the public urban transport less attractive for the inhabitants of Kravari. Figure 2 shows the line of public urban transport No. 14, together with the stops [1].

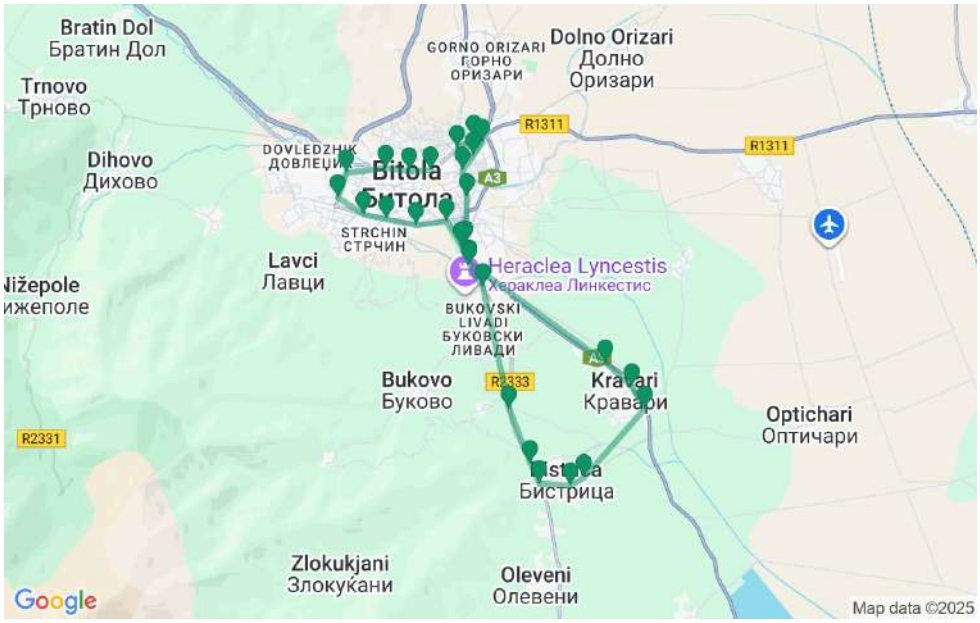



**FIGURE 2: The line of public urban transport No. 14, together with the stops**

## III. RESULTS AND DISCUSSION

In a survey conducted by households, in the rural environment of Kravari the following outputs were obtained:

- In the survey, most respondents were women, 53% and 47% men.
- Of those surveyed, 40% were aged between 36 and 65, 33% were over 65, 20% were aged between 18 and 36 and the rest were under 18.
- Most of the respondents were pensioners 40%, unemployed 27%, employed 23%.
- The respondents had a secondary education and that 56%, the percentage of basic and higher were the same.
- Most families have two or four members.
- When it comes to income, it usually ranges from 30.000,00 to 50.000,00 dinars, and above 50.000,00 denars.
- When asked how many family members are employed, most responded that they are not employed, and some one to two of the members, and the same travel outside of Kravari to get to the workplace.
- Most of the respondents don't take a motorized trip.
- The families of the respondents did not have students or students traveling, and that's 70%, and those who have the trip do it by public transport 23% and 7% by car.

- To travel to Bitola as a means of transport they use the car, and the trip is done with the motive of protecting, for a walk or for work. The motive for the journey is shown in Figure 3.

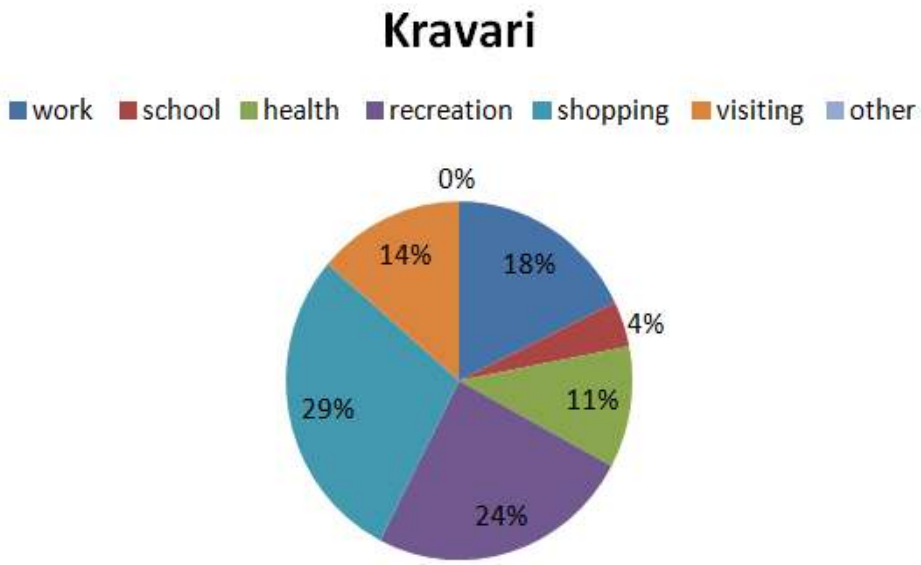



**FIGURE 3: The motive for the journey**

- Of the vehicles offered, most of the respondents own a car and most have one in the family.
- If there's an on-call car, would you use it? A huge percentage will use it, 77%. Maybe 13%, not 10%. This is shown in Figure 4.

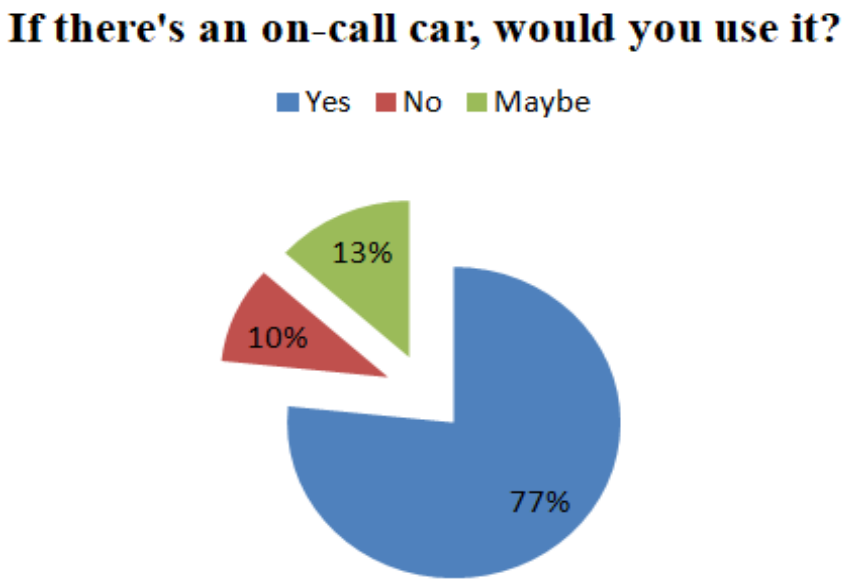



**FIGURE 4: If there's an on-call car, would you use it?**

- Usually, the trip to Bitola is done once at the bottom level.
- The quality of the street network is considered good.
- Although public transportation is available, respondents rarely or never use it.
- To improve living conditions, they believe there should be more jobs, more income.
- Table 1 shows tabularly what are the problems with the public urban transport in Kravari [7].

**TABLE 1**
**PROBLEMS FACE WITH RURAL TRANSPORT?**

| What problems do you face with rural transport? | |
|---|---|
| Kravari | • Non-regular city public transport<br>• Failure of vehicles<br>• Low frequency of vehicles<br>• Small number of lines |

- Table 2 shows in tabular form the proposals for improving services and mobility [8-9].

**TABLE 2**
**PROPOSALS FOR IMPROVING SERVICES AND MOBILITY**

| The proposals for improving services and mobility. | |
|---|---|
| Kravari | To have direct transport to Kravari, regular, to improve public transport, to increase the frequency, to educate the population to use public transport, to publish the driving schedule, to have a direct line not to pass through Bistrica, to have transport every 1h |

Figure 5 shows a proposed urban public transportation line, which will run from Scheherazade to Kravari and there will make a circular turn and return on the same route.

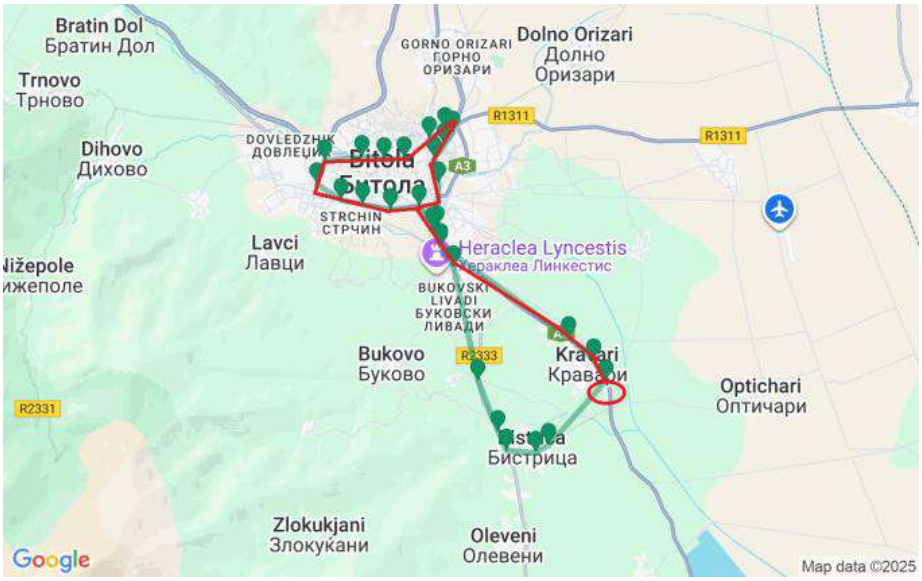



**FIGURE 5: Shows a proposed urban public transportation line**

## IV. CONCLUSION

Mobility is a key element in the development of any society, especially in rural environments where access to services, jobs and institutions directly depends on the quality of public transport [10]. Urban public transport, as a sustainable transport system, has the task of providing accessible, regular and economically beneficial movement of the population, thereby reducing dependence on automobiles and encouraging more even regional connectivity [6].

In that direction, the village of Kravari, as one of the larger rural settlements near Bitola, has a real need for functional public transport. Line No. 14, which runs on Scheherazade - Bistrica - Kravari, is the only public transportation option available to residents. To get a glimpse of the real situation, a survey was conducted with the aim of determining the travel habits, the level of satisfaction and the specific problems faced by the inhabitants of Kravari [12].

The results showed that although public transportation is available, a significant proportion of the population does not use it. The reasons for this are numerous: traffic irregularities, delays, frequent cancellations, and bus-free hours. Due to these shortcomings, residents often travel by their own car to Bitola, which reduces the role of public transportation as a sustainable

and affordable alternative. The survey also provided clear suggestions for improvement.

The most common requests are:

- the introduction of a direct service to Kravari,
- increased frequency and regularity of traffic (every 1 hour),
- improvement of the quality of public transport and renewal of the fleet,
- publication of a clear and accessible driving schedule,
- the possibility that the line does not pass through Bistritca,
- educating the public on the benefits of using public transport.

In summary, the research indicates that the residents of Kravari have a real need for modern, efficient and affordable public transport that will enable better mobility and greater functional connectivity with the city. The upgrading of Line 14 represents a key step towards a sustainable transport system that will contribute to a better quality of life in rural areas.

## V. RECOMMENDATION AND FUTURE SCOPE

Based on the research conducted and the survey results obtained, several measures can be proposed to improve the mobility and quality of public transport on line No. 14 and in the village of Kravari in general:

### 5.1 Improving bus regularity and frequency:

Establish a stable schedule with buses running every 1 hour, allowing for greater predictability and use of public transport as the primary transportation option.

### 5.2 Introducing a direct line to Kravari:

Many residents point out that routing through Bistrica prolongs travel time and creates unnecessary stops. The direct line Scheherazade -Kravari would increase the efficiency and attractiveness of public transport.

### 5.3 Renewal and modernization of the fleet:

To provide a quality service, it is necessary to use technically correct, economical and comfortable vehicles that offer safety and comfort to passengers.

### 5.4 Digital availability of the driving schedule:

Posting the timetable on a website, mobile app, social networks and putting up physical tables of the standings in the village. The availability of information is key to increasing trust and use of the service [11].

### 5.5 Monitoring and controlling the operation of the line:

The carrier should regularly monitor the line, carrying out checks for delays, cancelled deadlines and technical problems, in order to maintain continuity in the service.

### 5.6 Improvement of road infrastructure in Kravari:

Sanitation of the street network, and installation of appropriate signalling and lighting will increase safety, as well as the possibility for public transport to operate without interruptions.

### 5.7 Educating residents on the benefits of using public transport:

There is a need to raise awareness of the environmental, economic and traffic benefits of using public transport, thereby reducing congestion and pollution.

### 5.8 Introduction of additional carriers or alternative services:

If the existing carrier cannot provide sufficient frequency, the possibility of hiring other carriers or introducing minibus lines should be considered.

## ACKNOWLEDGEMENT

The authors would like to thank the students from the Department of Traffic and Transport of The Faculty of Technical Sciences – Bitola who were involved in conducting the field research - household survey in rural areas.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

[1] Cileva E, Talevski A. City bus routes and stops in Bitola: lines and bus stops. 2024.

[2] Municipality of Bitola. Bitola City Bus. 2025.

[3] Stojanoska M. Planning of public urban transport in small towns with the application of PTV VISION VISUM software. 2023.

[4] City Population. Bitola – Kravari population data. Available from: https://www.citypopulation.de/en/northmacedonia/pelagoniski/bitola/400858__kravari/

[5] Panov M. *Encyclopedia of villages in the Republic of Macedonia*. Skopje; 1998.

[6] Atanasova V, Stojanoska M. Sustainable transportation system: a case study. In: *Proceedings of the International Conference "Information Society and Sustainable Development (ISSD 2023)"*; 27–28 April 2023; Valletta, Malta.

[7] Atanasova V, Stojanoska M, Krstanoski N. Problems and proposed solutions for the planning of public transport in Bitola. In: *IX International Symposium "New Horizons 2023 of Transport and Communications"*; 24–25 November 2023; Doboj.

[8] Stojanoska M, Atanasova V. Practices from planning sustainable transport systems in urban environments. In: *XV Naučno-stručna konferencija sa međunarodnim učešćem "Klimatske promene i urbanizacija"*; 26 May 2023; Belgrade, Serbia.

[9] Stojanoska M, Atanasova V, Krstanoski N. How to better the quality of public city transport. In: *13th Congress on Transport and Transport Infrastructure – Roads*; 19–20 September 2024; Sarajevo.

[10] Stojanoska M, Atanasova V, Krstanoski N. Mobility analysis of the peripheral traffic zones of the city of Bitola. *Revista de Gestão Social e Ambiental (Environmental and Social Management Journal)*. 2024;18(8):e07232:1–21. doi:10.24857/rgsa.v18n8-147

[11] Stojanoska M, Atanasova V, Krstanoski N. Analysis of public transport information: example for the city of Bitola. *International Independent Scientific Journal*. 2024;68:32–36. ISSN 3547-2340.

[12] Stojanoska M, Atanasova V. Characteristics of the mobility of the inhabitants in rural areas. In: *XVII Naučno-stručna konferencija sa međunarodnim učešćem "Energetska efikasnost, životna sredina i održiv razvoj"*; 23 May 2025; Belgrade, Serbia.

# Urgent Installation of Micro Hydropower Plants in Unelectrified Villages and Territories of the Democratic Republic of Congo to Drive Industrialization

MOKE NGAMEY Trésor

Engineer Ao in Mechanical Energy Engineering; PhD candidate in Physics. Researcher and Lecturer, Higher Pedagogical Institute of Mbandaka

Received: 03 December 2025/ Revised: 11 December 2025/ Accepted: 17 December 2025/ Published: 31-12-2025
Copyright @ 2025 International Journal of Engineering Research and Science
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *The urgent deployment of micro hydropower (MHP) plants in the unelectrified villages and territories of the Democratic Republic of Congo (DRC) is a critical strategic intervention to stimulate sustainable industrialization. Despite the nation's immense hydropower potential, a profound energy deficit persists in rural areas, severely constraining socio-economic development. This article argues that localized electrification via micro plants provides a clean, stable, and adaptable energy solution tailored to rural communities. Employing a methodology that combines a literature review with field-based case analysis from 14 localities across five provinces, the study demonstrates that MHP deployment can significantly improve electricity access. The results indicate that this approach acts as a catalyst for job creation, fosters the development of local agro-industrial and artisanal activities, and directly reduces energy poverty. The discussion underscores that realizing this potential requires strong political commitment and the establishment of appropriate financing mechanisms. In conclusion, prioritizing these decentralized energy infrastructures is an essential lever for achieving sustainable and inclusive industrialization in the DRC.*

***Keywords— Micro hydropower plants; rural electrification; Democratic Republic of Congo; industrialization; renewable energy; rural development; energy poverty.***

## I. INTRODUCTION

Access to reliable energy remains a primary impediment to socio-economic development in the Democratic Republic of Congo, particularly in rural regions where electrification rates are critically low. This energy poverty not only hinders improvements in basic living standards but also severely limits the local processing of abundant natural resources and the emergence of productive industrial activities. Paradoxically, the DRC possesses exceptional hydrographic potential, with numerous streams and rivers in landlocked territories offering ideal characteristics for micro hydropower generation. These lightweight, relatively low-cost, and context-appropriate infrastructures represent a major opportunity to support decentralized industrialization, stimulate job creation, and enhance community energy autonomy.

Given the scale of the energy challenge and the growing demand for electricity to power local production, the strategic installation of micro plants presents a viable solution for accelerating integrated rural development. Their capacity to deliver stable, renewable, and locally manageable energy makes them a crucial tool for territorial modernization. However, successfully implementing this alternative requires a thorough analysis of the available potential, the attendant challenges, the anticipated socio-economic impacts, and the enabling conditions needed for success. Consequently, this study aims to highlight the urgency and relevance of promoting MHP installations in the DRC, proposing context-specific solutions and recommendations to guide policymakers and practitioners.

## II. MATERIALS AND METHODOLOGY

This study employs a mixed-methods approach, combining the analysis of secondary data from existing energy reports and hydrological studies with primary data gathered through field observations and interviews conducted across 14 localities in five provinces of the DRC.

The methodological framework is designed to address the multifaceted nature of MHP project implementation, ensuring environmental and social sustainability while aiming for economic viability. This framework encompasses several critical phases:

First, a **resource assessment** is conducted to evaluate the hydraulic energy potential of a site, determining key parameters such as flow rate and head to correctly size the plant. This is accompanied by **environmental and social impact studies** to minimize negative consequences on local ecosystems and communities. The **technical design** phase involves the hydraulic engineering of structures (dams, intakes, canals) suited to the local topography and flow characteristics, and the selection of appropriate electromechanical equipment, such as turbines (typically in the 21 to 500 kW range for micro power), generators, and electrical systems.

Subsequently, **construction planning** integrates consultation with local stakeholders and the design of compensatory measures for affected populations. Following commissioning, which includes the installation and testing of all equipment, a core focus is placed on **capacity building**. This involves training local community members in the operation, basic maintenance, and management of the plant to ensure its long-term sustainability. Parallel to this, a comprehensive **economic and financial analysis** is performed to evaluate project costs—which field data indicates range from $2,000 to $4,800 USD per kW—and ensure long-term viability. Finally, **regulatory coordination** with relevant authorities is maintained throughout to secure all necessary administrative authorizations.

## III. RESULTS

The analysis of primary and secondary data yields several key findings that underscore both the potential and the current reality of rural electrification in the DRC:

### 3.1 Underutilized Hydropower Potential:

The assessment reveals a significant and largely untapped local hydropower resource. In the surveyed areas, over 60% of identified hydraulic sites possess an annual flow compatible with micro plant installations (10–500 kW). Direct measurements from seven rivers showed consistent flows ranging from 1.2 to 12.5 $m^3/s$, confirming their technical suitability for low- and medium-head turbine technology.

### 3.2 Profound Rural Energy Deficit:

The study documents a severe structural energy deficit. In 12 of the localities studied, actual access to electricity was below 8%, despite the presence of permanent watercourses capable of power generation. This deficit forces households to rely almost exclusively on traditional biomass (fuelwood at 87% and charcoal at 9%), a dependency that accelerates deforestation and environmental degradation.

### 3.3 Positive Socio-Economic Impacts of Existing MHP Projects:

Case studies of operational micro plants in communities such as Idjwi, Minova, Luvungi, and Lubero demonstrate transformative effects. The primary impact has been a 35% to 70% increase in local agro-industrial production, including the processing of flour, coffee, palm oil, and dairy products. Reliable electricity has also spurred the creation of energy-intensive micro-enterprises in welding, carpentry, brick-making, and refrigeration, generating substantial new employment. Furthermore, social services have improved markedly; for instance, health centers reported a 50% reduction in cold-chain breaks for vaccines, and students benefited from an average increase of two hours of study time per day with electric lighting.

### 3.4 Project Viability and Performance:

The investigated MHP projects demonstrated encouraging economic and operational metrics. The installation costs were observed to be between $2,000 and $4,800 per kW, with an estimated return on investment period of 3 to 5 years, varying by the management model (cooperative, public-private partnership, or private entrepreneur). Notably, these plants maintained an average operational availability rate of 92%, indicating a reliable and stable energy supply.

## IV. DISCUSSION

### 4.1 MHP as a Catalyst for Rural Industrialization:

The results confirm that micro-hydropower is a potent enabler of small- and medium-scale industrialization in rural territories. By providing continuous, low-carbon, and locally managed power—a stark contrast to expensive and intermittent diesel

generators—MHP fosters energy autonomy. This reliable electricity supply acts as a direct catalyst for adding value to local production, particularly in agricultural processing, which constitutes over 60% of rural economic activity.

### 4.2 Technological and Contextual Suitability:

Micro plants are uniquely suited to the geographical and infrastructural realities of the DRC. Their relatively lightweight components facilitate transport to remote, landlocked areas, and their low ecological footprint (avoiding the large reservoirs of mega-dams) minimizes environmental impact. This makes them a more sustainable and scalable solution compared to isolated solar home systems, which are often insufficient for powering continuous industrial loads.

### 4.3 Persistent Structural Bottlenecks:

Despite the confirmed technical and economic potential, significant barriers persist. These include security instability in eastern regions, which deters investment; the absence of a specific national policy and regulatory framework for mini-grids and micro-power, stalling public-private partnerships; limited access to financing for crucial preliminary studies; and a shortage of local technical expertise in hydropower engineering. These obstacles highlight that a successful energy transition depends not only on natural resources but also on concurrent institutional strengthening and human capacity development.

### 4.4 Strategic Opportunities for Alignment:

Significant opportunities exist to overcome these challenges. MHP development directly supports multiple Sustainable Development Goals (SDGs 7, 8, 9, and 13). There is growing interest from international donors and development agencies (e.g., African Development Bank, European Union, UNIDO) in decentralized renewable energy. Furthermore, MHP can serve as the anchor for creating integrated rural industrial clusters and contribute to the socio-economic stabilization of fragile regions.

## V. RECOMMENDATIONS AND PHASED SOLUTIONS

To harness the potential of MHP for rural industrialization, a coordinated, multi-stakeholder approach is required.

### 5.1 Policy and Institutional Reforms:

It is imperative to develop and implement a specific regulatory framework for small-scale hydropower to de-risk and incentivize private, community, and public investment. Energy planning centered on MHP must be harmonized with local and regional development programs. Furthermore, the government should actively facilitate public-private partnerships (PPPs) to share investment risks in challenging rural markets.

### 5.2 Technical and Capacity-Building Measures:

A national protocol for standardizing hydrological assessments should be established. Technology transfer and adaptation programs should promote resilient, easy-to-maintain equipment suited to the Congolese context. Creating regional technical maintenance units and developing local training programs are essential to ensure the long-term operational sustainability of installations.

### 5.3 Integrated Socio-Economic and Ecological Planning:

Support should be provided to develop robust local energy management entities, such as cooperatives. Financing and business development services must be channeled to help establish agro-processing and artisanal units that utilize the new electricity supply. All projects must prioritize low-impact civil works and be subject to streamlined yet rigorous environmental impact assessments to protect aquatic and riparian ecosystems.

### 5.4 Phased Implementation Roadmap:

- **Short Term (0-3 years):** Focus on rapid identification of priority sites, implementation of pilot projects to validate models, securing targeted financing for equipment, and training local technicians for daily operations.

- **Medium Term (3-7 years):** Scale up to develop formal rural mini-grids, promote the creation of dedicated agro-processing hubs, establish sustainable financial instruments (e.g., micro-credit, results-based subsidies), and strengthen community governance structures for energy systems.
- **Long Term (7-15 years):** Plan for the strategic interconnection of mature mini-grids with the national grid, foster a local manufacturing industry for hydropower components, establish a national center of excellence for small hydropower research and training, and fully integrate MHP into the national industrial development strategy.

## VI. CONCLUSION

Micro hydropower plants represent a reliable, economically viable, and socially transformative energy solution for the rural DRC. The evidence presented demonstrates that their strategic development is an urgent priority to stimulate local industrialization, secure essential social services, reduce destructive energy dependency, create durable jobs, and strengthen overall community resilience. Given the country's exceptional hydrographic endowment, a concerted national policy to accelerate small hydropower—buttressed by innovative financing and dedicated local capacity building—has the potential to fundamentally transform the rural economic landscape. The path to inclusive and decentralized industrialization in the Democratic Republic of Congo is inextricably linked to this decentralized energy transition.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

***Books***

[1] Lundula, F. T. (n.d.). *Energy and environmental protection* (3rd ed.).

[2] Ministry of Hydraulic Resources and Electricity. (n.d.). *Manual for the assembly of micro hydropower plants*.

[3] United Nations Development Programme (UNDP). (2026). *Atlas of renewable energies*. UNDP.

[4] Ngamey Trésor, M. (2024). *Lecture notes: Fluid mechanics*. ISP–Mbandaka.

*Articles / Reports*

[5] Bompuluka, J. (2007). *Project to install a permanent electrical network in the physics and biochemistry laboratories of ISP/Mbandaka* (Final project). ISP/Mbandaka.

[6] Saimeka, M. (n.d.). *Interview with the head of studies in electricity, renewable and new energy*. National Energy Commission, Équateur Province.

***Dictionary***

[7] Rey-Debove, J., & Rey, A. (Eds.). (2018). *Le Petit Robert* (1st ed.). Le Robert.

***Internet Sites / Conference & Technical Reports***

[8] Bonduelle, B., & Rivoire, B. (1987). *Experimental Thermis plant: Results and projections*.

[9] Pharabod, F., & Philibert, C. (1991). *Luz solar plants*. Action Committee for the Sun.

[10] Neinecke, W., Bohn, M., & National Renewable Energy Laboratory. (1994). *Solar energy concentrating systems: Applications and technologies*. DLR (Germany); NREL (USA).

[11] Solar PACES. (1998). *Proceedings of the 9th Solar PACES International Symposium*. Font-Romeu, France.

[12] WP Tea Gam. (2001). *Review: Status of markets for solar thermal power systems*.

[13] Schuar, P., Zbozl, R., Buck, R., Sugarmen, A., Marcos Crespo, M., Altwegg, P., & Enrile, J. (2007, October 6–8). *Solar gas turbine systems*. Paper presented at the Solar PACES International Symposium, Oaxaca, Mexico.

# Research on the Impact of Digital Economy Participation on the Financial Asset Allocation of the Elderly

Zhong Xiu Luo

Big Data and Statistics School, Guizhou University of Finance and Economics

Received: 04 December 2025/ Revised: 11 December 2025/ Accepted: 18 December 2025/ Published: 31-12-2025
Copyright @ 2025 International Journal of Engineering Research and Science
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract*—** *Against the backdrop of a deepening aging population in China, the elderly face significant challenges in terms of old-age security. The development of the digital economy presents new opportunities for optimizing their financial asset allocation; however, technological barriers and insufficient financial literacy remain major obstacles. Based on data from the 2019 China Household Finance Survey (CHFS), this paper systematically analyzes the impact of household digital economy participation on the financial asset allocation of the elderly. The empirical results indicate that the digital economy can significantly optimize the asset allocation structure of the elderly by enhancing financial literacy, increasing attention to financial information, and strengthening risk tolerance. This effect is more pronounced in urban households and business-owning households. Based on these findings, this paper proposes improving age-friendly digital infrastructure and financial education systems, as well as optimizing information services and product supply mechanisms, to effectively translate the benefits of the digital economy into tangible improvements in the well-being of the elderly.*

***Keywords*— Digital Economy; Elderly Population; Financial Asset Allocation.**

## I. INTRODUCTION

With the increasing aging of China's population, the elderly population faces growing retirement risks. The issue of wealth management for the elderly has become increasingly prominent, and how to rationally allocate financial assets to ensure the quality of life in old age has become an urgent social problem. Simultaneously, the elderly population generally faces significant challenges in financial asset allocation: on the one hand, deepening societal aging increases pension pressures, with insufficient pensions and rising medical costs making their financial management needs more urgent; on the other hand, limitations such as single income sources, insufficient financial knowledge, and narrow investment channels make it difficult for them to make rational investment decisions. Although financial markets offer opportunities for wealth appreciation, most households, especially the elderly, remain under-participants. In recent years, the rapid rise of the digital economy has profoundly changed the forms and content of financial services. The proliferation of technologies like internet finance, mobile payment, big data, and artificial intelligence has broken the spatiotemporal constraints of traditional financial services, providing new financial service platforms for the elderly. These emerging technologies make financial asset allocation more convenient and diverse, particularly as internet finance offers the elderly more direct, low-cost investment channels and wealth management tools. However, many elderly still face technological barriers and knowledge gaps in applying digital technologies and allocating financial assets, placing them at a disadvantage within the digital economy and preventing them from fully leveraging these technological advantages to optimize household financial asset allocation. Against the backdrop of an increasingly aging population, how to use the digital economy to promote optimized financial asset allocation and enhance the welfare of the elderly has become a pressing practical issue. Therefore, this paper focuses on analyzing the impact of household digital economy participation on the financial asset allocation of the elderly, explores its specific mechanisms, and proposes corresponding policy recommendations considering the challenges faced by the elderly. Based on the above analysis, this paper utilizes data from the 2019 national micro-household survey conducted by the China Household Finance Survey (CHFS) at Southwestern University of Finance and Economics to explore the impact of household digital economy participation on the financial asset allocation of the elderly. The

study finds that digital economy participation significantly optimizes the financial asset allocation of the elderly. Mechanism analysis shows that digital economy participation primarily optimizes elderly financial asset allocation by enhancing attention to financial information, improving financial literacy, and increasing risk tolerance. Heterogeneity analysis results indicate that the optimizing effect of digital economy participation on household financial asset allocation is more pronounced in urban households and households engaged in business or industry. Further research finds that optimized financial asset allocation enhances the welfare level of the elderly. The marginal contributions of this paper are as follows: First, it examines the specific impact of household digital economy participation on the financial asset allocation of the elderly from a micro perspective. Existing literature on the impact of the digital economy on financial asset allocation mostly focuses on prefecture-level city digital economy indices. Second, it enriches the research framework on the digital economy and household financial asset allocation. By focusing on the unique needs of the elderly in the digital economy environment, this paper provides targeted suggestions for policymakers aimed at promoting financial inclusion for the elderly and enhancing the effectiveness of their asset allocation. This offers a new perspective for research on the digital economy and household financial asset allocation. Third, it explores the impact of financial asset allocation on the welfare level of the elderly. By analyzing the effect of digital economy participation on the financial asset allocation of the elderly, this paper further examines how optimized asset allocation enhances their welfare level.

## II. LITERATURE REVIEW AND THEORETICAL ANALYSIS

### 2.1 Literature Review:

The rapid development of the digital economy has become an important force driving economic transformation. With the widespread application of big data, cloud computing, artificial intelligence, and mobile internet technologies, the digital economy has penetrated deeply into various industries. Particularly in the financial sector, the digital economy provides strong support for the innovation and popularization of financial services (Wu Yu et al., 2021). The digital economy not only improves the efficiency of financial services but also reduces transaction costs in the traditional financial system through innovative business models, enhancing the accessibility and convenience of financial services (Zhang Lingshuang et al., 2023).Financial asset allocation is a core issue in household financial decision-making, involving the rational distribution of household assets across different financial products to achieve an optimal balance between risk and return. When allocating financial assets, households are influenced not only by wealth level and income sources but also closely related to financial knowledge and literacy (He Zongyue et al., 2020). For instance, households with higher financial literacy are typically able to make more rational choices among various investment products (Zhou Guangsu and Liang Qi, 2018). Furthermore, factors such as financial market accessibility, information asymmetry, and household risk attitude also significantly impact the efficiency and effectiveness of asset allocation (Wei Xianhua et al., 2014). With the continuous development of fintech and digital finance, household asset allocation strategies have become more flexible and diverse, a trend particularly evident among highly educated and high-income households (Wang Xiaohua et al., 2023). The impact of the digital economy on household financial asset allocation is gradually increasing. The application of digital technology not only enhances households' ability to access financial product information but also reduces the time and transaction costs associated with financial decisions, thereby improving the efficiency of household investment decisions (Wu Yu et al., 2021). Especially driven by digital inclusive finance and fintech, households can not only easily access various financial products but also configure them personally according to their needs, optimizing their risky asset portfolios (Zhang Xun et al., 2020). The widespread application of the digital economy has improved the accessibility of household financial services. Particularly with the promotion of fintech, financial participation among low-income households and in rural areas has significantly increased (Peng Yanling et al., 2022). However, some studies also point out that the digital divide and information asymmetry may negatively affect the elderly population, as their participation in the digital economy is relatively low, potentially limiting the effectiveness of their financial asset allocation (Zhu Wenpei and Lin Yi, 2024).Existing research primarily focuses on the impact of the digital economy on financial asset allocation at the prefecture-level city level, with few studies exploring the specific effect of household digital economy participation on the financial asset allocation of the elderly from a micro, household perspective. Especially considering the unique needs of the elderly in the digital economy environment, relevant literature is relatively scarce, lacking in-depth analysis of the effectiveness of their financial asset allocation and the improvement of their welfare levels. Therefore, this paper will explore the relationship between household digital economy participation and the financial asset allocation of the elderly from three aspects: the overall impact, the

mechanisms of impact, and heterogeneous effects, and further analyze the impact of financial asset allocation on the welfare of the elderly.

### 2.2 Theoretical Analysis and Research Hypotheses:

With the rapid development of the digital economy, the model of financial services has undergone significant changes, especially for household financial asset allocation, as the digital economy provides more flexible and diverse options. For the elderly, digital technology not only offers more opportunities to participate in financial markets but also promotes the transformation of their financial behaviors. However, how the digital economy affects the financial asset allocation of the elderly remains a question worthy of in-depth study. This research will focus on factors such as financial literacy, attention to information, and risk preference, and propose the following research hypotheses based on existing literature and theoretical frameworks. The rapid development of the digital economy has broken down the information barriers in traditional financial markets, making it easier for households, especially the elderly, to access information about financial products. According to information asymmetry theory, market participants usually face problems of asymmetric information acquisition, leading to decision-making biases and risks. However, with the popularity of digital platforms, the elderly can obtain detailed information about various financial products, market dynamics, and related investment analyses through the internet, thereby enhancing their market cognition and trust and optimizing their asset allocation decisions. Participation in the digital economy helps alleviate information asymmetry problems, lowers the threshold for information acquisition, and enables the elderly to make more rational and diversified asset allocation decisions based on more transparent and comprehensive market information (Zhang Lingshuang et al., 2023). Accordingly, the first hypothesis is proposed:

H1: Participation in the digital economy can optimize the financial asset allocation of the elderly. Information processing theory emphasizes that the quality of an individual's decisions is directly affected by the availability of information and their ability to process it. In the traditional financial system, the elderly often face difficulties in accessing information and have limited information channels. In the context of the digital economy, the volume of information has exploded. The elderly can easily access information about various financial products through digital platforms, including yield rates, risk analysis, and market trends. The increased availability and transparency of this information enable the elderly to understand the advantages and disadvantages of different financial products more comprehensively (Chen Nanxu et al., 2024). Therefore, the digital economy, by increasing the elderly's attention to financial information and enhancing their information processing capacity, prompts them to make more rational and scientific decisions in asset allocation. Furthermore, digital platforms can push personalized financial information and wealth management products based on the interests and needs of the elderly, further stimulating their interest and participation in financial markets, thereby optimizing their financial asset allocation (Zhou Li et al., 2024). Based on this, the second hypothesis is proposed:

H2: The digital economy optimizes the financial asset allocation of the elderly by enhancing their attention to financial information. Financial literacy theory holds that an individual's level of financial knowledge plays a crucial role in their investment decisions. Individuals with higher financial literacy are usually better able to understand the relationship between risk and return, and identify and avoid potential risks in investments. However, the elderly are generally relatively weak in financial literacy and lack systematic financial knowledge, making their asset allocation decisions susceptible to emotions or market noise, leading to decision-making errors. The rapid development of the digital economy, especially the popularization of online courses, videos, e-books, and investment tools, provides the elderly with more convenient ways to acquire financial knowledge. The elderly can learn about finance and improve their financial literacy at home or anywhere, effectively optimizing their asset allocation behavior, enabling them to make more rational and scientific decisions when facing complex financial markets (Yin Zhichao et al., 2015). The improvement in financial literacy allows the elderly to better understand the workings of financial markets, the risk characteristics of financial products, and financial strategies, thereby enhancing their judgment and decision-making ability in asset allocation (Wang Yake et al., 2024). Accordingly, the third hypothesis is proposed:

H3: The digital economy optimizes the financial asset allocation of the elderly by enhancing their financial literacy. According to risk preference theory, an individual's risk tolerance plays a vital role in their financial decisions. Especially when facing complex financial markets, individuals or households with higher risk preference tend to choose more diverse investment products and are willing to bear higher risks to achieve higher returns. In the context of the digital economy, if the elderly have

a higher risk preference, they may be more willing to participate in investments through digital platforms, particularly in higher-risk financial products such as stocks, funds, or other derivatives (Li Tao and Guo Jie, 2009). Digital platforms, by offering a rich selection of financial products and real-time market information, make it easier for the elderly to assess investment risks and make decisions. Therefore, this study proposes the fourth hypothesis:

H4: Risk preference plays a positive moderating role in the impact of the digital economy on the financial asset allocation of the elderly.

## III. RESEARCH DESIGN

### 3.1 Data Description:

This study utilizes data from the 2019 China Household Finance Survey (CHFS). This annual survey covers 29 provinces (autonomous regions, and municipalities) in China, comprising detailed information from over 40,000 households, including basic demographic characteristics and asset allocation. Based on the research objectives, this paper focuses on the financial asset allocation behavior of elderly households. Therefore, the sample is restricted to households where the head of the household is aged 60 or above. After screening, a final valid sample of 9,408 households is obtained (2). Model Specification and Variable Design to test Hypothesis 1, that household digital economy participation can optimize the financial asset allocation of elderly households, and to eliminate regional differences between cities, a fixed effects model is used to estimate the impact of household digital economy participation on the financial asset allocation of the elderly. The baseline model is defined as follows:

$$Pensionfinance_i = \alpha_0 + \alpha_1 Dig_i + \alpha_2 X_i + \mu_i + \varepsilon_i \quad (1)$$

In Equation (1), Finance_i represents financial asset allocation,$Dig_i$represents household digital economy participation,$X_i$ is a vector of control variables, i denotes the household, c represents city fixed effects, and $\varepsilon_i$is the random error term.1. Dependent Variable: Financial Asset Allocation Following the approaches of Zhu Wenpei and Lin Yi (2022), Wang Xiaohua et al. (2023), and others, financial asset allocation is measured from the following three aspects:(1)Variety of Financial Assets: The CHFS questionnaire covers eight types of financial assets: deposits, stocks, funds, wealth management products, bonds, non-RMB assets, precious metals, and financial derivatives. For each type of financial asset, a value of 1 is assigned if the household holds that asset, otherwise 0. These values are then summed to obtain the total number of different types of financial assets held by the household (2). Scale of Financial Assets:This is represented by the natural logarithm of the total value of financial assets held by the household. Although financial asset scale strictly speaking does not fall within the scope of asset allocation, it reflects the overall level of household wealth and has a significant impact on the financial stability and consumption capacity of elderly households. In the context of the digital economy, an increase in the scale of financial assets provides the elderly with more investment opportunities and income sources, thereby indirectly influencing their asset allocation decisions. Thus, this indicator is included in the measurement of financial asset allocation in this paper (3). Diversification of Financial Assets: The degree of pension financial asset diversification is calculated using the asset diversification formula proposed by Shin et al. (2017): Diversification = , where's_j represents the proportion of the j-th financial asset in the total financial assets.

### 3.2 Core Explanatory Variable: Digital Economy Participation:

This study focuses on the micro-household level, examining the extent of household participation in the digital economy from the perspective of household actors, and constructs a household-level digital economy participation index. Drawing on the research approach of Zhao Tao et al. (2020), this paper selects five specific indicators for measurement: (1) Credit card usage, assigned a value of 0 or 1 based on whether the household uses credit cards; (2) Online shopping expenditure, measured as the logarithm of the total household online shopping expenditure in the previous year; (3) Communication expenses, represented by the logarithm of the household's annual communication expenditure; (4) Whether household members are employed in digital economy-related industries, with industry matching based on the Statistical Classification of the Digital Economy and Its Core Industries (2021)and assigned a value of 0 or 1; (5) Smartphone usage, assigned a value of 0 or 1 based on whether household members use smartphones. The specific composition of each indicator is shown in Table 1. On this basis, this paper employs factor analysis to synthesize the above indicators into a comprehensive index, aiming to reduce redundancy among the indicators and more comprehensively and accurately reflect the overall level of household participation in the digital economy.

**TABLE 1**
**CONSTRUCTION OF THE DIGITAL ECONOMY INDICATOR SYSTEM**

| Primary Indicator | Secondary Indicator | Variable Description |
|---|---|---|
| Digital Economy Participation | Credit Card Usage | No = 0, Yes = 1 |
| | Online Shopping Expenditure | Logarithm of last year's online shopping expenditure |
| | Communication Expenses | Logarithm of last year's communication expenses |
| | Employment in Digital Economy Industries | No household member employed in digital economy industries = 0, Yes = 1 |
| | Smartphone Usage | Does not use smartphone = 0, Uses smartphone = 1 |

### 3.3 Control Variables:

To exclude other potential factors influencing financial asset allocation and improve the accuracy and reliability of the model estimation, this paper includes the following control variables: Household head characteristics include gender, age, education level, marital status, and health status. Household-level control variables include household registration type (hukou), household size, annual household income, and social insurance. By incorporating household head characteristics and household-level control variables, potential interference from individual and family background on financial asset allocation can be effectively controlled, thereby more accurately identifying the independent impact of digital economy participation on financial asset allocation. Variable definitions are shown in Table 2. Descriptive statistics are presented in Table 3.

**TABLE 2**
**VARIABLE DEFINITIONS**

| Variable Type | Variable Name | Variable Description |
|---|---|---|
| Explained Variables | Types of Financial Assets | Number of types among the following financial assets held: deposits, stocks, funds, financial wealth management products, bonds, financial derivatives, non-RMB assets, internet wealth management products, precious metals (one or more) |
| | Scale of Financial Assets | Logarithm of the total value of household financial assets held |
| | Financial Asset Diversification | Degree of financial asset diversification calculated according to Equation (1) |
| Explanatory Variable | Digital Economy Participation | Measured by factor analysis |
| Control Variables | Age | Age in years |
| | Marital Status | Unmarried = 0, Married = 1 |
| | Gender | Male = 1, Female = 0 |
| | Education Level | No schooling = 1, Primary school = 2, Junior high school = 3, Senior high school = 4, Vocational/technical high school = 5, College/associate degree = 6, Bachelor's degree = 7, Master's degree = 7, Doctoral degree = 8 |
| | Health Status | Very poor - Very good (1-5) |
| | Household Registration Type (Hukou) | Rural = 1, Urban = 0 |
| | Household Size | Total number of household members |
| | Annual Household Income | Logarithm of annual household income |
| | Social Insurance | Has social insurance = 1, Does not have = 0 |

**TABLE 3**
**DESCRIPTIVE STATISTICS**

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Types of Financial Assets | 9408 | 1.266 | 0.886 | 0 | 7 |
| Scale of Financial Assets | 9408 | 11.839 | 2.831 | 0 | 16.695 |
| Financial Asset Diversification | 9408 | 0.725 | 0.425 | 0 | 1 |
| Digital Economy Participation | 9408 | 0.318 | 0.187 | 0 | 1 |
| Average Digital Economy Participation in Same Community | 9408 | 0.318 | 0.101 | 0 | 1 |
| Age | 9408 | 68.386 | 6.553 | 60 | 95 |
| Marital Status | 9408 | 0.807 | 0.395 | 0 | 1 |
| Gender | 9408 | 0.727 | 0.446 | 0 | 1 |
| Education Level | 9408 | 3.004 | 1.442 | 1 | 9 |
| Health Status | 9408 | 3.085 | 0.992 | 1 | 5 |
| Household Registration Type (Hukou) | 9408 | 0.345 | 0.475 | 0 | 1 |
| Household Size | 9408 | 2.487 | 1.392 | 1 | 15 |
| Annual Household Income | 9408 | 10.312 | 1.35 | 0.693 | 14.509 |
| Social Insurance | 9408 | 0.632 | 0.482 | 0 | 1 |
| Risk Preference | 9408 | 1.409 | 0.857 | 1 | 5 |
| Financial Information Attention | 9408 | 1.761 | 1.039 | 1 | 5 |
| Financial Literacy | 9408 | 0 | 1 | -0.519 | 5.306 |
| Engaged in Industry/Commerce | 9408 | 0.045 | 0.208 | 0 | 1 |
| City Classification | 9408 | 2.171 | 0.898 | 1 | 3 |

### 3.4 Instrumental Variable:

Although the model controls for city fixed effects to avoid omitted variable issues at the city level, the factors influencing the financial asset allocation decisions of the elderly are complex and difficult to fully control for in the model. There may be other unobservable factors that simultaneously affect digital economy participation and financial asset allocation, i.e., an omitted variable problem. Furthermore, this study may also face a bidirectional causality issue, which refers to the possibility that households with higher levels of financial asset allocation may participate more actively in digital economic activities. To address these two endogeneity problems, and referencing the approaches of Zhu Jingjing (2024) and Wang Chen et al. (2025), the average level of digital economy participation of other households in the same community is used as an instrumental variable. On one hand, this community environmental characteristic is correlated with the individual household's participation level; on the other hand, it is independent of the specific household's financial asset allocation decisions, satisfying the relevance and exogeneity requirements of an instrumental variable.

## IV. EMPIRICAL RESULTS AND ANALYSIS

### 4.1 Benchmark Regression Results and Analysis:

To test the robustness of the research findings, this paper employs a stepwise regression method to examine the relationship between household digital economy participation and the financial asset allocation of the elderly. The benchmark regression results (Table 4) show that household digital economy participation has a significant positive impact on the financial asset allocation of the elderly. After including all control variables and controlling for city fixed effects, the regression coefficients for digital economy participation on the types, scale, and diversification of financial assets are 1.132, 1.642, and 0.209, respectively, all significant at the 1% level. This indicates that household participation in the digital economy helps increase the diversity and scale of financial asset allocation among the elderly and optimizes their asset structure, supporting Hypothesis 1. Regarding control variables, the coefficient for the household head's education level is significantly positive, suggesting that households with higher educational attainment possess stronger information identification and processing capabilities, which helps improve the efficiency of financial asset allocation. The health status of family members also has a positive impact on financial asset allocation. Furthermore, higher household income levels are associated with more optimized financial asset

allocation, reflecting that higher-income households exhibit greater diversification in their asset portfolios. This result is consistent with the findings of Chen Binkai and Li Tao (2011).

**TABLE 4**
**BENCHMARK REGRESSION OF DIGITAL ECONOMY AND HOUSEHOLD FINANCIAL ASSET ALLOCATION**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification |
|---|---|---|---|
| | -1 | -2 | -3 |
| Digital Economy Participation | 1.342*** | 1.132*** | 3.584*** |
| | -0.048 | -0.057 | -0.149 |
| Age | | 0.005*** | |
| | | -0.001 | |
| Gender | | -0.040* | |
| | | -0.021 | |
| Education Level | | 0.081*** | |
| | | -0.007 | |
| Marital Status | | 0.109*** | |
| | | -0.024 | |
| Health Status | | 0.048*** | |
| | | -0.008 | |
| Household Registration Type (Hukou) | | 0.017 | |
| | | -0.024 | |
| Household Size | | -0.042*** | |
| | | -0.007 | |
| Annual Household Income | | 0.061*** | |
| | | -0.008 | |
| Social Insurance | | -0.025 | |
| | | -0.022 | |
| Observations | 9408 | 9408 | 9408 |
| City Fixed Effects | Yes | Yes | Yes |

### 4.2 Robustness Tests:

Following the benchmark regression analysis, to ensure the robustness and reliability of the results, this paper conducts a series of robustness tests, including replacing the measurement method of the explanatory variable, excluding extreme values, and changing the econometric model. These methods aim to verify the consistency of the regression results under different data processing and model specifications. Through these tests, the interference of outliers can be eliminated, ensuring the stability of conclusions under various circumstances and enhancing the reliability of the results. 1. Replacing the Measurement Method of the Explanatory Variable To examine whether the benchmark regression results are affected by the variable measurement method, this paper further reconstructs the household digital economy participation index using the entropy method for robustness testing. The regression results in Table 5 show that after replacing the measurement method of the core explanatory variable, household digital economy participation still has a significant positive impact on the types, scale, and diversification of financial assets at the 1% significance level. This is consistent with the benchmark regression conclusions, indicating that the research findings of this paper are robust.

**TABLE 5**
**REPLACING THE MEASUREMENT METHOD OF THE EXPLANATORY VARIABLE**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification |
|---|---|---|---|
| Digital Economy Participation | 0.052*** | 0.081*** | 0.011*** |
| | -0.003 | -0.01 | -0.002 |
| Control Variables | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 |

### 4.3 Changing the Econometric Model:

To ensure the reliability of the conclusions, this paper replaces the OLS model with the Double Machine Learning (DML) model to test the robustness of the benchmark regression results. Compared with traditional regression methods, the DML model can effectively control biases caused by confounding variables and improve the accuracy and robustness of causal inference in scenarios with high-dimensional covariates or potential nonlinear relationships. Particularly when dealing with issues including multidimensional control variables, complex interaction terms, and uncertainty in variable selection, DML offers greater flexibility and estimation consistency. Therefore, selecting this method as a robustness test tool can more fully identify the actual impact of digital economy participation on the financial asset allocation of the elderly. The regression results (see Table 6) show that after changing the econometric model, the core coefficients remain significant and positive, further verifying the robustness of the conclusions in this paper.

**TABLE 6**
**CHANGING THE ECONOMETRIC MODEL**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification |
|---|---|---|---|
| Digital Economy Participation | 0.178*** | 0.260*** | 0.031*** |
| | -0.013 | -0.033 | -0.006 |
| Machine Learning Model | Random Forest | Random Forest | Random Forest |
| Control Variables | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 |

### 4.4 Excluding the Influence of Extreme Values:

To avoid the influence of sample extreme values on the regression results, this paper applies a bilateral 5% winsorization to the original sample. The results, shown in Table 7, indicate that household digital economy participation significantly increases the scale, enriches the types, and enhances the diversification of financial assets, demonstrating the robustness of the regression results.

**TABLE 7**
**EXCLUDING EXTREME VALUES**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification |
|---|---|---|---|
| Digital Economy Participation | 0.199*** | 0.280*** | 0.038*** |
| | -0.01 | -0.033 | -0.006 |
| Control Variables | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 |

### 4.5 Instrumental Variable Model:

Table 8 reports the estimation results of the instrumental variable (IV) method. In the first-stage regression, the F-statistic of the instrumental variable is 656.460, far exceeding the common critical value, indicating no weak instrument problem. The Wald test is significant at the 1% level, further rejecting the null hypothesis of exogenous explanatory variables and confirming the validity of the instrument. After controlling for endogeneity, the marginal effects of digital economy participation on the types, scale, and diversification of financial assets are 7.935, 0.360, and 1.152, respectively, all significant at the 1% level, further confirming the robust positive effect of household digital economy participation on the financial asset allocation of the elderly.

**TABLE 8**
**RESULTS OF THE INSTRUMENTAL VARIABLE MODEL**

| Variable | First-Stage Regression | Second-Stage Regression: Financial Asset Allocation |
|---|---|---|
| | Digital Economy Participation | Types of Financial Assets |
| Avg. Digital Econ. Participation in Same Community | 0.222*** | |
| | -0.016 | |
| Digital Economy Participation | | 7.935*** |
| | | -1.229 |
| Control Variables | Yes | Yes |
| City Fixed Effects | Yes | Yes |
| Observations | 9408 | 9408 |
| First-Stage F-statistic | 656.46 | |
| Wald Chi2 Test | | 1664.418 |
| P-value | | 0 |

## V. MECHANISM AND HETEROGENEITY ANALYSIS

### 5.1 Mechanism Analysis:

The research conclusions above indicate that household digital economy participation has a positive effect on optimizing the financial asset allocation of the elderly. Based on the theoretical analysis of the impact pathways of household digital economy participation presented earlier, this paper further empirically verifies its mechanism, exploring howhousehold digital economy participation optimizes the financial asset allocation of the elderly. Specifically, combining the two mediating variables proposed in the theoretical analysis—financial literacy and financial information attention—a mediation effect model is constructed for empirical testing to identify the impact pathways and transmission mechanisms of digital economy participation on the financial asset allocation of the elderly. 1. Financial Literacy Lusardi (2005) first proposed the measurement indicators for financial literacy, primarily involving three basic financial questions: compound interest, inflation, and risk diversification (measurement result is basic financial literacy). As financial products have become more complex, the measurement of financial literacy has been linked to investment portfolios. Rooij et al. (2011) expanded the measurement indicators for financial literacy, using questions related to stocks, funds, bonds, and insurance to measure respondents' advanced financial literacy. Therefore, this paper constructs a financial literacy index based on the following four questions from the CHFS questionnaire: (1) Interest: Assuming the bank's annual interest rate is 4%, if you deposit 100 yuan for a one-year term, what will be the principal and interest received after one year? (2) Inflation: Assuming the bank's annual interest rate is 5% and the annual inflation rate is 3%, after depositing 100 yuan in the bank for one year, will it be able to buy more, less, or the same amount of goods? (3) Stocks: In your opinion, generally speaking, which is riskier: main board stocks or growth enterprise board (ChiNext) stocks? (4) Funds: In your opinion, generally speaking, which is riskier: equity-oriented funds or bond-oriented funds? A correct answer is assigned a value of 1, otherwise 0, and factor analysis is used for measurement. Based on the analysis above, the mediation effect model is used to test the mediating mechanism of financial literacy on the financial asset allocation of the elderly. The specific results are shown in Table 9. According to column (1), digital economy participation is significant at the 1% level with a coefficient of 1.431, meaning household digital economy participation can significantly improve residents' financial literacy. Columns (2), (3), and (4) show the regression results after simultaneously introducing digital economy participation and financial literacy. It can

be seen that both digital economy participation and financial literacy have a significant positive impact on the types, scale, and diversification of financial assets, indicating that household digital economy participation can optimize the financial asset allocation of the elderly by enhancing residents' financial literacy.

**TABLE 9**
**FINANCIAL LITERACY MECHANISM TEST**

| Variable | Financial Literacy | Financial Asset Allocation | | |
|---|---|---|---|---|
| | -1 | Types of Financial Assets (2) | Scale of Financial Assets (3) | Financial Asset Diversification (4) |
| Digital Economy Participation | 1.431*** | 0.775*** | 1.413*** | 0.170*** |
| | -0.068 | -0.056 | -0.181 | -0.031 |
| Financial Literacy | | 0.250*** | 0.160*** | 0.027*** |
| | | -0.008 | -0.027 | -0.005 |
| Control Variables | Yes | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 | 9408 |

### 5.2 Financial Information Attention:

Access to financial information is a key channel for improving the efficiency of household financial asset allocation. The development of the digital economy not only provides convenient transaction platforms and improves financial market supply but also enhances households' attention to economic and financial information, thereby stimulating financial management demand, improving information acquisition efficiency, and ultimately optimizing asset allocation. To verify this transmission path, this paper constructs the "Financial Information Attention" variable based on the CHFS survey question, "How much attention do you usually pay to economic and financial information?" (scored 1-5). The regression results in Table 10 show that household digital economy participation significantly increases financial information attention. Furthermore, after controlling for this mediating variable, the coefficient for digital economy participation remains significantly positive, indicating that financial information attention plays a partial mediating role, thus supporting the hypothesis that household digital economy participation optimizes the financial asset allocation of the elderly by increasing their attention to financial information.

**TABLE 10**
**FINANCIAL INFORMATION ATTENTION MECHANISM TEST**

| Variable | Financial Information Attention | Financial Asset Allocation | | |
|---|---|---|---|---|
| | -1 | Types of Financial Assets (2) | Scale of Financial Assets (3) | Financial Asset Diversification (4) |
| Digital Economy Participation | 1.088*** | 0.996*** | 1.545***2 | 0.191*** |
| | -0.072 | -0.056 | -0.179 | -0.031 |
| Financial Information Attention | | 0.125*** | 0.089*** | 0.017*** |
| | | -0.008 | -0.026 | -0.004 |
| Control Variables | Yes | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 | 9408 |

### 5.3 Moderating Effect Test:

Risk preference is an important factor influencing household financial asset allocation (Guiso et al., 1996). Based on this, a dummy variable for risk preference is constructed using CHFS survey data, based on the question: "If you have a sum of money for investment, which of the following investment projects are you most willing to choose?" with 1-5 representing unwilling to take any risk to high risk. This section uses risk preference as a moderating variable to examine its moderating role in the impact of household digital economy participation on the financial asset allocation of the elderly. From column (1) of Table 11, the regression results for the types of financial assets show that the interaction term between digital economy participation and risk preference, as well as the coefficients for digital economy participation and risk preference, are all significantly positive at the 1% level. This means the higher the degree of risk preference, the stronger the promoting effect of digital economy participation on the types of financial assets held by the elderly, indicating that risk preference plays a positive moderating role in the process where household digital economy participation influences the financial asset allocation of the elderly. However, there is no significant moderating effect on the scale and diversification of financial assets.

**TABLE 11**
**TEST OF THE MODERATING EFFECT OF RISK PREFERENCE**

| Variable | Financial Asset Allocation | | |
|---|---|---|---|
| | **Types of Financial Assets (1)** | **Scale of Financial Assets (2)** | **Financial Asset Diversification (3)** |
| Digital Economy Participation * Risk Preference | 0.251*** | 1.455*** | 0.178*** |
| | -0.093 | -0.292 | -0.05 |
| Digital Economy Participation | 0.251*** | 1.455*** | 0.178*** |
| | -0.093 | -0.292 | -0.05 |
| Risk Preference | 0.047** | 0.028 | 0.021** |
| | -0.019 | -0.061 | -0.011 |
| Control Variables | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes |
| Observations | 9408 | 9408 | 9408 |

### 5.4 Heterogeneity Analysis:

To explore in depth the impact of digital economy participation on the financial asset allocation of the elderly in different types of households, this paper further conducts heterogeneity analysis by industry and urban-rural division. 1. Industry Heterogeneity The types of industries different households are engaged in may lead to differences in their asset allocation methods (Li Zibin et al., 2025), especially for households engaged in industry and commerce versus those not. Their economic structures, income sources, and risk preferences may differ significantly. Therefore, understanding the differential impact of digital economy participation in different types of households can help us more comprehensively understand the different mechanisms through which the digital economy affects household financial asset allocation. Based on this consideration, this paper classifies households by whether they are engaged in industry and commerce and conducts separate regression analyses for these two groups to explore the impact of digital economy participation on the financial asset allocation of different household types. Table 12 reports the heterogeneous regression results for households engaged and not engaged in industry and commerce. The results show that the impact of digital economy participation on financial asset allocation is more significant for households engaged in industry and commerce. Specifically, regarding the types, scale, and diversification of financial assets, the impact coefficients are higher for households engaged in industry and commerce than for those not engaged, and the Hausman test results show significant coefficient differences.

**TABLE 12**
**HETEROGENEITY TEST: ENGAGEMENT IN INDUSTRY**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification | | | |
|---|---|---|---|---|---|---|
| | Engaged | Not Engaged | Engaged | Not Engaged | Engaged | Not Engaged |
| Digital Economy | 1.277*** | 1.168*** | 2.945*** | 1.623*** | 0.452*** | 0.217*** |
| | -0.357 | -0.059 | -0.852 | -0.185 | -0.151 | -0.032 |
| Hausman Test | 7.05** | | 14.71** | | 16.08** | |
| Control Variables | Yes | Yes | Yes | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 427 | 8981 | 427 | 8981 | 427 | 8981 |

### 5.5 Urban-Rural Heterogeneity:

Due to the limitations of the urban-rural dual structure, rural households face more significant information asymmetry and resource constraints compared to urban households (Wang Wenbin and Wei Pengfei, 2025). On one hand, the construction of digital economy infrastructure in rural areas lags, restricting the channels for the elderly to access financial information and participate in the digital economy. On the other hand, the elderly in rural areas are at a more significant disadvantage in terms of digital literacy and financial knowledge, making them more prone to inefficient financial asset allocation. Analyzing urban-rural heterogeneity can more clearly reveal the differential impact of digital economy participation on the financial asset allocation of the elderly in different environments. Therefore, this paper divides households into urban and rural households for regression analysis to examine the different impacts of digital economy participation on the financial asset allocation of urban and rural households. Table 13 reports the regression results for urban-rural heterogeneity. The results show that the impact of digital economy participation on financial asset allocation is significantly higher for urban households than for rural households. Specifically, regarding the types and scale of financial assets, the impact coefficients for urban households are greater than those for rural households, and the Hausman test results show significant coefficient differences. This indicates that the optimization effect of digital economy participation on household financial asset allocation is more pronounced for urban households.

**TABLE 13**
**URBAN-RURAL HETEROGENEITY TEST**

| Variable | Types of Financial Assets | Scale of Financial Assets | Financial Asset Diversification | | | |
|---|---|---|---|---|---|---|
| | Rural | Urban | Rural | Urban | Rural | Urban |
| Digital Economy | 0.470*** | 1.386*** | 2.097*** | 2.109*** | 0.193*** | 0.185*** |
| | -0.085 | -0.072 | -0.321 | -0.217 | -0.061 | -0.034 |
| Hausman Test | 406.24*** | | 89.97*** | | 51.38*** | |
| Control Variables | Yes | Yes | Yes | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3247 | 6161 | 3247 | 6161 | 3247 | 6161 |

### 5.6 Analysis of the Impact of Financial:

Asset Allocation on the Welfare of the Elderly The goal of optimizing financial asset allocation is to reduce risk and achieve stable wealth growth through scientific and rational asset distribution and effective investment management, thereby providing reliable financial security for the elderly, improving their quality of life and overall welfare, and giving the elderly greater economic autonomy and satisfaction. This paper considers both objective and subjective welfare, using household daily consumption expenditure to measure objective welfare levels and happiness to measure subjective welfare conditions. It further empirically examines the actual impact of financial asset allocation on the welfare of the elderly. 1. Impact of Financial Asset Allocation on Daily Consumption Expenditure of the Elderly With participation in the digital economy, the optimization of financial asset allocation for the elderly brings more investment income, thereby increasing their disposable income. Optimized

financial asset allocation enables the elderly to manage their income more flexibly, thus increasing daily consumption expenditure. To further explore the impact of financial asset allocation on the daily consumption expenditure of the elderly, this paper uses CHFS survey data to construct a variable for household daily consumption expenditure. The question, "Last year, how much was your household's average monthly food expenses, including purchases of grain, oil, meat, fruits, vegetables, (baby) formula, snacks, dining out, and takeout expenses?" is used as the measure, and its logarithm is analyzed to examine the impact of the types, scale, and diversification of financial assets on the daily consumption expenditure of the elderly. The results are shown in Table 14. The scale of financial assets has a significant positive impact on the daily consumption expenditure of elderly households. This indicates that having a larger scale of financial assets can increase income sources for elderly households, thereby enhancing their consumption capacity. The expansion of financial asset scale provides more financial support, allowing the elderly to incur higher daily consumption expenditure. However, the impact of financial asset diversification on consumption expenditure is not significant. This may be because, although diversification helps reduce risk, the slight returns from excessive diversification do not significantly change their consumption expenditure patterns.

**TABLE 14**
**IMPACT OF FINANCIAL ASSET ALLOCATION OPTIMIZATION ON HOUSEHOLD DAILY CONSUMPTION EXPENDITURE**

| Variable | Household Daily Consumption Expenditure | | |
|---|---|---|---|
| | -1 | -2 | -3 |
| Types of Financial Assets | -0.009 | | |
| | -0.009 | | |
| Scale of Financial Assets | | 0.016*** | |
| | | -0.003 | |
| Financial Asset Diversification | | | 0.012 |
| | | | -0.018 |
| Control Variables | Yes | Yes | Yes |
| City Fixed Effects | Yes | Yes | Yes |
| Observations | 9197 | 9197 | 9197 |

### 5.7 Impact of Financial Asset Allocation on the Happiness of the Elderly:

To further explore the impact of financial asset allocation on the happiness of the elderly, this paper adds the dimension of happiness based on the analysis of household daily consumption expenditure. Optimized financial asset allocation can enhance the elderly's confidence in the future by reducing economic pressure and improving economic independence, thereby increasing their subjective happiness. Therefore, this paper introduces a variable for happiness based on CHFS survey data, using the question, "Overall, how happy do you feel now?" with scores from 1 (very unhappy) to 5 (very happy). Combined with the types, scale, and diversification of financial assets, it explores how optimized financial asset allocation affects the happiness of the elderly. The results are shown in Table 15. Financial asset diversification has a significant positive effect on the happiness of the elderly, while the types of financial assets do not have a significant impact on happiness. A possible reason is that diversified investment, as a risk aversion strategy, can effectively reduce the volatility risk associated with a single asset, helping the elderly alleviate uncertainty about their future financial situation. Since the elderly have a stronger demand for economic security, diversified investment gives them more confidence to cope with future financial challenges, thereby enhancing happiness. In contrast, although the types of financial assets can increase income and consumption expenditure, their impact on happiness is not significant, possibly because the elderly focus more on stability and security in wealth accumulation and consumption rather than the expansion of asset types.

**TABLE 15**
**IMPACT OF FINANCIAL ASSET ALLOCATION OPTIMIZATION ON THE HAPPINESS OF THE ELDERLY**

| Variable | Happiness | | |
|---|---|---|---|
| | -1 | -2 | -3 |
| Types of Financial Assets | 0.016 | | |
| | -0.011 | | |
| Scale of Financial Assets | | 0.009** | |
| | | -0.004 | |
| Financial Asset Diversification | | | 0.062*** |
| | | | -0.02 |
| City Fixed Effects | Controlled | Controlled | Controlled |
| Observations | 9404 | 9404 | 9404 |

## VI. CONCLUSIONS AND RECOMMENDATIONS

As China's population aging deepens, how to improve the wealth security level of the elderly population has become an important social issue that urgently needs to be addressed. Financial asset allocation, as a crucial means to achieve financial security and quality of life for the elderly, relates not only to the efficiency of family financial management but also directly affects the effectiveness of national policies in addressing pension risks. Against the backdrop of the rapid development of the digital economy, the deep integration of technological innovation and financial services provides new possibilities for improving the asset allocation efficiency of the elderly. However, given the practical challenges the elderly generally face, such as weak financial knowledge, high technical barriers, and limited information access channels, how to enable them to truly benefit from the digital economy has become the core issue of this study. Based on data from the 2019 China Household Finance Survey (CHFS), this paper focuses on the impact of household digital economy participation on the financial asset allocation of the elderly and systematically conducts empirical analysis. The study finds that household-level digital economy participation significantly optimizes the structure of financial asset allocation for the elderly, showing positive effects on the types, scale, and diversification of financial assets. Further mechanism analysis reveals that this impact is primarily achieved by enhancing the financial literacy and financial information attention of the elderly. Meanwhile, risk preference plays a positive moderating role, meaning that the elderly with higher risk tolerance are more likely to benefit from the digital economy. Additionally, heterogeneity analysis shows that this optimization effect is more pronounced in urban households and households engaged in industry and commerce. Further research also confirms the positive impact of optimized financial asset allocation on both the objective welfare (consumption expenditure) and subjective welfare (happiness) of the elderly. Based on the above findings, this paper proposes the following policy recommendations:

First, strengthen age-friendly digital infrastructure construction to bridge the urban-rural "digital divide." Increase investment in network and communication infrastructure in rural and underdeveloped areas, promote broadband access in rural areas, popularize smart devices, and implement user-friendly, age-appropriate adaptations for terminals. Simultaneously, establish digital service support windows in community service centers and village-level information stations to help the elderly access and use financial service platforms, narrowing the gap in digital participation between urban and rural areas.

Second, construct a multi-level system to enhance the financial literacy of the elderly, laying a solid foundation for investment awareness. It is recommended to promote multi-stakeholder cooperation (government, financial institutions, community organizations) with fiscal support to implement tiered and categorized financial education programs. Tailored training courses should be developed for the elderly with different education levels and information capabilities, covering topics such as risk identification, basic financial knowledge, and fraud prevention, to improve their investment judgment and rational decision-making abilities.

Third, improve the accessibility of financial information for the elderly to stimulate their willingness to pay attention to investments. Establish information dissemination channels that are closer to the elderly population. Encourage mainstream media to open "Senior Finance" columns, and financial platforms to launch age-friendly information sections, simplifying content and presenting operational processes visually. Promote a "one-stop" financial information acquisition and push mechanism, providing personalized, tiered, and clearly risk-indicated product information for elderly users, reducing cognitive costs, and

enhancing their willingness to invest. Fourth, enrich the system of financial products for the elderly that match their risk characteristics to achieve refined matching. The study finds that risk preference plays a moderating role between the digital economy and asset allocation. To guide the elderly with different risk preferences to allocate financial assets reasonably, it is recommended that financial institutions develop wealth management products categorized by risk level and provide customized asset allocation suggestions based on risk assessment results, helping the elderly achieve a balance between returns and security. Fifth, strengthen the effective conversion mechanism of digital economy achievements into the welfare of the elderly. The empirical results indicate that optimized financial asset allocation significantly improves the consumption capacity and happiness of the elderly. To promote the conversion of financial behavior into improved living standards for the elderly, relevant supporting mechanisms should be improved. For example, encouraging the allocation of part of the returns from digital financial products to health insurance, medical expenses, and life service consumption for the elderly, and promoting the integrated development of "finance + elderly care + health." At the same time, digital financial assistance policies for low-income elderly groups should be strengthened to achieve fair distribution of digital dividends.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES


[1] Wu, Y., Li, X., Li, J., et al. (2021). Digital financial development and the effectiveness of household financial asset portfolios. *Management World, 37*(7), 92–104, 107. (In Chinese)

[2] Zhang, L. S., Yi, X. J., & Yang, B. Y. (2023). Commercial insurance, digital economy participation, and household financial risk-taking: Empirical evidence from China Household Finance Survey data. *World Economic Papers*, (3), 58–77. (In Chinese)

[3] He, Z. Y., Zhang, X., & Wan, G. H. (2020). Digital finance, digital divide, and multidimensional poverty. *Statistical Research, 37*(10), 79–89. (In Chinese)

[4] Zhou, G. S., & Liang, Q. (2018). Internet use, market frictions, and household risk financial asset investment. *Journal of Financial Research*, (1), 84–101. (In Chinese)

[5] Wei, X. H., Zhang, Y. Y., Wu, W. X., et al. (2014). Research on influencing factors of financial asset allocation of Chinese households. *Management Review, 26*(7), 20–28. (In Chinese)

[6] Wang, X. H., Liu, Y., & Song, M. (2023). Digital capability and household risk financial asset allocation. *Chinese Rural Economy*, (11), 102–121. (In Chinese)

[7] Wu, Y., Li, X., Li, J., et al. (2021). Digital financial development and the effectiveness of household financial asset portfolios. *Management World, 37*(7), 92–104, 107. (In Chinese)

[8] Zhang, X., Wan, G. H., Zhang, J. J., et al. (2019). Digital economy, inclusive finance, and inclusive growth. *Economic Research Journal, 54*(8), 71–86. (In Chinese)

[9] Peng, Y. L., Zhou, H. L., & Su, L. L. (2022). Does digital economy participation enhance farmers' social class identity? Evidence from survey data in Ningxia, Chongqing, and Sichuan. *Chinese Rural Economy*, (10), 59–81. (In Chinese)

[10] Zhu, W. P., & Lin, Y. (2024). Does the elderly digital divide inhibit household allocation of pension financial assets? *Consumer Economics, 40*(3), 75–87. (In Chinese)

[11] Chen, N. X., Li, Y. X., & Wu, J. Y. (2024). From "supplementary" to "irreplaceable": The impact of digital literacy on the re-employment transition of the retired population. *Population Research, 48*(4), 51–68. (In Chinese)

[12] Zhou, L., Wu, Y., & Yi, X. J. (2024). Digital economy development, asset allocation efficiency, and residents' property income: Evidence from Chinese household micro survey data. *Journal of Financial Research*, (6), 151–168. (In Chinese)

[13] Wang, Y. K., Shao, J. Y., & Yang, J. H. (2024). Financial literacy, household asset allocation, and wealth accumulation. *Nankai Economic Studies*, (6), 167–184. (In Chinese)

[14] Yin, Z. C., Wu, Y., & Gan, L. (2015). Financial accessibility, financial market participation, and household asset choice. *Economic Research Journal, 50*(3), 87–99. (In Chinese)

[15] Li, T., & Guo, J. (2009). Risk attitude and stock investment. *Economic Research Journal, 44*(2), 56–67. (In Chinese)

[16] Shin, S. H., Seay, M. C., & Kim, K. T. (2017). Measurement of diversification between asset classes in the Survey of Consumer Finances. *Economics Letters, 156*, 22–26. https://doi.org/10.1016/j.econlet.2017.04.017

[17] Zhao, T., Zhang, Z., & Liang, S. K. (2020). Digital economy, entrepreneurial activity, and high-quality development: Empirical evidence from Chinese cities. *Management World, 36*(10), 65–76. (In Chinese)

[18] Zhu, J. J. (2024). The impact of digital economy participation on household allocation of pension financial assets: An analysis based on CHFS microdata. *Rural Finance Research*, (8), 30–42. (In Chinese)

[19] Wang, C., Zhao, Y. Y., Xue, R., et al. (2025). How does digital leadership drive green technology innovation in high-energy-consuming enterprises? *Science & Technology Progress and Policy*. Advance online publication, 1–12. (In Chinese)

[20] Chen, B. K., & Li, T. (2011). The current situation and determinants of assets and liabilities of urban households in China. *Economic Research Journal, 46*(S1), 55–66, 79. (In Chinese)

[21] Zhao, Z. X., & Wang, Y. K. (2023). Pension insurance and household risk asset choice. *Journal of Huazhong University of Science and Technology (Social Science Edition), 37*(2), 65–78. (In Chinese)

[22] Lusardi, A., & Mitchell, O. S. (2005). *Financial literacy and planning: Implications for retirement wellbeing* (CERP Working Paper No. 34–37). Center for Economic and Policy Research.

[23] Guiso, L., Jappelli, T., & Terlizzese, D. (1996). Income risk, borrowing constraints, and portfolio choice. *The American Economic Review, 86*(1), 158–172.

[24] Li, Z. B., Huang, C. Z., & Zhuang, M. M. (2025). Can social security fund shareholding curb the shift of real enterprises from real to virtual? *South China Finance*. Advance online publication, 1–16. (In Chinese)

[25] Wang, W. B., & Wei, P. F. (2025). The implementation dilemma and solution strategies of urban–rural integrated development policies: Based on the "structure–process–context" analytical framework. *Journal of Management, 38*(2), 45–54. (In Chinese)

[26] Ma, Y. F., Chen, X. Y., Lei, X. Y., et al. (2025). The impact of local government competition on green total factor productivity: Economic–environmental comprehensive competition and transformation effects. *Journal of Natural Resources, 40*(2), 459–477. (In Chinese).

# Thermodynamic Equations of Nonequilibrium System for Measuring Odors by Gas Analyzers. Practical Example of a Microcontroller Calculation for Digital Odor Detection by Gas Analyzers

Vlastopulo V.I

Biophysical Department, Reseach Institute of Life and Ecology, Odessa, Ukraine

Received: 07 December 2025/ Revised: 16 December 2025/ Accepted: 23 December 2025/ Published: 31-12-2025
Copyright @ 2025 International Journal of Engineering Research and Science
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *A method for the digital measurement of odors using gas analyzers is presented. This capability enables a new level of precision in identifying spoiled products (e.g., in grain storage and transportation), detecting narcotics, digitizing odors in the culinary and cosmetics industries, and developing olfactory television. This paper details a measurement approach and methodology based on thermodynamic equations for a nonequilibrium odor measurement system. A practical example of a microcontroller calculation for a digital odor detection device using MQ-type gas analyzers is provided, including the process for determining the empirical coefficients integrated into the algorithm.*

***Keywords— digital olfaction; electronic nose; gas sensor array; sensor fusion; microcontroller signal processing; odor profiling; grain spoilage detection.***

## I. INTRODUCTION

First, we must define what constitutes a measurable odor and how its digital detection can solve practical problems. An odor is manifested by the release of specific volatile organic compounds (VOCs) into the air. These VOC plumes, which form an odor's signature, propagate at characteristic speeds through a complex atmospheric environment. Their dispersion is influenced by factors including weight (molar mass), volume, temperature, humidity, incident light spectrum, air velocity, and other dynamic parameters that also affect biological olfactory receptors. While animals and humans use biological receptors to assess edibility or quality, digital odor detection provides an objective, quantifiable alternative. The application of odor analyzers allows for the determination of quality in products such as meat, fish, and grain. Specifically, this technology can identify the causes of spoilage in grain within elevators and shipholds, detect narcotics at security checkpoints in airports and customs, and has potential uses in creating odor-based multimedia and other fields.

## II. PROBLEM FORMULATION

Commercial gas analyzers (e.g., MQ series) are calibrated to measure specific gases at set temperatures and concentrations. The resulting calibration curve for a target gas is stored in a microcontroller's memory. During operation, the device calculates and displays the measured concentration. The concentration of key VOCs that constitute a perceptible odor typically lies within the range of $10^{-4}$ to $10^{-5}$ ppm. While standard industrial gas analyzers can measure down to $10^{-3}$ ppm, specialized sensors approach the $10^{-4}$ ppm range, placing odor measurement at the limit of their detectable accuracy.

Critically, odor measurement is not a simple linear process but represents a **thermodynamically nonequilibrium measurement system** [1-5]. It must account for multiple interacting subsystems: the functional of odorant movement in air ($E_1$), the influence of the light spectrum ($E_2$), the influence of temperature and air humidity ($E_3$), the influence of air velocity ($E_4$), and the influence of the odor source mass ($E_5$). The methodology presented here involves determining experimental coefficients for these factors ($E_1$-$E_5$) and integrating them into a system of nonlinear thermodynamic equations for odor measurement within the microcontroller.

Odorous VOCs are predominantly hydrocarbons. Their movement in air is influenced by molecular structure and molar mass. Below are general characteristics of key hydrocarbon classes:

- **Alkanes ($C_nH_{2n+2}$):** $sp^3$-hybridization; tetrahedral geometry with bond angles of ~109.5°.
- **Alkenes ($C_nH_{2n}$):** $sp^2$-hybridization; trigonal planar geometry with bond angles of ~120°.
- **Alkynes ($C_nH_{2n-2}$):** sp-hybridization; linear geometry with bond angles of 180°.
- **Arenes ($C_nH_{2n-6}$):** $sp^2$-hybridization; planar geometry (e.g., benzene ring) with bond angles of 120°.

The empirical observation guiding sensor placement is as follows: A substance with a higher molar mass than air tends to settle faster. For example, the molar mass of air is approximately 28.97 g/mol. Opium ($C_{17}H_{19}NO_3$), amphetamine ($C_9H_{13}N$), and many nitrogen-containing compounds have higher molar masses. In practice, this means multi-sensor arrays for detecting such substances are often installed at a low height to sample air strata where heavier molecules may concentrate. Each target substance has characteristic differentials of propagation path (*dS*) and time (*dT*) in air, which form part of the calibration basis alongside the electrical differentials of the sensor (Conductivity *dQ*, Current *dA*, Resistance *dR*).

The core calculation in the microcontroller for one sensor channel integrates these concepts:

adc1 // Analog value from the detector

coefV = 0.1875 // Constant for ADC scaling

d = 1000 // Divider to obtain voltage

V = 5 // 5-volt detector power supply

Rload = 10000 // Load resistor value in Ohms

Ro = 122 // Sensor resistance in clean air under standard conditions

All data are processed within a system of equations modeling the nonequilibrium measurement system.

For detection, an array of different MQ-type gas sensors (Winsen Guangoyu) is used. Each sensor is calibrated for specific VOC profiles associated with a target odor. The microcontroller analyzes responses from all sensors, compares them to calibrated profiles, and provides a detection output for target substances at very low concentrations ($10^{-4}$ – $10^{-5}$ ppm).

**Examples of target substances and sensor configurations:**

- **Heroin/Acetic Acid:** MQ-2, MQ-9 sensors.
- **Crack Cocaine/Burnt Rubber:** MQ-2, MQ-9 sensors.
- **Methamphetamine ($C_9H_{13}N$):** MQ-135, MQ-2, MQ-9 sensors.
- **Metformin/Fishy Odor:** MQ-135, MQ-2, MQ-9 sensors.

### 2.1 Thermodynamic Framework for a Nonequilibrium Odor Measurement System:

The measurement process is modeled using a thermodynamic framework for a system displaced from equilibrium. Let the system's state be defined by extensive parameters ($E_i$) and intensive parameters ($P_i$).

We introduce coefficient *A*, linking a change in an intensive parameter to changes in extensive parameters, and its reciprocal, the system capacity *K:*

$$K=1/A=dE/dP;A=1/K \quad (1)$$

The intensive parameters are functions of the extensive parameters:

$$P_1 = f_1(E_1, E_2, E_3, E_4, E_5); P_2 = f_2(E_1, E_2, E_3, E_4, E_5) \quad (2)$$

Differentiating these functions yields the system's response to changes in state:

$$dP_1 = A_{11}dE_1 + A_{12}dE_2 + A_{13}dE_3 + A_{14}dE_4 + A_{15}dE_5; dP_2 = A_{21}dE_1 + A_{22}dE_2 + A_{23}dE_3 + A_{24}dE_4 + A_{25}dE_5 \quad (3)$$

The state coefficients $A_{ij}$ link changes in extensials ($E_i$) to changes in intensials ($P_i$). These coefficients are themselves functions of the system's state and change as the system moves from one nonequilibrium state to another. They represent the "quality" or structure of the measurement interaction, such as the functional of odor movement ($E_1$), light influence ($E_2$), etc.

The main and cross coefficients are functions of the extensive parameters:

$$A_{11} = f_{11}(E_1, E_2, E_3, E_4, E_5); A_{12} = f_{12}(E_1, E_2, E_3, E_4, E_5); A_{21} = f_{21}(E_1, E_2, E_3, E_4, E_5); A_{22} = f_{22}(E_1, E_2, E_3, E_4, E_5) \quad \ldots.(4)$$

Differentiating these coefficients shows their dependence on the extensials:

$$\begin{aligned} dA_{11} &= B_{111}dE_1 + B_{112}dE_2 + B_{113}dE_3 + B_{114}dE_4 + B_{115}dE_5; dA_{12} \\ &= B_{121}dE_1 + B_{122}dE_2 + B_{123}dE_3 + B_{124}dE_4 + B_{125}dE_5; dA_{21} \\ &= B_{211}dE_1 + B_{212}dE_2 + B_{213}dE_3 + B_{214}dE_4 + B_{215}dE_5; dA_{22} \\ &= B_{221}dE_1 + B_{222}dE_2 + B_{223}dE_3 + B_{224}dE_4 + B_{225}dE_5 \end{aligned} \quad \ldots (5)$$

### 2.2 Microcontroller Implementation

The formalism above is implemented practically in the microcontroller algorithm. The core calculation for converting a raw sensor reading into an environmentally-corrected value uses the determined empirical coefficients ($E_1$-$E_5$).

The corrected sensor resistance (*Res_corrected*) is calculated as:

$$\text{Res_corrected} = \frac{\text{Res}}{E_1 \times E_2 \times E_3 \times E_4 \times E_5} \quad (6)$$

where *Res* is the raw measured resistance of the sensor.

This corrected resistance is then used to calculate a target gas concentration (*p*), using a known atmospheric baseline (e.g., for $CO_2$):

$$p = \frac{\text{Res_corrected}}{\text{ATM0_GAS}} \quad (7)$$

**Where:**

- Res = detector resistance in Ohms (calculated from ADC).
- $E_1$ = odor movement functional coefficient.
- $E_2$ = light spectrum influence coefficient.
- $E_3$ = temperature & humidity influence coefficient.
- $E_4$ = air velocity influence coefficient.
- $E_5$ = odor source mass influence coefficient.
- adc0 = analog value from the detector.
- U = (adc0 * 0.1875) / 1000 = converted voltage.
- coefV = 0.1875 = ADC scaling constant.
- Res = (U * V - 1) * Rload = raw sensor resistance calculation (for a specific divider circuit).
- V = 5 = sensor supply voltage.
- Rload = load resistor value (e.g., 10 kΩ).
- p = calculated target gas concentration (ppm).
- ATM0_GAS = baseline atmospheric concentration of the target gas (e.g., 417.99 ppm for $CO_2$ in 2022).

## III. RESULTS AND DISCUSSION

This approach was validated through practical experiments to determine the necessary empirical coefficients ($E_1$-$E_5$). Arrays of MQ gas analyzers (Winsen Guangoyu) were exposed to target odor sources under controlled variations: different distances, temperatures, humidity levels, wind speeds, light spectra, and source masses. Measurements were conducted within a controlled glass flask environment to isolate variables.

The work, conducted for the Greek-Ukrainian joint venture Harvard Marine LLC, led to the development of functional prototype "thermodynamic odor analyzers." The term "thermodynamic" reflects the use of the nonequilibrium system framework for calculation. Prototypes were built for:

1. Detecting specific narcotic substances.
2. Identifying grain spoilage via odors from bacteria, fungi, or pests.
3. Monitoring the onset of spoilage in meat and fish products in refrigerated retail displays.

These prototypes demonstrate the practical feasibility of the method, translating the theoretical framework into working devices for applied odor detection.

**FIGURE 1: Prototype thermodynamic odor analyzers developed for various applications**

## IV. CONCLUSION

1) An approach and methodology based on thermodynamic equations for a nonequilibrium system have been developed for the digital measurement of odors using gas analyzers.
2) Thermodynamic equations for the digital odor detection system have been formulated. Experiments were conducted to determine the empirical coefficients ($E_1$-$E_5$) for a range of target odors, including narcotics, spoilage in grain, and spoilage in meat/fish products.
3) A practical example of the microcontroller calculation algorithm for a thermodynamic gas analyzer has been provided, demonstrating the integration of the empirical coefficients into the device's operational logic.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

[1] Vlastopulo, V. (2009). Creation of electromagnetic structure-creating spaces to improve the growth of some types of cells and albumins. In *Recent advances in biology, biophysics, bioengineering and computational chemistry: Proceedings of the 5th WSEAS International Conference on Cellular and Molecular Biology, Biophysics and Bioengineering (BIO '09)* (Plenary Lecture 2). WSEAS. ISBN 978-960-474-141-0; ISSN 1790-5125.

[2] Vlastopulo, V. I., & Polichronidi, A. G. (2011). Equations of thermodynamics for expansion and filling by human civilization. *International Journal of Engineering Research (IJOER)*, November issue.

[3] Vlastopulo, V. I., Chaadaev, I. E., & Gazin, A. V. (2022). Gas analysis codivirus method for detecting the threshold of contagiousness and therapy adjustment. *International Journal of Engineering Research & Science (IJOER), 8*(5). ISSN 2395-6992.

[4] Vlastopulo, V. I., Lukashenko, A. V., & Tsaprika, E. S. (2025). Development of a 24/7 odor gas analyzer system for spoiled products in cryogenic warehouses and its market potential in Europe and Asia. *International Journal of Engineering Research & Science (IJOER), 11*(8). ISSN 2395-6992.

[5] Vlastopulo, V. I., Lukashenko, A. V., & Tsaprika, E. S. (n.d.). Development of a non-equilibrium thermodynamic system for monitoring and blocking freon leaks in cryogenic equipment with multiple monitoring points and large-scale deployment: Assessment of implementation in the European market. *Global Journal of Engineering and Technology (GJET)*. ISSN 2583-3359. Harvard Marine Research and Production Company LLC, Odessa, Ukraine.

# Dietary Diversity and Anthropometric Shifts in School-Going Adolescents: A Pre-Post Intervention Study in Urban India

Danika Manocha[1*]; Priya Singla[2]

[*1]Research Scholar, Faculty of Engineering and Applied Sciences, Desh Bhagat University, Mandi Gobindgarh, Punjab, India

[2]Assistant Professor, Faculty of Engineering and Applied Sciences, Desh Bhagat University, Mandi Gobindgarh, Punjab, India

*Corresponding Author

Received: 08 December 2025/ Revised: 14 December 2025/ Accepted: 23 December 2025/ Published: 31-12-2025

Copyright @ 2025 International Journal of Engineering Research and Science
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—***

***Background:*** *Indian adolescents face a severe dual burden of malnutrition driven by poor dietary choices. This study evaluated changes in Individual Dietary Diversity Scores (IDDS) and anthropometric measurements following a six-month structured, school-based nutritional counselling intervention among 400 urban school-going adolescents (200 boys and 200 girls; aged 12–16 years) selected via purposive sampling from two schools in Gurgaon, Haryana, India.*

***Methods:*** *Anthropometric measurements and 24-hour dietary recalls, stratified using the 9-group Individual Dietary Diversity Score (IDDS) (Food and Agriculture Organisation) framework, were assessed pre- and post-intervention. The six-month intervention comprised interactive sessions on balanced nutrition, recommended dietary allowances, healthy cooking methods, food hygiene, and healthy snack alternatives.*

***Results:*** *Post-intervention data revealed significant ($p<0.001$) improvements in anthropometric parameters and dietary optimization. Underweight prevalence declined from 41% to 18% in boys and from 54% to 38% in girls, with corresponding shifts into the normal-weight category while overweight and obesity rates remained stable. Mean IDDS improved for boys (4.12 to 4.78) and girls (3.54 to 4.59), driven by increased consumption of micronutrient-dense greens, vitamin A-rich produce, and quality proteins. Comparative analysis demonstrated that for boys, overall dietary diversity maintained a significant ($p<0.05$) positive correlation with linear growth and healthy mass accumulation. Conversely, girls' anthropometric changes were associated with specific food groups rather than overall scores; notably, regular intake of milk and milk products showed a negative correlation with BMI ($p<0.001$), suggesting a potential stabilizing effect against excessive adiposity.*

***Conclusions:*** *Structured school-based nutritional education was associated with enhanced dietary diversity and positive anthropometric changes in this cohort. The findings highlight distinct gender-specific nutritional responses and suggest that school-based interventions may offer a promising strategy to address adolescent malnutrition.*

***Keywords— dietary diversity, anthropometric measurements, adolescents, nutrition education.***

## I. INTRODUCTION

Indian adolescents face a double burden of malnutrition on a national scale, characterized by high rates of undernutrition alongside emerging overnutrition. The Comprehensive National Nutrition Survey indicated that stunting and thinness affected 27% and 24% of adolescents, respectively, while overweight and obesity rates stood at 5% and 1%. Nutritional disparities are heavily driven by socio-demographic factors (income, education, and location), with older adolescents facing higher odds of stunting and urban, younger demographics showing increased vulnerability to overweight (Pandurangi et al., 2022).

The anthropometric dual burden is accompanied by a widespread crisis of micronutrient deficiencies and escalating metabolic risks, driven largely by poor dietary diversity. Nationally, half of all adolescents suffered from anaemia, impacting 40% of girls and 18% of boys. Furthermore, metabolic markers indicated early risks for non-communicable diseases, with 50% of

adolescents presenting with at least one cardiovascular and metabolic risk factor, including hypertension, low high-density lipoprotein cholesterol (HDL) (affecting roughly 25% to 39% of various demographic groups), or elevated haemoglobin A1c (HbA1c) levels, which put up to 20% of older adolescents at risk for diabetes (Comprehensive National Nutrition Survey [CNNS], 2019).

Dietary diversity acts as a crucial qualitative indicator of both household food access and individual nutrient adequacy. An increasing reliance on low-quality foods and a lack of dietary diversity directly mirror physiological risks. Alarmingly, fewer than 20% of adolescents consumed pulses and green leafy vegetables, and less than 10% consumed fruits daily. The dietary shift from healthy to low-nutrient items is further reflected in data showing that ultra-processed foods contribute over 16% of total daily energy intake (371 kcal) (CNNS, 2019; Jain & Mathur, 2020). Consequently, replacing nutrient-void options with wholesome, low-fat, low-sodium, and low-sugar snacks is essential to safely meet the heightened micronutrient and energy demands of the developmental phase (Dietary Guidelines for Indians, 2024; Hu, 2002; Kennedy et al., 2010).

Expanding dietary diversity is a critical factor for metabolic health; low dietary diversity scores are positively associated with a higher prevalence of obesity. To bridge this gap, structured nutritional counselling and education serve as vital interventions. Targeted nutrition education has been shown to substantially enhance nutritional knowledge and directly translate into higher dietary diversity among adolescents. Notably, the benefits of educational strategies extend beyond dietary practices, showing a strong positive correlation with improved academic performance (Idrees et al., 2024; Sumiati et al., 2024; Yazew et al., 2024).

This study analyzed changes in dietary diversity scores and anthropometric measurements among Indian adolescents from two schools in Gurgaon, and evaluated the relationship between these parameters from baseline to post-intervention following a structured nutritional counselling program.

## II. MATERIALS AND METHODS

### 2.1 Study Design and Participants

A pre-post intervention study was conducted with a total sample of 400 adolescents (200 boys and 200 girls; aged 12–16 years) choosen from two selected schools in Gurgaon, Haryana, India, using purposive sampling.

### 2.2 Data Collection Procedures

- **Anthropometric Measurements:** Height (cm) and weight (kg) were measured at baseline and post-intervention using standardized procedures. Body Mass Index (kg/m²) was calculated using the standard formula (weight in kilograms divided by height in meters squared). Measurements were compared with age- and sex-specific reference standards (IAP, 2015; ICMR, 2024).
- **Dietary Assessment:** The foods consumed by participants were categorized across nine standardized groups using the FAO Individual Dietary Diversity Score (IDDS) framework. Assessment was conducted via 24-hour dietary recalls at baseline and post-intervention. Dietary diversity scores were stratified into Low (0–3 groups), Medium (4–5 groups), and High (6–9 groups) diversity tiers.

### 2.3 Intervention

Participants underwent a six-month nutrition educational intervention consisting of interactive sessions. Session content included:

- Balanced diet principles and recommended dietary allowances (RDA) for adolescents
- Healthy cooking methods and food hygiene practices
- Identification and selection of nutrient-dense foods
- Smart snack alternatives to replace junk food

### 2.4 Outcome Measures

Primary outcomes included changes in:

1) Anthropometric parameters (height, weight, BMI)

2) Individual Dietary Diversity Scores (IDDS)

3) Relationship between dietary diversity and anthropometric parameters

### 2.5 Statistical Analysis

Data were analyzed using IBM SPSS Statistics (Version [31.0.2.0]). Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables as frequencies and percentages. Pre- and post-intervention changes were evaluated using paired t-tests for continuous variables. Relationships between IDDS and anthropometric measurements were assessed using Pearson correlation coefficients (r).

## III. RESULTS AND DISCUSSION

### 3.1 Anthropometric Measurements of Participants

Table 1 reports the average changes in height, weight, and Body Mass Index (BMI) from baseline to post-intervention. The nutrition education program was associated with positive changes in physical development parameters for both boys and girls.

- **Height:** Average height increased by 1.03% for boys (166.31 to 168.02 cm) and 0.4% for girls (156.94 to 157.58 cm). These changes were statistically significant for both groups ($p<0.001$) and fell within the expected range based on reference standards (IAP, 2015; ICMR, 2024).
- **Weight:** Average weight increased from 56.11 to 57.80 kg for boys (3.01% increase) and from 47.16 to 47.89 kg for girls (1.55% increase). Both changes were statistically significant ($p<0.001$).
- **BMI:** Boys showed a statistically significant increase in BMI ($p<0.05$; 1.05%), moving from 20.09 ± 4.06 kg/m² to 20.30 ± 3.50 kg/m². Girls showed a slight increase in BMI from 19.25 ± 4.45 kg/m² to 19.34 ± 3.69 kg/m² (0.47%), which was not statistically significant ($p>0.05$). The non-significant change in girls' BMI reflects simultaneous height and weight increases maintaining the weight-to-height ratio.

These developmental trends are consistent with findings from urban Delhi involving boys and girls aged 11–17 years, which similarly observed that girls maintained higher BMI values between 14 and 16 years of age, prior to an acceleration in boys during later adolescence (Mani et al., 2022). This comparative regional data reinforces the distinct, gender-segregated growth trajectories seen during crucial pubertal years.

**TABLE 1**
**EFFECT OF COUNSELLING ON ANTHROPOMETRIC MEASUREMENTS OF BOYS AND GIRLS (12-16 YEARS)**

| Particulars | Boys (n=200) | | Girls (n=200) | |
|---|---|---|---|---|
| | **Pre-counselling** | **Post-counselling** | **Pre-counselling** | **Post-counselling** |
| **Height (cm)** | 166.31 ± 10.30 | 168.02 ± 10.29 | 156.94 ± 11.76 | 157.58 ± 11.73 |
| Height Std. | 149-170 cm | | 150-157 cm | |
| t-value | 32.512** (1.03%) | | 21.309** (0.4%) | |
| **Weight (kg)** | 56.11 ± 14.60 | 57.80 ± 13.47 | 47.16 ± 11.18 | 47.89 ± 10.04 |
| Weight Std. | 39-59 kg | | 40-52 kg | |
| t-value | 6.823** (3.01%) | | 3.471** (1.55%) | |
| **BMI (kg/m²)** | 20.09 ± 4.06 | 20.30 ± 3.50 | 19.25 ± 4.45 | 19.34 ± 3.69 |
| t-value | 2.196* (1.05%) | | 0.927 (ns) (0.47%) | |

***Values in () indicate % change.***
**(ns) = Not Significant (p>0.05); *p<0.05; **p<0.001**
***(IAP, 2015; ICMR, 2024)***

### 3.2 Adolescents' Distribution by BMI Category

The baseline data revealed a serious public health concern: more than half of the girls (54%) and nearly half of the boys (41%) were classified as underweight according to WHO criteria (WHO, 2025). The high rate of undernutrition points to severe gaps in baseline dietary habits, a lack of nutritional awareness, or skipping of nutrient-dense foods during crucial growth years (Table 2).

- **Major Decline in Underweight Status:** The percentage of underweight boys declined sharply from 41% to 18% (a recovery of 46 individuals). For girls, the underweight rate declined from 54% to 38% (a recovery of 32 individuals).
- **Surge in Normal Weight:** As students recovered from being underweight, they moved into the healthy, normal weight bracket (18.5–22.9 kg/m²). The proportion of normal-weight boys increased from 46% to 72%, while normal-weight girls expanded from 32% to 57%.
- **Management of Overweight and Obesity:** The counselling was also associated with stabilization at the upper end of the weight spectrum. Overweight boys declined from 12% to 10%, and obese cases dropped to nil. Overweight girls decreased from 12% to 4%, and obesity declined from 2% to 1%.

The adolescents were educated on improving dietary diversity, choosing calorie-dense whole foods, and meeting specific growth needs. The intervention promoted healthy, balanced mass accumulation rather than excessive weight gain. These findings suggest that introducing structured nutrition awareness programs in school settings may be a practical approach to support adolescent health and address nutritional deficiencies in urban school environments.

This trend is further supported by an intervention study among 100 adolescent girls aged 15–19 years across varied socioeconomic groups, which similarly demonstrated positive shifts toward normal BMI values, including a post-counselling mean BMI increase from 18.12 to 18.54 kg/m² among upper-class 16-year-olds within one month (Das & Das, 2023). Such comparable data supports the potential of structured nutritional education to address adolescent undernutrition.

**TABLE 2**
**FREQUENCY DISTRIBUTION PROFILING OF ADOLESCENTS BY BMI CATEGORY**

| Particulars | Boys (n=200) | | Girls (n=200) | |
|---|---|---|---|---|
| | Pre-counselling | Post-counselling | Pre-counselling | Post-counselling |
| Underweight (<18.5 kg/m²) | 82 (41%) | 36 (18%) | 108 (54%) | 76 (38%) |
| Normal weight (18.5–22.9 kg/m²) | 92 (46%) | 144 (72%) | 64 (32%) | 114 (57%) |
| Overweight (23–24.9 kg/m²) | 24 (12%) | 20 (10%) | 24 (12%) | 8 (4%) |
| Obese (≥25 kg/m²) | 2 (1%) | 0 (0%) | 4 (2%) | 2 (1%) |

***Values in () are percentages.***
***(A et al., 2014; WHO, 2025)***

### 3.3 Dietary Diversity by Food Group

Table 3 records specific foods that students added to their diets to achieve higher scores. The data showed a targeted increase in protective, micronutrient-dense whole foods rather than empty calories.

- **Green and Yellow Vegetables:** The most dramatic changes occurred in the vegetable categories. Dark Green Leafy Vegetable consumption rose from 25% to 45% among boys and from 14% to 45% among girls. Similarly, consumption of Vitamin A-Rich Fruits and Vegetables doubled and tripled (16% to 32% for boys; 9% to 31% for girls).
- **Vital Proteins and Energy Sources:** Legumes, nuts, and seeds grew into a major dietary staple, reaching 86% for boys and 83% for girls (from 80% and 66% at baseline). Daily intake of Milk and Milk Products also solidified, expanding to 93% for boys and 88% for girls (from 85% and 75%). Animal protein sources like Meat/Fish and Eggs showed smaller but steady improvements (5-10% for boys and 4-10% for girls), while Starchy Staples remained a baseline constant at 100% for everyone.

These findings demonstrate that structured nutritional counselling was associated with improvements in dietary diversity, correcting monotonous, carbohydrate-heavy baseline diets by introducing accessible proteins and micronutrient-dense vegetables. This pattern aligns with an intervention in Puducherry among 140 adolescents, which significantly increased protein intake ($p<0.001$) and reduced total calorie ($p<0.001$) and fat ($p<0.01$) consumption to control weight gain (Ponnambalam et al., 2022). Similarly, the increased intake of dairy, legumes, and greens in the cohort provided the structural tools necessary to support linear height and lean tissue development, suggesting that school-based education can drive objective anthropometric and macro-nutritional optimization.

**TABLE 3**
**DIETARY DIVERSITY FREQUENCY DISTRIBUTION (PRE- VS POST-COUNSELLING)**

| Food Group | Pre-counselling | Post-counselling | Pre-counselling | Post-counselling |
|---|---|---|---|---|
| | Boys (n=200) | | Girls (n=200) | |
| Starchy staples | 200 (100%) | 200 (100%) | 200 (100%) | 200 (100%) |
| Dark green leafy veg | 50 (25%) | 90 (45%) | 28 (14%) | 90 (45%) |
| Vitamin A-rich fruits/veg | 32 (16%) | 64 (32%) | 18 (9%) | 62 (31%) |
| Other fruits & veg | 186 (93%) | 192 (96%) | 170 (85%) | 186 (93%) |
| Organ meat | - | - | - | - |
| Meat and Fish | 10 (5%) | 20 (10%) | 8 (4%) | 20 (10%) |
| Eggs | 16 (8%) | 32 (16%) | 2 (1%) | 18 (9%) |
| Legumes, nuts & seeds | 160 (80%) | 172 (86%) | 132 (66%) | 166 (83%) |
| Milk and milk products | 170 (85%) | 186 (93%) | 150 (75%) | 176 (88%) |

***Values in () indicate percentages.***

### 3.4 Evaluation of Individual Dietary Diversity Scores (IDDS)

The overall score improvements recorded in Table 4 show that the school-based nutrition education program was associated with enhanced daily food variety among participants.

- **Average Score Changes:** The average IDDS for boys increased significantly from 4.12 ± 1.06 to 4.78 ± 1.02 ($p<0.001$; 16.02%), meaning the average male student added nearly one complete new food group to his regular diet. The improvement among girls was even more pronounced, increasing from a baseline mean of 3.54 ± 1.03 to 4.59 ± 0.99 ($p<0.001$; 29.6%), a net gain of more than one full food group.
- **Decline in Low-Diversity Diets:** Before the counselling sessions, 56% of girls and 33% of boys were in the "Low Diversity" bracket (eating 3 or fewer food groups per day). Relying on such a narrow selection of foods may help explain the high underweight rates observed at baseline. These percentages fell sharply to 16% for girls and 8% for boys post-counselling.
- **Expansion of Healthy Categories:** Most students shifted successfully into the "Medium Diversity" tier (4–5 groups), which grew to include 63% of boys and 67% of girls (from 50% and 35%, respectively). Furthermore, the ideal "High Diversity" tier (6–9 groups) expanded from 17% to 29% for boys, and doubled from 9% to 17% for girls.

**TABLE 4**
**CATEGORIES OF INDIVIDUAL DIETARY DIVERSITY (IDDS) FOR GIRLS AND BOYS**

| Particulars | Boys (n=200) | | Girls (n=200) | |
|---|---|---|---|---|
| | Pre-counselling | Post-counselling | Pre-counselling | Post-counselling |
| | IDDS Category | | | |
| Low (0-3) | 66 (33%) | 16 (8%) | 112 (56%) | 32 (16%) |
| Medium (4-5) | 100 (50%) | 126 (63%) | 70 (35%) | 134 (67%) |
| High (6-9) | 34 (17%) | 58 (29%) | 18 (9%) | 34 (17%) |
| **IDDS (0-9)** | 4.12 ± 1.06 | 4.78 ± 1.02 | 3.54 ± 1.03 | 4.59 ± 0.99 |
| t-value | 6.35** | | 10.39** | |

***Values in () are percentages.***
*****p<0.001***

### 3.5 Relationship between Dietary Diversity and Anthropometric Measurements

For the male cohort, overall dietary diversity showed a statistically significant positive association with all physical growth parameters during both phases of the study. At baseline, higher diversity scores correlated with greater height ($p<0.001$) and weight ($p<0.001$). This association continued post-counselling for both height ($p<0.001$) and weight ($p<0.001$). Higher diet scores also correlated with healthier BMI values both before counselling ($p<0.01$) and after counselling ($p<0.05$). These findings suggest that for boys, a broader, more diverse diet was associated with superior physical development (Table 5).

For the female group, the overall IDDS score showed non-significant correlations with height, weight, and BMI across both phases. This neutral trend indicates that for girls, the overall number of food groups alone was not sufficient to capture

nutritional adequacy. Instead, their physical changes were associated with specific, individual food choices rather than just a total score.

The significant positive correlation observed between overall IDDS and boys' anthropometric growth metrics aligns with established nutritional epidemiological frameworks. Multi-country evaluations demonstrated that overall dietary diversity scores functioned as reliable indicators of macro- and micronutrient adequacy, directly translating into linear skeletal growth and lean tissue accumulation during accelerated development phases (Arimond & Ruel, 2004).

**TABLE 5**
**COMPARISON BETWEEN DIETARY DIVERSITY (IDDS) AND ANTHROPOMETRIC MEASUREMENTS (PRE- AND POST-COUNSELLING)**

| Particulars | Boys (n=200) | | Girls (n=200) | |
|---|---|---|---|---|
| | Pre-counselling | Post-counselling | Pre-counselling | Post-counselling |
| | Dietary Diversity | | | |
| Height (cm) | 0.307** | 0.229** | 0.050 (ns) | 0.089 (ns) |
| Weight (kg) | 0.302** | 0.224** | 0.013 (ns) | 0.042 (ns) |
| BMI (kg/m²) | 0.215* | 0.139† | 0.032 (ns) | 0.032 (ns) |

***ns = Not Significant (p>0.05)***
***†Correlation is significant at the 0.05 level***
****Correlation is significant at the 0.01 level***
*****Correlation is significant at the 0.001 level***

### 3.6 Individual Food Groups vs. BMI Dynamics

Table 6 presents correlations between specific food groups and BMI, highlighting foods that showed the most notable associations.

- **Vitamin A-Rich Foods:** For boys, Vitamin A-Rich Fruits & Vegetables maintained a significant positive correlation with BMI at baseline ($p<0.001$) and post-counselling ($p<0.01$), suggesting a consistent association between nutrient-dense produce and healthy growth.
- **Dark Green Leafy Vegetables:** Baseline consumption of greens also showed a significant positive association with BMI ($p<0.05$).
- **Eggs:** Post-counselling, egg consumption showed a significant negative correlation ($p<0.05$), meaning it was inversely associated with higher body mass.
- **Dairy Products:** For girls, milk and milk products showed a significant negative correlation with BMI both at baseline ($p<0.001$) and post-counselling ($p<0.001$). The inverse relationship suggests that regular dairy intake was associated with lower BMI, potentially indicating protection against excessive weight accumulation. This pronounced vulnerability among female adolescents aligns with European research revealing that up to 73% of adolescents failed to meet daily dairy serving guidelines, leaving nearly two-thirds of female adolescents below the estimated average requirement for calcium (Dror & Allen, 2014).
- **Fresh Produce:** Girls also showed a strong baseline positive correlation between other fruits and vegetables and BMI ($p<0.001$), which normalized to a neutral status ($p>0.05$) post-intervention.

The correlation results provide statistical support for the intervention, demonstrating associations between structured dietary modifications and positive changes in adolescent anthropometrics. The data highlight distinct, gender-specific physiological pathways through which nutritional improvements may translate into structural development.

For boys, the findings demonstrate a physiological benefit derived from overall dietary variety. Higher IDDS—driven by increased consumption of micronutrient-dense vegetables—was associated with accelerated linear growth, weight gain, and healthy mass accumulation. The observed benefit of dietary variety in boys mirrors findings in Indian adolescents, where higher dietary diversity scores were associated with reduced stunting and thinness, serving as a critical driver of structural development during active pubertal growth spurts (Nithya & Bhavani, 2018).

Conversely, girls' body composition appeared more sensitive to the targeted quality of specific functional food groups rather than a cumulative score of food categories. The introduction of protective, calcium- and protein-rich dairy products was

associated with an inverse relationship with BMI, potentially serving as a metabolic stabilizer. Concurrently, targeted plant-based food groups were associated with recovery from baseline undernutrition states.

**TABLE 6**
**COMPARISON BETWEEN INDIVIDUAL FOOD GROUP CONSUMPTION AND BMI (PRE- VS POST-COUNSELLING)**

| Food group category | Boys (n=200) | | Girls (n=200) | |
|---|---|---|---|---|
| | Pre-Counselling BMI | Post-Counselling BMI | Pre-Counselling BMI | Post-Counselling BMI |
| Dark green leafy veg | 0.155* | 0.070 (ns) | 0.031 (ns) | 0.045 (ns) |
| Vitamin A-rich fruits/veg | 0.311*** | 0.215** | 0.042 (ns) | 0.031 (ns) |
| Other fruits & vegetables | 0.085 (ns) | 0.083 (ns) | 0.276*** | 0.053 (ns) |
| Meat and fish | 0.009 (ns) | 0.137 (ns) | 0.049 (ns) | 0.106 (ns) |
| Eggs | 0.130 (ns) | 0.168* | 0.103 (ns) | 0.077 (ns) |
| Legumes, nuts and seeds | 0.133 (ns) | 0.104 (ns) | 0.138 (ns) | 0.001 (ns) |
| Milk and milk products | 0.017 (ns) | 0.029 (ns) | 0.353*** | 0.283*** |

***ns = Not Significant (p>0.05)***
****Correlation is significant at the 0.05 level (2-tailed)***
*****Correlation is significant at the 0.01 level (2-tailed)***
******Correlation is significant at the 0.001 level (2-tailed)***

## IV. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Several limitations affect this study, including a pre-post design without a control group that prevents causal inference, and a purposive sample of two urban schools that restricts broader generalizability. Furthermore, the use of self-reported, single 24-hour dietary recalls introduces recall and social desirability biases, while the six-month follow-up may not confirm long-term sustainability. To address these gaps, future research should utilize randomized controlled trials (RCTs) with extended follow-up periods and multisite designs encompassing rural and diverse socioeconomic cohorts. Additionally, incorporating mixed-methods qualitative evaluations would significantly strengthen the evidence base.

## V. CONCLUSION

The study demonstrated that a six-month structured school-based nutritional counselling intervention was associated with improved dietary diversity and positive anthropometric changes among urban Indian adolescents. The intervention was associated with a substantial decline in underweight prevalence, driven by increased consumption of protective, micronutrient-dense food groups. The findings highlight distinct gender-specific nutritional responses: for boys, overall dietary diversity was significantly associated with physical development, while for girls, specific food groups—particularly dairy products—showed stronger associations with anthropometric outcomes.

The results suggest that structured school-based dietary education may be a promising strategy to address the dual burden of adolescent malnutrition. However, the pre-post design without a control group limits causal inference, and further research with randomized controlled designs, longer-term follow-up, and diverse settings is warranted to confirm these findings and establish the effectiveness and scalability of this approach.

The gender-specific findings underscore the importance of tailoring nutritional interventions to meet distinct biological requirements. As India continues to face a dual burden of undernutrition and emerging overnutrition among adolescents, evidence-based, scalable interventions that address gender-specific needs and improve dietary quality are urgently needed.

## ACKNOWLEDGEMENT

The authors thank Desh Bhagat University, Punjab, and the Faculty of Engineering and Applied Sciences for providing the academic support and facilities necessary to complete this study.

## CONFLICT OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work presented in this paper.

## REFERENCES


[1] Arimond, M., & Ruel, M. T. (2004). Dietary diversity is associated with child nutritional status: Evidence from 11 demographic and health surveys. *The Journal of Nutrition*, *134*(10), 2579-2585. https://doi.org/10.1093/jn/134.10.2579

[2] Comprehensive National Nutrition Survey (CNNS): National Report. (2019). Ministry of Health and Family Welfare, Government of India. https://www.unicef.org/india/media/2646/file/CNNS-report.pdf

[3] Das, D., & Das, A. (2023). *The impact of nutrition education and dietary counselling on anthropometric measurements of adolescent girls belonging to different socio-economic backgrounds, Bihar*.

[4] Dietary Guidelines for Indians. (2024). Indian Council of Medical Research, Department of Health Research, Ministry of Health and Family Welfare. https://nin.res.in/dietaryguidelines/pdfjs/locale/DGI_2024.pdf

[5] Dror, D. K., & Allen, L. H. (2014). Dairy product intake in children and adolescents in developed countries: Trends, nutritional contribution, and a review of association with health outcomes. *Nutrition Reviews*, *72*(2), 68-81. https://doi.org/10.1111/nure.12078

[6] Hu, F. B. (2002). Dietary pattern analysis: A new direction in nutritional epidemiology. *Current Opinion in Lipidology*, *13*(1), 3.

[7] Idrees, M., Mahmood, H., Habib, M. F., Haseeb, M., Jokhio, M., & Altaf, H. (2024). *Effectiveness of nutritional counselling on dietary habit and practices among school adolescents in a public school of Rawalpindi: A quasi experimental interventional study*.

[8] Indian Council of Medical Research - National Institute of Nutrition (ICMR-NIN). (2024). *Dietary Guidelines for Indians: A manual*. Expert Committee Report.

[9] Jain, A., & Mathur, P. (2020). Intake of ultra-processed foods among adolescents from low- and middle-income families in Delhi. *Indian Pediatrics*, *57*, 712-714. https://www.indianpediatrics.net/aug2020/aug-712-714.htm

[10] Kennedy, P. G., Ballard, T., & Dop, M. (2010). *Guidelines for measuring household and individual dietary diversity*. FAO.

[11] Khadilkar, V., Yadav, S., Agrawal, K. K., Tamboli, S., Banerjee, M., Cherian, A., Gokhale, J. P., Khadilkar, A., Kumar, V., Muthusamy, V., Dhepe, N., Ramakrishnan, I., & Yewale, V. (2015). Revised IAP growth charts for height, weight and body mass index for 5- to 18-year-old Indian children. *Indian Pediatrics*, *52*(1). https://doi.org/10.1007/s13312-015-0566-5

[12] Mani, K., Malhotra, S., Sati, H. C., & Malhotra, J. (2022). Smoothened percentiles for height, weight and body mass index of urban school going adolescents aged 11-17 years in national capital territory region of Delhi, India. *Journal of Family Medicine and Primary Care*, *11*(7), 3584. https://doi.org/10.4103/jfmpc.jfmpc_2314_21

[13] Nithya, D. J., & Bhavani, R. V. (2018). Dietary diversity and its relationship with nutritional status among adolescents and adults in rural India. *Journal of Biosocial Science*, *50*(3), 397-413. https://doi.org/10.1017/S0021932017000463

[14] Pandurangi, R., Mummadi, M. K., Challa, S., Reddy, N. S., Kaliaperumal, V., Khadar Babu, C., Telikicherla, U. R., Pullakandham, R., Geddam, J. J. B., & Hemalatha, R. (2022). Burden and predictors of malnutrition among Indian adolescents (10–19 years): Insights from Comprehensive National Nutrition Survey data. *Frontiers in Public Health*, *10*, 877073.
https://doi.org/10.3389/fpubh.2022.877073

[15] Ponnambalam, S., Palanisamy, S., Singaravelu, R., & Janardhanan, H. A. (2022). Effectiveness of a school-based nutrition education program on waist circumference and dietary behavior among overweight adolescents in Puducherry, India. *Journal of Education and Health Promotion*, *11*, 323. https://doi.org/10.4103/jehp.jehp_413_22

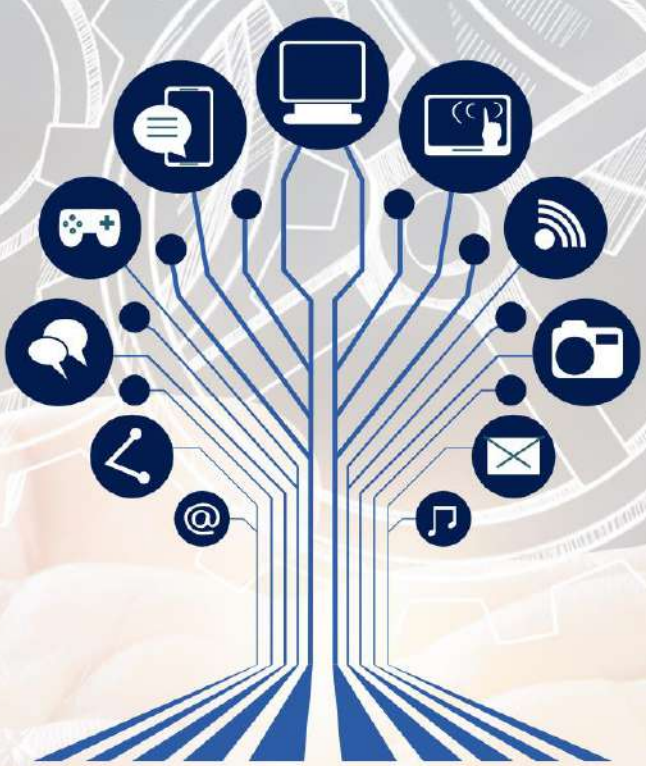
[16] Sumiati, S., Indrawaty Lipoeto, N., & Khairina, I. (2024). Dietary diversity score and adolescent obesity among West Sumaterans girl. *Nutrición Clínica y Dietética Hospitalaria*, *44*(1), 237-244.

[17] WHO. (2025). *Body mass index (BMI)*. https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index

[18] Yazew, T., Kuyu, C. G., Beressa, G., & Seyoum, G. (2024). Effect of nutrition education on dietary diversity and academic achievement among adolescent school girls in North Shoa Zone, Oromia, Ethiopia. *Nutrition*, *123*, 112416.
https://doi.org/10.1016/j.nut.2024.112416.

IJOER
ENGINEERING JOURNAL

# International Journal of Engineering Research and Science



## Published by

AD Publications

Contact us +91-7665235235 www.ijoer.com info@ijoer.com