PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

Interdisciplinary Journal of Papua New Guinea University of Technology (IJPNGUoT)

A platform for scholarly works from all disciplines of study

Volume 1, Issue 1

2024 - Publication

Vision

To Grow World-Class Technocrats for the Real World

Mission

To grow world class technocrats through high quality experiential teaching, research and ardent application of science, technology and innovation

Guiding Principles

- A sense of Community
- Commitment to Excellence
- Providing Service to Students
- Upholding Freedom of Thought, Enquiry and Expression
- Anticipation and Response
- Critical Assessment of our Performance
- Integrity
- Equity, Access and Participation

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Foreword

Inaugural Volume of the Interdisciplinary Journal of Papua New Guinea University of Technology (IJPNGUoT)

Over the past five years, the Papua New Guinea University of Technology (PNGUoT) has been diligently implementing its Strategic Plan for 2020–2024. A pivotal aim of this strategy has been to enhance research activities and foster a robust research culture, positioning PNGUoT as the knowledge hub for Science and Technology within Papua New Guinea and the broader region. To support these initiatives, a funding allocation ranging from K800,000 to K1 million has been designated to strengthen research capabilities across various schools within the university. Plans were devised to advance the research agenda by hosting the Research Science and Technology Conference at PNGUoT; unfortunately, this initiative faced disruption due to COVID-19. Nonetheless, post-pandemic, research activities have thrived once again, with academic staff and students collectively publishing between 80 to 90 papers annually in indexed journals.

Recognizing the necessity for young researchers to acquire publishing skills and embrace a research-oriented culture, the Academic Board resolved to establish the Interdisciplinary Journal of Papua New Guinea University of Technology (IJPNGUoT). In July 2024, PNGUoT successfully hosted the Research Science and Technology Conference, where numerous staff, students, and researchers from various national institutions presented ongoing research findings. The presentations spanned several subject areas, including agriculture and forestry, engineering, built environment, humanities and sciences, climate change, renewable energy, and environmental studies. Manuscripts from high-impact and well-presented papers have been selected for publication in this inaugural volume of the new PNGUoT journal.

I would like to express my gratitude to the industries, government bodies, and multi- and bilateral organizations that are partnering with PNGUoT to advance research initiatives and address critical issues facing our nation. The sponsorship of research programs is significantly contributing to the academic capacity within the university. PNGUoT requires more national academics—not only to pursue higher degrees but also to consolidate knowledge precincts that will nurture specialists who become authorities in science and technology relevant to PNGs resource development agenda.

I am immensely pleased to celebrate this milestone, as PNGUoT now has its own journal to showcase the research work of our staff and students. This journal will serve as a repository for knowledge in science and technology. I firmly believe that the understanding of Papua New Guinea's resources and the technology necessary for their development should originate from research conducted within the university, thereby being preserved within this journal's archives. IJPNGUoT aims to be a pivotal reference point for knowledge regarding Papua New Guinea's resources, driving the innovation of essential technologies crucial for the nation's development.
Happy publishing!

Professor Ora Renagi OL
Vice Chancellor

Message

Deputy Vice-Chancellor

The Interdisciplinary Journal of Papua New Guinea University of Technology (IJPNGUoT) marks a significant milestone in our university's commitment to fostering innovative and collaborative research across diverse fields of study. In today's rapidly evolving academic environment, the integration of knowledge from various disciplines is essential for addressing complex global challenges.

This interdisciplinary journal is important for several reasons: First, many of the challenges we face today—such as climate change, technological advancement, law and order issues, and public health crises—cannot be solved by one field of study alone. By drawing on expertise from areas like Engineering, Natural Resources, Sciences, Environment, Business, and Humanities, the journal facilitates the cross-pollination of ideas, leading to more complete solutions.

Second, since the journal draws contributions from five different faculties at PNGUoT, it benefits from a wide variety of research topics and perspectives. This diversity ensures that the journal will always have a steady stream of submissions, making it easier to publish regularly. The breadth of research across multiple disciplines means the journal can maintain continuity and remain dynamic, enhancing its reputation for consistent output.

Third, an interdisciplinary journal promotes interaction among researchers from different fields. By providing a platform where experts in engineering, natural sciences, social sciences, business, and other areas can share their work, the journal encourages collaboration. This exchange of ideas can lead to joint research projects, cross-disciplinary insights, and stronger networks among academics at PNGUoT and beyond.

Fourth, bringing together research from different disciplines encourages the integration of ideas and approaches that might not typically be combined. This interdisciplinary approach fosters innovation, as researchers are exposed to new perspectives and methodologies. By promoting the convergence of different areas of knowledge, the journal can lead to the development of creative solutions to complex issues, driving intellectual growth within PNGUoT and contributing to broader societal advancements.

Finally, the Interdisciplinary Journal of Papua New Guinea University of Technology is committed to publishing high-quality, peer-reviewed articles that reflect the depth and breadth of research conducted at our university. By promoting interdisciplinary collaboration, we believe the journal will play a key role in advancing knowledge and contributing to the betterment of society.

As we launch this journal, I congratulate the editorial board, reviewers, and contributors who have worked tirelessly to bring this vision to life. It is essential that this journal continues to be published annually and sustained over time, as it has the potential to gain recognition as a listed journal, earning both national and international acclaim. We hope that IJPNGUoT will inspire new ideas, foster meaningful collaborations, and serve as a valuable resource for the academic community, both within Papua New Guinea and beyond.

Dr Garry Sali
Deputy Vice-Chancellor

Message

Pro Vice-Chancellor (Academic)

It is satisfying to know about launching the Interdisciplinary Journal of *Papua New Guinea University of Technology* (IJPNGUoT), a double-blind peer-reviewed publication. This journal showcases the latest and most exceptional advancements across various interdisciplinary fields, including pure & applied sciences, engineering & technology, built environment, humanities, sustainable agricultural practices, and related disciplines. The IJPNGUoT is dedicated to publishing research that explores the opportunities and challenges of interdisciplinary studies to benefit society by bridging gaps between diverse research domains.

Furthermore, the IJPNGUoT will serve as a valuable platform for the university to share scientific knowledge with stakeholders, thereby advancing our pursuit of excellence in academics, research, and innovation. I am confident that the IJPNGUoT will attract a wealth of original and impactful research from scholars worldwide, further enhancing its reputation and influence in the academic community.

I would also like to take this opportunity to extend my heartfelt thanks to the Editorial Board members for their unwavering dedication and enthusiasm in making this journal a reality. I also extend my sincere gratitude to the authors who have chosen to publish their research in the inaugural issue of IJPNGUoT. Your contributions are invaluable, and we look forward to more such collaborations in the future.
I wish the journal great success in accomplishing its mission.

Professor Shamsul Akanda, PhD

Message

Chairman of the Postgraduate Studies, Research,
and Innovation Committee (PSR&IC).

It gives me great pleasure to welcome the maiden volume of the Interdisciplinary Journal of the Papua New Guinea University of Technology (IJPNGUoT) on behalf of the PSR&IC.

This journal will give scholars of the University and elsewhere, the wonderful opportunity to communicate the results of their research and other scholarly works to a wide range of stakeholders including those in academia, governments, the private sector and the general public in Papua New Guinea and the world. The IJPNGUoT, will provide the perfect prospect, especially for early career researchers and academics in the tertiary education sector and research institutes to share their knowledge, findings, theories and ideas with their peers and the general public. The importance of this endeavor cannot be overemphasized especially for developing countries, including PNG, where there is a great need for knowledge and skills which are necessary to enhance the livelihoods of people. This is also in line with PNGUoT's ambition to become a center of excellence in research, postgraduate training, and the knowledge hub for all disciplines which are relevant to the development of PNG and the region.

I wish to sincerely thank members of the editorial team of IJPNGUoT for their dedication and the hard work they put into making this publication a reality. I hope they will continue with the task of not only maintaining the quality of the journal but to also to raise it to the highest possible level. Finally, I would also like to thank members of the PSR&IC and management of the University for allocating resources and manpower that has made it possible for this maiden issue of the journal to be produced.

Professor Gariba Danbaro
Acting Dean, Faculty of Postgraduate Studies, Research and Innovation

Editorial

The Editor-in-Chief

On behalf of the editorial board of the Interdisciplinary Journal of PNG University of Technology (IJPNGUoT), I would like to express and extend my sincere congratulations on the inaugural publication of a new double peer-reviewed open-access journal of IJPNGUoT. We are pleased to present you the first two issues of IJPNGUoT (https://interdisciplinaryjournal.unitech.ac.pg/index.php/public).
Our IJPNGUoT prefers interdisciplinary as a research methodology. IJPNGUoT attracts an interdisciplinary perspective to develop research publications from different disciplines although this journal does not limit the disciplinary research publications.

Our IJPNGUoT has the following three visions. IJPNGUoT is a university research journal covering science, engineering, technology, and humanity at a macro-level and many disciplines at a micro-level such as business, mining, and electronic engineering, mechanical engineering. It appeals to scholars from the PNG University of Technology to contribute their original research submissions to IJPNGUoT to realize the vision and mission of the university's strategic plan.

IJPNGUoT is a PNG journal and then an Oceanic journal. It appeals to the contribution from the PNG and Oceanic researchers and scholars to promote the socio-economic-technological development in this region.
IJPNGUoT is an international journal. It appeals to the manuscript submissions from researchers and scholars in the world to contribute original, creative, and innovative research and development in the unknown world because the journal ignores the distance and time zone through online paper submissions, reviews, and publications.
IJPNGUoT will release 2 issues yearly from 2024 on. It publishes original and scholarly work covering a range of topics about disciplines of science, technology, engineering, computing, business and management, and human sciences from a variety of intellectual perspectives.

We are aware of the ever-growing number of scientific journals and web-based sources of information and knowledge in the field of multidiscipline; however, we are very positive that there is a need for this particular journal in the region: a high-quality publication of multidisciplinary information, knowledge, and advances in the multidisciplinary field. I am sure that the IJPNGUoT will significantly contribute to the multidisciplinary research; and will help in improving understanding and knowledge of the nature among our scholars and readers. I hope that IJPNGUoT will allow everyone to share information and knowledge of all disciplines and learn from one another in the ever-growing competitive world.

I thank the founding executive editor, editors, and Editorial Board members for their hard work and dedication to the IJPNGUoT. It is great coordination, collaboration, cooperation, enthusiasm, and spirit of the well-known international and national editorial board members that made and will make IJPNGUoT a great success!
A Chinese proverb tells us "A journey of a thousand miles begins with a single step". Therefore, let's work together using our collective intelligence to make our Interdisciplinary Journal of Papua New Guinea University of Technology to become an excellent one in the world.

Prof. Dr. Zhaohao Sun, PhD
Editor-in-Chief of Interdisciplinary Journal of Papua New Guinea University of Technology

Message

Executive Editor

Welcome to the inaugural issue of the *Interdisciplinary Journal of Papua New Guinea University of Technology-IJPNGUoT.* In today's rapidly evolving world, the boundaries between disciplines are increasingly hazy and the most unrelenting challenge we face - whether in health, technology, environment, or social sciences – is the demand of innovative solutions that resort to multiple areas of expertise. *IJPNGUoT*, aims to be at the forefront providing a space where researchers, engineers, agriculturists and social scientists can share insights, debate ideas, and inspire one another.

This first issue features a range of articles that exemplify the breadth and depth of interdisciplinary research. We are committed to maintaining the highest possible standards of academic rigor and integrity. Our double-blind peer-review process ensures that each submission is evaluated by experts from relevant fields, ensuring that the research we publish is both credible and impactful.

As we embark on this exciting journey, I invite you to join us in exploring the intersections what are possible and make meaningful contributions to the global academic and scientific community.
Thank you for your support and engagement.

Sincerely,

Prof Jojo Panakal John
Executive Editor

Editorial board

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3. **Basic Sciences (Applied Physics, Applied Sciences, Mathematics, etc.)**

4. **Arts and Humanities (DBS, CDS)**

5. **Built Environment (Architecture and Construction Management, Surveying and Land Studies)**

In this Issue:

Validation of Turbulent Flow in a Two-Stroke Grail Engine Cylinder

[1]Shoeb Ahmed Syed*, [2]Peter O. Oyekola

[1]School of Mechanical Engineering, Papua New Guinea University of Technology
Lae, Papua New Guinea
[2]Department of Mechanical Engineering, Tennessee Tech University
Cookeville, TN 38505, USA

*Corresponding author Email: shoeb.syed@pnguot.ac.pg

Abstract: The validation of results obtained from a static computational fluid dynamics (CFD) simulation of a state-of-the-art hybrid two-stroke Grail internal combustion engine design to analyze the effects of the intake hole and channel shape on in-cylinder flow turbulence is presented in this research. The turbulent flow dynamics within the cylinder have a significant impact on combustion efficiency and pollution production in an internal combustion engine. Turbulent kinetic energy (TKE) is almost entirely generated during the in-take stroke in most engines. This considerably improves the mixture of fuel and air during the compression stage, resulting in better mixing. Therefore, in the current investigation, a considerable effort was made to focus on analyzing the effects of the intake hole, the duct shapes of the Grail engine on the in-cylinder flow dynamics. The analysis of the Grail Engine design flow field using Autodesk CFD software has produced promising results. A violent tornado-like effect is seen in the flow field. The swirl effect of the flow was observed with a single vortex located at the cylinder's axis. The Grail Engine's resulting flow field will provide an ideal homogeneous/stoichiometric fuel-air combination for increased combustion efficiency. The result of 3-D static simulations of the flow through the engine had provided guidelines on selection of several geometrical parameters for optimal performance. The values of velocity profiles and the velocity vector contours obtained from the numerical simulation are well within the limits obtained from the references.

Keywords: Grail Engine, Internal Combustion, Fluid Flow, Turbulence.

1. Introduction

While Internal combustion (IC) engines play a major role in the automotive industry today due to its physical size, economics as well as reliability. However, in understanding the operation parameters which affects system efficiency such as flow characteristics (turbulence in particular), theoretical experimental and practical analysis becomes imperative. However, several obstacles and challenges are associated with a thorough analysis of this factors given that turbulence is a fundamental physical condition which is critical in the enhancement of reliable and cleaner combustion engines. Because the in-cylinder flow pattern has such a large impact on the performance of IC engines, it's vital to numerically validate the flow field so that it can be compared to experimental data in order to improve and alter engine design for maximum performance.

IC engines remains significant despite the increasing popularity of electric vehicles which only accounts for an estimate of 2% of total automobile sale as well as 0.5% of global fleet [1]. While the increasing popularity of the electric automobiles have been primarily due to pollution concerns, intensive research efforts have been applied in reducing the impact of pollution caused by the IC engines in practical applications. Negative consequences such as the emission of carbon monoxide, unburnt hydrocarbons as well as nitrogen oxide which tends to be emitted from IC engines have been significantly reduced. However, there is still possibilities of further efficiency given the large amount of IC engines in service across a wide range of fields of which electronic systems cannot be substituted.

The shape, position, orientation of components such as the valve when combined with the cylinder head design will determine the flow pattern i.e., tumble or swirl within the cylinder [2, 3, 4]. This is further influenced by the injection mechanism, air-fuel mixing ratio, piston position etc. During the engine intake stroke, the valve allows high stream jets of air-fuel mix into the cylinder which generates swirls flow where

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the fluid angular velocity goes around the axis of the cylinder. Tumble flow, on the other hand, follows an axis that runs parallel to the cylinder axis. Better understanding of this flow pattern has previously been investigated using steady swirl test rigs in the cylinder. This also aid in the improvement of combustion chamber design of IC engines such as homogeneous-charged compression ignition (HCCI) engines, gasoline direct injection (GDI) engines, and so on.

According to Heywood [3] experimental study, tumble and swirl vortices which are formed during the intake stroke of the engine is the factor which initiates high turbulence towards the compression stroke which in turns leads to higher combustion efficiency. Similar studies have implemented the particle image velocimetry (PIV) technique to investigate cylinder mixing pattern to estimate the angular velocity and intensity of turbulent flows in premixed charge compression ignition (PCCI) engine [4], cylinder tumble flow in IC engine operating at variable speed for the duration of the intake and compression stroke of the engine [5]. This is because the PIV methodology is a non-intrusive technique which is capable of determining multiple velocity components in both two and three dimensions.

Reynolds Averaged Navier Stokes (RANS) have also been used in analyzing and optimizing engine geometry as it provides a mean quantity of values at a relatively low computational cost. However, it is not capable of detailing information on the individual cycle as opposed to the large eddy simulation (LES), which details underlying small scales however at the expense of higher computational resources [6, 7].

There are different methods to the adaptation of the PIV technique in engine performance analysis depending on the quantity of interest for instance when analyzing a system with one exposure per cycle, then the regular low repetition rate PIV is utilized [8, 9, 10, 11, 12]. This have been used in the analyses of spatial flow structures in the characterization of turbulent properties [13, 14]. The volumetric instantaneous flow field have also been investigated using the tomographic PIV and holographic PIV in assessing the overall strain tensor and vorticity vector in the cylinder [15, 16, 17, 18, 19]. The goal of this research is to conduct a CFD simulation of the flow dynamics and turbulence efficiency of a single-cylinder two-stroke Grail engine to aid Grail Engine Technologies' ongoing design efforts. This CFD analysis involves static and dynamic mesh simulations of flow inside the intake valve and its channels to determine the best shapes for these regions to generate enough turbulent kinetic energy (TKE) within the cylinder and increase engine performance.

2. Grail Engine Technology

The Grail engine used in this study is a unique two stroke engine which features a unique configuration and design characteristics as compared to the commercially available models. As seen in the figure 1, the major components are the single intake valve which sits on the piston head, exhaust valve centralized on top of the cylinder head surrounded by three ignition sparkplugs and a single fuel injector. There are also two intake tube channels on opposing side of the piston port with intake tunes attached.

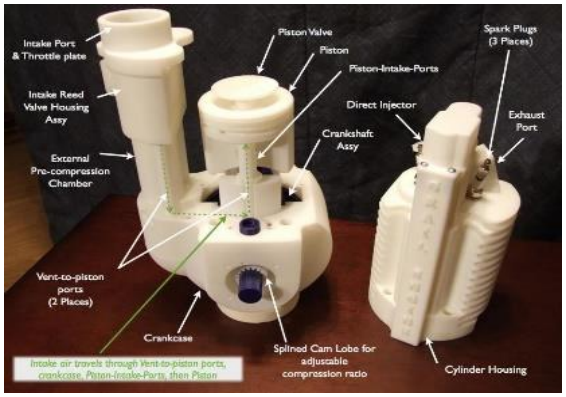

Fig. 1. Parts of Grail engine model [1]

Because of the design's uniqueness, when the piston moves upward, a vacuum is created in the tube channels, allowing fresh air to charge the tube through the one-way reed valve after fuel injection in the combustion chamber during the compression stroke. The air-fuel mixture is ignited by the three sparkplugs. The resulting explosion pushes the piston downwards, creating compression pressure in the tube channel, which forces fresh air into the combustion chamber while wasted gases are evacuated from the exhaust valve at the cylinder's top.

This cycle introduced the Grail cycle, which is a hybrid of homogeneous-charged compression ignition and forced semi-homogeneous-charged compression ignition that works in tandem with the Miller cycle (FS-HCCI). his means that in this engine architecture, there is no cross contamination of fuel and air, thereby reducing emissions while providing great power and torque with significantly less fuel than conventional IC engines. The engine is also designed to operate using multiple fuel type, variable compression ratio and thus can boast of better efficiency as well as higher mileage projection.

3. Cylinder Fluid Flow

Different flow characteristics are exhibited in the grail engine at different cycle stages. During the intake stroke, air flows inside the cylinder from the inlet valve in the form of a jet whose flow depends on the design characteristics such as geometry of the ports, location, valves, timing etc. the incoming jet fluid flow energy creates flow structures featuring large scale turbulence in the cylinder in the form of swirl flow which rotates round the cylinders axis or tumble flow characterized by a flow pattern perpendicular to the axis of the cylinder as in figure 2. This accelerates the transport phenomenon as well as spread the air-fuel mixture withing the cylinder uniformly.

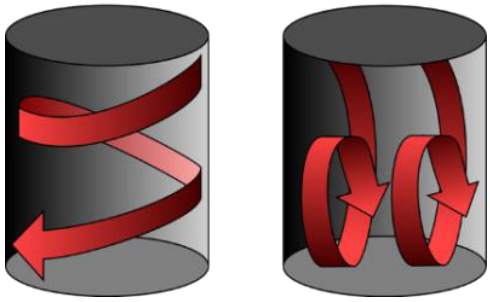

Fig. 2. Swirl and tumble flow structures [3, 19]

Most of the turbulence is further diminished due to fluid viscosity at the second phase of the intake stroke. The compression strike of the piston increases the density which changes the turbulence length scale of the flow which increases the turbulence despite continual presence of viscous decay. This turbulence is minimal at the end of the exhaust stroke.

4. Numerical Methodology

Modelling fluid turbulence analytically is quite tasking especially when analyzing practical problems. Simulations and computer aided tools are then applied in solving the governing equations. Due to the limits of high computational needs when using the direct numerical simulation (DNS) method in IC applications, RANS and large eddy simulation (LES) have been used [20]. Typically, the mesh required in modelling the RANS model is capable of capturing up to 85-90% of the fluid global characteristics and kinetic energy [21] and was applied in this study using the Autodesk CFD simulation solver based on the standard K-ε model [22]. The operating conditions and specifications of the Grail engine model are listed in Table 1.

The compressible flow Navier-Stokes's equations were solved by applying the implicit segregated solver as well as the monotone streamline upwind scheme governing the in-cylinder flow.

The governing PDEs are shown below [23]-[24]:

Continuity equation: $\nabla.(\rho V) = 0$ (1)

Momentum equation: $\rho(V.\nabla V) = \rho g - \nabla P + (\mu + \mu_t)\nabla^2 V + S_\omega + S_{DR}$ (2)

Energy equation: $\rho C_p(V.\nabla T) = (k + k_t)\nabla^2 T + q_V$ (3)

Table 1. Engine Specification for CFD Analysis

Engine Parameters	Unit	Value	Engine Parameters	Unit	Value
Cylinders	-	1	Connecting rod length	(in)	5
Engine Type	-	two-stroke	Crank radius	(in)	1.5
Displacement Volume	(in^3)	36.08644844	Compression ratio	-	15.06
Bore	(in)	3.8	Max intake valve lift	(in)	0.25
Stroke	(in)	3	Max exhaust valve lift	(in)	0.25

For driven flow, the cylinder walls had a no-slip boundary condition, and the intake and outflow pressures were 10 and 0 psig, respectively. The default simulation variables were utilized to calculate the tangential velocity component in terms of translational and rotational motion of the boundary walls, while the solid viscous surfaces were subjected to an adiabatic temperature condition and a zero-pressure gradient. A SIMPLE-R algorithm was implemented as the segregation solver and the finite alement Galerkin's weighted residual method was applied on the diffusion and source terms.

5. Results and Discussions

Given that Autodesk CFD finite element solver is new to IC engine applications, such as the Grail engine, it is required to determine the solver's current applicability to an IC engine and to validate the solver using published experimental models. Accordingly, two flow validation model is considered in this paper. The work presented here is part of my PhD thesis [25]. The two validation models are shown in Figure 3.

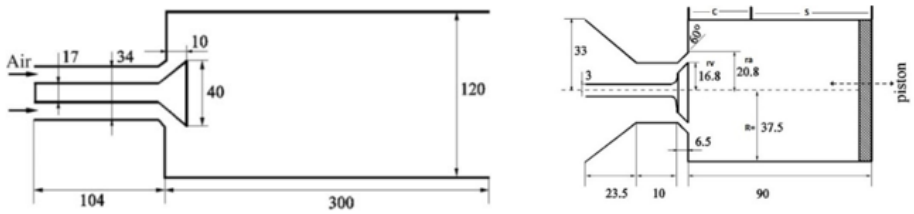

Fig. 3. Validation model 1 and 2 geometrical details (dimensions in mm) [26, 28]

An axis-symmetric rapid expansion with a stationary valve is used in validation model 1. The downstream pipe's diameter is 3.5 times that of the upstream pipe. With a Reynolds number of 30,000, a constant mass flow rate of 0.05 kg/sec is provided at the input. The results are validated by comparing them to Grosjean et al experimental LDA measurement data [26]. The RANS flow equations are solved using the Autodesk finite element solver. These calculations are carried out on a full three-dimensional (3-D) unstructured mesh with 4.1 million components using the Autodesk standard k-ε turbulence model.

Figure 4 shows two-dimensional (2-D) mesh slices for the validation model and the boundary-layer elements near the intake valve, respectively. The mesh is grouped at the valve head, as seen, in order to properly model the vortices while limiting CPU time. Boundary-layer elements near the wall and unstructured tetrahedral elements away from the wall make up the mesh. The region around the valve is fine-tuned using three levels of Autodesk's auto-gradation mesh technology. The wall function is used to compute the distance between the wall and the stresses that occur near the wall.

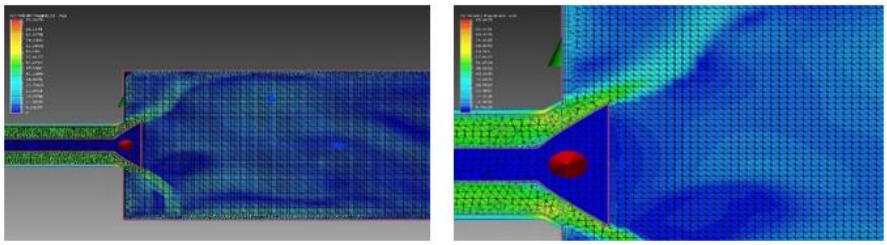

Fig. 4. 2-D slice of mesh for validation model 1

During the intake stroke of a typical IC engine, large-scale vorticial fluid motion arises downstream of the intake valve. Turbulence is created by the vorticial motions created during the intake stroke, which aids in greater fuel-air mixing and combustion efficiency in the later phases of the engine's operation. The effectiveness of the Autodesk CFD solver to capture these vortices in the sudden-expansion geometry is assessed using this model. Figures 5 and 6 illustrate axial mean velocity and root mean square (RMS) velocity profiles from the cylinder head at z = 20 mm and z = 70 mm, respectively. When the RANS simulation results are compared to the LDA measurements of Grosjean et al. [26], they indicate that the RANS and LDA data are in good agreement. RANS is superior at predicting the peaks of axial mean velocities at both axial sites due to valve jet breakdown. RANS simulations capture the steep peaks of fluctuations (RMS velocities) reasonably effectively.

The peaks are slightly dispersed, and the peak's position is slightly shifted. The wall model utilized in the Autodesk finite element solver is to blame for the disparity between numerical and experimental results in the region near to the cylinder wall.

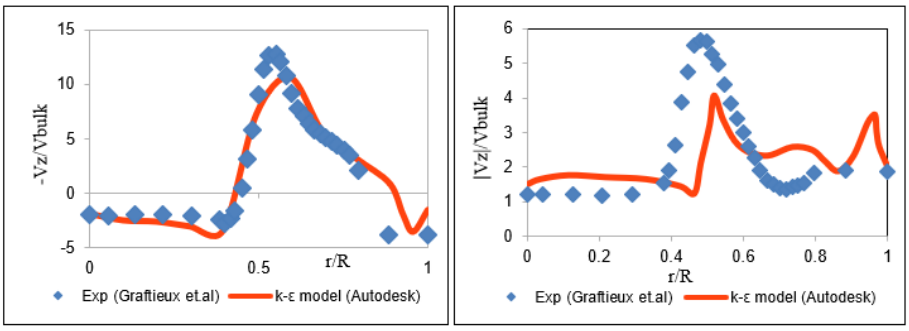

Fig. 5. Validation Model 1 Axial Velocity Profiles at z = 20 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

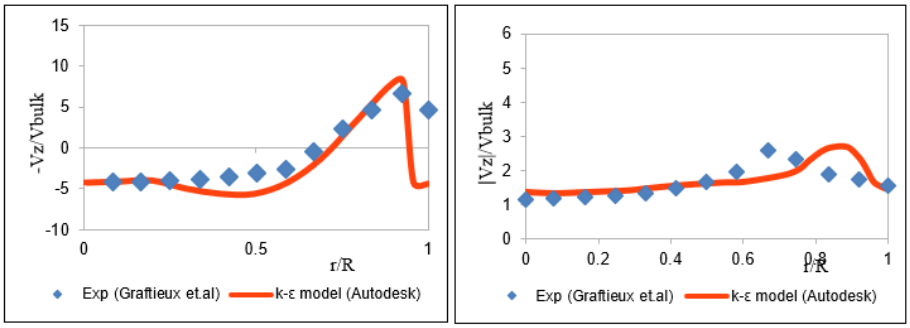

Fig. 6. Validation Model 1 Axial Velocity Profiles at z = 70 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

The velocity vector contour plot in Figure 7(a) confirms the creation of large-scale vorticial fluid motions downstream of the valve and in the cylinder head and cylinder wall corners. The accelerating fluid jet enters the cylinder and collides with the walls, splitting the flow into three zones. The wake-like flow structures are created by the vortices that develop at the corners of the cylinder near the head on either side, and the reflected section near the wall.

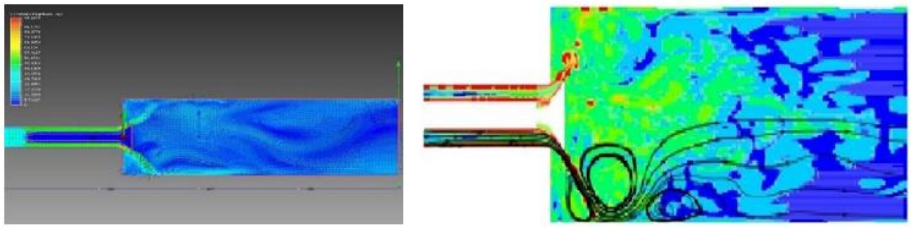

Fig. 7 (a) Validation Model Velocity vector contour-plot (b) Streamline flow structures [27]

The flow structures reported by Banaeizadeh et al. [27] are illustrated in Figure 7(b), which corresponds to the velocity vector contour plot shown in Figure 7(a) from the current simulation. Figure 8 depicts the validation model 2, which is a simple piston-cylinder arrangement with a stationary open valve. The chosen flow was ideal for deciphering in-cylinder flow dynamics and evaluating the Autodesk CFD solver technique in complex geometries with shifting boundaries and turbulence model capabilities to capture turbulence. With a low RPM of 200, the model has a stationary open valve with the piston moving in simple harmonic motion. Based on the cylinder diameter and piston action, the flow Reynolds number is 2000. The non-dimensional velocity profile in the data is plotted using the calculated mean piston velocity (Vp) of 0.4 m/sec. The experimental data was available for the numerical results to be validated. Morse et al. [28] used LDA to measure phase-averaged mean and rms radial profiles of axial velocity at 10 mm increments starting from the cylinder head for crank angles 36 deg and 144 deg after top dead center for crank angles 36 deg and 144 deg after top dead center for crank angles 36 deg and (ATDC).

Validation model 2 was simulated using a 3-D unstructured mesh with 6.6 million elements. Figures 8 illustrate 2-D mesh slices showing the clustered mesh region surrounding the valve and piston. Because the model includes a moving piston, Autodesk CFD's moving mesh techniques are used in the simulation. To perceive the interaction between a moving solid and the fluid in its path, the mesh density of the solid and the fluid in its path must be dense enough. The piston surface mesh size is 0.09, while the fluid mesh size is 0.1, yielding a mesh of 6.6 million elements. In the region of the valve and the piston, the wall function is used, resulting in a wall y+ value of 30.

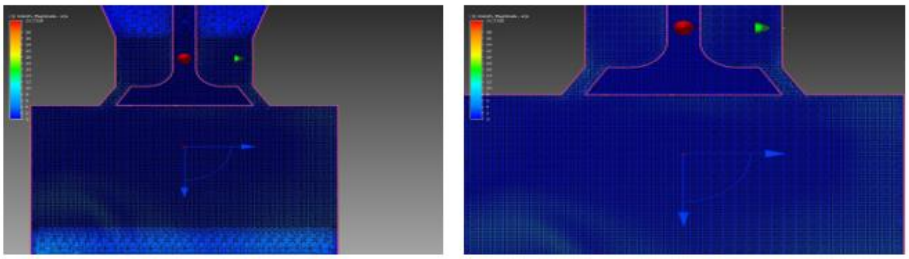

Fig. 8. Validation Model 2 2-D Slice Mesh

The governing equations are discretized using a segregated finite element solver. To solve governing equations, the RANS model is used. To provide a converged solution, a time step of 0.001 seconds was chosen with 10 internal iterations. The ideal gas model was used to model air. The advection term is discretized using the ADV1 technique, which is more numerically stable. A constant static atmospheric pressure is applied to the model's intake as a boundary condition. Solid walls are adiabatic, which means they don't slip. The piston was programmed to move in a linear motion at 200 RPM.

Figures 9–11 illustrate the comparison of numerical and experimental mean and rms radial profiles of axial velocity at 36 degrees after top dead center (TDC) at z = 10 mm, z = 20 mm, and z = 30 mm from the cylinder head, respectively. The numerical results are in good agreement with Morse et al experimental data [28]. The RANS model is clearly better at predicting mean profiles, as seen in the Figures. The rms profiles, on the other hand, are quite well captured by the model. Because of the more dissipative nature of the turbulence model, which tends to smooth out all velocity gradients, the peaks of rms profiles are a little flat. Figures 12 to 14 show the identical profiles as Figures 9 to 11 but with a crank angle of 144 degrees after TDC, with excellent results. At different crank angles, the profiles have the same level of agreement. One thing to keep in mind is that the flow varies significantly from cycle to cycle, and this change in velocity profiles should be considered.

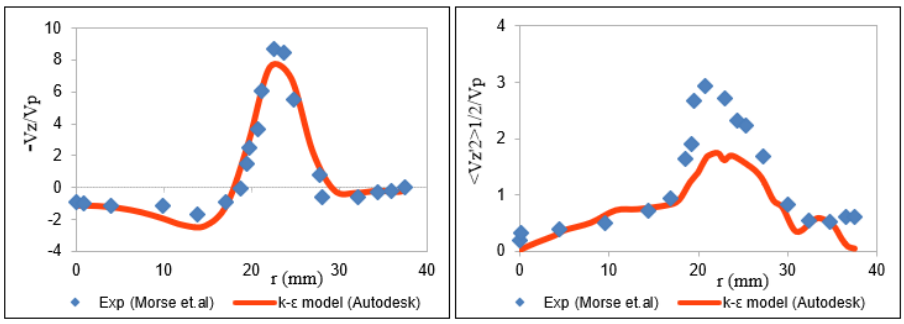

Fig. 9. Validation Model 2 Velocity Profiles for 36^0 CA at z = 10 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

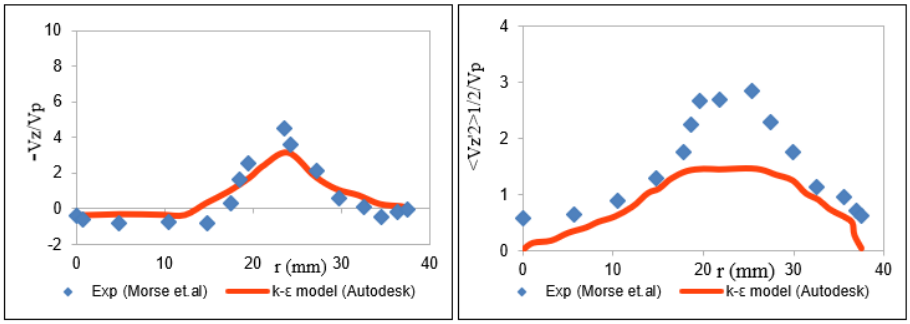

Fig. 10. Validation Model 2 Velocity Profiles for 36^0 CA at z = 20 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

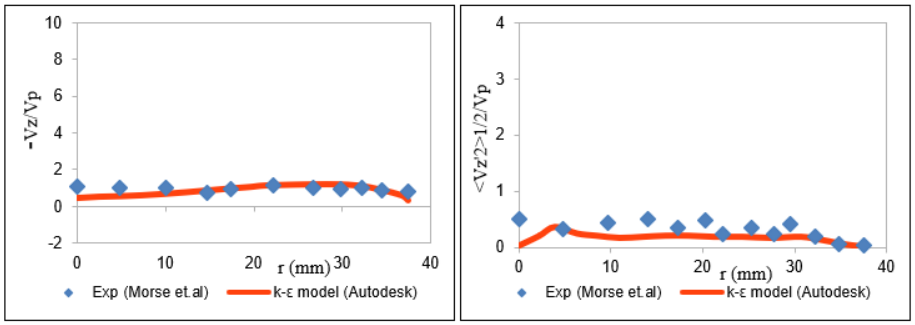

Fig. 11. Validation Model 2 Velocity Profiles for 36^0 CA at z = 10 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

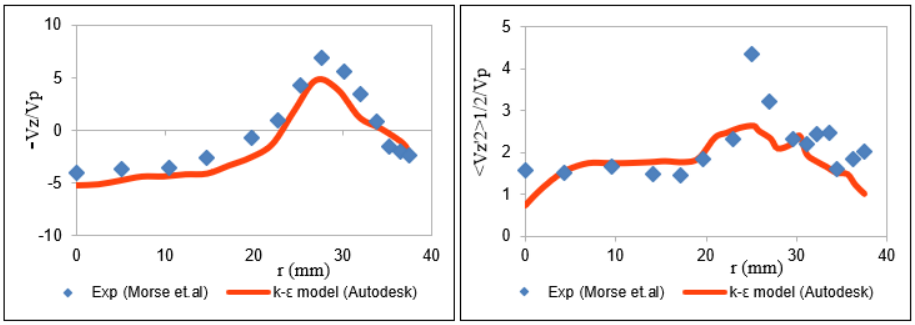

Fig. 12. Validation Model 2 Velocity Profiles for 144^0 CA at z = 10 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

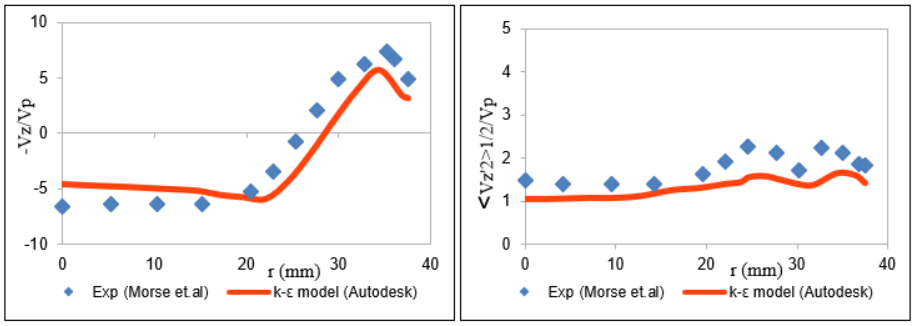

Fig. 13. Validation Model 2 Velocity Profiles for 144^0 CA at z = 20 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

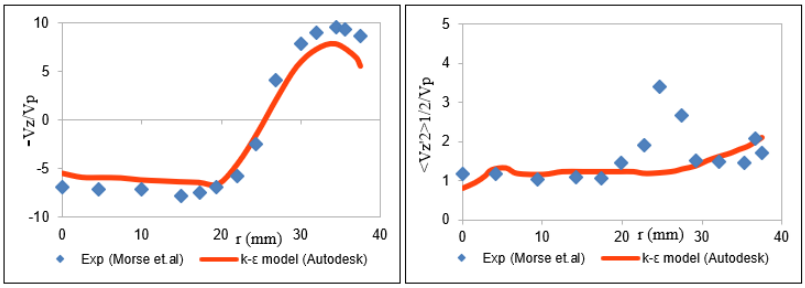

Fig. 14. Validation Model 2 Velocity Profiles for 1440 CA at z = 30 mm (a) Mean Axial Velocity (b) RMS Axial Velocity

Jet enters the cylinder through the annular gap between the valve and the cylinder head as the piston descends. Due to viscous factors, this high-speed jet impinges on the side of the cylinder wall, separating the flow into vorticial flow structures. The vortices, which grow in size as the piston moves down, entirely dominate the flow. Figure 16 displays velocity vector graphs obtained from the RANS model at crank angles of 90 degrees and 180 degrees, respectively, demonstrating the same behavior. Figures 16 and 17 compare these figures to the large Eddy simulation (LES) of the same model at the same crank angles performed by Verzicco et al. [29]. The flow structures in both simulations are similar, with the exception that the LES simulation has more tiny flow structures, as expected.

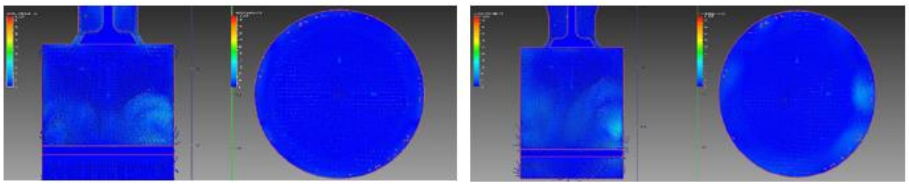

Fig. 15. Validation Model 2 RANS Velocity Vector Contour Plot at 90 and 180 degrees, respectively

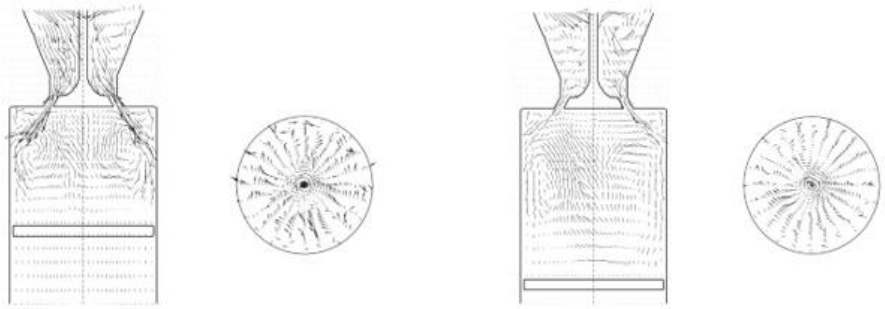

Fig. 16. Validation Model 2 LES Velocity Vector Contour Plot at 90 and 180 degrees, respectively [29]

6. Conclusion and Recommendation

This paper presents the static CFD simulation of the inflow In-cylinder flow dynamics of the Grail engine by a comparative analysis of two different model of flow which were based on flow round a fixed intake valve and a piston cylinder assembly with a top mounted fixed open valve. The result of the simulation aligns with the results obtained from experimental data. The paper focused on the initial static analysis of the Grail engine. From the CFD analysis, it was concluded that the optimal design of the piston will be a rectangular hole as well as a D-tube configuration. Furthermore, the efficiency determination criterion was based on the combination of all characteristics i.e., intake swirl flow, minimum drop in pressure in channel flow as well as an ideal mass flow rate within the cylinder.

Lastly, it is recommended in the later part of research to add in the dynamic simulation and as well as to use LES simulation model to validate the turbulent kinetic energy and the turbulence in the engine.

References

1. Global E V Outlook 2020 – Analysis - IEA. https://www.iea.org/reports/global-ev-outlook-2020 (accessed May 15, 2021).
2. Murali Krishna, B., Bijucherian, A., Mallikarjuna, J. M.: Effect of intake manifold inclination on intake valve flow characteristics of a single cylinder engine using particle image velocimetry, World Acad. Sci. Eng. Technol. (2010).
3. Heywood, John B.: Internal Combustion Engine Fundamentals. 2nd ed. New York: McGraw-Hill Education. https://www.accessengineeringlibrary.com/content/book/9781260116106 (2018)
4. Zegers, R.R., Meyden, V.D., Luijten, C.C., Dam, N.N., Baert, R.R., Goey, D.: Crank angle resolved flow field characterization of a Heavy-Duty (PCCI) Engine (2009)
5. MuraliKrishna, B., Mallikarjuna, J. M. : Effect of engine speed on in-cylinder tumble flows in a motored internal combustion engine - An experimental investigation using particle image velocimetry, J. Appl. Fluid Mech. (2011) doi: 10.36884/jafm.4.01.11895.
6. Irannejad, A., Banaeizadeh, A., Jaberi, F : Large eddy simulation of turbulent spray combustion, Combust. Flame (2015). doi: 10.1016/j.combustflame.2014.07.029.
7. Fox, R. O.: Large-eddy-simulation tools for multiphase flows, Annu. Rev. Fluid Mech. (2011) doi: 10.1146/annurev-fluid-120710-101118.
8. Lacour, C., Pera, C.: An Experimental Database Dedicated to the Study and Modelling of Cyclic Variability in Spark-Ignition Engines with LES," SAE Technical Paper 2011-01-1282 (2011) https://doi.org/10.4271/2011-01-1282.
9. Agarwal, A. K., Gadekar, S, Singh, A. P.: In-cylinder air-flow characteristics of different intake port geometries using tomographic PIV," Physics of Fluids, vol. 29, no. 9, p. 095104 (2017).
10. Richard, S., Dulbecco, A., Angelberger, C., Truffin, K.: Development of a one-dimensional computational fluid dynamics modeling approach to predict cycle-to-cycle variability in spark-ignition engines based on physical understanding acquired from large-eddy simulation, Int. J. Engine Res. (2015) doi: 10.1177/1468087414560592.
11. Robert, A., Truffin, K., Iafrate, N., Jay, S., Colin, O., Angelberger, C. : Large-eddy simulation analysis of knock in a direct injection spark ignition engine, Int. J. Engine Res. (2019), doi: 10.1177/1468087418796323.
12. Sofianopoulos, A., Rahimi Boldaji, M., Lawler, B, Mamalis, S.: Investigation of thermal stratification in premixed homogeneous charge compression ignition engines: A Large Eddy Simulation study, Int. J. Engine Res. (2019)
doi: 10.1177/1468087418795525.
13. Bücker, I., Karhoff, D. C., Klaas, M, Schröder, W.: Stereoscopic multi-planar PIV measurements of in-cylinder tumbling flow, Exp. Fluids (2012) doi: 10.1007/s00348-012-1402-5.
14. Dannemann, J., Pielhop, K., Klaas, M., Schröder, M.: Cycle resolved multi-planar flow measurements in a four-valve combustion engine (2011) doi: 10.1007/s00348-010-0963-4.
15. Baum, E., Peterson, B., Surmann, C., Michaelis, D., Böhm, B., Dreizler, A.: Investigation of the 3D flow field in an IC engine using tomographic PIV, Proc. Combust. Inst., (2013) doi: 10.1016/j.proci.2012.06.123.
16. Peterson, B., Baum, E., Ding, C. P., Michaelis, D., Dreizler, A., Böhm, B.: Assessment and application of tomographic PIV for the spray-induced flow in an IC engine, Proc. Combust. Inst., (2017) doi: 10.1016/j.proci.2016.06.114.
17. Buchmann, N. A., Atkinson, C., Jeremy, M. C., Soria, J.: Tomographic particle image velocimetry investigation of the flow in a modeled human carotid artery bifurcation (2011) doi: 10.1007/s00348-011-1042-1.

18. Zentgraf, F., Baum, E., Böhm, B., Dreizler, A., Peterson, B.: Analysis of the turbulent in-cylinder flow in an IC engine using tomographic and planar PIV measurements, 17th Int. Symp. Appl. Laser Tech. to Fluid Mech. (2014).
19. Gadekar, S., Singh, A. P., Agarwal, A. K.: Tomographic PIV Evaluation of In-Cylinder Flow Evolution and Effect of Engine Speed (2016) doi: 10.4271/2016-01-0638.
20. Sirignano, W. A. : Volume averaging for the analysis of turbulent spray flows, Int. J. Multiph. Flow (2005), doi: 10.1016/j.ijmultiphaseflow.2005.02.005.
21. EL TAHRY S., HAWORTH, D.: Directions in turbulence modeling for in-cylinder flows in reciprocating engines (1991) doi: 10.2514/6.1991-516.
22. Launder B. E., Spalding, D. B.: The numerical computation of turbulent flows, Comput. Methods Appl. Mech. Eng. (1974) doi: 10.1016/0045-7825(74)90029-2.
23. Discretization Method | CFD | Autodesk Knowledge Network. https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2014/ENU/SimCFD/files/GUID-DEE0664D-771B-4446-9ED4-1498267D13FB-htm.html (accessed Apr. 25, (2021).
24. General Fluid Flow and Heat Transfer Equations | CFD Autodesk Knowledge Network.https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2014/ENU/SimCFD/files/GUID-83A92AE5-0E9E-4E2D-B61F-64B3696E5F66-htm.html (accessed Apr. 25, 2021).
25. Syed, S. A.: Numerical simulation of turbulent flow inside the cylinder of a new two-stroke grail engine design, PhD Thesis, Wichita State University (2015).
26. Grosjean, N., Graftieaux, L., Michard, M., Hübner, W., Tropea, C., Volkert, J.: Combining LDA and PIV for turbulence measurements in unsteady swirling flows, Meas. Sci. Technol. (1997), doi: 10.1088/0957-0233/8/12/015.
27. Banaeizadeh, A., Afshari, A., Schock, H., Jaberi, F.: Large-eddy simulations of turbulent flows in internal combustion engines, Int. J. Heat Mass Transf. (2013) doi: 10.1016/j.ijheatmasstransfer.2012.12.065.
28. Morse, A. P., Whitelaw, J. H., Yianneskis, M.: Turbulent flow measurements by laser-doppler anemometry in motored piston-cylinder assemblies, J. Fluids Eng. Trans. ASME (1979) doi: 10.1115/1.3448937.
29. Mohd-Yusof, J., Orlandi, Paolo, Haworth, D.: LES in complex geometries using boundary body forces". Proceedings of the Summer Program (1998).

Advanced Condition Monitoring Practices for Improving Plant Reliability

Granville Embia, *Kamalakanta Muduli, Shoeb Ahmed Syed

School of Mechanical Engineering, Papua New Guinea University of Technology,
Lae 411, Papua New Guinea

*Corresponding author: kamalakanta.muduli@pnguot.ac.pg

Abstract: The paper's objectives are to examine the application of state-of-the-art statistical methods and artificial intelligence in monitoring of vital assets to offer timely intervention in case of failures and enhance maintenance procedures. Moreover, this research also intends to assess the effectiveness of Fast Fourier Transform and Wavelet Transform tools in determining the health condition of rotating machinery and also in diagnosing early mechanical faults. Following data preprocessing, a model is developed which can then be used for the prognosis of subsequent failures and their assessments pertaining to your maintenance planning. In "Prediction" cluster, predictions to future failure based on outputs attained from the set model are made. 'Visualization' is one of the clusters that show how maintenance distribution can be represented besides showing how one can forecast the next failure. As shown in this research, it provides a structure to the planning and scheduling of maintenance work orders by the generation and display of graphical representations derived from sensor data, thereby improving outcomes of operational reliability and cost in industrialized environments. This research provides a comprehensive analysis of the use of predictive maintenance practices of a manufacturing environment. This paper discusses the use of these methods in combination with the real-time monitoring of sensors and methods of detecting anomalies. This paper discusses the ability of machine learning algorithm like the Random Forest classifiers for supporting the prediction of equipment failures from the sensors data. Therefore, this research will give more insight into the use of predictive maintenance systems and how they can be used to maximize the performance of the equipment and also increase the useful life of the assets.

Keywords: Random forest classifier, Real time data analysis, Anomaly detection, Condition based maintenance strategies

1. Introduction

The highly volatile energy sector offers the gas turbine industry a litany of problems that include the need for flexibility, lower operating costs, reliability and environmental considerations. There is therefore this big focus on the innovation especially when organization are privatizing and competing intensely. These imperatives call for engine health assessment, diagnostic and prognostic systems [1]. From the current trends, it is clear that monitoring of engine performance has been accorded a lot of attention. This paper is a comprehensive review on the type of development focusing on the evolution of performance monitoring, a review on how to enhance dataset and a review on the use of computational intelligence in improving the efficiency of fault diagnosis [1]. It also focuses on the advancements in prognosis approaches that have been made in the recent past with an emphasis on enhancing maintenance decision making. Thus, this paper uses prior literature with emerging views on what might be in the future. According to Tahan et al., the authors of the paper intend to acquaint the stakeholders in gas turbine related field with the knowledge that is required in strategizing or planning for the future or to give foundation for the subsequent research.

Specifically, the development of super thermal power plant has been quite significant over the years primarily driven by the desire for better economic outlook. Nevertheless, it should be noted that there is an equivalent growth of plant complexity together with the designed capacity which in turn raises the probability of system failure. These are the types of flaws that need to be discovered as soon as possible in order to avoid massive catastrophes and to allow for flawless maintenance. In this regard, condition monitoring

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assumes great importance, thus applying advanced diagnostic techniques such as vibration analysis and oil analysis that assist to diagnose likely future issues with industrial gears. This paper aims to identify whether such complex techniques are useful in revealing problems at an early stage so that corrective and preventive actions can be taken leading to enhanced system dependability. The general application of condition monitoring techniques in many industries underlines as to how useful it is to have them as an extra back up to normal maintenance methods. Failure Mode, Effect, and Criticality Analysis (FMECA) is an improved procedure which determines the criticality of a plant component based on probable failure modes and their related risks accompanied by their implications on operational performance. For enhancing the efficiency of a super thermal power plant and to make its operation more robust, the FMECA approach is applied here to identify the essential pieces of equipment in correlation with a variety of condition monitoring techniques [2]. Due to the emergent applications of wind energy, it becomes necessary to see the reliability of wind turbine; however, there is a conspicuous absence of the reliability data in public domains. In response to this, this work does a review of thirteen reliability studies with available literature and with differing methodology and findings.

The continual advancement of large scale industrial systems in glob environment of Industry 4. 0 also goes on to show how paramount it is to also solve safety and reliability problems. The emergence of online operations raises an urgent concern: the implied consequences of degrading system performance that range from financial losses to significant safety risks. While modern fault diagnostic systems are capable to identify the presence of faults and the root of these faults, there is a huge gap when it comes to quantifying when and whether corrective actions are required and defining what level of tolerance to faults is required, what maintenance is required and how should fault recovery be performed.

This requires a further examination of how these identified morphological faults influence overall plant performance. This paper looks at how traditional performance measures, new performance measurement techniques, and improved process control mechanisms in helping in giving a more complete picture of the operating situation of the plant. It basically shows a direction map for the advancement of industrial systems in the posterity, especially during the advanced technologies, defines some critical research questions, and shows research directions [3]. Thus, the equipment's availability, reliability and maintainability, operating and service experience as power plant nuclear, hydraulic, and thermal equipment is described by long operating cycles; low demands for maintenance and higher costs for repairs due to equipment failures. One can identify that regular monitoring of the important pieces of equipment, which are in service, is quite possible to manage meaning that failure occurrences in the future will not significantly bring down the performance of the units which are already functional.

There is a constant pressure on decreasing the costs of operation and maintenance resulting in increased interest in Condition Based Monitoring (CBM) of Induction Motors (Ims). Regular tour increases chances of discovering early sign of motor degradation, a situation that can be addressed adequately to minimize avert unplanned system shut down and malfunctions. To the engineers and researcher operating in different industrial sectors such as mining, oil and gas extraction industries, rail roads, industrial drives and agriculture, CBM has become one of the significant projects. Therefore, understanding this study offers a comprehensive review of the other advanced sophisticated diagnostic methods which are useful in the identification of various forms of IM defects. Different kinds of monitoring methodologies used in diagnosing IM faults are briefly described with emphasis on the applications of each. The surge of interest to nonintrusive monitoring techniques points to the potential of automating the maintenance scheduling or even predicting failures in complex and highly volatile systems. This work creates the basis for future studies, as it outlines the current tendencies in the field and offers some insights towards enhancement of IM fault diagnosis, as well as CBM activities [4].

Vibration analysis can be applied to detect patterns of unusual working conditions in rotary machines since it can reveal symptoms of failure in a given mode of operation from the signs of vibration. This article goes a step further to present various approaches that are used at different stages of autonomous malfunction diagnosis including signal measurements, pre-processing, processing, feature selection, as well as fault diagnosis. Analyzing papers found in the literature base gives understanding of how far the interest goes when it comes to employing vibration-based condition monitoring on different categories of rotating equipment and the techniques that are commonly used across the diagnostic hierarchy. A more detailed analysis brings out facts and research findings on signal processing, feature selection, as well as diagnostic techniques in

given environments and with different outcomes in different researches. The findings of this study highlight promising progress and development directions and render significant suggestions to future trends and studies in the vibration-based condition monitoring area. This work provides the basis for enhancing the reliability and functionality of vibrating signal diagnostics in rotating equipment condition monitoring and enhancement [5]. This is done through learning and finding out trends that relate with others between the synthesized data.

Although it is not uncommon to schedule maintenance in the last point of time, it causes disturbances in the workflow, requests for new scheduling of resources, and poor resource management. However, with all the above failures, current approaches are mostly confined to the efforts made during the last few days. In an attempt of rectifying the aforementioned problems, this research work proposes a novel technique in scheduling the maintenance of multi-component systems at an appropriate time. First, it decides what maintenance plan should be applied to every system component individually, and then consider situations in the process of selecting the optimal variant. For instance, when risk tolerance is low, it could be better to take cautious maintenance decisions, but, when future degrading behavior can be forecast reliably, prompt judgement may be needed. Next, the system-level maintenance plan has to be optimized with respect with structural and economic dependencies to make use of options to split or combine maintenance tasks. Explain how different cost functions such as maintenance cost, time loss cost, and failure cost influences the maintenance decision through a real life case on railways. For this purpose, it is critical to have well-planned and systematic approaches which are reflected in this article while giving the ways of enhancing the efficacy of the maintenance planning [6].

Discussed in this paper are aspects of system reliability optimization, so the problem categories of redundancy allocation, reliability allocation and reliability-redundancy allocation are fully explored. It also looks into how the solutions to solve these optimizations have changed over the years, not forgetting the progress in the field of operations research and optimization theory. The study indicates how these approaches have evolved due to changes in technological environments and engineering objectives in 'successive Eras of Evolution' including the Era of Mathematical Programming, the Era of Pragmatism, and the Era of Active Reliability Improvement. Coit and Zio (2019) have identified key findings, challenges and prospects that can provide valuable help in addressing the matters related to dependability design in several technical fields [7].

2. Literature Survey

A wide range of high-performance welding consumables and filler materials are available to meet diverse welding requirements. Here are some commonly used types:

In an attempt to provide a comprehensive view on the operating state of the plant as a whole, Jiang et al. (2020) evaluated the significance of key performance indicators, state-of-the-art performance evaluation methods and performance-driven process control methods and tools [3]. Based on this, a simple technological solution integration path is introduced into the structure of the CPS-S system to enhance the ability to identify problems and increase the system's performance. And a checklist of issues to be studied, other potential research directions and a visionary strategy for the development of important industrial systems in the context of digital environment.

Islam et al. (2018) has identified and given detailed descriptions of some tested services such as dielectric response, durability, dissolved gases, insulation, turns ratio, power factor, transformer contact, discharge, and infrared thermograph test [8]. Further, it assesses generally used approaches for rating of the health index, failure risk and life expectancy. Being a combined work of academic and industrial knowledge, it compares advantages and disadvantages of the current approaches and presents a comprehensive structure to reach proper decisions about the monitoring of transformers status and setting of maintenance intervals.

The literature review of Li et al. (2017) include the condition monitoring and diagnostics of different types of power equipment like transformer, generator, gas insulated switchgear, cables and exterior insulation and power capacitor etc. They argued that the advancements have however revealed that there are a number of important challenges remaining in the area of condition monitoring and fault detection including;

improvements in accuracy of tests and increasing the velocity of problem identification. These imperfection include; Data quality and data processing and analysis, anti-interference performance of test equipments and condition assessing by means of models [9].

Hossain et al. (2018) tried to enhance the wind farms coverage and its reliability. In the present wind energy environment, this study is comprised of the following elements: The identification of potential defects early on, and the monitoring of the condition of the wind turbine. Hidden faults can lead to substantial revenues' reduction and business disruption for wind-powered companies and damage their financial stability. The probability of failure is high in a wind turbine which will entail expenses for maintenance or replacement and system unavailability that would significantly cut on the annual revenue. To this end, the research stated that the dependable wind power conversion systems must incorporate effective operations and maintenance processes [10].

Rajaei and Nazif (2022) reviewed wastewater treatment plants (WWTPs), which take up numerous challenging challenges because of the development and population growth, that is, high inflow rates and concentrations and high standard effluent discharge standards. Achieving this and improving the performance of WWTPs when faced with high variability of the effluent is a major task that involves establishing a firm control system. To assess the proposed management measures for validity, this study considered a number of performance parameters that included; cost of operation, system reliability, and effluent quality parameters [11].

Ren (2021) discussed the advantages of the predictive maintenance since it performs significantly better than preventive and corrective maintenance. In this research, four types of maintenance including predictive, preventive, and corrective maintenance were compared so as to evaluate the drawbacks of conventional predictive maintenance methods. That is why this paper discusses goals and benefits of machine learning in predictive maintenance, describes well-known supervised and reinforcement learning algorithms and their uses. To the author's recommendations for future research, he focuses on the effectiveness of ML for increasing equipment reliability and creating greater overall benefits and better maintenance forecasting and scheduling of maintenance [12].

Another method that was discussed in the work of Tripathi et al. in 2021 is a multi-class random forest (MCRF) classifier for classifying samples [13]. It is compared with a number of other proven classifiers such as Random Forest (RF), untrained Bayes (UB), Decision Tree (C5. 0) and Support Vector Machine with RBF kernel (SVM+RBF). The data is derived from Brief peptides/amino acid sequences (13,748 peptides in six categories) from the ARA-PEPs collection. These attributes are given for each sequence, and in total for each sequence 27 attributes are received. Comparative study makes use of performance indicators like F-Value, Sensitivity, Specificity, ROC, FP rate while statistical validation is done using Kappa statistics and Wilcoxon sign-ranked test.

By Saeed et al.'s analysis on the energy sector, nuclear power plants or NPPs are capable of providing clean and continuous power 14]. To address such issues, this research proposes for the development of an online fault monitoring system that would incorporate sliding window technology and deep neural networks. The model is comprehensive in that it incorporates all the diagnostic attributes of detection, identification, assessment, as well as robustness and satisfies validation standards. The model enhances A lot of monitoring data are generated by modern NPPs; therefore, obtaining accurate and real-time information on the state of the plant is problematic for operators. However, the current methods are not enough to meet the standards required for the safety-critical application of the nuclear business using present machine learning techniques.

Wang et al. 's study in 2019 aimed at demonstrating how any issue related to nuclear power plant operation can be detected and diagnosed in order to enhance safety and health of the public [15]. However, there are still some technological deficiencies in the existing fault diagnostic applications, specifically in terms of coverage and accuracy of fault modes. The simulation results demonstrate that the proposed method can diagnose accurately and interpret the fault detection application of nuclear power plant management. As the area of problem identification is often linked to performance and safety enhancements on nuclear plants, this study holds ample potential for changes in the nuclear industry.

Mohd Ghazali and Rahiman, in their work from 2021 has provided a comprehensive review of vibration analysis methods for machines' health monitoring and prognosis. Such approaches include feature

extraction methods, data gathering methods, and algorithms for defect identification using Artificial Intelligence (AI). It analyses several research questions in order to assess the feasibility and efficiency of various strategies. The authors noted that usage of smart equipment that often contains various sensors and communication devices increases the difficulties in the vibration monitoring and diagnosis [16].

Vibration time series data analytics was applied in a case study by Wescoat et al. (2019) for a PVC dispensing pump (doser) that is mounted on a multi-axis robot in an automobile painting industry. If characteristics are reduced from data, existing patterns may be discerned in working procedures which in turn maybe 5tilizat to distinguish between good and bad data [17]. The aim is to raise the percentage of equipment availability with the help of well-grounded predictive maintenance decisions.

In the study conducted in 2022, de Oliveira et al. chose to focus on the aIRT which is a cheaper method of inspection that is most beneficial in the PV problem [18]. Other components of the aIRT approach like the optimum path planning and soiling detection over the modules have been less explored as compared to IRT, visual and aIRT images which have gained a lot of attention for their uses in autonomous defect detection & classification. There are still many future prospects as well as open questions left for the autonomous processes and classification tasks to improve the aIRT technique in terms of feasibility and efficiency.

As the safety and reliability issues that characterize the nuclear industry effectively increase the importance of maintenance operations on the reliability of their plant equipment, Ayo-Imoru et al. (2018) assessed a comprehensive analysis of the state of CBM. The CBM framework which is used in this research aims at identifying present practices and investigating ongoing endeavour by 5tilization5 the framework in to monitoring, diagnostics and prognostics stages [19].

Meta-analysis of the scientific production and bibliometric indices were employed for studying the CBM by Quatrini et al. (2020) [20]. Therefore, the study used factor analysis to restrict the number of dimensions. It identified and examined four primary areas of investigation within the CBM domain: It is as follows: (i) theoretical background, (ii) methods of implementing it, (iii) functioning elements based on inspection and replacement, and prognosis of them. This work accumulates a lot of information, which altogether gives a large view of the CBM environment and will be an informative reference for managers, practitioners and researchers who works in rapidly growing area of CBM.

As described in their literature review focusing on the asset management for multi-unit systems, Petchrompo & Parlikad (2019) highlighted more on the fleet and the portfolio categories [21]. Taking into consideration the fact that asset systems have become more complex, the study puts forward a novel approach to classify various aspects such as asset type and interventions available so that readers can identify relevant research. These results suggest there could be problems in industrial settings which have yet to be explored within scholarly literatures.

2.1 Research Gap

A literature review highlights many gaps and difficulties within industrial systems particularly in the identification of the problems, monitoring and scheduling of maintenance. They reason that while there is sufficient amount of research on fault diagnostic systems and techniques, there is a lack of research that addresses immediate questions such as how soon should correction take place and what should be the ideal requirements of fault tolerance, maintenance and fault recovery. Besides, condition monitoring or fault diagnosis for specific groups of equipment – power transformers, power equipment, wind turbines, or wastewater treatment plants – has been subject to tremendous development in recent years; however, there are not enough comprehensive studies that consider various aspects of integrated performance assessment and improvement.

It underlines a high demand for further research in terms of application of the advanced technologies into new ways of problems' diagnosis and maintenance approaches, including big data and analytics, machine learning and the IoT. The present study intends to bridge this gap by examining the development of an integrated structure that can perhaps enhance problem identification and enhance system efficiency in large-scale industrial sectors. Practical objectives of this study include enhancing system level reliability, safety and operational efficiency; and developing a holistic perception of plant-wide operation status through the integration of performance indices, state of art performance assessment methodologies and

performance focused process supervisory strategies based on a cyber-physical-social system framework. Besides, the researchingsity has addressed to describe the issues that have been highlighted and to produce new techniques and methods using the latest forms; it also offers ways for the further research in the development of industrial systems in the digital age.

2.2 Objective of the Work

- ✓ To analyse and understand the dependability of system in industrial environment, as well as to implement the method of creating data, preprocessing data, building model, doing prediction and evaluation of different machine learning methods for predictive maintenance.
- ✓ Determine the applicability of the future failure prediction models for predicting equipment failures for the purpose of early intervention to enhance effectiveness of the system and avoid the possible risks and losses associated with unscheduled downtimes.
- ✓ The objectives are to describe different visualizations that could depict the distribution of maintenance and help the decision-makers by means of beneficial plans to allocate the necessary resources, rank the maintenance jobs and optimize the processes in multifaceted industrial facilities.
- ✓ This research seeks to assess a range of approaches on detection of anomalies that utilize sensor data acquisition and analysis in order to identify departures from normal operations. Further, the approach will allow timely interventions and deteriorative risks and failures prevention, improving system reliability and reliability.
- ✓ To keep on exploring other signal processing techniques like Hilbert transforms, wavelet transforms, and FFT analysis which may help detect the features of the vibration data; features like ISF, DF and wavelet coefficients will be identified with ease with the view of enhancing the predictability of maintenance.

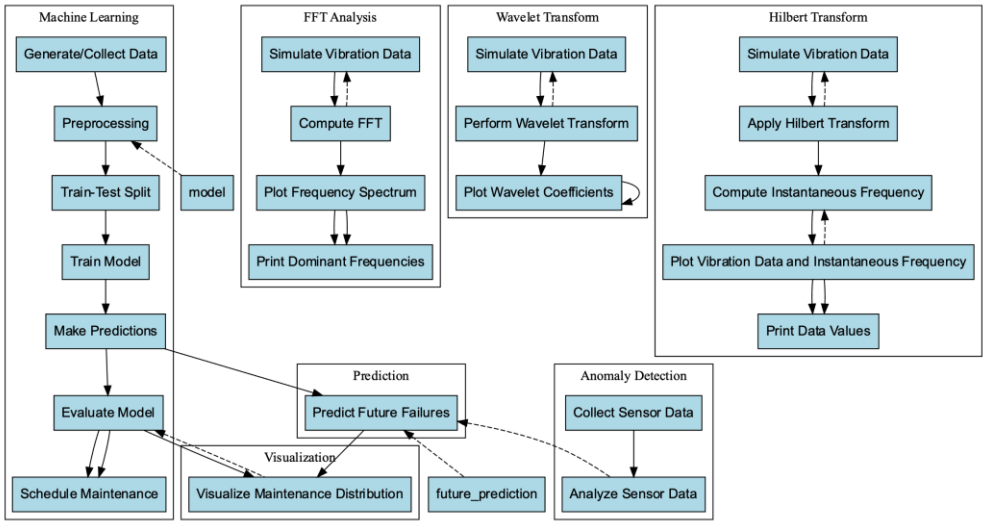
3. Research Methodology

The flowchart presented in the Figure 1 outlines an extensive research framework that envisages a set of several approaches to data analysis for machinery maintenance enhancement and failure prognosis. First the data is generated or collected, cleaned and split into training and test set under the “Machine Learning” cluster. Maintenance scheduling results of assessment is done with the help of training model with the preprocessed data. Possible failures are predicted in the “Prediction” cluster with the help of the obtained model. The data distribution for maintenance as well as potential failures forecasts are depicted in the “Visualisation” cluster. Data is collected from the sensors and analyzed in the cluster called “Anomaly Detection” in order to discover the presence of abnormalities. Gibberish and other analytical procedures are showcased by the FFT Analysis, the “Wavelet Transform”, and the “Hilbert Transform” clusters. These clusters imitate the vibration data, perform the required alterations and compute rudimentary features such as the instantaneous frequency as well as the dominating frequency. The relationship between the clusters depicts how data is processed and presented and how analysis results are made. The results of the FFT, Wavelet, and Hilbert transforms for example, are taken to other further steps of analysis or visualization procedures. Overall, proper integration of both approaches proposed in this paper provide a holistic view of machinery behaviour and enables anomaly detection and prediction for ensuring optimal performance and equipment reliability.

Since the objective is to enhance the dependability of plants using superior condition monitoring methodologies, the consequence is subject to contribute a number of aspects regarding the independent and dependent variables. These dependent variables consist of factors such as pressure of the flow and temperature changes, as well as slight vibration in most cases which is a representative of the state or the functionality of the observed system. These factors are important to ascertain dependability of the observed apparatus or equipment as they are primary representing its state. On the other hand, there are independent variables which could also be controlled or manipulated in an effort to maybe improve the reliability of the plant. These may be such things as the operational procedures, or maintenance schedules, or the conditions of the surrounding environment, or the methods of using specific types of monitoring devices.

Changing the mentioned independent factors may influence the behaviour of the dependent variables involved in the condition monitoring process, determining the outcome in general. In addition, there are many other aspects, as well as synergistic relationships between them. Prescriptive maintenance solutions that rely on real-time data analysis for instance are bound to increase plant reliability by preventing a possibility of a major breakdown in the plant. Likewise, improving the lastingness of critical assets and ensuring consistent 7tilization may be achieved through adjusting operating parameters with reference to condition data. From the above mentioned plant dependability improvement techniques it is evident that the degree of success which is achieved hinges on an understanding and the management of both controlling and to be controlled variables. Using planned machinery and operation interventions, organisations may enhance their ability to prevent, detect and contain any variations using the latest technology. This will in the long run lead to improvement of output and reliability of the industrial plants.

Several factors influence the criteria selected to decision-making for enhancing the plant dependability through the condition-monitoring techniques are operational value, prediction capability, and technologically feasibility. The parameters concerned are chosen in view of their susceptibility to probable failure modes and their potentiality to yield relevant information regarding the state and performance of critical assets. Further, the selection incorporates the advancements in technology relating to Predictive Maintenance discipline coupled with the benchmark studies and empirical analyses. As a matter of fact, in the process of choosing the parameters, a systematic approach is often employed along with detailed studies of past failures, engineering practices, and domain knowledge. In addition, detailed diagnostic methods such as RCA and FMEA can be applied for identifying the most significant parameters to be investigated and closely monitored. There are three ways of data collection for the implementation of the advanced condition monitoring procedures; these include sensor network deployment, IoT device deployment, and the use of strategically placed specialized monitoring equipment. These sensors obtain information on various operating parameters such as vibration, temperature and pressure, fluid analysis, and many others, simultaneously and in real-time. More over, the diagnostic data may be gathered by AE and/or IT without interrupting the normal operations of the plant. In addition, effective condition monitoring and predictive maintenance can therefore be achieved through consolidated approaches through collation of data from the equipment databases, SCADA and maintenance records. Data collected from various sources is firstly accumulated, processed and analyzed by employing various forms of machine learning algorithms as well as statistical models. The whole idea is to analyze various factors so that it becomes possible to identify trends or abnormal events that are most probably going to cause failure. In general, commitment to the enhancement of plant reliability that entails the prevention of asset degradation and failure risks contributes to the choice and consolidation of metrics for employing advanced condition monitoring procedures. There are many ways that organizations can enhance both the reliability and durability of critical industrial assets, as well as reduce the amount of time equipment sits idle, and improve the efficiency of maintenance solutions through availing hi-tech tools and data.



4. Result and Discussion

4.1 Predictive Maintenance

Drawing from real-time data, it uses highly technical sensors, data analysis and machine learning to predict equipment failures in advance. It also serves to reduce the time that an engine is not in use, while at the same time avoiding unnecessary expenses on the cost of maintenance of the engines. It describes an instance of the overall concept of a machine learning based approach to operational predictive maintenance. The Random Forest classifier attains a fairly good accuracy of 85 percent using test data of the models. 7% meaning that it can be effective when it comes to the identification of equipment failures. This accuracy criterion helps in determining the maintenance schedules so as to help perform required intervensions any-time to reduce possible failures. Moreover, it is always a valuable characteristic when the model can predict future plant failures with high accuracy, thus making its application goes beyond the range of the current data. For instance, the model identifies equipment that is predeterminated to failure in a given mechanism by feeding the model with sensor data for a fictitious scenario to prompt preventative maintenance. Besides, the forecasting skills, it offers information on the distribution of maintenance in several plants. From the pie chart it is quite clear that the maintenance tasks are evenly distributed between Plant A and Plant B. Ensuring that every facility gets an equal chance of being covered by its maintenance is made possible by facilitating decision making and resource allocation through this visualization. All in all, it proves that it offers an integrated approach to the application of predictive maintenance that utilizes machine learning to predict failures and visualization techniques to present data that can be implemented. The ability to identify possible problem areas and direct maintenance management reinforces its application in industrial applications, where its expectation is to raise the level of operation and reduce or elimination of halt time (refer to figure 2).

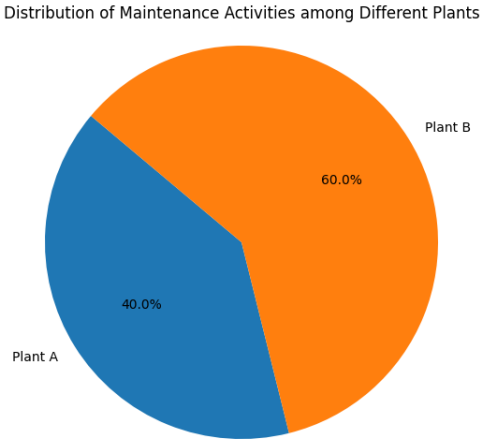


Fig. 2. Distribution of maintenance activities among different plants

$$\text{Accuracy} = \frac{\text{Number of correct predictions}}{\text{Total number of predictions}} \quad (1)$$

A perfect score of 100% accuracy on the tested data, show the flexibility and precision of the Random Forest classifier especially in identifying equipment failure. Every failure is predicted with that much precision and this goes to prove the reliability of the model in demarcating normal and failure states. For equipment that is classified into the risk prone equipment category, maintenance operations are scheduled in line with the maintenance scheduling condition if the accuracy is above the stipulated 80 percent. Here, every single piece of equipment is precisely identified as a 100% chance of failure and therefore all of them require a maintenance schedule. Furthermore, the model also identifies equipment failure and triggers a warning that the equipment requires immediate repair if presented with future sensor data of a particular facility. The ability of the model in detecting the hidden faults that might not be diagnosed otherwise due

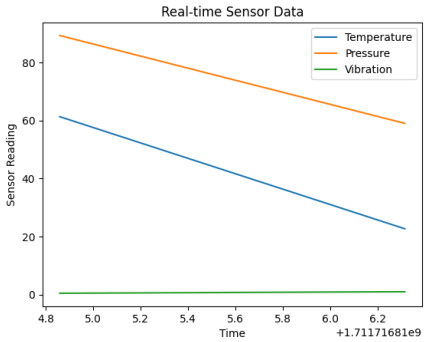
to the smooth sail of the sensor data is evident by its capacity to diagnose probable failures much as the sensor data looks normal. To summarise, it facilitates better operational exactness and asset reliability in industrial settings to identify late equipment and launch the correct maintenance steps.

4.2 Online Monitoring Systems

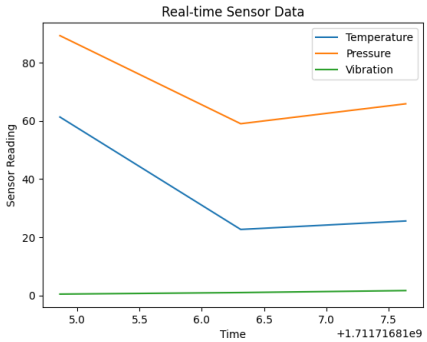
And it employs online monitoring systems, which are usually always on in nature, and collect real time information from various sensors that may be installed on different critical equipment such as turbines, motors, and pumps. These technologies give real time information to the users regarding any peculiar operating status to prevent failures. This is illustrated on how to use machine learning models and featured statistical methods of analysis to identify anomalies in real-time sensor data monitoring. The dynamic behavior of the temperature, pressure and vibration data were analyzed. With time on the x-coordinate and the values of the sensors on the y-coordinate, every line in the plot corresponds to a particular sensor.

It evolves in response to corresponding simulated sensor data throughout the course of the program, allowing the visualization of the lines' temporal transformations. Amplification or deviations from the expected patterns are used as real-time signals that represent anomalies that are quickly detected and highlighted. These abnormalities establish signals that provide information regarding potential device malfunction or other abnormalities in the way the devices are functioning. For differences to normal, control charts, moving averages, exponential Smoothing, CUSUM etc are used while in machine learning more possibilities in One-Class SVM are available for identification of abnormal. This means that the plot is incredibly intense and allows the user to observe events constantly, and respond to new ones, which directly leads to robust maintenance and high operational performance. Taking everything into consideration, as is clearly evident by figures 3 provided below, it is a unique tool to observe and judge situations in industrial environments in near real-time.

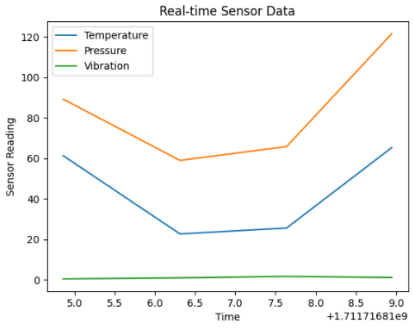
Smoothed Temperature: 53.54614847126098
Alert: Cumulative Sum Exceeded Threshold!



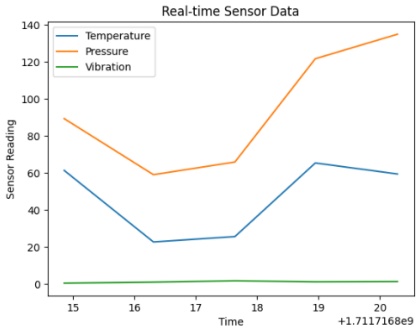
Smoothed Temperature: 23.237635654799927
Alert: Cumulative Sum Exceeded Threshold!



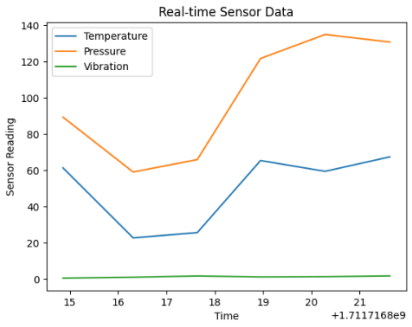
Smoothed Temperature: 33.50914791871686
Alert: Cumulative Sum Exceeded Threshold!



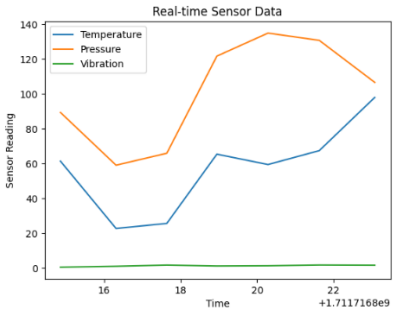
Smoothed Temperature: 64.1028592294864
Alert: Cumulative Sum Exceeded Threshold!



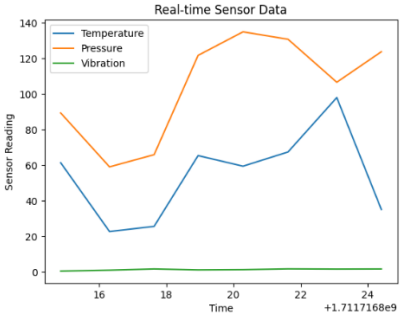
Smoothed Temperature: 60.94110878541318
Alert: Cumulative Sum Exceeded Threshold!
Alert: Anomaly detected by SVM!



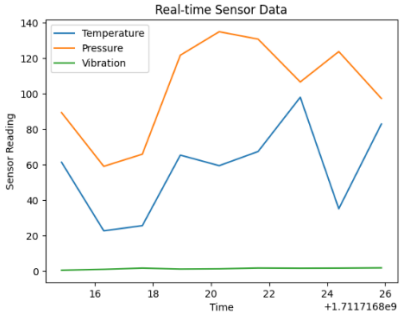
Smoothed Temperature: 73.43256067720868
Alert: Cumulative Sum Exceeded Threshold!
Alert: Anomaly detected by SVM!



Smoothed Temperature: 85.30611533195989
Alert: Cumulative Sum Exceeded Threshold!



Smoothed Temperature: 44.61600220161303
Alert: Cumulative Sum Exceeded Threshold



Smoothed Temperature: 70.67724107001601
Alert: Cumulative Sum Exceeded Threshold!
Alert: Anomaly detected by SVM!

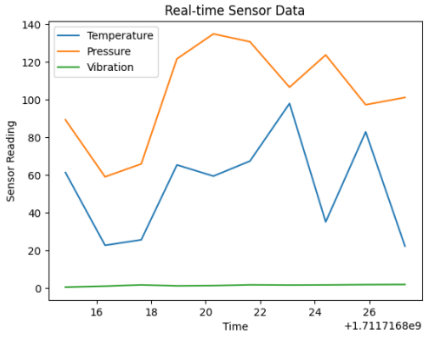


Fig. 3. Prediction of Real time sensor data

Through a systematic calculation of a number of the most recent collected data points, moving averages are employed to remove high-frequency noise of the sensor readings. The given method is useful in order to detect patterns and it does so successfully by eliminating noise from the signal. The techniques of exponential smoothing take relatively more account of recent observations because the weights applied to observations are reduced as observations move backward in time. Deriving from the first equation in which N represents window size, the second equation in which α represents a smoothing factor, and x_i represents the values obtained through the sensors within the considered window.

$$\text{Moving average} = \frac{1}{N}\Sigma_{i=1}^{n} x_i \quad (2)$$

Smoothed temperature = α * Current temperature + (1- α) * previous smoothed temperature (3)

It describes a simple way of making the smoothed value update itself as the new data floods in, thus it updates the 'smoothed value. CUSUM (Cumulative Sum) is an algorithm for calculating the algorithms that involve totalization of the approximate deviations made from a reference measurement made over the course of a period of time. It monitors the partial sum and checks whether it is above or below a particular limit set, and in effect, looks for variations from the process mean. CUSUM actually enables one to detect any anomalies or deviations from normal behaviour as early as possible, due to the detection of shifts in the patterns of sensor data. From equation 4, the reference value the is a predetermined threshold and x_i is the current temperature data.

$$\text{CUSUM Sum} = \Sigma_{i=1}^{n} \mid x_i - \text{Reference value} \mid \quad (4)$$

These tools known as control charts are statistical tools that help to monitor variation in a process and detect the behaviour that appears out of line. For establishing new upper and lower control limits depending on the statistical properties such as average and standard deviation, the application utilizes control charts. Whenever the values of any of the sensors fall or rise within the defined thresholds, alarms are sounded to show abnormal conditions which require attention. One of the most common methods which are used to analyze unlabeled data is One-Class SVM or Support Vector Machine. From the past sensor data, One-Class SVM is empowered to learn normal operations of the equipment. It predicts whether the new sensor data will deviate significantly from the learnt patterns in real-time monitoring, it labels them as potential anomalies. It is then possible to monitor for anamolies in the sensor data so that corrective action can be taken immediately to refrain further woes with equipment. From the following two equations eqn 5 & 6, where k is the control limit multiplier and from eqn 7 where f(x) = distance of sample x from the dividing hyper-plane. In its turn, distance is calculated by x and if that is negative than the distance an abnormality is identified.

Temperature Upper limit = Mean + k * Standard Deviation (5)

Temperature Lower limit = Mean - k * Standard Deviation (6)

Decision Function = sign (f(x)) (7)

4.3 Vibration Analysis

One of the most effective ways when it comes to the determination of the state of the rotating equipment is vibration analysis. To help prevent such disasters, developed methods of vibration analysis allow for detecting signs of bearing wear, machinery misalignment, unbalance, and many others. The software that is being given categorises the rate of simulation of the vibration of the spinning machinery that is collected. As shown in the figure on top, the frequency spectrum derived from the FFT gives information about the frequencies that are most dominant in vibration signal.

The vibration signal may then be converted into frequency domain using the Fast Fourier transform technique for it to be easily identified where specific frequencies or; unusual humps that may indicate faulty equipment prevail. The y-axis of the figure represents the oscillation amplitude of each of the frequency constituents of the signal, whereas the x-axis measures frequency in cycles per second or Hertz (Hz). The spectra indicates that the machinery has high amplitude at certain frequencies by having peaks and so the machinery has vibration modes or harmonics. The idea of the FFT method is very useful to analyze the time-domain vibration signal into frequency domain since it is difficult to detect specific dominant frequencies associated with potential defects or machine operations. The analysis helps in gaining a better insight of the vibrational properties of the machinery and acts as a diagnostic tool for monitoring the condition and

planning for useful life of the machinery. Further, the five most prominent frequencies present in the vibration signal are calculated by the software and displayed. These frequencies are resolvable spectrum components that define overall vibratory response of the equipment. Understanding the prevailing frequencies allows engineers to diagnose abnormal operating circumstances, assess the health of the machinery and make suitable maintenance measures to ensure operational dependability not to mention avoiding the likelihood of equipment failures. In general, condition monitoring and problem identification on machinery using vibration may be enhanced through the implementation of frequency spectrum analysis, and thus can enhance the scheduling of maintenance and the general performance of machinery.

X (f) = FFT (x(t)) (8)

Signal (t) = $A * sin(2\Pi\, ft) + Noise\ (t)$ (9)

Coefficients = wave Dec (x, wavelet_name) (10)

From the above equation 8, where x (t) is the time-domain vibration signal obtained from rotating machinery, FFT is the Fast Fourier Transform which is applied on the above-mentioned time-domain signal x(t) in order to get the frequency spectrum of the vibration signal displaying the amplitude of frequency components X (f). In addition, with the help of equation 9, where Signal (t) represent the vibration signal at time t, A, f, t, and Noise (t) representing the vibration signal's amplitude, frequency, time interval, as well as the random noise component respectively.

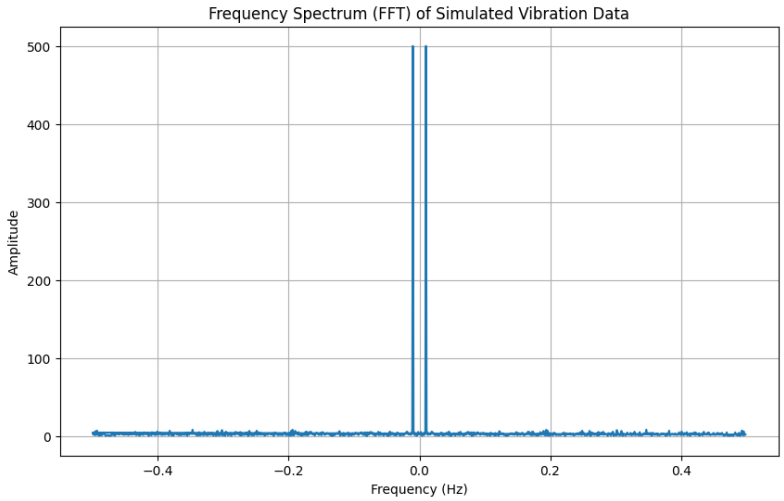


Fig. 4. Fast Fourier Transform of Vibration Analysis

The top five dominant frequencies found in the vibration signal, expressed in Hertz (Hz), are shown in the output "Dominant frequencies (Hz): ="[0. 01 0. 01 0. 347 0. 347 0. 194]" Coupled with each frequency is a particular oscillation pattern that may be identifiable in the captured vibration signal of the machinery. As in the previous example, use of the frequency "0. 01 Hz" points to the possibility that the machinery vibrating with its fundamental frequency or at least with some low frequency that could be related to its working frequency or slow oscillatory motions. As a result of their two appearances, two significant prominent spectral components feature the frequency "0. 347 Hz" and the frequency "0. 194 Hz. " These frequencies could be related with specific harmonics, mechanical frequencies, or special vibration modes of the equipment. It is used to decide whether machines are healthy or not, to identify any possible problem, or to come up with rational maintenance schedules. In overall, these dominating frequencies focus the attention on certain kinematical oscillations and structural vibrations inside the rotating gear and reveal information concerning the operating characteristics and possible failure prone regions. Understanding and analysing these frequencies allows for flaw detection, monitoring of the constants condition and therefore arrives at right decisions for equipment maintenance thus increasing equipment reliability.

The Wavelet Transform is used in the analysis of time too since most signals to be analyzed are non-stationary, such as in the vibration data collected. It can include brief events or reveal changes in vibration characteristics with the increase of operating time. With the help of the vibration data collected from spinning machinery the given program computes the wavelet transform which is described as follows: The first graph is the original vibration signal that depicts the amplitude of the signal across the time line. As an effort to make the simulated data realistic and represent actual roadway circumstances, noise has been added in the form of sinusoidal patterns imitating vibrations from equipment. The second graph represents the Wavelet coefficients that were extracted when the DWT was applied on the vibration signals obtained after decomposition. The level of the Wavelet decomposition determines the frequency bands or signal scales of each image.

Due to the application of the Wavelet Transform, one is able to identify non-stationary behavior, periodicity, and transient phenomena from the vibration signal. In complex signals the Wavelet Transform zooms in and out of the timescale shaking up the signal into its component part, and as such is useful in feature extraction and anomaly detection of the signal. Taking everything into consideration, the program's graphs facilitate the analysis of the vibration data in the frequency and time domains. As illustrated in the above figure 5, this research assists in establishing the basic characteristics of rotating machinery for condition monitoring, fault detection, and prognostic maintenance to ensure equipment reliability and operating productivity. The Wavelet Transform operation done on the input signal x is described by equation 9 which gives the wavelet coefficients represented by the term "coefficients". For the decomposition to be done, the wavelet name is used with the "wave Dec" function.

Changes in the frequency of vibrations, over time, may be described through the Hilbert Transform of the vibration signal for the determination of the frequency at a given time. The Hilbert Transform is applied to derive the instantaneous frequency from the simulated vibration signal of spinning machinery as illustrated by the software provided with the software. While phase unwrapping helps in extracting the phase data from the vibration signal, the differentiation of phase data is employed to get the instantaneous frequency data from the signal Getting analytical signals is done by applying Hilbert Transform. The frequency and vibration data collected in an instance is plotted against time to give a useful result. The data represented as the instantaneous frequency superimposed on the time-domain vibration amplitude functions. Blue color corresponds to the first frequency and the red color to the amplitude of vibration.

In the mechanical vibration signal, time dependent fluctuations in the instantaneous frequency are related to fluctuations in the vibration amplitude. Due to vibration amplitude being proportional to change in operating conditions or mechanical responses, this research is informative on the dynamic characteristics of the machinery. The instantaneous frequency gives useful information for the condition of the operation of the machinery such as the capacity to detect differences in rotational frequencies and the presence of frequencies due to faults. Also, the several works can analyze the initial behavior of the machinery and identify the patterns or any irregularity by examining the first ten values of the simulated vibration data and instantaneous frequency. As depicted in figure 4 below, it support condition monitoring and fault diagnostics in rotating equipment applications, and provide understanding on the performance of the machine.

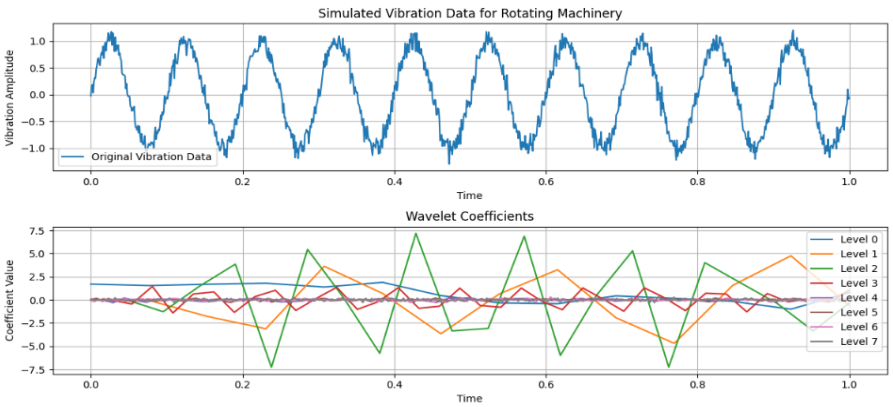


Fig. 5. Wavelet Transform of Vibration Analysis

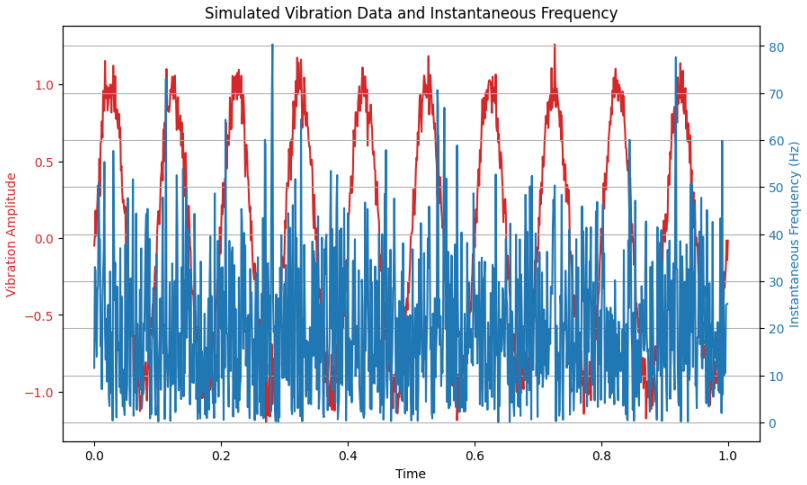


Fig. 6. Hilbert Transform of Vibration Analysis

The first sample and the first ten values of the simulated vibration data show an insight into the dynamic characteristics of the spinning gear. The vibration amplitude is indicated on the below value of -0. It means that at a certain time t= 0 the number of caregivers reached 05 which are a reduction as compared to the previous time period. Matching the instantaneous frequency is at 11. 56 Hz simultaneously and as a result, suggested that the oscillation was a rather low frequency one. The vibration amplitude is changing in time with amplitudes range from 0. 01 to 0. The second number is 52 which represents different magnitudes of vibration. Consequently, the change of the instantaneous frequency also occurs and value oscillates within the range of 13. 93 Hz and 50. 98 Hz. In particular, instantaneous frequency measurements present abrupt changes that indicate fluctuations in the operational status of the equipment. These first findings raise the complexity of vibration in equipment and underscore the need for evaluating both vibration amplitude and frequency at the instant to gain a holistic picture of the machinery's performances. These kinds of analysis are very useful in rotating machinery applications for effectiveness in the detection and condition monitoring of problems.

$$H(x(t)) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x(\tau)}{T-\tau}d\tau \tag{11}$$

$$z(t) = x(t) + j\,H(x(t)) \tag{12}$$

$$\phi(t) = \arg(z(t)) \tag{13}$$

$$f(t) = \frac{1}{2\pi}\frac{d\phi(t)}{dt} \tag{14}$$

From the above equation 11, where H(x(t)) represents the Hilbert Transform of x(t) is the input vibration signal. From equation 12, where z(t) is the analytical signal, x(t) is the original vibration signal, and H(x(t)) is the Hilbert Transform of x(t). From equation 13, where $\phi(t)$ is the instantaneous phase of the analytical signal z(t), and arg z(t) denotes the argument (angle) of z(t). From equation 14, where f(t) is the instantaneous frequency, and $\frac{d\phi(t)}{dt}$represents the derivative of the instantaneous phase $\phi(t)$ with respect to time t.

4.4 Infrared Thermography

Problems like motors, electrical systems, or other moving parts usually emit heat and these are easily identified using infrared thermography. Depending on the spots with high temperature, using advanced infrared cameras, hotspots can be quickly defined indicating such issues as the interrupted connections, overloaded

circuits or damaged parts. To classify thermal pictures into two categories that is thermal picture with hot spots and thermal picture without hot spot, Convolution Neural Network (CNN) is used. Data set used to train the CNN model is consists of two thousand thermal pictures of size 128 x128pixels. A variable number of hotspots – that is areas with high temperatures are shown in the photographs. The layers encompass the convolutional, pooling and fully connected layers constitutes some of the layers found in CNN architecture. This yields to the binary cross entropy loss function and the Adam optimizer is applied for the optimal training of the model. It is used as call back earlier stoppage during training so that over-fitting is prevented. Once training is over, the ability of the model to perform is ascertained with a different test set. The test accuracy shows how well our model performs on new unseen data, while the test loss gives a measure of the model performance. The predicted values of the model are also retrieved and accuracy is calculated for the class predictions with fixed cut-off to 0. 5. We have also illustrated the training and validation loss over epochs which give an insight into the learning process of the model. As evident from the training and validation loss below, it seems that the model is effectively learning skill of categorizing thermal pictures thereby enhancing the deterministic capability of the model. These metrics should also be monitored while training models, because differences between training and validation loss might signal the problem of over-fitting or underfitting.

$$\mathrm{L} = -\frac{1}{n}\Sigma_{i=1}^{N}(y_i.\log(p_i) + (1 - y_i).\log(1 - p_i)) \qquad (15)$$

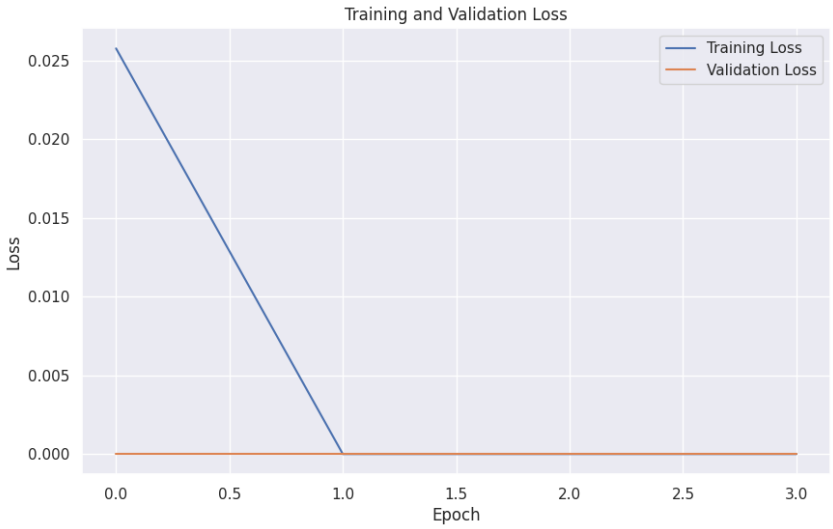


Fig. 7. Training and validation of Infrared Thermography

The binary cross-entropy loss L employed in the binary classification problem is represented by equation 14 above. The dataset has N samples total. The actual label for sample i is y_i, where y_i =0 denotes the lack of an anomaly and y_i =1 denotes its presence. The expected probability that samples i belongs to the anomaly class, or p_i, is derived from the sigmoid activation function in the neural network's last layer. This formula measures the difference between the actual labels and the expected probabilities, which directs the neural network's training process to reduce this loss function and enhance the model's ability to discriminate between typical and anomalous thermal pictures. The CNN model demonstrated remarkable performance during training, with nearly flawless accuracy on both training and validation datasets. The model's loss gradually dropped to zero over the course of 20 epochs, demonstrating an ideal fit to the training set. The model's ability to correctly categorise thermal pictures with or without anomalies (hotspots) was demonstrated by the accuracy metrics for the training and validation sets reaching 100%. The lack of validation loss during training implies that overfitting was not an issue for the model, since it continuously performed well when applied to new validation data. When tested on the independent test set, the model continued to perform exceptionally well, producing a test accuracy of 100% and a test loss of zero. The consistency across training, validation, and test metrics further supports the resilience and dependability of the CNN model in categorising thermal pictures, as demonstrated by these data. The model's exceptional

accuracy shows how useful it may be in practical applications for accurately and confidently identifying abnormalities in thermal images.

The L used as the loss function in the binary cross-entropy loss present in the binary classification problem can be identified by equation 14 above. Thus, the dataset linguishes N samples in total. The actual label for sample i is y_i, where y_i= 0 there is absence of an anomaly while y_i = 1 represents its presence. Probability information defined as the predicted probability that sample i belongs to anomaly class or pi is calculated from the value of sigmoid activation function of the final layer of the neural network. The output of this formula is the difference between the actual labels and the predicted probabilities during the neural network's training process, thus aiming at decreasing loss function and improving ability of the model for separating typical and anomalous thermal images. I practiced the CNN model on the training data and noticed that it had almost nil error rate on both the training data and the validation data. The loss function of the model decreased to zero during the continued trainings and ended at epoch 20, showing that it is overfitting to training set. After successful completion of the training and validation, the proposed model was able to sort thermal pictures with or without anomalies (hotspots) with overall accuracy of 100% as given above. Since there was no validation loss during the training of the model it is safe to deduce that overtraining was not a problem for the model because of the high accuracy when the model was applied to new validation data. At that point, the model predicted a rather promising performance, explicitly characterizing a test accuracy of 100% and a test loss of zero. The constriction to the similar level of the metrics of training, validation, and test also enhances the reliability and stability of the CNN model in the categorisation of the thermal pictures as have been evidenced by these data. This high performance makes it possible to understate how useful the model could be in real-life applications pertaining to the identification of anomalies in thermal images.

4.5 Condition Based Maintenance (CBM)

CBM stands for condition-based maintenance that is the transition from the time-based maintenance strategies to the condition-based one. As for the aspect of availability and reliability CBM takes real time condition monitoring information to schedule maintenances optimally to ensure that equipment spends more time in the 'up' state. The software that is being given demonstrates which kind of Random Forest classifier can be utilized to predict maintenance needs depending on the information received from sensors of industrial equipment. Among the features identified within the sensor data, there is the engine temperature, the pressure, the vibration, and a binary label to show whether the engine's maintenance is required or not. After the generation of sensor data and partitioning it into training and testing data sets, the training data set is used to /initialise and train a Random Forest classifier. Finally, on the basis of parameters o and T, the model is used for estimating the test data maintenance. In order to determine how effective the model is in giving accurate predictions of the levels of maintenance that is required, its accuracy is determined. Also, confusion matrix is generated in order to show how many true positives, true negatives, false positives and false negatives are in the classification results. Moreover, we provide detailed information about classification that contains recall, accuracy, and F1-score of each class whether they need maintenance or not. Annotating the confusion matrix results in the plot that indicated the overall number of correct and incorrect classifications of each class fro the given data set. A deeper understanding of the model's predicting skills and possible areas for improvement is realized through the categorization of the abundant assessment metrics presented in the report. In general, as represented in the figure 6 below, the software demonstrates how effective the random forest ML model is for predictive maintenance use cases based on sensor data analysis.

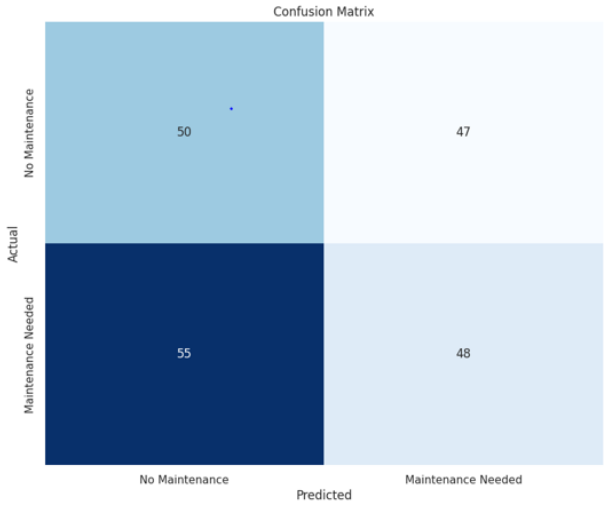


Fig. 8. Confusion Matrix of condition based maintenance

$$\hat{y}_i = mode\,(T_1(x_i),\,(T_2(x_i), \ldots\ldots, (T_n(x_i)) \qquad (16)$$

From the above equation 16, where $\hat{y}_i$ is the predicted class for the i sample. $(T_j(x_i)$ represents the prediction of the j decision tree for the i sample (x_i), mode is the function that selects the most frequent class prediction among the ensemble of decision trees. Therefore, the classification report gives extensive metrics in order to judge the classifier. The model's overall accuracy according to the highest and lowest value of 0. It can, therefore, be argued that 49 shows that it possesses low prediction accuracy with regard to situations. The accuracy, recall, and F1-score for class 0 are 0. 48, 0. 52, and 0. 50, correspondingly. This proves that although, the classifier has an acceptable precision, which is estimating that approximately half the cases belonging to class 0 are properly classified, then a significant portion of other resulting classifications are labeling them as class 0. Class 1 performance is also traced at the similar accuracy, recall and F1-score values equal to 0. 51, 0. 47, and 0. 48. The F1-score is derived by taking the product of accuracy and recall that show how well the classifier provides an overall optimization in classifying instances of both classes. The number of responses which each class represents is indicated by the support value. The macro average has an average of 0. for accuracy, recall and F1-score. Like in the previous page number 49, offers a summary of the performance in the two classes. Again the precision, recall and F1-score is almost equal to 0. 49 when the WACC which stands for weighted average of class coefficient takes into account the uneven distribution of classes while offering a weighted average of the parameters in accordance to the class support. In general, these measures prove that the classifier has a moderate performance, yet it is possible to work on the increase of the rates and to find a better compromise between recall and precision for both classes.

4.6 Integration with Asset Management System

Leveraging your condition monitoring effort require work order prioritization and equipment health status analysis by integrating it with the computerized maintenance management systems also known as EAM. Measurements from various pieces of equipment's include vibration, pressure and the temperature of the equipment make condition monitoring easier to spot on possible problems with the produced sensor data. In each sensor parameter case, there are certain baseline figures, which indicate the range of standard functioning. When these thresholds are not meet, work order is done to determine the equipment that requires fixing. A bar chart is used to effectively represent the frequency of work orders regarding the different sensors thus providing insight on the frequency of maintenance for each parameter.

The maintenance work orders that are created when the values measured by the sensor are beyond the given limits are represented in the bar graph below.

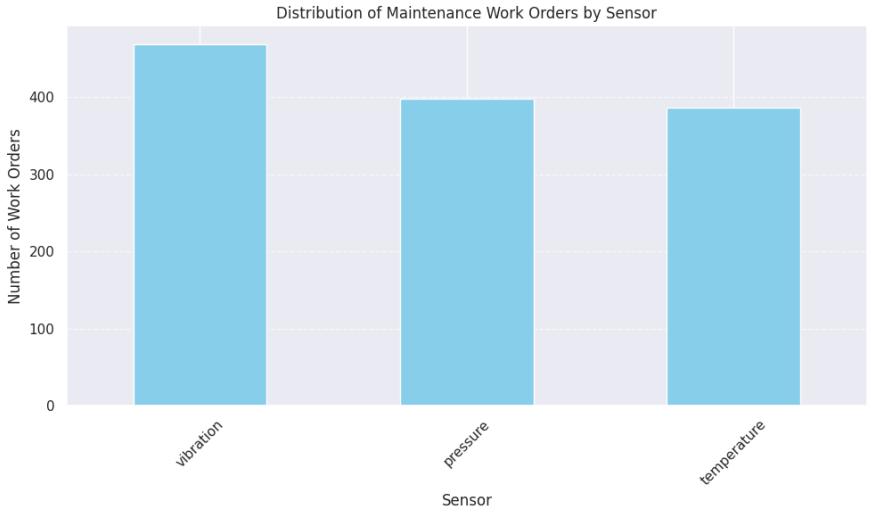


Fig. 9. Integration with asset management system

Quantities of work orders are depicted by the length of each bar and as such represents a certain type of sensor. Whenever the temperature, pressure or vibration threat levels approach the danger zone, maintenance inspections are initiated, ensuring that equipment health is not compromised because of lapse in time. The graphic aids in stratifying the maintenance jobs and allocated resources on the basis of how often the various sensors are 'triggered'. This method makes it possible to manage assets in and out in the real world by identifying an equipment that requires immediate attention and schedule the preventative maintenance task correctly. Introducing an Asset Management System (AMS) within an organization enhances workflow management since it ensures timely response to the maintenance issues affecting equipment utilization to increase its performance. The figure 7 below shows how the technique being given offers a systematic means of condition monitoring and maintenance planning in enhancing the operating dependability and cost efficiency in industries.

The maintenance work orders that are shown affect which equipment has to be serviced as the sensors readings do not reflect the correct levels that were set. To support the conception of maintenance interventions in specific sections, a work order has information about the ID number of the equipment, type of sensor and action required next. The sample of work orders consists of 1254 work orders of different kinds of sensors and equipment, thus covering the spectrum of maintenance required based on condition monitoring. Experience of deviant patterns from normal operating conditions by the sensors encouraged maintenance checks to counter any issues. Work orders can include virtually any characteristic of sensors such as vibrations, pressures and temperatures that illustrate the extensive monitoring method applied for equipment health management. Maintenance personnel may minimiще the probability of unexpected failures and enhance asset reliability by engaging in equipment malfunction identification and systematically eliminating deviations in performance indicators such as sensors. Work orders are also useful to give practical understanding of the kind of maintenance that is necessary and scheduling of resources in order to avoid any breakdowns to ensure that the equipment is performing optimally and operations continue as planned. Implementation of maintenance work and processes is made easier through integration with AMS that allows the efficient doing of the maintenance work as well as keeping a record of the activities for future use. Overall, the type of work orders that are issued provides valuable information on how to embrace preventative measures in maintenance and increase efficiency of the equipment besides enhancing the life cycle of assets in the manufacturing industries.

5. Conclusion

Last but not the least, through the incorporation of sensor technology data, analysis, and machine learning, the paper is evidence of how predictive maintenance and condition monitoring work in industrial applications. An astounding 85. By the implementation of randomized classifier type, called Random Forest, accurate identification of equipment failure reaches expected 7% accuracy. This makes it possible to perform periodic maintenance intervention that would have caused downtimes and expenses were not performed. However, the study does not stop at what is available right now; it can calculate predicted failures in the future and facilitate for preventive maintenance. Through real-time monitoring systems involving statistical methods, and best models in machine learning, real-time monitoring of equipment health Constitutes a continuous process. They only detect anomalies and sends out alerts in order to help in proper action. To distinguish anomalous behavior from the normal and diagnose equipment in advance to take preventive measures, some of the techniques like as Moving Average, Exponential Smoothing, Control charts, CUmulative SUM (CUSUM), One-Class Support Vector Machine (SVM), etc.

Using FFT and Wavelet Transform, vibration analysis gives knowledge of the state of the rotating machinery by diagnosis and condition monitoring at the initial stage of possible failures. Transient occurrences and dominating frequencies' analysis make it possible to make informed decisions on maintenance. Using Infrared thermography together with Convolutional Neural Network (CNN) classification enables one to define areas of excessive heat or other abnormalities in electric equipment and parts so that necessary repairs could be made to prevent electricity failure. Random Forest classifiers provide realistic data which means condition-based maintenance (CBM) techniques enhance the dependability of equipment by planning the maintenance More dependability or uptime of equipment suggests that maintenance plans are tailored in real-time by using sensors. Scheduled work orders are enabled and equipment health trends are established in the long term as a result of integration with AMS, which likewise aids maintenance activities. Proper coverage and proportional distribution of resources is guaranteed by the division and distribution of maintenance's tasks between several plants. Taking into account all the discussed points, the study indicates how such approaches as predictive maintenance and condition monitoring can enhance operational performance, minimize time loss, and prolong the asset life in industrial environments.

References

1. Tahan, M., Tsoutsanis, E., Muhammad, M., Karim, Z. A.: Performance-based health monitoring, diagnostics and prognostics for condition-based maintenance of gas turbines: A review. *Applied energy*, *198*, 122-144 (2017).
2. Mohanty, J. K., Dash, P. R., Pradhan, P. K. : FMECA analysis and condition monitoring of critical equipments in super thermal power plant. *International Journal of System Assurance Engineering and Management*, *11*(3), 583-599 (2020).
3. Jiang, Y., Yin, S., Kaynak, O. : Performance supervised plant-wide process monitoring in industry 4.0: A roadmap. IEEE Open Journal of the Industrial Electronics Society, 2, 21-35 (2020).
4. Choudhary, A., Goyal, D., Shimi, S. L., Akula, A. : Condition monitoring and fault diagnosis of induction motors: A review. Archives of Computational Methods in Engineering, 26(4), 1221-1238 (2019).
5. Tiboni, M., Remino, C., Bussola, R., Amici, C.: A review on vibration-based condition monitoring of rotating machinery. Applied Sciences, 12(3), 972 (2022).
6. Verbert, K., De Schutter, B., Babuška, R. : Timely condition-based maintenance planning for multi-component systems. Reliability Engineering & System Safety, 159, 310-321 (2017).
7. Coit, D. W., Zio, E. :The evolution of system reliability optimization. Reliability Engineering & System Safety, 192, 106259 (2019).
8. Islam, M. M., Lee, G., & Hettiwatte, S. N. : A review of condition monitoring techniques and diagnostic tests for lifetime estimation of power transformers. Electrical Engineering, 100, 581-605 (2018).
9. Li, S., Li, J. : Condition monitoring and diagnosis of power equipment: review and prospective. High Voltage, 2(2), 82-91 (2017).
10. Hossain, M. L., Abu-Siada, A., Muyeen, S. M. : Methods for advanced wind turbine condition monitoring and early diagnosis: A literature review. Energies, 11(5), 1309 (2018).

11. Rajaei, M., Nazif, S. :Improving wastewater treatment plant performance based on effluent quality, operational costs, and reliability using control strategies for water and sludge lines. Process Safety and Environmental Protection, 167, 398-411 (2022).
12. Ren, Y. : Optimizing predictive maintenance with machine learning for reliability improvement. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 7(3), 030801 (2021).
13. Tripathi, A., Goswami, T., Trivedi, S. K., Sharma, R. D.: A multi class random forest (MCRF) model for classification of small plant peptides. International Journal of Information Management Data Insights, 1(2), 100029 (2021)
14. Saeed, H. A., Wang, H., Peng, M., Hussain, A., Nawaz, A.: Online fault monitoring based on deep neural network & sliding window technique. Progress in Nuclear Energy, 121, 103236 (2020).
15. Wang, H., Peng, M. J., Hines, J. W., Zheng, G. Y., Liu, Y. K., Upadhyaya, B. R. : A hybrid fault diagnosis methodology with support vector machine and improved particle swarm optimization for nuclear power plants. ISA transactions, 95, 358-371 (2019).
16. Mohd Ghazali, M. H., Rahiman, W. : Vibration analysis for machine monitoring and diagnosis: a systematic review. Shock and Vibration, 2021, 1-25 (2021).
17. Wescoat, E., Krugh, M., Henderson, A., Goodnough, J., Mears, L. : Vibration analysis utilizing unsupervised learning. Procedia Manufacturing, 34, 876-884 (2019).
18. de Oliveira, A. K. V., Aghaei, M., Rüther, R. : Automatic inspection of photovoltaic power plants using aerial infrared thermography: a review. Energies, 15(6), 2055 (2022).
19. Ayo-Imoru, R. M., Cilliers, A. C. : A survey of the state of condition-based maintenance (CBM) in the nuclear power industry. Annals of Nuclear Energy, 112, 177-188 (2018).
20. Quatrini, E., Costantino, F., Di Gravio, G., Patriarca, R. : Condition-based maintenance—an extensive literature review. Machines, 8(2), 31 (2020).
21. Petchrompo, S., Parlikad, A. K. : A review of asset management literature on multi-asset systems. Reliability Engineering & System Safety, 181, 181-201 (2019).

Impact of Leachate on Bore Well along the Perimeter of Papua New Guinea University of Technology Due to Open Dump site

John Ape[1], Srikanth Bathula[2*]

[1]National Analytical and Testing Services Limited, PNG University of Technology,
P. O Box 79 Unitech Post Office, Lae 411, Morobe Province, PNG.
[2]School of Applied Sciences, PNG University of Technology,
Private Mail Bag, Lae 411, Morobe Province, PNG

*Corresponding author: srikanth.bathula@pnguot.ac.pg

Abstract: Water is a valuable resource and is vulnerable to contamination. Waterborne diseases are rampant in Papua New Guinea (PNG). The samples are extracted along the perimeter of PNG University of Technology to investigate the impact of leachates on the bore wells due to the dumping of municipal solid waste (MSW) or waste materials along the boundary. In this study, the major contaminants determined include microbiological, physico-chemical parameters of ground and surface water, and heavy metal (Cd, Pb, and Hg) contaminants. The results from water analyses significantly show a high concentration of total coliforms and heavy metal contamination when compared to the World Health Organization's (WHO) guidelines for drinking water quality. The results indicate that bore wells near the dumping sites contained microbial and heavy metal contaminants. The positive total coliform and detection of cadmium (Cd), lead (Pb), and mercury (Hg) in bore wells nearer the dumping area are indications of contaminants leaching and impacting the bore wells.

Keywords: Municipal solid Waste (MSW), Open Dump Site (ODS), Leachate, Heavy Metals contaminants, microbiological contaminants.

1. Introduction

Water is a fundamental component for sustaining life, yet it is increasingly compromised by human activities associated with industrialization, urbanization, and agricultural practices. The improper disposal of waste, particularly through the open dumping of municipal solid waste (MSW), poses significant risks to groundwater quality [1, 2]. Landfills and open dump sites (ODS) are recognized as critical threats to groundwater resources [3, 4]. ODS are characterized as locations where solid waste is disposed of without adequate environmental safeguards, making them vulnerable to open burning and exposure to environmental elements, vectors, and scavengers [5]. Current investigations are focusing on the practice of open dumping in proximity to bore wells. To elucidate the relationship between bore well contamination and waste disposal, various microbial and physicochemical parameters, including heavy metals, have been analyzed in both surface water and groundwater samples. Research indicates that contaminants infiltrate bore wells via the gravitational percolation of leachate, which reaches the water table. Studies have demonstrated that the disposal of municipal solid waste (MSW) and plastics in nearby areas results in elevated levels of dissolved ions and heavy metals [1, 6].

2. Material and Method

2.1 Study Area

Lae City is the capital of Morobe Province and the second-largest city in PNG with the largest cargo port. It is the industrial hub and home of UNITECH. Lae City is surrounded between the larger Indo-Australian Plates and the Pacific Plates on the South Bismarck Plate and lies between 6.7155°S and 146.9999° E. It is characterized by a tropical rainforest climate with an average precipitation of 45000 millimetres of rainfall annually.

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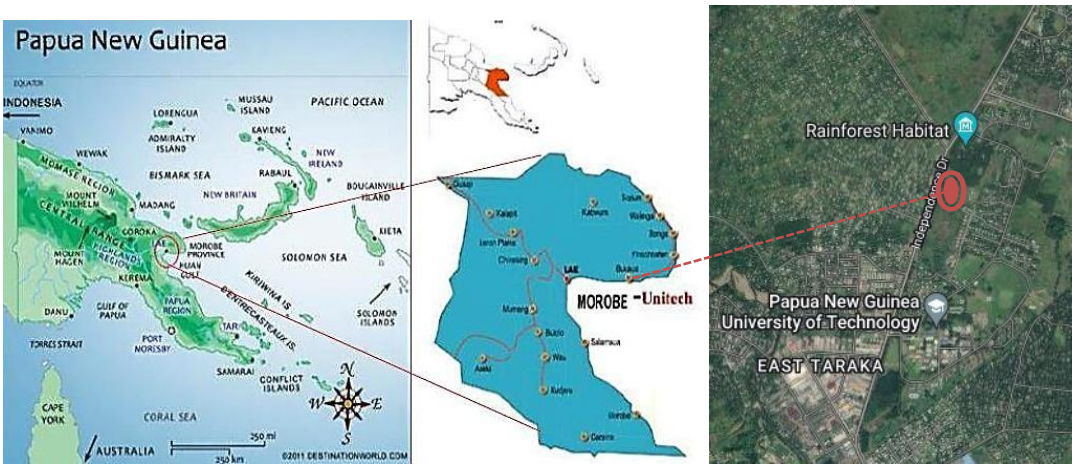


Fig 1: Map of Study Area (Source: Google Map)

The generation of municipal solid waste (MSW) in Lae City is dumped at the oldest landfill at the Second Seventh dump site, which is northeast of UNITECH and lies between 6.6598°S and 147.0123°E. The current practice of open dumping along the boundary of UNITECH is under investigation. This open dump site shown in Figure 2 is close to the bore wells where water is extracted, treated, and distributed by Water PNG Limited throughout Lae City and surrounding communities for domestic and commercial purposes.

A survey was conducted in the study area on Bore Wells along the boundary of the UNITECH dump site during April and June 2022. The methodology for the selection of test parameters was based on the sources of contaminants and the availability of analytical techniques.

The materials and plastics in the close vicinity of the UNITECH boundary are shown in Figure 2, and a map showing the dump site of the current study area is shown in Figure 3.

Fig 2: Types of Solid Waste Dumped at the Landfill

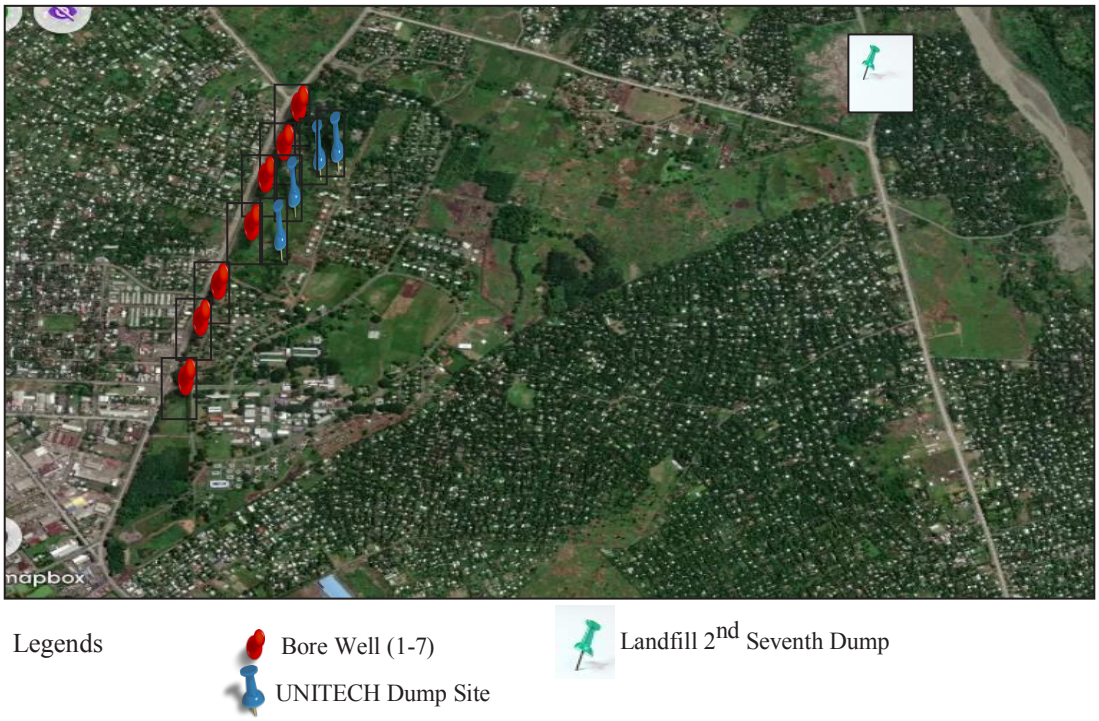


Fig 3: A Google Earth Map Showing the UNITECH Perimeter, The Dump Site, and the Bore Wells

2.2 Investigation Design

The biological, physicochemical, and heavy metal concentrations of surface waters and groundwater along the study zone were assessed to test the hypotheses that the dumping of municipal solid waste (MSW) has been affecting groundwater quality.

2.3 Sampling Plan

Water samples from both surface and bore sources (groundwater) were obtained from seven distinct locations to evaluate the extent of pollution caused by the disposal of municipal solid waste (MSW), as well as plastic and electronic waste near the bore wells. The sampling was conducted around the waste dumping site and the bore wells, following the perimeter boundary outlined in Table 1. It is important to note that samples from BW1, BW2, BW3, and BW5 were not collected due to the malfunctioning of the pump during the sampling process.

Table 1: Locations of Sampling

Description	**Sample ID**	**Longitude**	**Latitude**
Surface water 1	SW1	146° 59' 41.0676" E	6° 39' 47.7576" S
Surface water 2	SW2	146° 59' 36.6756" E	6° 39' 51.9732" S
Bore well 1	BW1	146° 59' 26.8152" E	6° 40' 21.1764" S
Bore well 2	BW2	146° 59' 28.3164" E	6° 40' 12.252" S
Bore well 3	BW3	146° 59' 31.0308" E	6° 40' 8.3676" S
Bore well 4	BW4	146° 59' 33.5364" E	6° 40' 1.3476" S

Bore well 5	BW5	146° 59' 35.5308" E	6° 39' 55.746" S
Bore well 6	BW6	146° 59' 37.3056" E	6° 39' 50.0724" S
Bore well 7	BW7	146° 59' 37.3056" E	6° 39' 43.4592" S
Water Before Treatment	WBT	146° 59' 23.2872" E	6° 40' 8.8716" S
Water After Treatment	WAT	146° 59' 18.8844" E	6° 40' 7.5648" S

2.4 Analytical Technique

All microbiological samples were collected in sterilized bottles that were aseptically kept chilled, taken to the laboratory without delay, and analyzed using the membrane filter (MF) technique to test for total coliforms.

Physico-chemical parameters such as pH, Total Dissolved Solids (TDS), Cadmium (Cd), Lead (Pb), and Mercury (Hg) were analyzed according to the Standard Method of Examination of Water and Wastewater [7].

Heavy metals samples were field spiked with 10% nitric acid to preserve the analyte of interest, filtered using a 0.45um filter, and analyzed using Inductive Couple Plasma-Mass Spectroscopy (ICP-MS) at the 7900 Agilent Mass Hunter. Instrument calibration was done using 0. 0, 0.2, 0.5, and 1.0 mg/L calibration solutions prepared by diluting a mixed standard solution spiked with 1% nitric acid.

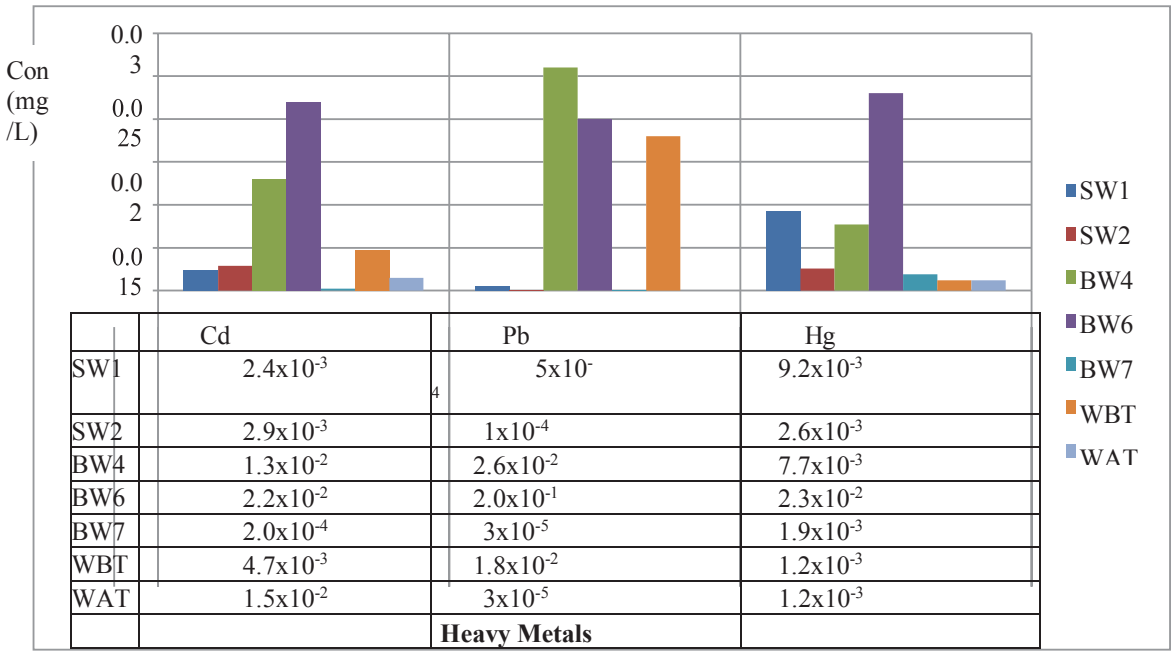
3. Results and Discussion

The bore well located within the study area serves primarily domestic and commercial functions. Consequently, it is crucial to assess the contamination levels of bore wells situated in proximity to waste disposal sites. Table 2 illustrates the analytical findings regarding the quality parameters of surface and groundwater in accordance with World Health Organization standards (Organization 2022). The current investigation reveals that the microbial contamination of total coliforms varies from 0 colony-forming units (CFU) per 100 mL to 14,600 CFU per 100 mL, which exceeds the acceptable limits set by WHO for drinking water. The highest concentrations of coliforms were recorded in surface water samples, specifically SW1 at 6800 CFU/100 mL and SW2 at 14,600 CFU/100 mL. The bore wells BW4 and BW6, which are near SW1 and SW2, respectively, exhibited coliform counts of 120 CFU/100 mL and 500 CFU/100 mL, demonstrating a correlation with the surface water results. In contrast, bore wells located further from the dumping sites, such as BW7, WBT, and WAT, showed no detectable coliforms. The presence of coliforms in BW4 and BW6 suggests contamination of the bore wells adjacent to the dumping sites, indicating significant microbial leaching in these areas. The average standard deviation recorded was 3145.71 ± 5633.17 CFU/100 mL. The lowest pH and total dissolved solids (TDS) measured were 6.8 and 110 mg/L in the surface and bore water samples, respectively. The detection of coliforms points to the presence of organic pollutants, while the identification of heavy metals such as cadmium (Cd), lead (Pb), and mercury (Hg) in samples BW4, BW6, and WBT indicates heavy metal contamination. The open dump site is known to receive fluorescent lamps, batteries, and electronic waste (Figure 2), which are likely sources of heavy metal pollution. The test results clearly demonstrate that heavy metals leach and infiltrate groundwater in the vicinity of the dumping sites. The average standard deviations for cadmium (Cd), lead (Pb), and mercury (Hg) were found to be 0.0066 ± 0.0079, 0.0092 ± 0.012, and 0.0066 ± 0.0071, respectively

Table 2: Bore Well and Surface Water Average Standard Deviations

Parameters	**Sampling Sites**									
	SW1	SW2	BW4	BW6	BW7	WBT	WAT	Average	SD	Permissible Limit WHO
Coliform Total (CFU/100mL)	6800	14600	120	500	0	0	0	3146	*5633*	0
pH Values	6.8	7	7.3	7.5	7.4	7.3	7.4	7.3	*0.2*	7-8.5
TDS (mg/L)	220	110	120	125	163	185	182	158	*40.8*	<500
Cd (mg/L)	0.0024	0.0029	0.0130	0.0220	0.0002	0.0047	0.0015	0.0066	*0.008*	0.003
Pb (mg/L)	0.0005	0.0001	0.026	0.020	0.00003	0.018	0.00003	0.009	*0.01*	0.01
Hg (mg/L)	0.009	0.003	0.008	0.023	0.002	0.002	0.002	0.007	*0.001*	0.006

The WHO's allowable limits for cadmium (Cd), lead (Pb), and mercury (Hg) were exceeded, respectively, by 0.003, 0.01, and 0.006 mg/L. Cadmium (Cd), lead (Pb), and mercury (Hg) were found in samples BW4, BW6, and WBT, while mercury (Hg) was found in samples SW1, BW4, and BW6.
Figure 4 shows a visual representation of the concentration of heavy metals.



	Cd	Pb	Hg
SW1	$2.4x10^{-3}$	$5x10^{-4}$	$9.2x10^{-3}$
SW2	$2.9x10^{-3}$	$1x10^{-4}$	$2.6x10^{-3}$
BW4	$1.3x10^{-2}$	$2.6x10^{-2}$	$7.7x10^{-3}$
BW6	$2.2x10^{-2}$	$2.0x10^{-1}$	$2.3x10^{-2}$
BW7	$2.0x10^{-4}$	$3x10^{-5}$	$1.9x10^{-3}$
WBT	$4.7x10^{-3}$	$1.8x10^{-2}$	$1.2x10^{-3}$
WAT	$1.5x10^{-2}$	$3x10^{-5}$	$1.2x10^{-3}$

Figure 4: Concentration of Heavy Metals at Specific Sampling Locations

4. Conclusion

To conclude, the analysis reveals that total coliform bacteria and heavy metals, specifically cadmium (Cd), lead (Pb), and mercury (Hg), are leaching through the soil and contaminating the bore well, as evidenced by the water sample testing. Total coliform encompasses bacteria typically found in soil, surface water, and the waste of humans or animals. The detection of total coliform bacteria in bore wells BW4 and BW6 suggests the presence of both microbial and chemical contaminants, corroborated by the concentrations of heavy metals (Cd, Pb, and Hg) observed at the study site. Additional analytical sampling and testing of bore wells along the UNITECH boundary will be undertaken, given the presence of microbial and heavy metal contaminants in BW4 and BW6, indicating significant leaching and percolation of pollutants in proximity to the waste disposal areas.

Acknowledgment

My special thanks to the management of National Analytical and Testing Services Limited, through Executive Manager Mr. Vincent Koddy, and staff, support in the form of analytical services, and to Mr. Parkop Kurua, Managing Director, and staff of Water PNG Limited, for granting permission to access bore Wells and assistance during sampling.

References

1. Usman, M., Hafsa. Y., Abdul, N., Waqas M. : A case study of groundwater contamination due to open dumping of municipal solid waste in Faisalabad, Pakistan. *Earth Sciences Pakistan (Zibeline International Publishing)* 1, 15–16 (2017).
2. Akinbile, C.O. : Environmental impact of landfill on groundwater quality and agricultural soils in Nigeria. *Soil and Water Research,* 7, 18–26 (2012).
3. Fatta, D., Papadopoulos, A. Loizidou, M. : A study on the landfill leachate and its impact on the groundwater quality of the greater area. *Environmental Geochemistry and Health,* 21, 175–190 (1999).
4. Vaverková, M. D., Jakub, E., Eugeniusz, K., Dana A., Ayla, B., Vojtěch L., Anna P., et al. :Chemical composition and hazardous effects of leachate from the active municipal solid waste landfill surrounded by farmlands." Sustainability (MDPI) 12: 4531 (2020).
5. Fodor, L. and Szabó, L.: Study of heavy metal leaching in the soil. Proceedings of the 13th International Soil Conservation. Organization Conference (2004).
6. Raju, M. V. S. : Contamination of ground water due to landfill leachate." *International Journal of Engineering Research (Innovative Research Publications),* 1, 48–53 (2012).
7. Rice, E. W., Laura B., :American Public Health Association, and others. (2012). Standard methods for the examination of water and wastewater. Vol. 10. American public health association Washington, DC.

Evidence of Radon Emission Associated with 7th October 2023 Earthquake off the Coast of Madang in Papua New Guinea

Felix Pereira B., Jojo Panakal John, Shameka Banta, Simeon Ifu, David Kolkoma

School of Applied Physics, PNG University of Technology,
Private Mail Bag, Lae 411, Morobe Province, PNG.

*Corresponding Author: felix.pereira@pnguot.ac.pg

Abstract: Radon is the only radioactive gas which is a progeny of Radium. Prior to earthquake, a large amount of radioactive radon gas is also emitted along with other gases from within the earth. Radiation due to radon gas is observed using Radon Eye+2 instrument in the UNITECH campus. Radon emission is observed to be low during dry season compared to wet season. A correlated variation is observed between radon emission and humidity. Emission of radon gas is observed during seismically active periods. A large peak of 565 Bq/m^3 was observed prior to a series of earthquakes on the 7th October 2023 ranging from 5.1 to 6.9 magnitude off the coast of Madang Province approximately 183 km from Lae which is higher than the safe limit of 148 Bq/m^3 radiation. Excess radon emission is observed ten days prior to the earth earthquake. The detection of radon emission prior to earthquake can be used as a tool for the prediction of earthquakes.

Keywords: Radon gas, Inhalation dose, Earthquake.

1. Introduction

Radon is the only radioactive gas with half-life 3.82 days which is the decay product of radium (^{226}Ra) that is a part of ^{238}U series. ^{226}Ra is found in Uranium ores, phosphate rocks, shale, granite and schist and a small amount in lime stone. Radon gas emits due to tectonic stress in fault regions. It is believed that radon escapes through the cracks and cavities formed during earthquake. Papua New Guinea is located in the tectonically active region. This has resulted in frequent earthquakes. Radon emission in the atmosphere during earthquake period is reported in many studies [1, 2, 3]. Radon concentration in ground water is found to increase prior to earthquake [4]. Emanation of radon is linked with atmospheric electric field and ionospheric disturbances [5]. Radon and its progenies are the major contributors responsible for inhalation and ingestion radiation dose to the population. Radon inhalation is the second largest cause of lung cancer after tobacco smoking.

In this paper, we have studied the seasonal variation of radon emission and its association with humidity in the atmosphere by measuring indoor radon gas and humidity using Radon Eyeplus2 instrument. We also calculated the average inhalation dose to human. The radon emission associated with earthquake on 7th October 2023 in Madang Province is also studied.

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2. Materials and Methods

2.1 Measurement of Radon using Radon Eyeplus2

Fig. 1: Radon Eyeplus2 instrument for the measurement of Radon gas

Radon Eye Plus Two is a real time detector with sensitivity of 0.5 cpm/pCi/l. It consists of a passive diffusion chamber which allows air to pass through it. The photodetector placed inside the chamber counts the amount of daughter nuclei of Rn atoms in the air sample. The detector is sensitive to alpha particles emitted by Rn and its progeny. Then new samples are filled in the chamber in about 30-45 minutes.

3. Results and Discussion

3.1 Seasonal Variation Radon

The Radon Eyeplus2 instrument is installed in the laboratory and continuous measurements of radon and humidity were done from 10th October 2022 to 21st July 2023. The smoothened variation of radon and humidity for the period of study are given in Fig. 2. A correlated variation with correlation coefficient 0.74 is obtained between the two. The radon emission was observed to be low during the dry season where humidity was low compared to the wet season.

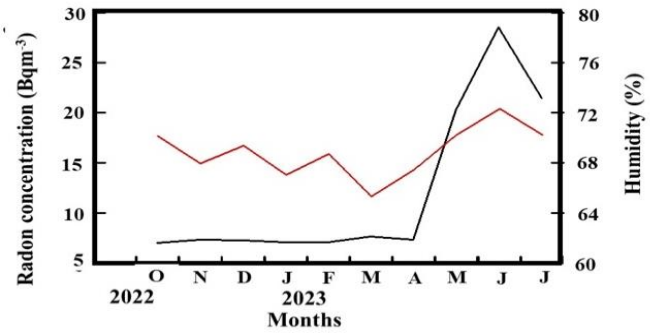

Fig. 2: Variation of Radon and Humidity for the period 10th October 2022 to 21st July 2023.

3.2 Radon Emission during Seismically Active Period

3.2.1 Study Area: Five locations within the UNITECH campus were selected where the Radon Eyeplus2 instruments were installed. The locations are 1. Boys' Dorm, 2. Boys' dorm Emaru, 3. Adventist Residence College, 4. Girls' dorm and 5. Fly Drive. The study areas are selected randomly. In Adventist Residence College, the instrument is kept in a room in the ground floor and in other centers, the instrument is kept in the first floor.

3.2.2 Inhalation Dose Estimation: The radon concentrations in the five locations are measured using Radon Eye+2 instruments for two months duration. The Mean Effective Dose (H) for the inhabitants was calculated from the experimentally determined value of radon concentration (C_{Rn}) using the expression

$$H(mSv/y) = C_{Rn} \times F \times O \times DCF \quad (1)$$

where F is the global average (0.4) of equilibrium factor for Rn and its progeny, O is the global average indoor occupancy factor (7000h/y) and DCF is the dose conversion factor 9nSv/h/(Bq/m^3) for Rn and its progeny [6].

Table 1: The Radon concentration and Indoor Annual Effective Inhalation Dose in the five locations.

Location	Period of observation		Rn Conc. (Bq/m^{-3})	AED (mSv/y)
	Start	End		
Boys' Dorm	04/08/2023	21/09/2023	10	0.252
Boys' Dorm Emaru	04/08/2023	05/11/2023	17	0.428
Adventist Res. College	21/09/2023	05/11/2023	29	0.731
Girls' Dorm	06/08/2023	22/09/2023	7.26	0.183
Fly Drive	25/08/2023	01/11/2023	2.89	0.073
Mean			**13.23**	**0.33**
St. Dev.			**9**	**0.23**

The average radon gas concentrations and the indoor inhalation dose in 5 locations are presented in the table 3. The radon concentration was found to vary from 2.89 to 29 Bq m^{-3} with arithmetic mean 13.23±9 Bq m^{-3}. The most important factor of radiological concern, the annual inhalation dose resulting from radon and their progeny varied from 0.073 to 0.731 mSv with average value of 0.33±0.23 mSv. Indoor radon concentrations vary very widely depending on several factors all over the world. The global average of radon concentration is 40 Bqm^{-3} [7]. PNG is situated in the volcanic and earthquake prone region of 'ring of fire' in the pacific. Therefore, the houses are mostly made on pillars to resist the frequent tremors. Therefore, the possibility for accumulation of radon or thoron gas underneath the dwellings is very rare. The tropical weather conditions give ample chance for good ventilation and thereby dilution of indoor air. The common building materials used in the region may also not contribute much to the indoor radon.

The world average annual inhalation doses due to radon, thoron and their progeny have been reported to be in the range of 2 to 10mSv. The estimated inhalation dose to the inhabitants of dwellings in UNITECH was found to be much less. The estimated inhalation dose was found to be higher in Adventist Residence College location (Fig. 3) compared to other centres because in Adventist Residence College location, the instrument is kept closer to the ground.

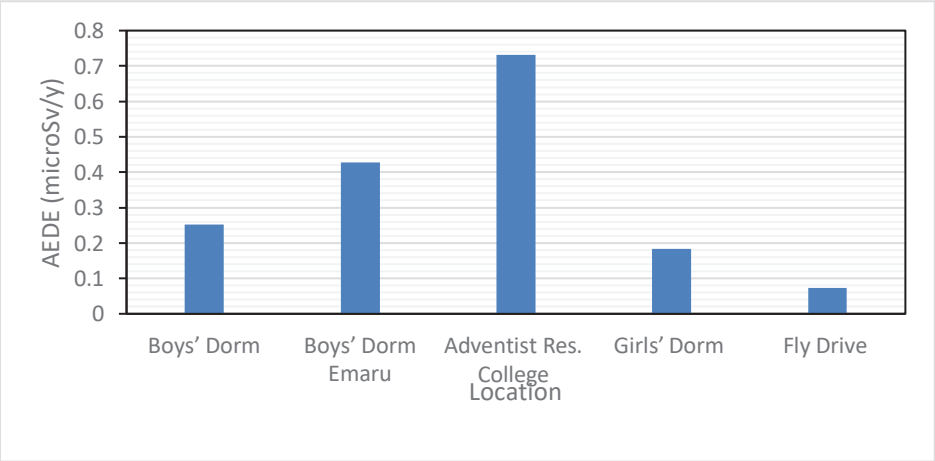

Fig. 3: The Annual Effective Inhalation dose in the five locations of Unitech campus.

3.3 Radon Observations during Earthquake Period

In the context of radon monitoring, the US Environmental Protection Agency recommends taking action to mitigate radon levels in buildings that exceed 143 Bq/m^3, as concentrations above this level are considered potentially hazardous. Radon testing was carried out at five locations, with four showing average and maximum levels within safe limits. However, at Location 3: Adventist Residential College, a maximum reading of 565 Bq/m^3 was recorded, significantly surpassing the safety threshold. This elevated radon level was attributed to a series of earthquakes on October 07, 2023, during which the PNGUOT Seismic Station recorded 12 earthquakes. Due to power outages, data from seven earthquakes with magnitudes ranging from 5.1 to 6.9 on the Richter Scale were obtained. These seismic events had their epicenter near Saidor, located just off the coast of the Madang Province, approximately 183km aerial distance from Lae. Figures 4 and 5 below show recorded tectonic activity on the date mentioned above.

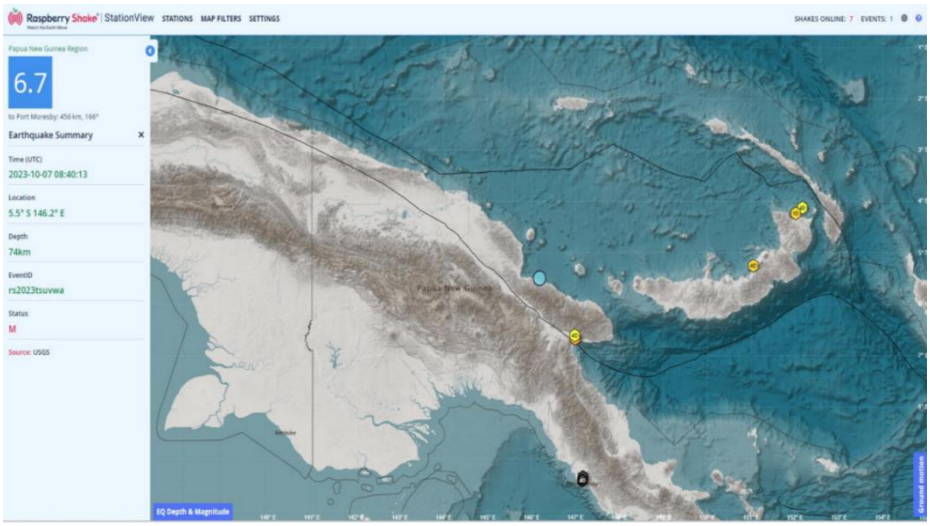

Fig. 4: Map of Papua New Guini. The epicenter of the earthquake is represented by the blue circle in Madang Province and the PNGUOT Seismic Center is represented by the yellow hexagon just below it.

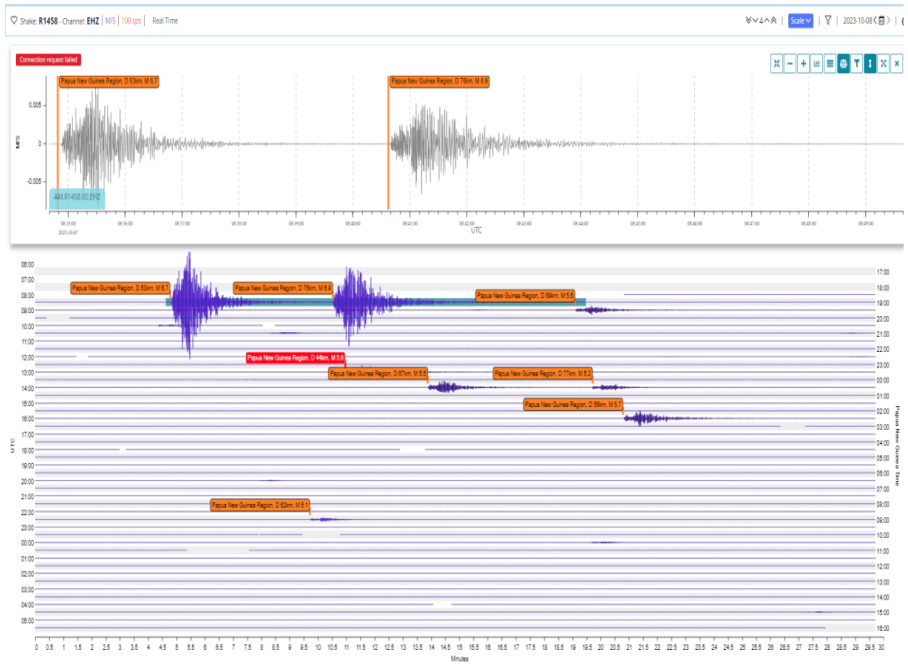

Fig. 5: Seismogram on 7th October 2023 on which date earthquake occurred.

The empirical relationship between earthquakes and indoor radon measurements is given by

$$M = 2.4log_{10}D - 0.43 \quad (2)$$

where M is the magnitude and D is the distance from the epicenter [8]. Radon gas can be detected up to a radial distance of 1132 km for an earthquake of magnitude 6.9. Since the radial distance from the epicenter and Lae is only 183 km, we can expect radon emission at Lae.

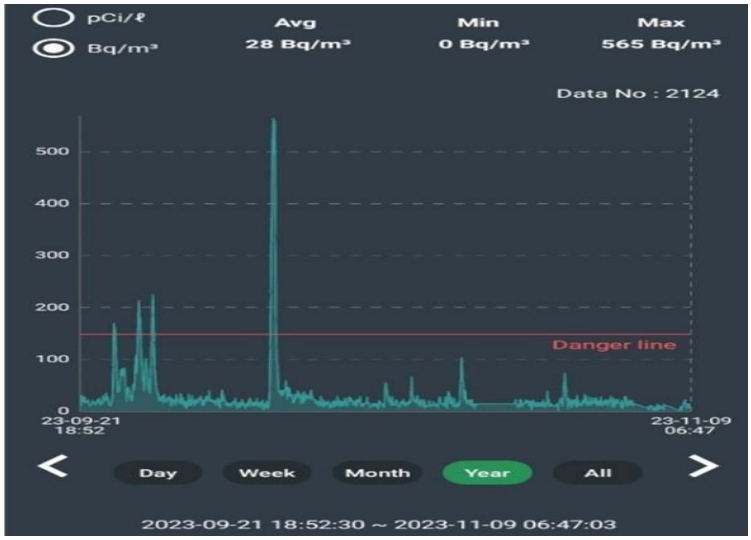

Fig. 6: Radon observation from 21/09/2023 to 09/11/2023 in Adventist Residence College

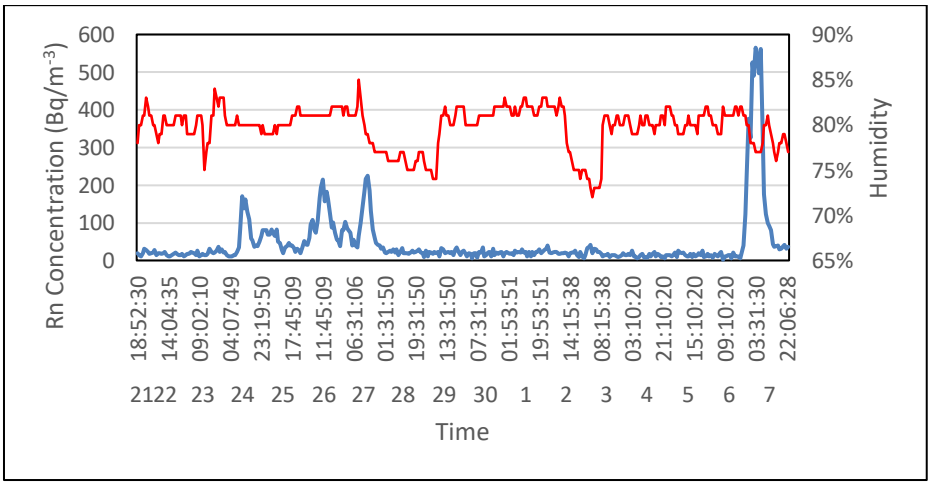

Fig. 7: Radon observations (blue) and humidity (red) from 21/09/2023 to 07/10/2023.

Fig. 6 gives the radon observations from 21/09/2023 to 09/11/2023 in Adventist Residence College. Radon observations and humidity from 21/09/2023 to 07/10/2023, a few days prior to the earthquake is drawn in Fig. 7.

In Fig. 7, we can observe that, about ten days prior to the earthquake, radon emission peak is observed to be 170 Bq/m^3 (above 4 standard deviations) on 24th, 214 Bq/m^3 (above 5 standard deviations) on 26th and 225 Bq/m^3 (above 5 standard deviations) on 27th September 2023 and these peaks obtained are statistically significant. It again started to increase on 6th October at 18:10 hours in the evening and reached a value of 565 Bq/m^3 and lasted till 13:30 on 7th October. Two major earthquakes occurred on 7th October, one at 19:05 (LT) with magnitude 6.7 and another at 19:11 (LT) with magnitude 6.9. Humidity variations are observed to be less during the earthquake precursor period.

Before the 2011 Tohoku-oki earthquake in Japan, radon anomaly observed prior to the earthquake, exceeded 3 standard deviations [9]. Planinic et al. (2004) derived an empirical relation by analyzing the radon peaks with magnitude >3M at epicentral distances < 200 km. The precursor time can be calculated using the relation [10]

$$\text{Log}(DT) = 0.63\,M + b \quad (3)$$

where b is 0.15 for gaseous geo-seismic precursors of earthquake, T is the precursor time (day), D is the epicentral distance and M is the magnitude. So, excess radon emission prior to earthquake can be used as a tool for earthquake prediction but further study has to be done to confirm this.

Though we have installed the radon monitoring instruments in five locations, we could be able to measure radon only in one location during earthquake period because of frequent power failures. The instrument installed in Adventist College has a power back up system.

4. Conclusion

The Unitech campus situated in Lae falls in the 'Ring of Fire' region which is tectonically active. The tectonic activity results in frequent earthquakes and volcanic eruptions. The soil in Lae region is influenced by volcanic activity, sediment deposition and organic matter decomposition. The radioactive radon gas which is a progeny of ^{238}U is measured in the regions of study using Radon Eye+2 instrument and the inhalation dose were calculated. The inhalation dose varies from 2.89 to 29 with an average value of 13.23 ± 9 Bq/m^3. The inhalation dose was found to be less than the world average value of 40 Bq/m^{-3}. Radon gas emission is found to be associated with earthquakes. Excess radon emissions greater than 100 Bq/m^3 were observed ten days prior to earthquake. A peak value of 525 Bq/m^{-3} of radon emission for a few hours was observed one day prior to a massive earthquake followed by a series of earthquakes on 7th October 2023. Further studies are required to study the actual relationship between radon emission and earthquakes which help in predicting earthquakes.

References

1. Jae Wook Kim, Joo, H. Y., Kim, R., Moon. J. H.: Investigation of the relationship between earthquakes and indoor radon concentrations at a building in Gyeongju, Korea, Nuclear Engineering Technology, 50, p.512-518 (2018).
2. Sac, M. M., Harmansah, C., Camgoz, B, Sozbilir, H.: Radon monitoring as the precursor in Fault line in Western Turkey, Ekoloji 20, 79, p. 93-98 (2011)
3. Igarashi, G., Saeki,S., Takahara N. : Ground-water radon anomaly before the Kobe earthquake in Japan, Nature, 269, p. 60-61 (1995).
4. Wakita, H. et al., : Radon anomaly: A possible precursor of the 1978 Izu-Oshima kinkai earthquake, Science, 207(4433), p.882-883 (1980).
5. Omori Y. et al.: Anomalous radon emanation linked to preseismic electromagnetic phenomena, Natural Hazards and Earth Syst. Sci., 7(5), p.629-635 (2007).
6. UNSCEAR, 2000. : Sources and Effects of Ionizing Radiation," *UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation),* vol. Volume 1: Sources., no. New York: United Nations (2000)
7. Ramola, R., et al., Dose estimation derived from the exposure to radon, thoron and their progeny in the indoor environment, Scientific Reports, doi: 10.1038/srep31061 (2016).
8. Hauksson, E., J. G. Goddard. : Radon earthquake precursor studies in Iceland, J. Geophys. Res., 86 (B8), p. 7037-7054 (1998).
9. Tsuchiya, M., Nagahama, H., Muto, J. et al.: Detection of atmospheric radon concentration anomalies and their potential for earthquake prediction using Random Forest analysis. *Sci Rep* 14, 11626 (2024) https://doi.org/10.1038/s41598-024-61887-6
10. Planinić, J., Radolić, V., Vuković, B. : Radon as an earthquake precursor, Nuclear *Instruments and Methods in Physics Research A*, 530, 568–574 (2004).

Borehole Image Log Interpretation in Fractured Basement of Contai Area, Bengal Basin, India for Hydrocarbon Exploration

Muhammad Ali

School of Applied Physics, Papua New Guinea University of Technology,
Lae 411, Morobe Province, PNG

Corresponding author: mohammad.ali@pnguot.ac.pg,

Abstract: Fractured basement reservoirs are not being explored fully despite of their proven commercial success globally. Basement reservoirs consist of rocks such as granite, granodiorite, gneiss, basalt etc. All basement is not fractured. Fractures finding in basement rock through conventional petrophysical tools is not possible. Borehole image logging tools such as Formation micro resistivity image (FMI) and Circumferential borehole acoustic image log (CBIL) are most important tools in petroleum industry to find the fractures, dip magnitude and its direction of fractures, in-situ horizontal stress direction (S_H), bedding plane and lithological boundaries etc. Fractures in conductive nature can be identified by both micro resistivity and acoustic image tools. Resolution of resistive image tool for identifying conductive fractures is much better than acoustic tool. But the demerit of resistivity image tool is that it cannot detect whether conductive fractures are either open or close. Acoustic tool can identify open or close fracture through amplitude and travel time. For open fracture, both amplitude and travel time of acoustic image tool will show low amplitude sinusoidal nature. Amplitude of acoustic tool has been reduced in open fracture due to mud entry in open fracture as a result dissipation of acoustic energy against open fractures occur and so amplitude is reduced. For closed fracture there is no mud entry within fractures, so amplitude of acoustic tool would be strong but travel time will not show any sinusoidal because of no dissipation of energy in travel time. When fractures are mineralized by minerals, they are called closed fractures and certainly those close fractures are devoid of hydrocarbon. Both FMI & CBIL tools were lowered in well R of 'Oil & Natural Gas Corporation Ltd' for finding fractures in basement of Contai block, Bengal basin, India. Well R was drilled up to the depth of 3950 m. Basement top is at a depth of 3606m and bottom depth was 3950m. Huge number of fractures in the depth interval 3606m – 3950m in basement of Bengal basin were identified by both tools of FMI and CBIL. Most of them are closed due to mineralization by conductive minerals. We may conclude that basement of area of Contai, Bengal basin, India is having fractures which are closed and therefore, this basement is devoid of hydrocarbon.

Key words :Fracture basement, Conductive fracture, Open and close fracture, Sub vertical fracture, In-situ horizontal stress direction

1. Introduction

Commercial production of hydrocarbon has begun from fractured crystalline basement across the globe since decades. Several oil discoveries are found in the basement of North Sea and the West of Shetlands [1, 2]. The examples of producing fractured reservoirs are belonging to the Cuulong Basin, Vietnam and Southern Sumatra Basin, Indonesia along with other significant basins in Yemen, China, and India [3, 4, 5]. The petroleum system components of basement reservoirs are no different from those of conventional clastic reservoirs. The basement reservoir typically comprises of lithologies such as granite, granodiorite and gneiss with secondary lithologies including dolerite and basalt. The permeability of this reservoir is provided by fractures ranging in scale from faults detectable from seismic data to those fractures that can be detected and quantified from the evaluation of core [6, 7]. Basement reservoirs may tend to have complex geological histories with fracture properties resulting from a combination of tectonic, hydrothermal and epithermal processes. Drilling of production wells is usually to be perpendicular to the dominant fracture system. Wells are to be deviated rather than vertical in order to optimally intersect the dominant fracture systems. Borehole image logs will provide information of the fractures with sufficient accuracy at well location [4, 8]. Many seismic techniques have been developed recently for providing fracture information

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between wells or exploring fractured basement before drilling a well [7]. Our study area is Contai block. Contai block is located in the continental shelf area in the southern part of Onland Bengal basin with an aerial extent of 610 sq.km (Figure1). From 2D seismic section of Contai block, Gondwana formation shows as a good reflector as well as basement also indicated presence of possible fractures. Therefore, Directorate General of Hydrocarbon (DGH), India had assigned ONGCL to drill 4 wells in Contai area for exploration of hydrocarbon in Gondwana formation and fractured basement. Initially three wells C, G and H were drilled up to Gondwana and drilling could not be completed in these 3 wells up to basement due to difficulties faced while drilling further below Gondwana formation.

Finally, a well R was drilled by 'Oil & Natural Gas Corporation Ltd" (ONGCL) for the purpose of finding fractures in Contai area, Bengal basin, India. FMI and CBIL tools were lowered with conventional tools. Fractures in basement were identified by both image logs. Most of the fractures are closed as they were mineralized. Therefore, basement in Contai area is devoid of hydrocarbon.

2. Geology of Bengal Basin

Bengal basin is a foreland basin with a succession of mainly deltaic sediments derived from the erosion of the Himalaya and Indo-Burmese ranges. The Bengal basin developed into isolated graben-controlled basin in basement during the breakup of Gondwana land. The Bengal Basin is one of the major sedimentary basins in Indian Sub-continent. The Indian part of the basin encompasses an area of approximately 57000 sq. km. in onland and 33,700 sq. km. in offshore part. The area is bounded by Indian Shield to the northwest, Surma Basin to the east, deeper part of Bay of Bengal to the south-southeast and Mahanadi Basin to the southwest [9, 10]. The Ganga-Brahmaputra rivers and their tributary/distributary system transport sediments from the Himalayas and surrounding Indian cratonic part to pour into the basin, forming one of the biggest modern delta systems of the World [11]. Contai block was given to 'Oil & Natural Gas Corporation' by Directorate General of Hydrocarbon, India for finding hydrocarbon. Tectonically Contai block is located in the stable shelf area in the southern part of onland Bengal Basin with an aerial extent of 610 sq. km. (Figure 1).

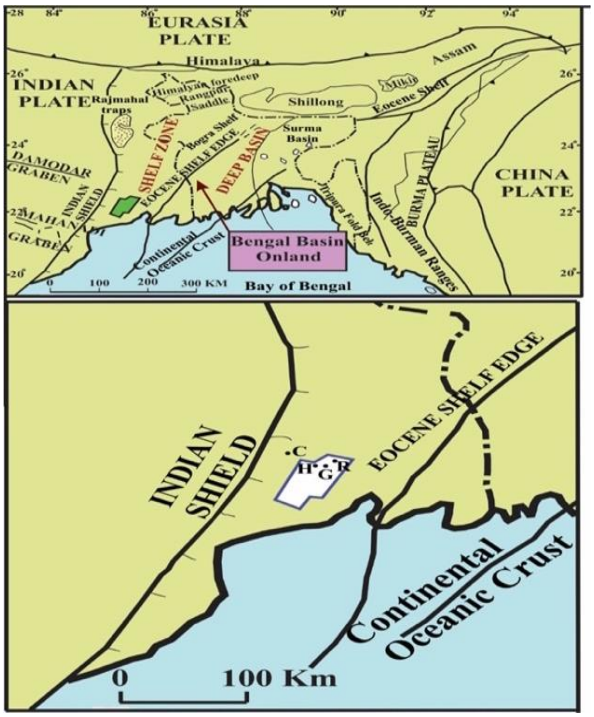

Fig 1: Tectonic Map of Bengal basin showing Contai block (White polygon) with wells [12].

In Contai area, four wells, namely; C, G, H and R have been drilled by ONGC. The well C was drilled in the year 1989-90 to explore possible hydrocarbon accumulation in Paleocene-Cretaceous sequence and stratigraphic information and hydrocarbon potential of upper part of Gondwana sequence. The well was drilled down to 3862 m and was terminated within Lower Gondwana (Talchir Formation). The stratigraphic correlation between these four wells is shown in Table 1. Based on the hydrocarbon show and Log data in Paleocene (Jalangi Formation), six objects within Paleocene were tested by means of open hole / cased hole testing methods. One object (3102-3096 m) was although identified within Gondwana but could not be tested due to non-availability of packer. All the zones tested, produced formation water with minor inflammable dissolved gas.

Table 1: Showing the stratigraphic correlation between four wells, Contai area.

AGE	FORMATION		Well R K.B: 9.93m	Well H K.B. 10.21 m	Well G KB: 9.37m	Well C KB: 11.6m
Plio-Pleiostocene to Recent	Bengal Alluvium &Debagram Formation		0 - 1512	0 – 1453	0 – 1490	0 – 978
Miocene	Pandua		1512 - 2007	1453 – 1952	1490 – 2015	978-1427
Oligocene	Memari		2007 - 2030	1952 – 1969	2015 – 2035	1427 – 1452
	Burdwan		2030 - 2363	1969 – 2261	2035 – 2333	1452 – 1820
Eocene	Hooghly		2363 - 2416	2261 – 2324	2333 – 2395	1820 - 1827
	Kalighat		2416.5 - 2796	2324 – 2736	2395 – 2771	1827- 2047
Paleocene	Jalangi		2796 - 2911	2736 – 3051	2771 – 2994	2047 – 2294
Late Cretaceous	Ghatal		2911 - 2940	3051 - 3087	2994 – 3031	2294- 2355
	Bolpur		2940 - 3124	3087 – 3147.5	3031 – 3095	2355 – 2412
Lower to Upper Cretaceous	Rajmahal Trap		3124 - 3252	3147.5-3557	3095 – 3244	2412 – 2500
Permian to Lower Triassic	Gondwana	Panchet	3252 - 3320	3557-3665	3244 – 3330	2500 – 2732
		Raniganj	3320 - 3400	3665 - 4318	Not drilled	2732 – 3340
		Barakar	3400 - 3532	4318 - 4491	Not drilled	3340 – 3640
		Talchir	3532 – 3606	4491 – 4590		3640 – 3862
Archaean	Basement		3606 – 3947	Not drilled		Not drilled

The well G was drilled down to 3330 m and bottomed within Upper Gondwana sequence. Electrolog correlation with well C indicates that the well G is structurally down by 746m, 778m and 572m at Gondwana, Paleocene and Eocene level w.r.t to well C located 20km away towards NW in up dip. Three objects were tested in Paleocene-Cretaceous section. The depth intervals: 2863-2857.5 m and 2854.5-2850.5 m, belonging to the Middle Jalangi, gave encouraging lead in the form of continuous flow (for about a month) of mainly dry methane gas (about 98% methane) @ 60 m^3/day and water @ 18 m^3/day. This

drilled well has thus proved both generation and presence of hydrocarbon in this part of the basin. The wells C, G and H were not drilled in basement. Only well R was drilled to basement covering 300m interval within basement. Our study area is basement only for fracture findings.

3. Analysis of Image Log in Study area

The well R was the well where drilling is completed to the depth of 3950m. Basement interval in this well R is 3650 m to 3950m= 300m.Conventional tools such as Dual Latero tools, Litho Density-Neutron porosity tools, Sonic and natural Gamma ray tools were lowered and log data were obtained from bottom depth 3950m to 1000m for formation evaluation. Borehole image logging tools such as formation micro resistivity imager (FMI) and Circumferential borehole acoustic image (CBIL) logging tools were lowered and image log data recorded only in basement interval 3650 – 3950m in the well R for finding and study fractures in basement for hydrocarbon exploration in basement. Main objectives are to characterize the fractures from the image logs and to integrate micro resistivity and acoustic image log for estimation of maximum horizontal stress (S_H) direction, dip of the fracture, type of fractures, bedding plane and lithological boundaries etc. The tadpole plot shows dip of fractures, bedding and lithological boundary following the symbols of classification of dip:

Classification

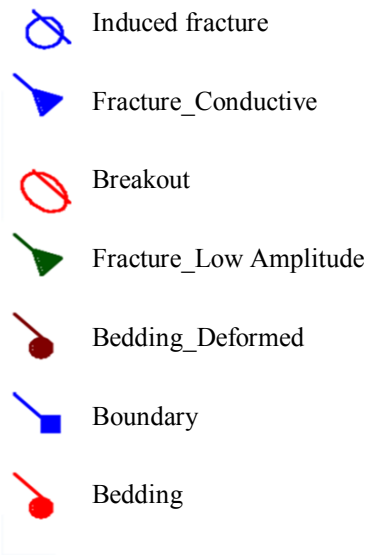

Figure 2 to Figure 9 is the processed output of Borehole Image log data of micro resistivity and Circumferential borehole acoustic image data in the interval of 3650 -3950m of basement of Bengal basin. Data is processed by author after using Electro log Analysis software.

3.1 Bedding Plane Identification in the Interval 3650-3655 m

This depth interval 3650-3655m displays FMI and CBIL logs to identify bedding planes and its orientation. Bedding planes are marked in Figure 2. Resistive image log (FMI) is much more resolved vertically than acoustic image log (CBIL) for delineation of bed boundary (Figure 2). Tadpole plot shows the dip amount and azimuth of the bedding plane. Figure 3 shows the Rosette (Rose) diagram of bedding plane within basement striking NE-SW direction for depth interval 3650-3950m (Figure 3)

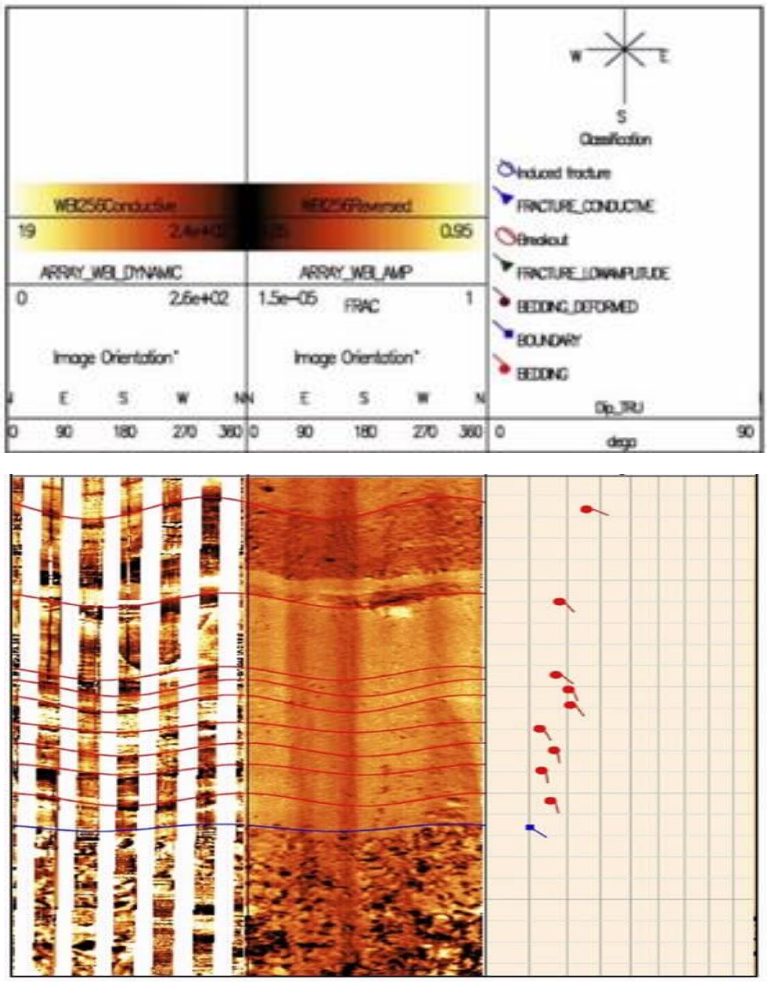

Fig 2: Showing the bedding plane of FMI and CBIL log in the interval 3650- 3655m of well R of Contai area

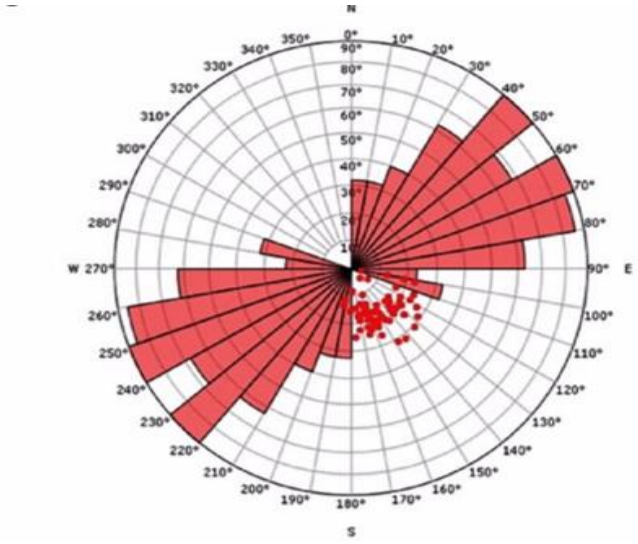

Figure 3: Showing the strike direction of bedding plane in the interval 3650m-3950m of well R of Contai area

3.2 Conductive Fractures

The low amplitudes fractures are identified from 3650 to 3950m of basement of Contai area. Figure 4 typically shows few low amplitude conductive fractures in both resistive and acoustic images**.** The acoustic amplitude and micro resistivity image logs indicate sinusoidal shaped fractures but acoustic travel time image log does not indicate any such types of features. Since these fractures are mineralized, there is no dissipation of acoustic energy. Travel Time image does not show any sinusoidal features due to the mineralized fractures. Micro resistivity image shows dark colored sinusoidal features due to presence of low resistive/ conductive mineral in the fractures. The closed fractures in basement are devoid of hydrocarbon. Therefore, the depth interval of 300m in basement from 3650-3950 m is devoid hydrocarbon. Figure 5 indicates the mean strike direction of N45ºE of mineralized fractures for 300m depth interval. The strike direction shows the paleo stress direction of the basement fractures.

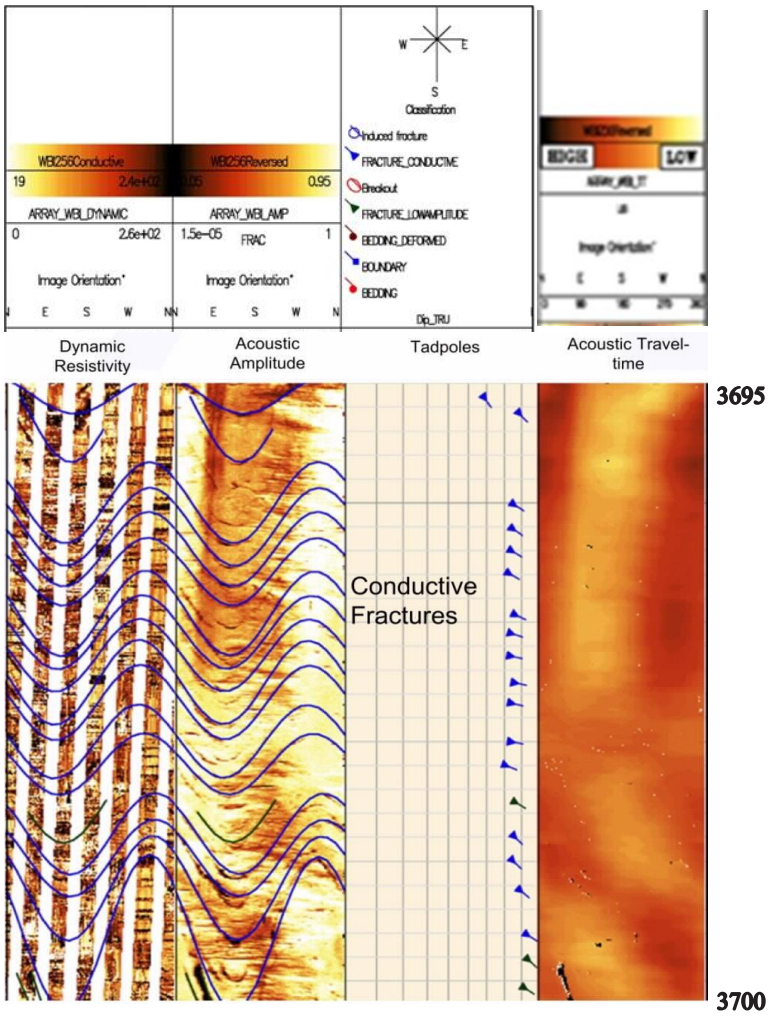

Fig 4: Showing conductive fractures (mineralized) in depth 3695-3700m of well R

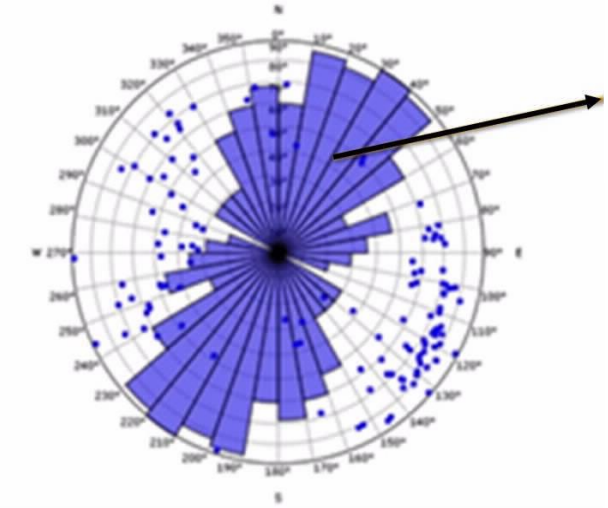

Fig 5: Strike of conductive fractures in the interval 3650-3950 m of well R

3.3 Drilling Induced Tensile Fracture in the Depth Interval 3746-3750 m

Figure 6 represents the drillings induced fractures (DIF) which are observed very distinctly in acoustic borehole image log in the interval 3746-3750 m in basement. The orientation of DIF is aligned with the orientation of maximum horizontal stress (S_H). Strike direction of DIFs is NE-SW indicating that the orientation of S_H is NE-SW (Figure 7)

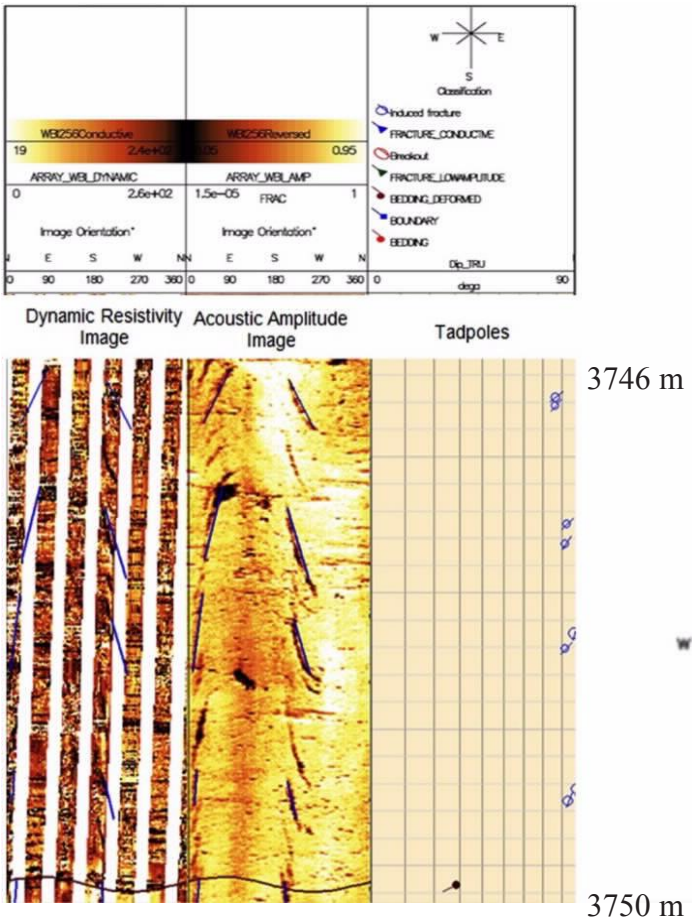

Fig 6: Showing drilling induced fracture in the interval 3746 m to 3750 m in basement

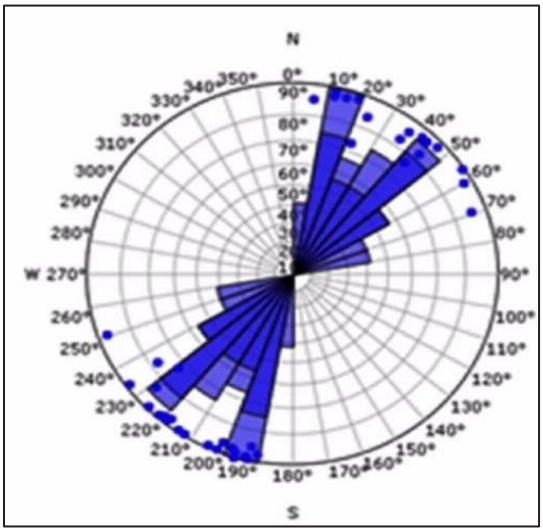

Figure 7: showing azimuth direction of Drilling induced tensile fracture and this direction also the In-situ Maximum Horizontal Stress (S_H) direction of well R

3.4 Open Fractures in the Depth Interval 3710 – 3713 m

The fracture observed in acoustic image log in the interval 3710-3713m (Figure 8) is low amplitude open fracture. Acoustic travel time (TT) image characterizes total loss of energy indicating black sinusoidal features and striking parallel to S_H direction.

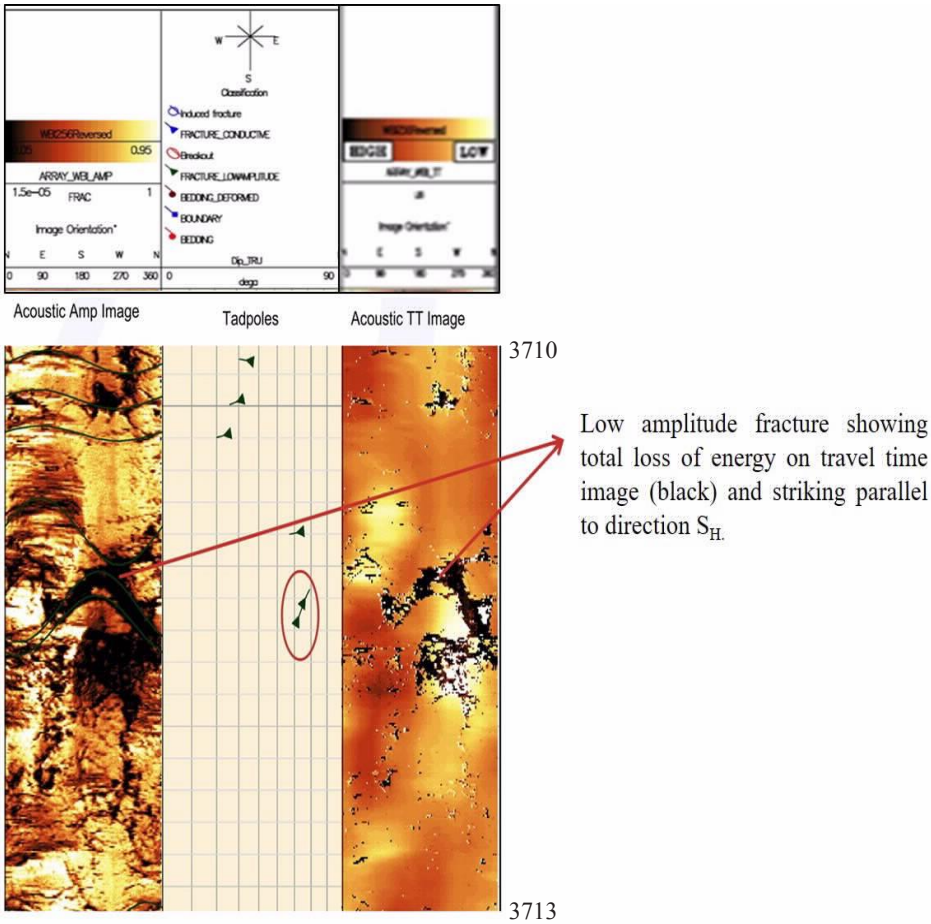

Figure 8: Shows the open fracture in interval 3710 -3713 m of CBIL tool of well R

3.5 Sub-vertical Open Fracture at the Depth Interval of 3924 to 3932 m in the Basement

Figure 9 elaborates features indicating low amplitude sub-vertical fracture terminated against the fracture right above it. Total energy loss on travel time image (dark) indicates that it is open in nature. Striking direction is parallel to the orientation of SH.

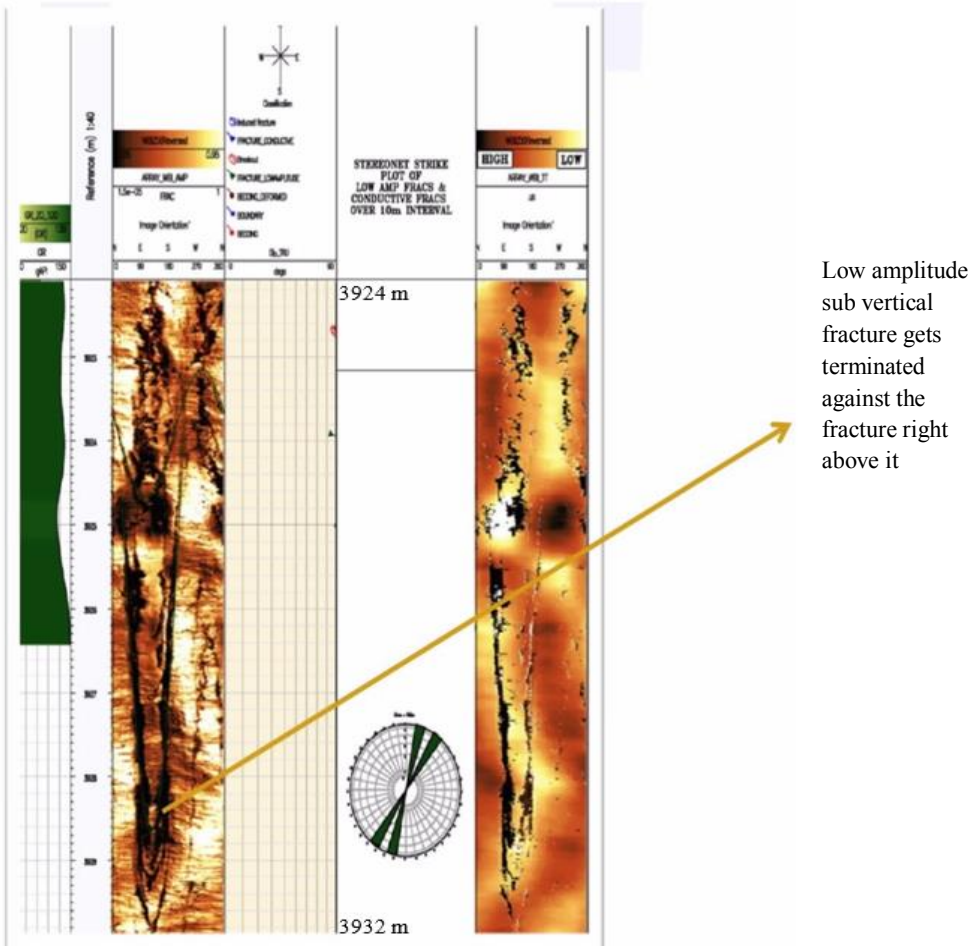

Fig 9 Shows sub vertical open fracture in the interval 3924 – 3932m of acoustic tool of well R

4. Results

Fractured basement of Bengal basin of one well is studied through micro resistivity and circumferential borehole acoustic image logs. From the above image log studies, it is inferred thar few natural fractures in the basement are open and they are oriented parallel to the maximum horizontal stress direction. Acoustic travel time image in the basement shows that most of the fractures are mineralized and closed. This closed mineralized fracture characterizes with strong amplitude acoustic information along due to presence of energy on travel time image. Very few fractures observed in acoustic image log are open. Sub vertical open fracture exists in the depth interval 3924-3932m striking parallel to the maximum horizontal stress (S_H) direction. Fracture basement of Bengal basin is devoid of hydrocarbon as most of the fractures in basement are mineralized and as a result they are closed observed from image tool. Low amplitude open fracture is showing total loss of energy on travel time.

5. Discussion

There is a great interest and value in fracture detection and evaluation of fractured basement reservoirs in Bengal basin. The procedure for identification and evaluation of natural as well as induced fractures in basaltic basement of the Cambay basin has already been presented previously [13]. The Deccan trap basaltic basement in Tarapur-Cambay block has potential for holding commercial hydrocarbon due to presence of fractures and weathered basement. Electrical and ultrasonic borehole images along with conventional sonic logs have been used to characterize fracture system. Electrical image logs assume that all conductive fractures are open and can transmit fluid. In reality the majority of the fractured reservoirs flow hydrocarbon from only a few isolated fractures or from a specific fracture set or system. A combination of image logs and acoustic logs characterize fractures and other form of high permeability geological flow conduits [14]. The combination of these measurements allows a detailed analysis of fracture type (open, closed and plugged), fracture orientation, and most importantly the ability of individual open fractures and fracture sets to flow fluid. Image logs identify three types of fracture including open (Conductive), partially open and closed(resistive) fractures of which open and partially open fractures are important for hydrocarbon accumulation. Finding of this discussion is to utilize acoustic and resistivity image logs for identification of low amplitude fractures, open and mineralized fractures as well S_H direction. Dip of the fractures in the Contai area ranges from 10 to 80 degrees. Image logs identify conductive and mineralized fractured zones. Subvertical fractures are delineated. The strike direction of open fractures for a well in Contai area ranges from $N20^0E$ to $N40^0E$. The S_H orientation is varying from N20 to 40^0E in the basement of Contai area. Fractured basement of Bengal basin is devoid of hydrocarbon as most of the fractures in basement are mineralized and as a result, they are closed identified from CBIL tool.

Acknowledgement

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References

1. Austin, J. A., Cannon, S. J. S. Ellis, D.: Hydrocarbon exploration and exploitation West of Shetlands, Geological Society, London, Special Publications, 397, 1-10 (2014).
2. Thrice, R.: Basement exploration, West of Shetlands: progress in opening a new play on the UKCS, Geological Society, London, Special publications, 397, 81-105 (2014).
3. Guttormsen, J.: Naturally Fractured Basement Reservoirs: Using South Sumatra to Characterize the Challenges of Exploring and Exploiting Fracture Basement (2010).
4. Datta Gupta, S., Chatterjee, R. Farooqui, M. Y.: Formation evaluation of fractured basement, Cambay basin, India, Journal of Geophysics and Engineering, 9, 162-175 (2012).
5. Goyal, U., Chintis, S. N. Ray, B. B.: Challenges in identifying hydrocarbon potential in fractured Basement in Mumbai High field, 10th Biennial International Conference & Exposition, Kochi, India, P286 (2013).
6. Jolly R. J. H., Cosgrove J. W. : Geological evidence of patterns of fluid flow through fracture networks: examination using random realizations and connectivity analysis in Fracture and In-situ Stress Characterization of Hydrocarbon Reservoirs, Geological Society, London, Special Publication, ed Ameen M. S. 209, pp 177–187 (2003).
7. Nguyen, H. N., Sahalan, B. A., Nguyen, A.D.: The application of seismic attributes for reservoir characterization in Pre- Tertiary fractured basement, Vietnam – Malaysia offshore, Interpretation, 2(1), SA57-SA66 (2014).
8. Ali, M., Paul, S., Chatterjee, R.: Cleat Orientation from Ground Mapping and Image Log Studies for In-Situ Stress Analysis: Coal Bed Methane Exploration in South Karanpura Coalfield, India, Energy & Fuels, 31(7), 6812-6824 (2017).
9. Curray, J. R., Emmel, F.J., Moore, D.G.: The Bengal Fan: Morphology, Geometry, Stratigraphy, History and Processes, Maine and Petroleum Geology, 19, 1191-1223 (1993).
10. Alam, M., Alam, M. M., Curray, J. R., Chowdhury, M. L. R., Gani, M. R.: An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin fill history, Sedimentary Geology, 155, 179–208 (2003).
11. Roy, A.B., Chatterjee, A.: Tectonic framework and evolutionary history of Bengal basin in the Indian subcontinent, Current Science, 109 (2), 271-279 (2015).
12. Mukherjee, A., Fryar, A. E., Thomas, W. A.: Geologic, geomorphic and hydrologic framework and evolution of the Bengal basin, India and Bangladesh, Journal of Asian Earth Sciences, 34, 227–244 (2009).
13. Chatterjee, R., Datta Gupta, S., Mandal, P. P.: Fracture and stress orientation from borehole image logs: A case study from Cambay basin, India, Journal of Geological Society of India, 89, 573-580 (2017).
14. Suardana, M., Smodra, A., Wahidin, A., Sule, M. R.: Identification of Fractured Basement Reservoir using Integrated Well Data and Seismic Attributes: Case study at Ruby field, North west Java basin, AAPG, Annual Convention and Exhibition, Pittsburgh, Pennsylvaniya, May 19-22, Article id .20195 (2013).

Radiation Dosimetry and their Effects on Humans on the UNITECH Campus

Felix Pereira B.*, Jojo Panakal John, Shameka Banta, David Kolkoma

School of Applied Physics, PNG University of Technology,
Private Mail Bag, Lae 411, Morobe Province, PNG.

*Corresponding author: felix.pereira@pnguot.ac.pg

Abstract: Radiation effects on human are generally high in earthquake-prone areas like Papua New Guinea. In this context, radiation effects are studied in UNITECH campus by analyzing soil samples collected from different locations within the campus and analyzed in a gamma ray spectrometer. The calculated values of indoor and outdoor Annual Effective Dose were 229.91±48 and 57.48±12 μSv y^{-1} and the measured indoor and outdoor effective dose rates were found to be 520±66 and 130±16 μSv y^{-1} respectively which are less than the permissible limit of 1000 μSv y^{-1}. The average value of Radium equivalent is observed to be 101.43±20.97 Bqkg^{-1} which is less than the permissible value of 370 Bqkg^{-1}. The internal and external Hazard Indices calculated are 0.028±0.06 and 0.36±0.9 which are within the safe limit of 1. The Excess Lifetime Cancer Risk (ELCR) was found to be 1.5±0.3X10^{-4} whereas the global average is 1.45X10^{-4}.

Keywords: Dose rate, Radium equivalent, Hazard indices, ELCR.

1. Introduction

The crust of the earth consists of natural elements as well as radioactive elements. The chief contributor of radioactivity is ^{238}U, ^{234}Th and ^{40}K [1]. The naturally occurring radioactive elements undergo decay process and release radiation. This radiation varies from location to location around the world due to change in the soil structure and texture. Terrestrial radiation is emitted from the soil while extra-terrestrial radiation comes from cosmic rays. Thus, everyone on earth is exposed to background radiation. About 82% of humans are exposed to the natural radiation internally [2]. Naturally occurring radionuclides are found in soil, water and vegetation [3 4]. For a human being, external exposure occurs from soil and building materials while internal exposure is through inhalation and ingestion. In this context, assessment of gamma dose from natural source is very important. There are many mineral resources in Papua New Guinea. The major radioactive sources are ^{238}U, ^{234}Th and ^{40}K but traces of other elements like ^{45}Ca, ^{131}I, ^{203}Hg, ^{51}Cr, ^{60}Co, ^{109}Cd, ^{47}Sc, ^{198}Au, ^{140}Ba and ^{59}Fe are also present [5].

In this paper, we calculated the external and internal dose equivalent in different locations of Unitech campus by analyzing soil samples collected from five locations and also measured the dose rates in the same locations with Dosimeter. We also calculated the Radium Equivalent, Indoor and Outdoor Hazard Indices and Excess Lifetime Cancer Risk.

2. Materials and Methods

2.1 Study Area

Fig. 1a shows the location of UNITECH in Papua New Guinea and Fig. 1b shows the map of Unitech campus where study has been conducted. The five locations from where the soil samples were collected are shown in the map. The locations are 1. Swamp Area, 2. Cook's Town, 3. Sepik Drive, 4. Agriculture Farm and 5. School Dump. The study areas are selected randomly.

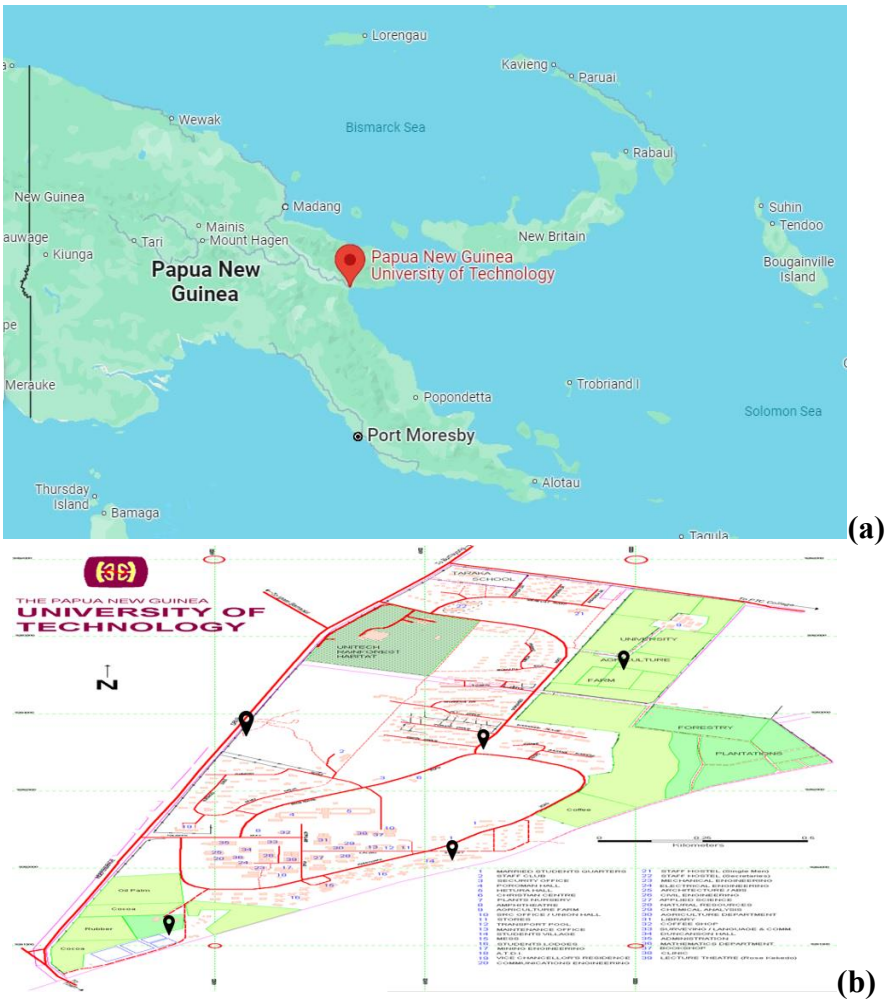

Fig. 1: a) Location of UNITECH campus in Papua New Guinea and b) Locations in UNITECH campus from where soil samples are taken.

2.2 Instrument and Measurement Techniques

The instrument used in our analysis is LB 2045 NaI(Tl) Gamma Spectrometer which can detect very low energies of the order of ~10 keV. The system consists of a computer unit, graphical display with touch panel and a power supply unit.

Radiation dose in air at a distance of 1.0 m above the surface of the soil where the samples were collected were measured using SOEKS Quantum Professional GM pocket survey meter. The locations of sample collection were measured using Garmin eTrex® 30x GPS with Digital Compass.

2.3 Sample Preparation

The soil samples, three samples each, were collected from the five locations using the ASTM C998 – 17 (American Society for Testing and Materials) Standard Practice for Sampling Surface Soil for Radionuclides). The samples were collected in plastic bags, brought to the Lab and exposed to florescent lamp to dry out. It was then powder and filtered with a strainer of micrometer diameter. The filtered samples are then kept in 20 ml containers and kept for one month for the radionuclide progenies to reach in equilibrium. The sample was put in the chamber of the Gamma ray detector for counting gamma rays of radionuclides. Two windows were used for different radionuclides whose energy ranges do not overlap. The counts were integrated over the energy range and compared with the energy ranges of the elements stored in the instrument. Observations were done for all the samples and tabulated in Table 1.

Table 1: The Specific activity of ^{232}Th, ^{226}Ra and ^{40}K, their absorbed Dose rate, Outdoor and Indoor Annual Effective Dose Equivalent, Radium Equivalent, Outdoor and Indoor Hazard indices and Excess Lifetime Cancer Risk in five different locations in UNITECH campus

Sample	Specific Activity (Bq/kg)			Outdoor Absorbed Dose (nGyh^{-1})	Indoor Absorbed Dose (nGyh^{-1})	Outdoor AEDE (µSvy^{-1})	Indoor AEDE (µSvy^{-1})	$Ra_{eq.}$ (Bq/kg)	H_{ex}	H_{in}	ELCR x10^{-3}
	^{232}Th	^{226}Ra	^{40}K								
1.1		36.29	277.5	57.04	98.11	69.95	481.28	124.78	0.34	0.44	0.179
1.2	38.1	30.06	205.1	45.10	77.16	55.32	378.52	98.90	0.27	0.35	0.141
1.3	43.8	45.36	432	64.69	111.30	79.34	545.97	138.23	0.38	0.50	0.203
2.1	17.7	17.36	308.9	31.07	55.25	38.10	271.05	64.29	0.18	0.23	0.100
2.2	35	10.96	267.1	36.89	66.93	45.24	328.33	79.71	0.22	0.25	0.121
2.3	33	22.35	372.3	45.15	80.31	55.37	393.98	95.60	0.27	0.33	0.146
3.1	36.9	18.02	249.2	40.58	71.95	49.77	352.95	88.23	0.24	0.29	0.131
3.2	46.1	24.49	150.1	45.16	78.05	55.39	382.89	100.92	0.28	0.34	0.142
3.3	46.9	32.94	336.6	57.01	99.28	69.92	487.02	123.57	0.34	0.43	0.181
4.1	41.2	46.24	232	55.53	92.78	68.10	455.15	121.40	0.33	0.46	0.170
4.2	36.6	62.03	261.1	61.21	99.87	75.07	489.91	132.65	0.36	0.53	0.184
4.3	32.2	40.84	189.2	45.88	76.07	56.27	373.15	100.13	0.27	0.38	0.140
5.1	21.6	22.67	233.3	32.85	56.71	40.29	278.21	69.89	0.19	0.25	0.104
5.2	33.1	26.25	292.7	43.83	76.39	53.75	374.76	94.07	0.26	0.33	0.139
5.3	29.5	32.64	202.9	41.01	69.12	50.30	339.08	89.03	0.24	0.33	0.127
Av.	**36.00**	**31.23**	**267.33**	**46.87**	**80.62**	**57.48**	**395.48**	**101.43**	**0.28**	**0.36**	**0.15**
STD	**8.23**	**12.49**	**68.94**	**9.50**	**15.37**	**11.65**	**75.40**	**20.97**	**0.06**	**0.09**	**0.03**

2.4 Dose Calculations

The naturally occurring radioactive materials (NORM) are ^{238}U, ^{232}Th and ^{40}K. The absorbed dose rate was calculated using the formula

$$D(nGyh^{-1}) = 0.462\,A_{Ra} + 0.604\,A_{Th} + 0.04A_K \quad (1)$$

where A_{Ra}, A_{Th} and A_K are the specific activities of Radium, Thorium and Potassium [6].

Annual Effective Dose Equivalent (AEDE) calculated in Sieverts (Sv) helps in setting up safety standards to protect people from harmful effects of radiation. The amount of time people spend indoor and outdoor varies significantly. The outdoor and indoor AEDE are given by

$$E_X = DR.\ T.\ K1.\ G1 \quad (2)$$

$$E_Y = DR.\ T.\ K2.\ G2 \quad (3)$$

where DR = Dose rate in micro-Sievert per hour in air at 1.0m from surface
T = time in hours in one year (8,760)
K1 = dose conversion factor (0.70)
G1 = indoor occupancy factor (0.80)
G2 = outdoor occupancy factor (0.20).

Radium Equivalent

Radium Equivalent is a measure used to simplify the assessment of radiation exposure from materials that contain multiple radioactive substances. It quantifies the total radiation hazard in terms of an equivalent amount of radium, which is a single, well understood radioactive element. It is a way to express the combined radiation risk of a material in terms of how much radium would produce the same radiation dose, making it easier to understand and regulate.

The equation used is:

$$Ra_{eq}(Bq.kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (4)$$

Radiation Hazard Indices

Radiation Hazard Indices are like safety measures to help us understand and control radiation exposure. Think of them as warning signs to keep us safe from harmful radiation.

They were calculated using the equations:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

A value less than 1 indicates that the radiation is within safe levels signifying lower risk.

Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk is the extra chance or probability of getting cancer due to exposure.

Calculations were made using the following equation:

$$ELCR = AEDE_{tot} \times DL \times RF \quad (7)$$

where DL = Duration of life which is taken to be 65 years average for Papua New Guineans and RF = risk factor which is 0.05

3. Results and Discussion

The dose rate, Annual Effective Dose Equivalent, Radium equivalent, Hazard indices and Excess Lifetime Cancer Risk were calculated using equations (1) – (6) and tabulated in Table 1. The outdoor and indoor AEDE values were found to be less than the threshold safe value of 1000 μSvy^{-1}. For all the samples analyzed, the radium equivalent was observed to be less than the threshold value of 370 $Bqkg^{-1}$. The external and internal hazard indices were found to be less than the maximum safe value of 1. The ELCR calculated was $1.5 \pm 0.03 X10^{-4}$ whereas the world average value is $1.45X10^{-4}$.

The dose is measured using a Dosimeter in the five locations and the Annual Effective Dose are calculated and tabulated in Table 2

Table 2: The Outdoor and Indoor Annual Effective Dose measured using Dosimeter in the five locations.

Sample	Latitude	Longitude	cpm	µSv/hr	Outdoor AED (µGy/yr)	Indoor AED (µGy/yr)
1	6.40422	146.59265	15.7	0.09	110.38	441.50
2	6.674361	146.99845	13.9	0.11	134.90	539.62
3	6.668179	146.9979	22.7	0.1	122.64	490.56
4	6.662663	147.00119	19.2	0.1	122.64	490.56
5	6.667038	146.99273	19.2	0.13	159.43	637.73
Mean					**130.00**	**520**
STD					**16.64**	**66.5**

The dose measured using dosimeter and the dose calculated by analyzing the samples were plotted in Fig. 2. The measured value of dose in all the regions were found to be higher than the calculated value. This is because the theoretical value is formulated under the assumption that the radiation is calculated 1m above the ground from a point source on the ground. Moreover, influence of other radiation sources such as cosmic rays and other radioactive elements were not considered in calculation. The weather conditions also influence the dose rate. The building materials in the region will also influence the dose measurements in that region [7]. Radon in air and ground water in the campus will also contribute to a small extend to the radiation level in the campus. These will be studied in our future work.

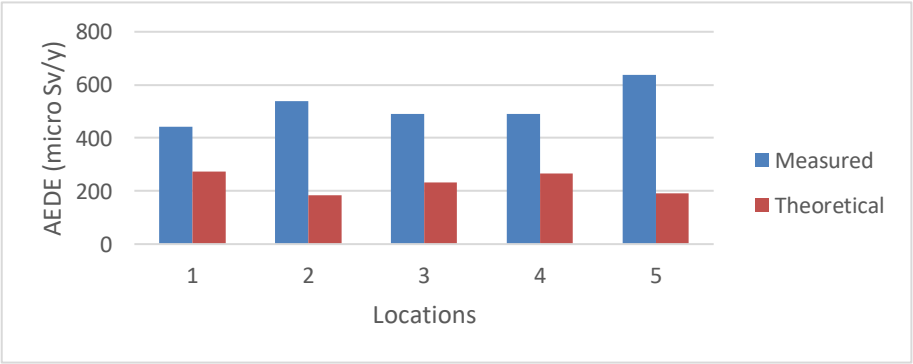

Fig. 2: The Annual Effective Dose Equivalent a) measured (Blue) and b) calculated (Red) in the five locations of Unitech campus

4. Conclusion

The Unitech campus situated in Lae falls in the 'Ring of Fire' region which is tectonically active. The tectonic activity results in frequent earthquakes and volcanic eruptions. The soil in Lae region is influenced by volcanic activity, sediment deposition and organic matter decomposition. The study of primordial radionuclides in soil gives insight into the radiation effects on inhabitants in the region. The soil samples collected from different regions were analyzed with LB 2045 NaI(Tl) Gamma ray spectrometer and the annual effective dose rates were calculated. The dose rates vary from 31.07 to 69.92 with an average value of 46.87$\pm$9.5 $nGyh^{-1}$. The indoor and outdoor Annual Effective Dose Equivalent varies from 152.4 to 317.35 with an average value of 229.91$\pm$48.12 μSvy^{-1} and 38.1 to 79.34 with an average value of 57.48+12.03 μSvy^{-1}. The dose rates were also measured using SOEKS Quantum Professional GM pocket survey meter. The measured dose rates were observed to vary from 0.09 to 0.13 with an average value of 0.106 $mSvh^{-1}$. The Indoor and Outdoor Annual Effective Dose varies from 441.5 to 637.7 with an average value of 520$\pm$66.5 μGyy^{-1} and 110.38 to 159.43 with an average value of 130$\pm$16.6 μGyy^{-1}. The measured value is greater than the calculated value because the measured value is influenced by weather conditions, cosmic rays and presence of radionuclides other than ^{238}U, ^{232}Th and ^{40}K and their progenies. The Radium Equivalent was found to be 101.43$\pm$20.97 $Bqkg^{-1}$ which is much less than the maximum permissible limit of 370 $Bqkg^{-1}$. The indoor and outdoor Hazard Indices were found to be 0.028$\pm$0.06 and 0.36$\pm$0.9 which are within the safe limit of 1. The Excess Lifetime Cancer Risk is 1.5$\pm$0.3X10^{-4} comparable with the world average value of 1.45X10^{-4}.

References

1. Md. Samiul Ehsan et al.: The activity concentration of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil samples and associated health hazards in Natore, Kushtia and Pabna District of Bangladesh, J. Bangladesh Acad. Sci., 43(2), p. 169-180 (2019).
2. Shahbazi-Gahrouel, D., Gholami M., Setayandeh, S. S.: A review on natural background radiation, Adv. Biomed. Res., 2(1), 65 (2013).
3. National Research Council (US) Committee on evaluation of EPA Guidelines for exposure to NORMs. Technologically enhanced NORM, Washington (DC), National Academy Press (US), doi: 10.17226/6360 (1999).
4. Kandari, T. et al.: Estimation of annual effective dose from radon concentration along Main Boundary Thrust in Garhwal Himalaya, J. Rad. Res. And App. Sci., 9(3), 228-233 (2016).
5. Kolkoma, D., Pereira F. B., Jojo P. J., Michael K. : Assessment of Radioactive elements in the Ramu Nickel and Yandera mining sites of Papua New Guinea related to radiation pollution of the environment, *Poll Res.*, 41(2), 440-444 (2022).
6. UNSCEAR, 2000. Sources and Effects of Ionizing Radiation," *UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation),* vol. Volume 1: Sources., no. New York: United Nations (2000).
7. Sonkawade R. G., Kant, K., Muralithar, S., Kumar, R., Ramola, R.C. :Natural radioactivity in common building construction and radiation shielding materials, Atmospheric Environment, 42(9), 2254-2259 (2008).

Identification and Distribution of Trichoderma Species in the Four Regions of Papua New Guinea

Dollah Inapo, Gwendolyn Ban*, Shamsul Akanda

School of Agriculture, Papau New Guinea University of Technology,
Lae 411, Morobe Province, PNG

*Corresponding author: gwendolyn.ban@pnguot.ac.pg

Abstract: *Trichoderma*, a soil-dwelling fungus, is a reliable biocontrol agent that combats crop diseases, enhances plant resistance to environmental stresses, improves nutrient uptake efficiency, and promotes plant growth. Studies were conducted in the Papua New Guinea University of Technology (PNGUoT) laboratory using soil samples collected from four regions across 16 provinces in PNG. The objectives were identifying Trichoderma species, determining their phylogenetic relationships, and analyzing their population distribution. Twenty isolates were morphologically identified as *Trichoderma,* and further categorized into five species, i.e., *T. harzianum*, *T.virens*, *T. hamatum*, *T. lixii,* and *T. asperellum*, through molecular characterization. The phylogeny analysis generated an outgroup and two clades. *Trichoderma lixii* from Chimbu Province was an outgroup compared to the other four species. The first clade showed that *T. harzianum* (SHP) is closely related to *T. virens* (Manus) with a bootstrap value of 100%. The second clade showed that *T. harzianum* (Sandaun) is closely related to *T. asperellum* (East Sepik); *T. harzianum* (Central) with *T. harzianum* (NCD) and *T. harzianum* (Morobe); *T. virens* (Madang) with *T.virens* (New Ireland); and *T. asperellum* (Madang) with *T. hamatum* (ENB), respectively. *Trichoderma harzianum* was the dominant species. The highest population of *Trichoderma* was found in New Ireland Province with 15 882 CFU (*A. manihot*), while the lowest of 47 CFU (*I. batatas*) was in Western Highlands Province. The findings from this study can contribute towards the potential development of a *Trichoderma* species into a biological control against soil-borne pathogens in PNG.

Keywords: Prevalence, morphology, molecular identification, phylogeny.

1. Introduction

Trichoderma, a soil-inhabiting fungi, is a formidable weapon against many plant pathogenic fungi and nematodes. Its production of volatile and non-volatile metabolites allows it to effectively counter these threats (Kumar & Ashraf, 2017). But, its significance goes beyond disease suppression. *Trichoderma* also serves as a plant growth promoter, promising improved crop yields and agricultural productivity [1,2].

Trichoderma species are widely distributed in various soil types, habitats, and climatic zones. They can adapt to various habitats, including a tropical rainforest's diverse habitat and a biotechnological fermenter's environments. The diversified metabolic capacity and aggressive competitive character may be the basis of their prevalence in soil [2, 3]. Apart from a few research focusing on specific ecological niches, most studies on the diversity of *Trichoderma* have been undertaken in Asia, Europe, and America [4, 5].

The growth, distribution, and population of *Trichoderma* are affected by various factors. It prefers mesophilic temperatures (25-35°C), a wide range of pH, and moist conditions, and it does not tolerate water stress conditions [6].

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Despite the overwhelming importance of *Trichoderma* spp, few systematic and detailed studies have been conducted in Papua New Guinea. Ban (2015) demonstrated that *Trichoderma* species effectively controlled key soil-borne pathogens affecting vegetable crops in Papua New Guinea [7].

Hence, the study was conducted to isolate, identify, and determine the biodiversity and phylogenetic relationship of the *Trichoderma* isolates from the four different regions of Papua New Guinea.

2. Materials and Methods

2.1 Study Location

The study was conducted at the Papua New Guinea University of Technology (PNGUoT) Biotechnology Centre (UBC) and PNGUoT Analytical Services Laboratory (UASL). In addition, Macrogen Inc., South Korea, performed DNA fingerprinting to identify specific *Trichoderma* species.

2.2 Isolation of *Trichoderma* Species

Trichoderma was isolated from soil samples collected in 2020 and 2021 from 16 provinces covering four regions of PNG. These include the Highlands region, the Momase region, the Southern region, and the New Guinea Islands region with varying climatic conditions (Table 1). Composite samples were prepared from soils from different cropping areas in the various provinces. The soil moisture and pH of the soils were recorded on a subsample using the protocol by Robertson & Simmons at the UASL [8]. The samples were sealed in plastic bags and refrigerated at 4^{o}C in the UBC for *Trichoderma* isolation.

Table 1: Information regarding the soil samples from four regions of PNG.

Regions	Provinces	Sample number per province	Districts	Average temperature (^{o}C)	Average rainfall (mm)	Cropping site
Highlands	Eastern Highlands (EHP)	2	Goroka Unggai-Bena	17.9	2097	Sweet Potato (*Ipomoea batatas*) & Taro (*Colocasia esculenta*)
	Chimbu	1	Sinasina Yongomul	16.9	378.5	Sweet Potato (*I. batatas*)
	Jiwaka	1	Banz	15-22.8	243.8	Sweet Potato (*I. batatas*)
	Western Highlands (WHP)	1	Hagen Central	17.5	335.1	Sweet Potato (*I. batatas*)
	Southern Highlands (SHP)	2	Ialibu Pangia Mendi	19.5	376.8	Sweet Potato (*I. batatas*) & Peanut (*Arachis hypogaea*)
	Hela	1	Dauli	20	630.0	Sweet Potato (*I. batatas*)
Momase	Morobe	2	Markham Lae	23.6	6797	Banana (*Musa acuminata*) & Taro (*C. esculenta*)
	Madang	2	South-Coast Usino Bundi	25.5	3665	Cocoa (*Theobroma cacao*) & Sugarcane (*Saccharum officinarum*)
	East Sepik	1	Ambunti-Drekikia	24.9	366.3	Cocoa (*T. cacao*)
	Sandaun	1	Vanimo- Green River	26.2	262.8	Bokchoy (*Brassica rapa*) & Aibika (*A. manihot*)
Southern	NCD	1	NCD	25.8	1526	Peanut (*A. hypogaea*)

	Central	1	Kairuku-Hiri	28.0	237.5	Banana (*M. acuminata*)
NGI	East New Britain (ENB)	1	Kokopo	25.8	2413	Cocoa (T. *cacao*)
	West New Britain (WNB)	1	Kandarian-Glouster	29.0	432.75	Oil Palm (*Elaeis guineensis*)
	Manus	1	Los Negros LLG	29.0	436.02	Mixed Cropping: (Coconut (*Cocos nucifera*), Cassava (*Manihot esculenta*))
	New Ireland	1	Kavieng	27.0	287.8	Aibika (*A. manihot*)

Trichoderma was isolated from the soil samples using the dilution plate method [9] using *Trichoderma* Selective Media (Lincoln University TSM-LU). Each sample had three replicates. The colonies were purified through a single spore culture, transferred to PDA slants, and stored in the refrigerator.

2.3 Enumeration of *Trichoderma* in Soil

When visible colonies appeared on the TSM plates, Colony Forming Units (CFU) were counted based on color and compaction on the TSM plates. The population per gram of soil was calculated using the following formula [9]:

Total population per gram of soil = Mean number of colonies per plate X *dilution factor*

2.4 Morphological Identification

Trichoderma was identified morphologically by observing the appearance, color, and growth rate of the colony and a microscopic view of the hyphal branching structures and conidia shape. *Trichoderma* isolates were morphologically identified according to Ranasingh et al. [10].

2.5 Molecular Identification

A pure culture of *Trichoderma* was used for DNA extraction. *Trichoderma* tissues were scraped from 5-day-old cultures using sterile scalpel blades on PDA plates. Twenty milligrams of the sample were disrupted using a sterile mortar and pestle under liquid nitrogen. The total DNA of *Trichoderma* was isolated as per the protocol by DNeasy Plant Mini Kit (Qiagen) [7].

The DNA of the *Trichoderma* isolates identified morphologically [10] were amplified using Polymerase Chain reaction (PCR) in the automated Eppendorf Mastercycler. Bidirectional generic primers, ITS1('5'-TCCGGTAGGTGAACCTGCGG-'3') and ITS4 (5'-TCCTCCGCTTATTGATATGC-3'3'), were used (Ban, 2015).

The un-purified PCR products were loaded onto electrophoresis gel for DNA detection, according to Ban [7]. A Gel Doc EZ Imager was used to view bands and was saved on the computer.

Sixteen isolates of un-purified PCR products of the *Trichoderma i*solates that showed morphological characteristics for *Trichoderma* and bands on the electrophoresis gel were sent to Macrogen Inc (South Korea) for sequencing to identify the isolates to species. The processed sequences were edited using the DNA subway platform. The Basic Local Alignment Search Tool (BLAST) of the National Centre for Biotechnology Information (NCBI) was used to match and confirm *Trichoderma* species [7].

The nucleotide sequences sent from Macrogen Inc (South Korea) were used to construct a phylogeny tree using the DNA subway platform (https://dnasubway.cyverse.org/). The nucleotide sequences were submitted, trimmed, and paired, and the phylogeny tree was constructed from the identified species using the platform [7].

3. Results

3.1 Morphological Characterization

Table 2 presents the morphological characteristics of twenty isolates of *Trichoderma* collected from sixteen provinces of PNG. The table includes observations of the fungal growth on the PDA medium and microscopic observations of the colony characteristics, conidiospores, and conidia.

Table 2: Morphological characteristics and species prediction of 20 *Trichoderma* isolates from 16 provinces of PNG.

Isolate ID	Province	Morphological characters	Specie prediction
D6 D11 D10	EHP (Goroka) Chimbu NCD	Colony: Whitish mycelium, grew densely and cushion-like. Conidiospores: in compact turfs. Side branches are short and thick. Phialides: crowded, short, and plump. Phialospore: Hyaline, small. No discoloration of media.	*T. polysporum*
D3 D4 D24 D22 D9	EHP (Unggai-Bena) WHP SHP (Ialibu-Pangia) Madang (South-coast) ENB	Colonies: yellowish, dull to dark green. Long and slender. Thick, cushion-like. Conidiospore: branches long and slender. No sterile hyphae. Phialides: not crowded. Phialospore: Rough Discoloration of media.	*T. viride*
D13 D16 D12 D1 D5	Jiwaka SHP (Mendi) Hela Morobe (Markham) Sandaun	Colonies: Yellowish, Dull dark green. Velvety, Hard on the media surface. Conidiospore: in a compact tuft, side branches are long and slender. Phialide: not crowded Phialospore: smooth, elliptical, simple branching. No discoloration of media.	*T. longibrachiatum*
D2 D15 D17 D8	Morobe (Lae) East Sepik WNB New Ireland	Colonies: Whitish green, long and thick, often sterile hyphae. The texture is velvety. Conidiospores: in compact turfs, side branches are short and thick. Phialides: crowded, short, and plump Phialospore: short ovoid. No discoloration of media.	*T. harzianum*
D14 D7 D23	Madang (Usino-Bundi) Manus Central	Colonies: Whitish green. Often sterile hyphae. Thick and cushion-like. Conidiospores: in compact tufts, side branches are short and thick. Phialides: crowded, short, and plump Phialospore: Oblong, angular No discoloration of media	*T. koningii*

The morphological characteristics of *Trichoderma* isolates, i.e., D1, D5, D12, D13, and D16 resembled *T. longibrachiatum. Trichoderma isolates* D7, D14, and D23 resembled *T. koningii.* Isolates D2, D8, D15, and D17 resembled *T. harzianum*. Isolates D3, D4, D9, D22 and D24 resembled *T. viride* and isolates D6, D10 and D11 resembled *T. polysporum. Trichoderma longibrachiatum* and *T. viride were* found to be the dominant species.

3.2 Identification of *Trichoderma* Using Molecular Techniques

The sixteen *Trichoderma* isolates were amplified, and the results are shown in Figure 1. From the agarose gel electrophoresis, detection under ethidium bromide showed 12 isolates. D2, D3, D5, D7, D8, D10, D11, D12, D14, D15, D2 and D23 produced expected amplified products of ≈ 600 bps. Isolates D1, D4, D9, and D16 revealed some morphological similarities, such as those of Trichoderma, but they did not show any bands on the gel. Unpurified PCR products were sent to Macrogen Inc. (South Korea) for sequencing, and the results are shown in Table 3. From the similarity indices from Genbank, twelve isolates were confirmed to be *Trichoderma,* in which isolates D2, D5, D10, D16, and D23 were identified as *T. harzianum* in which D2 and D10 closely resembled *T. harzianum* strain CEN859 from Brazil, D5 matched *T. harzianum* strain NECC21358 from China, D16 matched *T. harzianum* strain TBR-12 from India and D23 matched *T. harzianum* strain CEN732 from Brazil. Isolates D7, D8, and D22 were identified as *T. virens* strains and matched strain Tvien 3 from China, *T. virens* G1D9 from China, and *T. virens* strain SVPRT-Tvir01 from India, respectively. Isolate D9 was identified as *T. hamatum* strain resembling *T. hamatum* strain JAHLH2 from Iraq; isolate D11 was *T. lixii* and closely resembled isolate *T. lixii* Thar-10 from India. Isolate D14 and D15 were identified as *T. asperellum* strains and resembled *T. asperellum* strain AMUTA-2 from India, and D15 resembled strain T203 from Israel. *T. harzianum* was the dominant species identified based on molecular characterization. Nucleic acid sequence analysis showed a range of 85-100% similarity and an average nucleotide length of 600-700 bps for the twelve isolates.

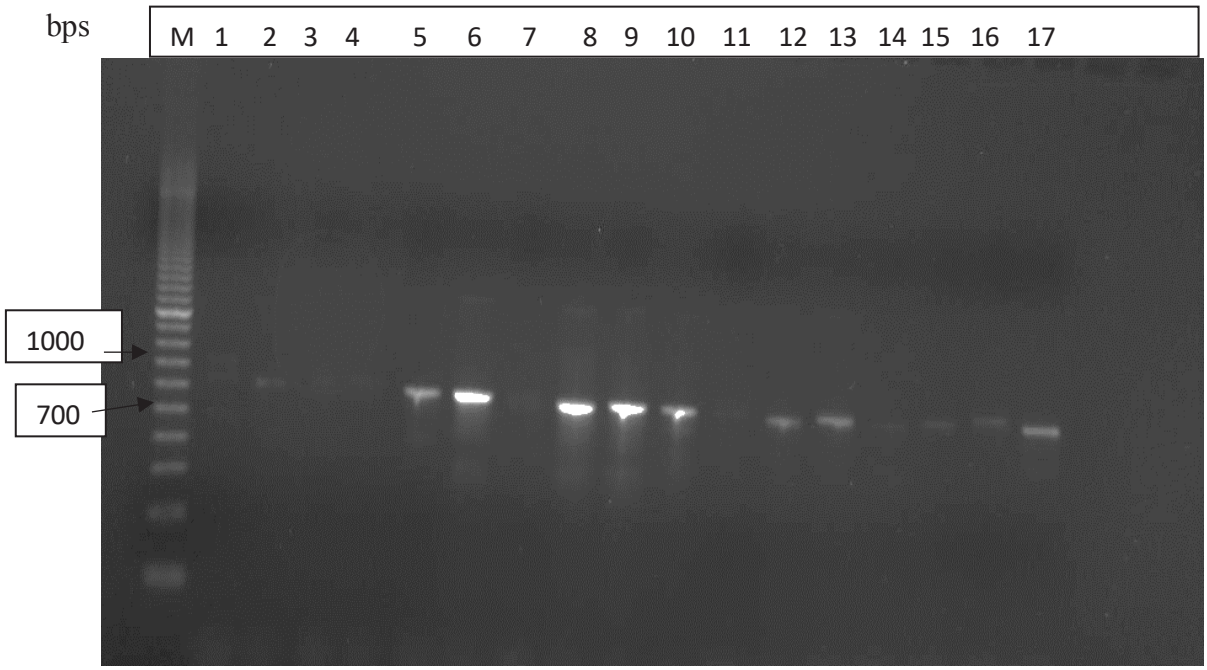

Fig 1: Amplified products of 16 *Trichoderma* isolates using primers ITS 1 and ITS 4. The DNA molecular marker is denoted as Lane M; Lane 1 is negative control (water); Lanes 2,5, 6, 8, 9, 10, 12, 13, 14, 15, 16, and 17 are isolates D2, D5, D7, D9, D10, D11, D15, D14, D16, D22, D23 and D24, respectively. Lanes 3, 4, 7, and 11 are isolates D3, D4, D8, and D12 confirmed *Trichoderma* species but appeared negative under electrophoresis.

Table 3: Molecular identifications of *Trichoderma* isolates by sequence analysis using NCBI Database.

Trichoderma isolates	*Trichoderma* isolates ID	Sequence nucleotide size	Sequence homology (%)	Matched *Trichoderma* species
Morobe	D2	1401	98.1	*T. harzianum*
Sandaun	D5	1 320	99.5	*T. harzianum*
Manus	D7	1 454	99.7	*T. virens*
New Ireland	D8	1 459	99.8	*T. virens*
ENB	D9	1 494	99.1	*T. hamatum*
NCD	D10	1 367	98.4	*T. harzianum*
Chimbu	D11	1 387	100	*T. lixii*
Madang 1	D14	1359	99.8	*T. asperellum*
East Sepik	D15	743	88.9	*T. asperellum*
SHP 1	D16	591	90.0	*T. harzianum*
Madang 2	D22	1 321	99.7	*T. virens*
Central	D23	1376	98.3	*T. harzianum*

3.3 Phylogeny Studies

The neighboring joining analysis generated a consistent phylogeny tree with two clades and one outgroup. For this study, *T. lixii* from Chimbu province was outgrouped from the other species in the same genus. This is because it has a nucleotide sequence that differs from the other clade members, occupying a base position on the tree. The two clades are apart from outgrouped species. The first clade showed that *T. harzianum* (SHP) is closely related to *T. virens from* (Manus) at a bootstrap value of 100 %. The second clade had two sub-branches in which *T. harzianum* (Sandaun) is closely related to *T. asperellum* (East Sepik) at a bootstrap value of 76% in the first sub-branch. The second sub-branch had two sub-branches at 100% bootstrap value. The first sub-branch indicated that *T. harzianum* from central and NCD are closely related (53% bootstrap value) and related to *T. harzianum* from Morobe (78% bootstrap value). The second sub-branch showed that *T. virens* from Madang and New Ireland are closely related (60% bootstrap value), *T. asperellum* (Madang) and *T. hamatum* (ENB) are closely related (100% bootstrap value), and all four isolates are related to each other (Figure 2).

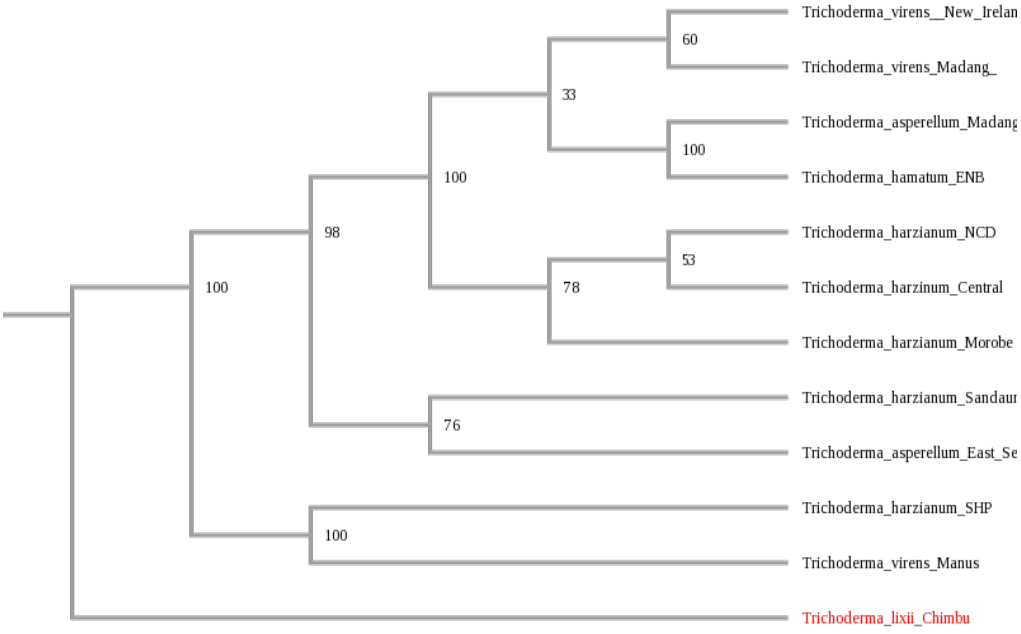

Fig 2: Phylogenic tree from Neighbouring Joining (NJ) of the 12 taxa of *Trichoderma* isolates of 700 base pairs aligned sequences of ITS 1 and ITS 4 primers.

3.4 Soil Characteristics and Population Distribution of Trichoderma Isolates

Table 4: Soil pH, moisture, and *Trichoderma* population from different cropping areas.

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Province	Soil pH (potentiometry)	Soil moisture (% w/w)	*Trichoderma* population g-^{1} of dry soil (CFU)
EHP (Goroka)	5.55	11.3	372
EHP (Bena)	6.37	5.51	95
Chimbu	7.70	9.33	414
Jiwaka	6.45	6.82	585
WHP	5.64	14.0	47
SHP	5.77	13.2	426
Hela	7.84	19.6	871
Morobe (Mutzing)	6.74	11.0	1607
Morobe (PNGUoT Farm)	5.68	7.40	2181
Madang (Ramu)	5.82	6.69	514
Madang (South-Coast)	7.15	16.5	4790
East Sepik	8.09	12.7	2222
Sandaun	8.09	4.68	4,474
ENB	7.62	8.38	589
West New Britain	5.83	7.97	575
New Ireland	8.05	25.7	15,882
Manus	7.87	22.4	1,231
Central	5.33	15.0	365
NCD	7.86	7.82	1,307

The soil pH, moisture content, and the average population of *Trichoderma* recorded from the different provinces under various cropping areas are presented in Table 4. The highest population of *Trichoderma* was recorded from New Ireland province with 15 882 CFU under *A. manihot* soil with a pH of 8.05 and soil moisture of 25.7%ww, followed by Madang (South-Coast) province (4 790 CFU, pH 7.15, 16.5% ww) under *T. cacao* soil, and Sandaun province (4 474 CFU, pH 8.09, 4.68%ww) under *B. rapa* and *A. manihot*. The lowest population of *Trichoderma* was recorded from Western Highlands province with 47 CFU under *I. batatas* soil at a pH of 5.33 and moisture content of 14.0%ww. The population per gram of dry soil for the Highlands Region (Eastern Highlands, Chimbu, Jiwaka, Western Highlands, and Southern Highlands) and some provinces in the coastal regions (Madang (Usino-Bundi), East New Britain, West New Britain, and Central) were lower than that of the soil samples collected from other provinces in the coastal regions (New Ireland, Manus, NCD, Sandaun, East Sepik, Madang (South-Coast) and Morobe) of Papua New Guinea. The total population for soil pH below 7 is 6,767 g^{-1} of dry soil, while the total population for soil above 7 is 31,780 g^{-1} of dry soil.

4. Discussion

In the present study, the population of the *Trichoderma* isolates varied for each province and the cropping sites. The highest *Trichoderma* population was recorded from New Ireland province under the Aibika cropping area, while the sweet potato cropping area from the Western Highlands had the lowest population. In addition, the diversity and abundance of the *Trichoderma* strains varied with cropping type and climatic conditions of the respective provinces from which the soil samples were collected.

The growth and distribution of *Trichoderma* are affected by biotic and abiotic factors in the soil. Abiotic factors, such as temperature, moisture, nutrients, and pH, significantly affect the growth, sporulation, and effectiveness of *Trichoderma* against phytopathogens [11]. Two critical factors affecting occurrences of *Trichoderma* are the soil temperature and the pH. This explains the higher population in the Coastal regions than in the Highlands regions of PNG, as the temperature ranges between 20-35°C on the coast. This confirms the research findings of Singh et al. [12] and Srivastava et al. [11] that *Trichoderma* strains prefer optimum temperatures ranging from 25-30°C to produce sufficient biomass. The pH is another critical determinant of the occurrence of *Trichoderma*. Bitton and Boylan reported that the development of *Trichoderma* is more efficient in acidic than alkaline soils [14]. Studies conducted by several researchers revealed that *Trichoderma* species showed optimum growth and biomass production at different pH values ranging from 4 to 7 [13]. Other studies showed that *Trichoderma* strains could grow at high pH values between 9 and 11 [15]. The different pH preferences of *Trichoderma* strains for proliferation explain the variations in the population with the respective soil pH for each province.

The type of plant cultivated in an area determines the growth and distribution of *Trichoderma* [16]. *Trichoderma* proliferates better under plants with widespread and shallow rooting systems than those deeply rooted perennial crops like coffee and tea trees. In addition, studies by Ban [7] showed that cropping type determined the population distribution of *Trichoderma* in the rhizospheres. The different plants also affect soil nutrients as they add to the litter formation [3, 17], confirming the high population of *Trichoderma* in aibika, taro, peanut, and vegetables and the low population in cocoa and oil palm soil in this study. Sweet potato soil in WHP had a low *Trichoderma* population due to continuous intensive cultivation as it is a staple crop in the region. According to Okoth et al. [16], continuous cultivation of the same crop results in the depletion or altering of soil nutrients that may affect the occurrence and population of *Trichoderma*.

In the present study, five species, i.e., *T. harzianum, T. koningii, T. viride, T. polysporum,* and *T. longibrachiatum*, were tentatively identified morphologically. However, morphological species identification of *Trichoderma* was unreliable due to the lack of similarity in the morphological characteristics and the increasing number of cryptic species of *Trichoderma,* resulting in incorrect identification [18]. This observation was confirmed by the results from the molecular identification performed in the current study; *T. harzianum*, *T. virens, T. hamatum, T. asperellum, and T. lixii* were identified.

The phylogeny analysis showed the genetic relativeness of the twelve identified species. Phylogenetic trees show the degree of relationship between taxa. On a phylogenetic tree, nodes closer to the ends of the tree connect terminal taxa that are more closely related, and the nodes closer to the base of the tree connect terminal taxa that are distantly related [19]. For example, *T. lixii* from Chimbu Province was out-grouped from the other species in the same genus. This is because it has a nucleotide sequence that differs from the other clade members, occupying a base position on the tree [20, 21]. Clade one showed that *T. harzianum* from SHP is closely related to *T. virens* from Manus. The second clade showed that *T. harzianum* from Sandaun is closely related to *T. asperellum from* East Sepik, *T. harzianum* from Central, and NCD are closely related and associated with *T. harzianum* from Morobe. *T. virens* from Madang and New Ireland are closely related*, and T. asperellum* from Madang and *T. hamatum* from ENB are closely related. All four species are related to each other under the same sub-branch.

The phylogenetic analysis conducted in this study reveals the relationships between these species and their distribution within the country. Identifying *Trichoderma* species across the four regions of Papua New Guinea provides a foundation for future research to develop biocontrol agents and growth-promoting supplements for farmers.

References

1. Contreras-Cornejo, H. A., Macías-Rodríguez, L., Cortés-Penagos, C., López-Bucio, L. :*Trichoderma virens*, a plant beneficial fungus, enhances biomass production and promotes lateral root growth through an auxin-dependent mechanism in *Arabidopsis*. *Plant Physiology 149*, 1579-1592(2009).
2. Kredics, L., Hatvani, L., Naeimi, S., Körmöczi, P., Manczinger, L., Vágvölgyi, C Druzhinina, I. : Chapter 1. *Biodiversity of the Genus Hypocrea/Trichoderma in Different Habitats*. Editor(s): Vijai K. Gupta, Monika Schmoll, Alfredo Herrera-Estrella, R.S. Upadhyay, Irina Druzhinina, Maria G. Tuohy. Biotechnology and Biology of *Trichoderma*, 3-24. Elsevier. Retrieved from: https://doi.org/10.1016/B978-0-444-59576-8.00001-1(2014).
3. Schuster, A., Schmoll, M., :Biology and biotechnology of *Trichoderma*. *Applied Microbiology and Biotechnology 87*, 787-799 (2010).
4. Jaklitsch, W. M., Voglmayr, H. :Biodiversity of *Trichoderma* (Hypocreaceae) in Southern Europe and Macronesia. *Studies in Mycology 126*, 1-87 (2015)
5. Wuczkowski, M., Druzhinina, I., Gherbawy, Y., Klug, B., Prillinger, H., Kubicek, C. P. : Species pattern and genetic diversity of *Trichoderma* in a mid-European, primeval floodplain-forest. *Microbiological Research 158* (2), 125-133 (2003).
6. Kubicek, C. P., Mach, R. L., Peterbaue, C. K., Lorito, M. :*Trichoderma*: From genes to biocontrol. *Journal of Plant Pathology 83*, 11-23 (2001).
7. Ban, G. :*Study the effects of Trichoderma species on selected soilborne fungi in Papua New Guinea* (Doctoral thesis). Papua New Guinea University of Technology. Morobe, Papua New Guinea (2015).
8. Robertson, G., Simmons, J. : Agronomic Soil Test Results at the Kellogg Biological Station, Hickory Corners, MI (1992 to 2019) ver 23. *Environmental Data Initiative*. https://doi.org/10.6073/pasta/3c4c64c828c5281b28aa355bdcb81363 (Accessed 2024-03-01) (2020).
9. Reynolds, J. :Serial dilution protocols. *American Society of Microbiology*. Retrieved from: http://www.microbelibrary.org/component/resource/laboratory/test/2884-serial-dilution-protocols(2005).
10. Ranasingh, N., Saturabh, A., Nedunchezhiyan, M. : Use of Trichoderma in disease Management. *Orissa Review*, September-October, pp.68-70 (2006).
11. Srivastava, A., Singh, R. P., Srivastava, A. K., Saxena, A. K., Arora, D., Arora, D. K. :Growth promotion and charcoal rot management in chickpea by *Trichoderma harzianum*. *Journal of Plant Protection Research 48*, 81-94 (2014).
12. Singh, A., Shahid, M., Srivastava, M., Pandey, S., Sharma, A., Kumar, V. : Optimal physical parameters for growth of *Trichoderma* species at varying pH, temperature and agitation. *Virology & Mycology 3*(1), 1-7. Retrieved from: http://dx.doi.org/10.4172/2161-0517.1000127(2014).
13. Rousk, J., Brooks, P. C., Baath, E. : Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied Environmental Microbiology 75*, 1589 (2009).
14. Bitton, G., Boylan, R.A. : Effect of precipitation on soil microbial activity: I. Soil core studies. *Journal of Environment Quality 14*, 66-68 (1985).
15. Kumari, M. E. R., Gopal, A. V., Lakshmipathy, R. :Effect of stress tolerant plant growth promoting rhizobacteria on growth of black gram under stress condition. International *Journal of Current Microbiology and Applied Sciences 7*(1), 1479–1487(2018).
16. Okoth, S.A., Roimen, H., Mutsotso, B., Muya, E., Kahindi, J., Owino, J.O., Okoth, P. :Land use systems and distribution of *Trichoderma* species in Embu regions, Kenya. *Tropical and Subtropical Agroecosystems 7,* 105-122 (2007).
17. Samuels, G. J :*Trichoderma*: Systematics, the sexual state, and ecology. *Phytopathology, 96 (2*), 195–206 (2006).
18. Kamala, T., Indira, S. : Molecular characterization of *Trichoderma harzianum* strains from Manipur and their biocontrol potential against *Pythium ultimum*. *International Journal of Current Microbiology and Applied Sciences 3*(7), 258-270 (2014).
19. Zapata, F., Goetz, F. E., Smith, S. A., Howison, M., Siebert, S., Church, S. H., Sanders. S. M., Ames, C. L., McFadden, C. S., France, S. C., Daly, M., Collins, A. G., Haddock, S. H. D, Dunn, C. W., Cartwright, P. :Phylogenomic analyses support traditional relationships within Cnidaria. *PLoS ONE* 10(10): e0139068. Retrieved from: https://doi.org/10.1371/journal.pone.0139068 (2015).
20. Nuankaew, K., Sotome, K., Lumyong, S., Boonlue, S. :*Trichoderma polyalthiae* sp. nov., an endophytic fungus from *Polyalthia debilis*. *Phytotaxa 5,* 371 (2018).
21. Hermosa, M. R., Grondona, I., Iturriaga, E. A., Diaz-Minguez, J. M., Castro, C., Monte, E., Garcia-Acha, I. :Molecular characterization and identification of biocontrol isolates of Trichoderma spp. *Applied and Environmental Microbiology 66*(5*)*, 1890-8 (2000).

Potential Application of Black Soldier Fly Larvae (BSFL; *Hermetia illucens*) as Efficient Converters of Under-utilized Organic Farm Wastes in Papua New Guinea

Arthur Roberts*, Michael Dom

National Agricultural Research Institute Livestock Research Program,
Labu, P O Box 1639, Lae, 411 MP, PNG

*Corresponding author: arthur.roberts@nari.gov.pg

Abstract: Food gardens and farms generate a lot of organic waste in the form of crop residues and animal manure, much of which may not be recycled back into reusable forms as compost, mulch or manure fertilizer. There is scant attention paid to the means of regenerating valuable farm inputs from fibrous crop residues and nutrient dense manures which are available as by-products of smallholder farming enterprises. Such options do exist in the form of biowaste management strategies which would enhance the notably low input-output crop-livestock farming systems practiced in Papua New Guinea. The bioconversion of organic material provides a unique opportunity to use animal manure and crop residues in a manner that allows the recycling of essential nutrients, particularly protein and energy, which may otherwise be lost, back into farming systems as processed feed and fertilizer. The larvae of Black Soldier Fly (BSF; *Hermetia illucens*) can digest an array of organic materials, bio-converting nutrients into harvestable insect larval mass, thereby providing a protein feed source for fish, chickens and pigs. In our recent, work Black solider fly larvae (BSFL) was used to reduce household kitchen waste and animal manure and provide a nutritionally valuable protein, fat and energy for small-scale livestock production. The BSFL bioconversion of organic residue was also demonstrated to provide a high nutrient compost which may be used as a soil additive for growing vegetable crops. This paper aims to propose the potential application of BSFL as a bio-converter of organic farm waste and highlights the significant reduction of waste by 48% and the generation of a nutrient-rich compost, emphasizing the dual benefit of waste reduction and resource generation.

Keywords: bioconversion, biowaste, black soldier fly, feed, larvae, wastes

1. Introduction

Insects are particularly rich in protein, fats with a notable array of mineral content for human consumption or a feed source for poultry, fish and pigs [1, 2]. A multitude of insect life also supports the breakdown and decomposition of organic wastes within farming ecosystems. Papua New Guinea's (PNG) mixed livestock-crop farming systems generate wastes in the form of agricultural field wastes (weeding, pruning, harvesting), fibrous crop residue (food gardens), food wastes (pre & post-consumed) and livestock manure which may be generally used for compost mulch, manure fertilizer or animal food [3,4]. While reliable data on the amount, composition and waste streams are unavailable, it is estimated that about one million tons of wastes are produced annually to which 60% may possibly be organic [5, 6].

The mechanisms to reuse, recycle or effectively recover valuable nutrients remain unexplored in PNG [7]. While the commonly used landfills, composting and incineration practices are done in most PNG urban to rural localities [7] these practices are considered unsustainable with serious negative impacts on the environment [8, 9]. The prospect of recovering valuable nutrients from organic wastes through farming of insects has gained attention in developing countries because of their utility to manage organic wastes while using less resources yielding valuable products for food, feed, fertiliser and fuel with lesser impacts on carbon emissions compared to domesticated livestock [9,10].

The common houseflies (*Musca domestica*), Mealworm (Tenebrio molitor) and Black soldier fly (BSF; Hermetia illucens) are the most extensively studied insects for the bioconversions of organic wastes [2]. The most promising is the BSF demonstrating its versatility to dispose a large range of waste streams while accumulating nutrient rich protein-fat larvae [11]. Studies have shown BSF to be an effective waste

management tool for human feces, pigs and poultry manure [12, 13, 14] to Municipal solid wastes ideal for under resourced low-income countries [15]. We propose that exploring potential applications of BSFL to recycle organic farm wastes may have greater utility at a smallholder level and be particularly beneficial for village farming of fish and poultry, where valuable protein feeds are less available.

2. Black Soldier Fly Characteristics and Advantages

Hermetia illucens, the Black Soldier Fly (Diptera: Stratiomyidae) is a native to North America with indigenous strains identified to have migratory routes from the Australasian region [16]. The earliest Hermetia specie record dates back to the early 1970's where the H. palmivora was identified in West New Britain [17] while recent emergence of a rare new Hermetia on mainland New Guinea [18]. Widely distributed throughout the sub-tropical and tropical regions tolerating a broad range of environmental conditions [19] BSF may be observed colonizing decomposing fruits, vegetables, agro-industrial wastes (cocoa, coconut wastes, coffee pulp, palm kernel, oil palm) and animal manure or decaying animal tissues. BSF thrives well in temperatures between 24.4 to 34.8 ºC for pupation [19]. Reduced activity is experienced below 20 ºC, causing hibernation and reducing larval activity. Temperatures above 40 ºC reduce larval survivorship dramatically [32]. The optimal humidity levels for mating, hatching and rearing range between 30- 90% with 70% being the most desired for larval development [15]. Our work at the National Agriculture Research Institute (NARI) has reported similar productive conditions for larval rearing and growth [20].

The larvae of BSF are frequently mistaken for the common housefly maggot, Musca domestica. BSF best resembles a wasp-like features and is more differentiated for its larval feeding behaviour and migratory characteristics during pupation [19]. The adult BSF do not occupy human settlements and do not feed as an adult fly; rather digests its own stored fats accumulated during its pre-pupation period [13]. Moreover, BSF does not transmit diseases and is not a disease vector unlike the common housefly [21]. The Black Soldier Fly Larvae (BSFL; Hermetia illucens), is voracious feeder that can eliminate large amounts of organic wastes edible enough in size to feed upon [22]. It is well known to outcompete other filth-inhabiting flies dominating its feed sources reducing biomass by up to 55 – 70% [21, 23]. In addition, BSFL has shown to be effective in reducing concentrations of enteropathogenic and enteric diseases such as Salmonella spp. and E. Coli in human faeces, cattle, chicken and pig manure [23, 24]. The larvae are also less likely to bioaccumulate toxins or drugs [3] and are known to degrade pesticides and pharmaceuticals preventing contaminants re-entering the environment [11].

The BSFL are also tolerant to a wide range of pH [25]. Experimenting with different readily available growth media, fermented household kitchen waste 8.9 and fermented sweet potato (SP) silage 5.8 pH value, it was found that larval mass was greater in the former, while individual larvae weights was higher in the latter [20]. Although, larval proliferation was influenced by several other external factors, it was noted that the kitchen waste provided sufficient loose material for larval movement whereas the SP silage was slightly denser in the packing of wet material. Overall, the application of BSFL significantly reduced the mass of household kitchen waste supplied as larval growth media, bio-converting it into compost. This demonstrates an immediate applicability at household level for producing protein feed from food waste and crop residues.

3. Benefits of Rearing BSFL for Biowaste Conversion

The BSFL is becoming a highly desirable product for food additives, fat extracts [2], fish and livestock feed [26] biodiesel [9] and pharmaceutical derivatives [11] have grown exponentially. Similarly, the rearing of BSFL is increasingly documented elsewhere for managing biowastes in low to middle income countries [11]. Depending on the type of waste mediums used to farm BSFL, the protein content may reach up to 40 to 44% protein, 15 to 25% fatty acid composition [26] generating a comparable amino acid profile rich in lysine with similar compositions to soybean sued in poultry and fish diets. It is also a high value source of vitamins and rich in minerals with an Ash content of 20% [26].

Numerous research using BSFL as protein replacement source in diets for chickens, pigs [13, 27] and several different fish and aquatic species have been well documented as a potential substitution for commonly used protein sources. Pig and chicken manure are the most commonly used waste streams to

farm BSFL [26] while other waste mediums like organic household wastes or crop residues have been considered to be useful BSFL mediums [21].

It was reported elsewhere that at smallholder household level, farming BSFL fits well as an integrated waste management system suited for small scale production [26]. Several benefits that may be more beneficial to smallholder farms is the capacity for less space, water and resources to initiate a BSF colony while taking advantage of its higher feed conversion efficiency, high fecundity, omnivorous feeding habits, and BSFL migratory behaviour [9,22].

Moreover, in earlier studies BSFL demonstrated its ability to reduce odorous compounds from poultry, pig and dairy manure to almost 90% [28] providing additional benefit of using BSFL as an environmentally friendly method in managing livestock manure. In addition, the by-products from the rearing process commonly referred to as "frass" (i.e., composition of insect faecal, substrate residue, shed exoskeletons) yields beneficial properties for soil amendments. The decomposed matter, which is odourless and highly fertile is used to germinate seeds, improve biomass for ornamental plants and green leaf vegetable gardens [29, 30]. The frass is an expected by-product of BSFL rearing which can add up to 75% of the feed substate [29]. The same techniques for fertilizer mulch and composting can be applied to food gardens similar to current practices used on manure wastes. BSF may have the potential to create a circular economy for smallholder farms processing decaying organic matter into larval biomass forming a closed loop recycling system (Figure 1). biowaste conversion creates a circular economy by transforming organic waste into valuable resources, such as protein-rich feed and nutrient-rich compost, thereby closing the loop on waste and resource use in farming systems. At NARI's Labu Station the piggery maintains a natural black soldier fly population which is utilized for reducing pig manure in large 80 L buckets. This also provides a means of reducing pest flies and bad odours, apart from reducing organic run-off and a beneficial soil amendment from the frass material supplied to banana plants.

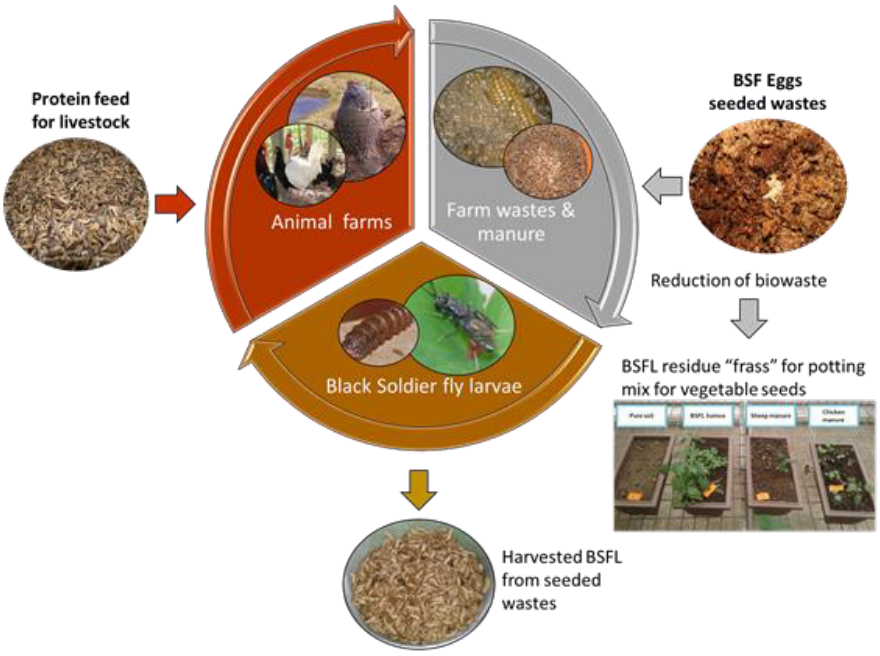

Fig 1: A closed loop recycle diagram using the Black soldier fly to recover farm biowastes from larvae used as feed for livestock.

4. Case study: An Application of BSF as a Biowaste System

PNG estimates its per capita municipal solid waste (MSW) per persons generated to be 0.45 kg daily [6, 7]. This estimate may be undervalued due to drastic population differences and urbanization in cities and townships in PNG in contrast to village households. However, what is clear is that 60% of MSW are arguably organic implicating waste management decisions on a household level. A study collecting weekly kitchen wastes averaged a household collection of 1.9 kg averaging 52.8 kg wet weight per month [20].

The application of BSF as a bioconversion system potentially reduces 29 kg within 14 days (using 48% conversion rate) [20] whilst producing insect larval biomass of 528g wet weight. A third in weight of this, constitutes about 176 g of available crude protein in the form of larval biomass. Three quarters of the 29 kg are rich in N, P and K with potentials for soil amendment application [31]. Our study sample size of 5 to 10 households may perhaps be insufficient; however, provides a decent snapshoot into the potentials of utilizing household wastes to recover nutrients and elements that are occasionally lost through compost dumping. Moreover, the recent work was relatively small in production scale purposely executed for assessing BSFL's bioconversion using natural populations in farming environments. First discovered thriving on ensiled sweet potato root tubers for feeding pigs and occupying pig wastes, BSF was well fitted into cyclic process of a biowaste system. Smallholder farms depend entirely on the low-input system which are based on the farms biological recycling of organic waste products for energy and nutrients. The study demonstrated a 48% reduction in kitchen waste through bioconversion, yielding an average of 200 grams (20%) of Black Soldier Fly Larvae (BSFL) per kilogram of waste consumed [20]. Nutrient proximate analysis from the larvae indicated a crude protein of 34.1% and 30% fat from kitchen waste which compares well with commonly used feed ingredients found in PNG (Table 1). The bioconversion of organic wastes using BSFL potentially addresses low availability of nutrients on farms through bioconversion of organic waste into larval biomass while providing a high value protein source for livestock.

Table 1: A comparison table of feed ingredient resources used as a protein source in comparisons to the Black Soldier Fly larvae

Ingredient	**BSFL[3]**	**Fish meal[1]**	**Soybean[1]**	**Copra Meal[1]**
Dry Matter	91.3	89.55	89	89.25
Gross Energy ($MJkg^{-1}$)	23.1	19.09	39.89	17.13
Crude Protein (%)	32.1	51.32	48	20.57
Crude Fibre (%)	7	1.56	3	12.46
Ether Extracts (%)	30	10.37	2	-
Phosphorus (%)	1.5	2.44	0.65	0.25
Calcium (%)	5	3.3	0.25	0.66
Ash (%)	20.6	34.97	4.9	7.14
Level of inclusion (Fish)	[2]7.5-30	[1]60	[1]60	[1]20-35
Level of inclusion (Chickens)	[2]12.0	[1]12.0	[1]15.0	[1]20-40
Costs in Kina (PGK)	-	61.90*	70.0*	64.80*

[1]Inclusion rates for Copra meal, Soybean and Fish meal for fish and village chickens taken from E. Thomas (2006).
[2]Inclusion rates for fish are for channel catfish (*Ictalurus punctatus*) Bondari et al (1981) and chickens taken from Hale [27].
[3]Literature for nutrient specifications on Black Soldier Fly Larvae from kitchen waste [20].
*Current price value for fish meal at Frabelle Limited, Soy bean imported and purchased from Lae Feed Mill and Copra meal from Coconut and Products Limited in Madang.

It should be noted that the study was conducted in an open shed environment using natural populations of Black soldier fly larval biomass. The experiment used seeded larvae stock (3rd and 4th larvae instar stage) from pig manure to initiate the bioconversion process without any artificial breeding process to produce egg clutches for seeding. The average larval mass produced of 528g (200 g dry matter) produced may have not reached its full potential due to disturbances from daily monitoring of the waste mediums (i.e., pH, Moisture, humidity etc.). It has been observed that feeding larvae are best kept under darked conditions for a period of 7 to 14 days to allow feeding to reach maximum yields and allow larvae to migrate from its feeding source [19, 32]. In Addition, the open shed environment lured adult flies to lay egg clutches around biodigesters (Figure 2). These eggs were re-seeded as an additional seed stock into the waste matrix for bioconversion.

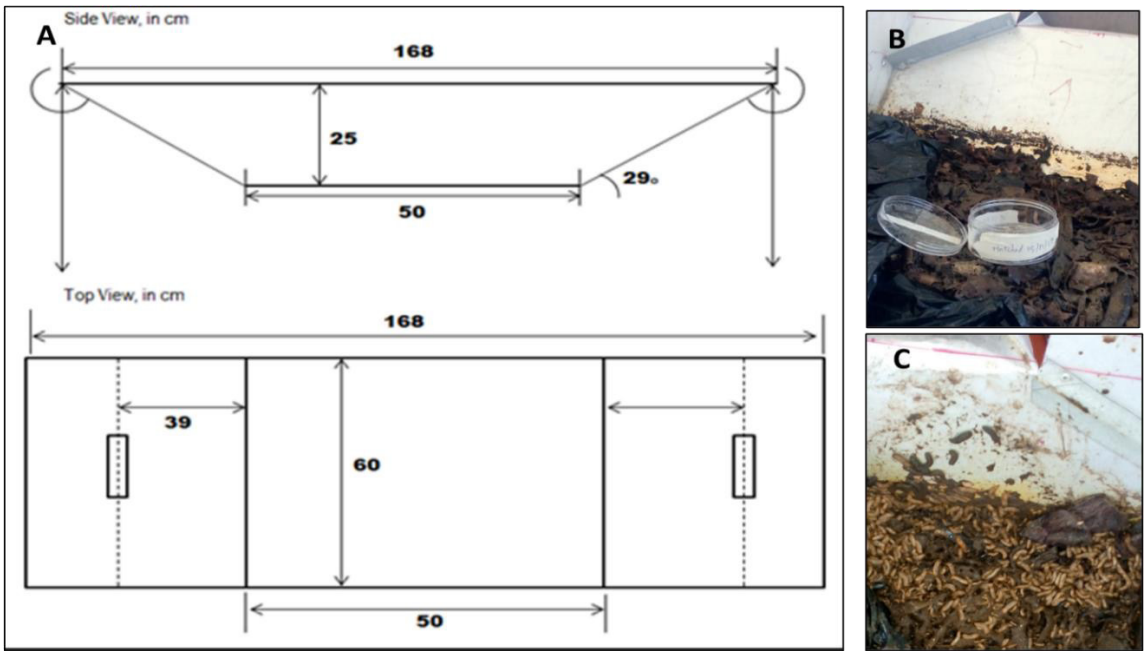

Figure 2: BSFL biodigesters used for the bioconversion of collected kitchen waste; **Insert A:** A prototype biodigester was modified for rearing black soldier fly larvae from a shared video link: https://www.youtube.com/watch?v=ycl3B6-y73 [20] **Insert B:** Eggs clutches laid around the biodigesters collected and seeded into the waste matrix. **Insert C:** BSFL feeding after being seeded after approximately 14 days.

The study indicated that there was a natural decline in larval biomass during the 90-day period observation suggesting a natural decline in the population within the open shed. This may be case of BSF selecting more preferred mediums such as pig manure around the farm. It appears that breeding BSF to maintain regular supply of eggs for seeding waste mediums would be a pre-requisite in initiating breeding stock. While current BSFL rearing practices are small and growing exponentially with technological advancements [26] natural BSF populations may be inconsistent because of their variability to source feeding medium [9]. Artificial breeding may perhaps be more consistent for larval mass production considering organic waste inputs are more heterogenous and reliable [9].

For better utility in the application of BSF in managing household for MSW, the ‘reduce, reuse, recycle’ concept for waste management also fits well with household composting systems that are rarely considered. BSFL may be proposed as a concept idea to complement the proposed vermicomposting for MSW for Lae city waste management hierarchy systems [7]. However, an awareness into segregating wastes would probably be required in terms of the benefits of organic composting and green fertilizer applications for MSW and smallholder farms. BSFL adds value to composting and reduces acidic leachates into interconnected ecological water ways and biological systems [25].

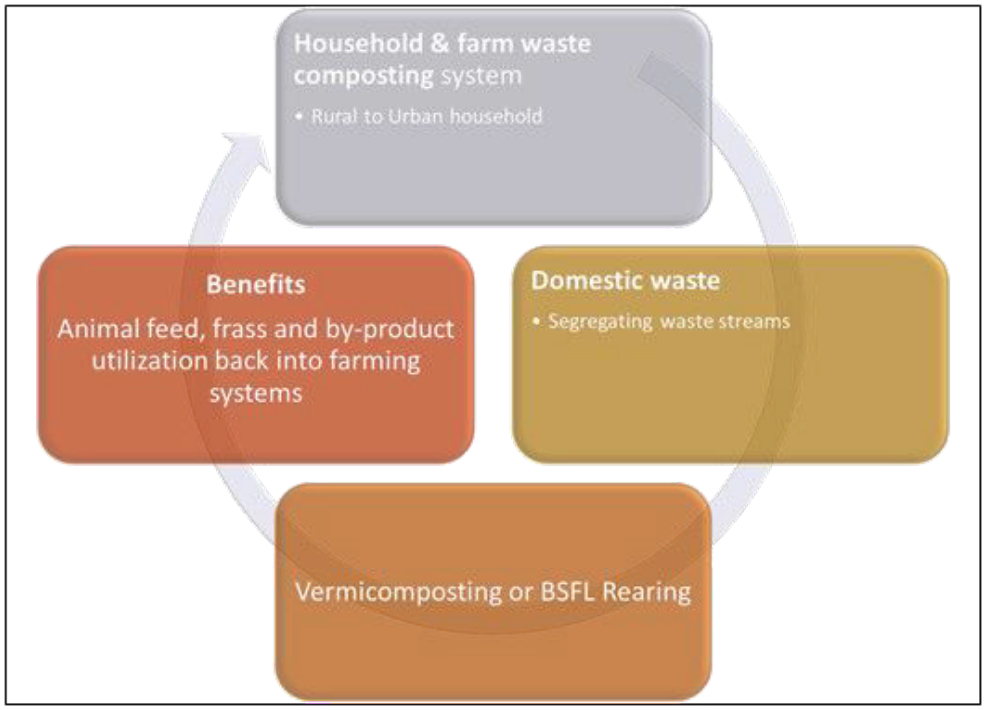

Fig 3: Suitable household composting system concept with BSFL rearing for managing MSW [7].

5. Conclusion

The application of the black soldier fly as a recycling technology in converting biowaste into useful products is undeniable. BSFL can be an easily sourced protein source as feed for fish, chickens or pigs and addresses some of the nutritional aspects of livestock rearing while adding value to food gardens by use of frass for smallholder farmers. It is environmentally friendly and has a diverse versatility for waste streams demonstrating its novelty and appealing potential for recycling organic wastes to BSFL for smallholder farms or households producing poultry or fish as a supplementary feed.

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References

1. Wang, Y. S., & Shelomi, M. (2017). Review of black soldier fly (*Hermetia illucens*) as animal feed and human food. *Foods*, 6(10), 91.
2. Van Huis, A. (2020). Insects as food and feed, a new emerging agricultural sector: a review. Journal of Insects as *Food and Feed*, 6(1), 27-44.
3. Shelomi, M. (2020). Potential of black soldier fly production for Pacific small island developing states. *Animals*, 10(6), 1038.
4. Hazenbosch, M., Sui, S., Isua, B., Beauchamp, E., Frouz, J., Imale, K., Jimbudo, M., Milner-Gulland, E. J., Novotný, V., Veselá, H., & Morris, R. J. (2021). Using locally available fertilisers to enhance the yields of swidden farmers in Papua New Guinea. *Agricultural Systems*, 192, 103089.
5. Nicholls, S. (2004). The priority environmental concerns of Papua New Guinea. International Waters of the Pacific (IWP)-*Pacific Technical Report* (1).

http://archive.iwlearn.net/sprep.org/att/publication/000367_PNG_PEC_Report.pdf (accessed July 7, 2022).
6. Woodruff, A. (2014). Solid Waste Management in the Pacific: Papua New Guinea Country Snapshot. Asian Development Bank. https://www.adb.org/sites/default/files/publication/42664/solid-waste-management-png.pdf (accessed July 7, 2022).
7. Doaemo, W., Dhiman, S., Borovskis, A., Zhang, W., Bhat, S., Jaipuria, S., & Betasolo, M. (2021). Assessment of municipal solid waste management system in Lae City, Papua New Guinea in the context of sustainable development. *Environment, Development and Sustainability*, 23(12), 18509-18539.
8. Food and Agriculture Organization (FAO). (2014). Food wastage footprint: Full-cost accounting. http://www.fao.org/3/i3991e/i3991e.pdf (accessed June 30, 2022).
9. Siddiqui, S.A., Snoeck, E.R., Tello, A., Alles, M.C., Fernando, I., Saraswati, Y.R., Rahayu, T., Grover, R., Ullah, M.I., Ristow, B. & Nagdalian, A.A., (2022). Manipulation of the black soldier fly larvae (*Hermetia illucens*; Diptera: *Stratiomyidae*) fatty acid profile through the substrate. *Journal of Insects as Food and Feed*, 8(8), pp.837-855.
10. Ravi, H. K., Degrou, A., Costil, J., Trespeuch, C., Chemat, F., & Vian, M. A. (2020). Larvae mediated valorization of industrial, agriculture and food wastes: Biorefinery concept through bioconversion, processes, procedures, and products. *Processes*, 8(7), 857.
11. Surendra, K. C., Tomberlin, J. K., van Huis, A., Cammack, J. A., Heckmann, L. H. L., & Khanal, S. K. (2020). Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (*Hermetia illucens* (L.)) (Diptera: *Stratiomyidae*) (BSF). *Waste Management*, 117, 58-80.
12. Sheppard, D. C., Newton, G. L., Thompson, S., & Savage, A. (1994). A value-added manure management system using the black soldier fly. *Bioresource Technology*, 50, 274-279.
13. Newton, L., Sheppard, C., Watson, D. W., Burtle, G., & Dove, R. (2005). Using the black soldier fly, Hermetia illucens, as a value-added tool for the management of swine manure. Animal and Poultry Waste Management Center, *North Carolina State University*, Raleigh, NC.
14. Lalander, C., Diener, S., Zurbrügg, C., & Vinnerås, B. (2019). Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (*Hermetia illucens*). *Journal of Cleaner Production*, 208, 211-219.
15. Diener, S., Zurbrügg, C., & Tockner, K. (2009). Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. *Waste Management & Research*, 27, 603-610.
16. Kaya, C., Generalovic, T. N., Ståhls, G., Hauser, M., Samayoa, A. C., Nunes-Silva, C. G., Roxburgh, H., Wohlfahrt, J., Ewusie, E. A., Kenis, M., & Hanboonsong, Y. (2021). Global population genetic structure and demographic trajectories of the black soldier fly, *Hermetia illucens*. *BMC Biology*, 19(1), 1-22.
17. James, M. T. (1972). A new *Hermetia* of potential economic importance (Diptera: *Stratiomyidae*). Pacific Insects, 14, 73-75.
18. Wachkoo, A. A., Shah, G. M., Jan, U., & Akbar, S. A. (2017). A checklist of soldierflies (Diptera, *Stratiomyidae*) in India. *Journal of Asia-Pacific Biodiversity*, 10(1), 44-54.
19. Tomberlin, J. K., Adler, P. H., & Myers, H. M. (2009). Development of the black soldier fly (Diptera: *Stratiomyidae*) in relation to temperature. *Environmental Entomology*, 38(3), 930-934.
20. Roberts, A. D., Elly, S., Martin, L., & Michael, D. (2020). Bioconversion of fermented kitchen waste or sweetpotato roots by Black Soldier Fly (*Hermetia illucens*) larvae reared in an open shed environment. *Journal of South Pacific Agriculture*, 22, 1-9.
21. Barragan-Fonseca, K. B., Dicke, M., & van Loon, J. J. (2017). Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed–a review. *Journal of Insects as Food and Feed*, 3(2), 105-120.
22. Tomberlin, J. K., Sheppard, D. C., & Joyce, J. A. (2002). Selected life-history traits of black soldier flies (Diptera: *Stratiomyidae*) reared on three artificial diets. *Annals of the Entomological Society of America*, 95(3), 379-386.
23. Lalander, C., Fidjeland, J., Diener, S., Eriksson, S., & Vinneras, B. (2015). High waste-to-biomass conversion and efficient Salmonella spp. reduction using black soldier fly for waste recycling. *Agronomy for Sustainable Development*, 35, 261-271.
24. Erickson, M. C., Islam, M., Sheppard, C., Liao, J., & Doyle, M. P. (2004). Reduction of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar Enteritidis in chicken manure by larvae of the black soldier fly. *Journal of Food Protection*, 67(4), 685-690.
25. Popa, R., & Green, T. R. (2012). Using black soldier fly larvae for processing organic leachates. *Journal of Economic Entomology*, 105(2), 374-378.

26. Makkar, H.P., Tran, G., Heuzé, V. and Ankers, P., (2014). State-of-the-art on use of insects as animal feed. *Animal feed science and technology*, 197, pp.1-33.
27. Hale, O. H. (1973). Dried Hermetia illucens larvae (Diptera: *Stratiomyidae*) as a feed additive for poultry. *Journal of the Georgia Entomological Society*, 8, 16-20.
28. Beskin, K. V., Holcomb, C. D., Cammack, J. A., Crippen, T. L., Knap, A. H., Sweet, S. T., & Tomberlin, J. K. (2018). Larval digestion of different manure types by the black soldier fly (Diptera: *Stratiomyidae*) impacts associated volatile emissions. *Waste Management*, 74, 213-220.
29. Klammsteiner, T., Turan, V., Fernández-Delgado Juárez, M., Oberegger, S., & Insam, H. (2020). Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization. *Agronomy*, 10(10), 1578.
30. Song, S., Ee, A. W. L., Tan, J. K. N., Cheong, J. C., Chiam, Z., Arora, S., Lam, W. N., & Tan, H. T. W. (2021). Upcycling food waste using black soldier fly larvae: Effects of further composting on frass quality, fertilising effect and its global warming potential. *Journal of Cleaner Production*, 288, 125664.
31. Lalander, C., Senecal, J., Calvo, M. G., Ahrens, L., Josefsson, S., Wiberg, K., & Vinnerås, B. (2016). Fate of pharmaceuticals and pesticides in fly larvae composting. *Science of the Total Environment*, 565, 279-286.
32. Bullock, N., Chapin, E., Elder, B., Evans, A., Givens, M., Jeffay, N., Pierce, B., Robinson, W., & Mattox, J. (2013). Implementation of black soldier fly breeding and chicken feed production at Pickards Mountain Eco-Institute

A Character Level Word Encoding Deep Learning Model for Combating Cyber Threats in Phishing URL Detection

Rajendran Bhojan

School of Mathematics and Computer Science,
The Papua New Guinea University of Technology, Private mail bag, Lae 411,
Morobe Province, Papua New Guinea

Corresponding author: rajendran.bhojan@gmail.com, rajendran.bhojan@pnguot.ac.pg

Abstract: A cyber threat is generally a malicious activity which tend to damage or steal data or in general something which disrupts the digital life. Security errors, DoS attacks, malware, and data theft are some of these dangers. A kind of cyber threat known as "phishing" occurs when attackers impersonate a legitimate URL or website to collect user information. Out of the total cyber-crimes reported in last quarter around the globe, 21% falls in the phishing category. Phishing is often performed as a social engineering method and the conventional detection techniques were largely relied on the manual reports. Recently, techniques for machine learning have been used to identify phishing. Owing to the recent advancement in the deep learning methods, many possibilities have also been discussed on using the same for achieving better performance. To identify malicious URLs, this research presents a lightweight deep-learning model that can function quite efficient enough even in energy-saving systems. The experimental results of the proposed model showed substantial improvements considering the parameters of comparison to other cutting-edge methods. There was an enhancement in the rate of accurately detecting true positives. Furthermore, the experiments confirmed that the proposed approach operates quite efficiently even when phishing detection systems are in energy-saving modes.

Keywords: Cyber Security, Cyber-crimes, Data Sanitization, Tokenization, Machine Learning, Deep Learning.

1. Introduction

Cyber-crimes and threats are nowadays becoming more frequent which brings out lot of hindrance and struggle for any business and end users to move along digitally. Recent findings from cybersecurity analysts [1] indicate a marked increase in the amount of data that has been compromised and stolen, even from commonplace sources like workplaces, IoT devices, and mobile devices. Additionally, recent studies highlight that many individuals are vulnerable to phishing sites, leading to substantial losses in data and finances. To combat these threats effectively, raising awareness among companies and individuals is essential, along with the implementation of robust computational methods for detecting phishing attacks.

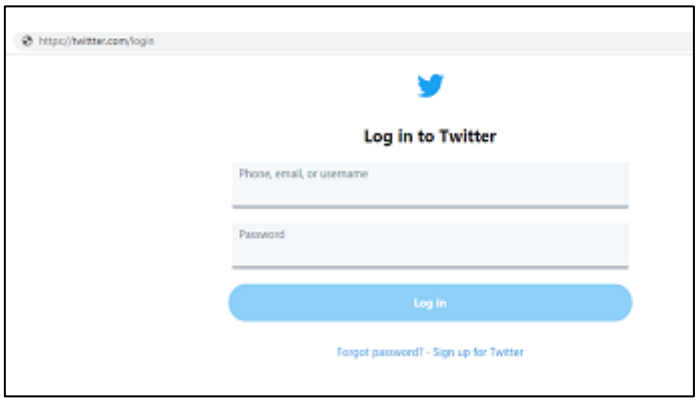

Fig. 1. Phishing Twitter site

Phishing URLs typically employ social engineering tactics to mimic genuine website URLs, intending to deceive users into giving attackers access to private information. Such a scenario, where a well-known social networking site is being phished as illustrated (see Fig. 1). In this example, The URL of the authentic website has an extra character appended, "t", while maintaining an identical appearance to the official site. If visited by an unsuspecting user, this fraudulent site prompts them to enter their credentials, which are then captured by the site's backend and sent to the attackers. In recent times, these types of websites have proliferated and are inflicting significant harm on the digital ecosystem. In the last quarter of 2019 alone, 138,564 phishing sites were discovered, according to the US Council's most recent report on cyber threats. The study emphasizes how rapidly these behaviors have increased, which are increasingly challenging to detect due to attackers' adeptness at employing multiple layers of redirection, thereby obfuscating URLs. The FBI's 2019 report [3] underscores the staggering financial impact, estimating nearly $44 billion in total losses attributed to phishing websites.

Identifying malicious websites is straightforward for cybersecurity experts but challenging for naive computer users who often overlook exact URLs (see Fig. 2). To develop techniques for detecting phishing websites that are based on machine learning, researchers often draw on the experience of security experts. One commonly employed method is URL blacklists, maintained by organizations that anti-cyber threats [4], can provide databases of verified phishing sites in real-time. Anti-cyber threat groups depend more and more on technical contributions from the research community as a result of the notable rapid increase in the number of phishing sites. Maintaining an updated URL blacklist requires active participation from both organizations and individuals. Although these manual techniques are efficient, they are also expensive and time-consuming [5]. Hand-crafted methods can prevent phishing incidents upon repeated encounters but do not provide warnings for initial interactions when users are about to enter their data.

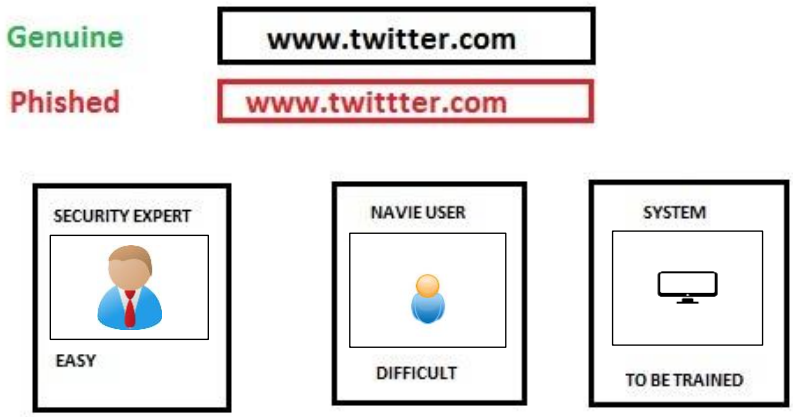

Fig. 2. Difficulty level of detecting phishing

Providing a basic model for phishing detection is the aim of this effort. It presents a strategy based on deep learning to improve the efficacy and precision of phishing using URLs. This study is new in that it investigates if the model can be implemented on devices with limited resources. The suggested technique builds a training set and evaluates its effectiveness using a large dataset of legitimate and phishing URLs. In summary, this paper presents its main contributions as follows:

- Presenting a character-level multi-space technique-based deep learning model for phishing URL detection, exploring improvements over conventional models like CNN.
- Conducting experimental testing and assessments to show the model's efficacy and functionality.

The following is the format of the paper's succeeding sections: While Section 3 offers an overview of previous research addressing related topics; Section 2 expands on the problem statement in depth. Section 4 outlines the research background, followed by Section 5 which details the proposed model, its application,

assessment, and outcome discussion. The paper's conclusion, Section 6, discusses potential directions for further study.

2. Problem Definition

Phishing site detection has been accomplished via the use of conventional machine learning approaches [6-7]. The URLs of websites are first examined to identify characteristics suggestive of malicious intent (see Fig. 3). Subsequently, using traditional machine learning techniques like SVM and k-NN, these labeled features are used by machine learning algorithms to create a training set and create detection models. However, these methods often struggle to detect newly injected phishing sites, relying heavily on existing databases or repositories. Recently, there has been a significant shift towards adopting deep learning methods for this purpose, driven by their successful applications. Unlike traditional approaches that involve complex feature selection processes, deep learning allows ML experts to utilize data directly without explicit feature engineering by cybersecurity experts (see Fig. 3).

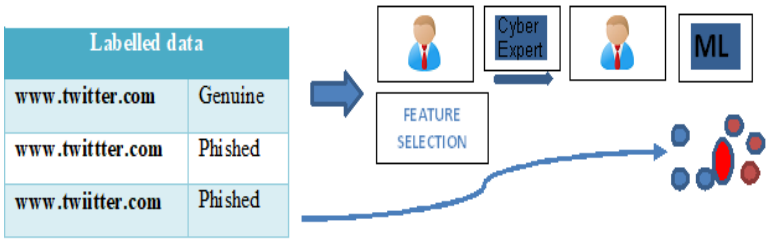

Fig. 3. Problem with Conventional Method

3. Related Works

Recently, phishers target users' financial information, personal information, and other sensitive data, and website phishing has become a serious security concern [10]. The literature has proposed several list-based classical phishing detection techniques, but they have not been able to keep up with the internet's phishing sites growing exponentially. An overview of numerous significant techniques for identifying phishing websites that have been suggested in the literature is given in the following section.

P. Yang et al (2019) the MFP method, introduced in [11], utilizes multi-dimensional feature selection through deep learning. Initially, it extracts character sequences from the current URL and swiftly classifies them using a deep learning approach. Subsequently, it combines features related to statistics and web code into a multi-level feature set. This method significantly reduces the detection time for phishing URLs. Evaluations conducted on a dataset containing thousands of phishing URLs obtained a minimum of 0.61% for false positives and 92.15% for accuracy.

Rao S et al (2019) proposed a categorization technique to overcome the disadvantages of conventional methods by using meta-heuristic characteristics taken from source codes, URLs, and outside services [12]. To assess the model, eight distinct machine-learning techniques were used; random forest performed the best. Multiple evaluations were conducted with various classifiers to determine the optimal approach. The PCA-based random forest (PCA: RF) outperformed other configurations, achieving a high accuracy of 89.61%.

Surya Srikar et al (2020) introduced an anti-phishing mechanism for URLs. Initially, they extracted lexical and host properties of websites. The following phase included training machine learning (ML) and deep learning (DL) models using a combination of host data, URL features, and natural language processing (NLP) properties [13]. The proposed approach achieved a detection rate of 82.5% for identifying phishing URLs.

Yerima et al (2020) introduced a deep learning approach to enhance accuracy in detecting phishing URLs, utilizing traditional CNNs to achieve high classification accuracy [14]. They used 5984 phishing sites and 6598 real websites to test their model. Results from the experiments showed how well the CNN model performed at identifying new phishing URLs. Moreover, the technique produced a 90.36% accuracy rate and an F1 measure of 0.91, outperforming conventional ML classifiers tested on the same dataset.

Somesha et al (2020) introduced a model for phishing URL detection employing deep neural networks. Their approach combined Long Short-Term Memory (LSTM) and CNN features, reducing them to just 10 features [15]. The overall accuracy for the approach was 80.12%. By relying on a single third-party service, their approach enhanced robustness against failures and increased efficiency in the detection process.

Feng et al (2018) introduced an innovative algorithm that uses a neural network-based classification technique to identify phishing websites. The model used a low-risk minimization strategy to improve both accuracy and generalizability. The Monte Carlo approach was also used to simplify and stabilize the training process [16]. The suggested model's usefulness was shown by experimental research, which showed high True Positive and False Negative rates. There was a noticeably high True Positive Rate (TPR) and False Negative Rate (FNR). Additionally, studies showed that the accuracy level was around 92%.

W. Ali et al (2019) enhance phishing prediction ability, a hybrid model integrating evolutionary feature selection techniques and Deep Neural Networks (DNNs) was developed [17]. In this model, to determine which traits are the most important and to assign them the proper weights, a heuristic technique called GA is used. These selected website features are then weighted by GA for training to enhance accurate phishing site prediction. The experimental findings show that in contrast to other methods, the recommended technique performs higher in terms of specificity, sensitivity, and Mean Squared Error (MSE).

4. Background and Motivation

Detecting phishing websites computationally is typically approached as a supervised machine learning problem. Models are trained using elements from websites, including URLs, methods, and HTML text, to perform harmful detection tests. For phishing detection, the classifier is an essential component of many machine-learning techniques [18]. A typical supervised learning procedure for identifying dangerous websites (see Fig. 4), since highly informational features may greatly improve speed, feature selection is an important first step in these approaches. Optimal feature selection requires expert knowledge, and selecting common features can be challenging due to variations across different application domains. Incorrectly selecting features can lead to substantial loss of significant information. Therefore, deep learning methods are suitable because they eliminate the need for feature selection, thereby enabling faster system performance without degradation from inappropriate feature choices. Deep learning models can utilize unprocessed data directly for training, simplifying the process, and effectively identifying patterns for accurate decision-making. Inspired by these benefits, this work presents a deep learning model based on deep learning principles that develop a phishing detection system using raw Uniform Resource Locators (URLs).

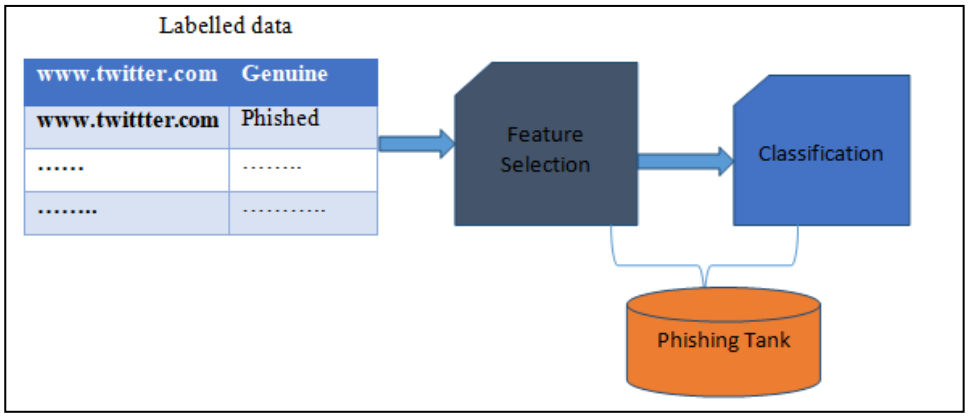

Fig. 4. Classical Phishing detection

5. Proposed Methodology

Deep Learning Framework: Phishing URL Detection (DLF:PUD)

The suggested methodology DLF:PUD (see Fig. 5).

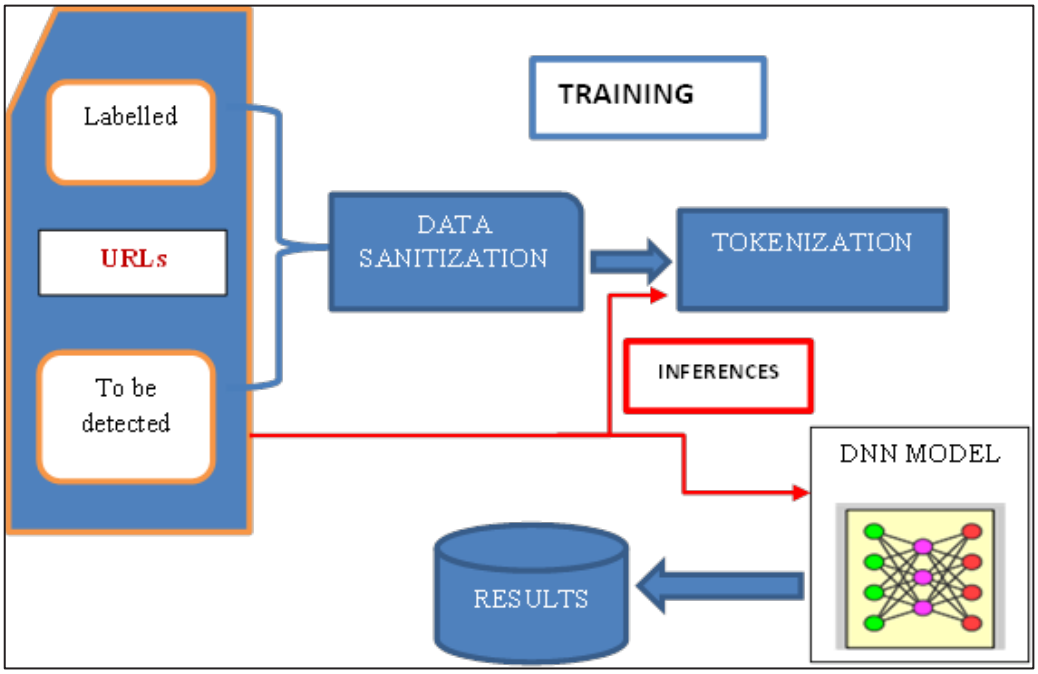

Fig. 5. The proposed Methodology

5.1 Data Sanitization

Sanitizing data is the first step in the suggested model. To avoid their impact on the detection performance of phishing URLs across various datasets, this procedure eliminates popular URL prefixes like "http://" and "https://". Failure to remove these prefixes could lead to inconsistency in URL representations, significantly impacting the model's accuracy. For instance, if a phishing repository's URLs all have the same prefix, the model might incorrectly classify all URLs with that prefix as phishing sites. To vectorize the characters in the URL, a tokenizer is employed. The proposed method utilizes character-level tokenization to ensure that the model does not rely on the semantic meaning of words within URLs, which is crucial since many phishing site names are constructed at the character level. Malicious URLs often contain slight variations from the original site that can easily go unnoticed by users. For example, as per the case under discussion, the original website "twitter.com" becomes "ttwitter.com" when the character "t" is added. There are several layers in the proposed Deep Neural Network (DNN), including embedding, convolutional, dropout, and sigmoid layers (see Fig. 6). Table 1 provides a comprehensive overview of the layer setup of the DNN model, including information on the kernel's size, the filters that were used, and the word embedding layer's output.

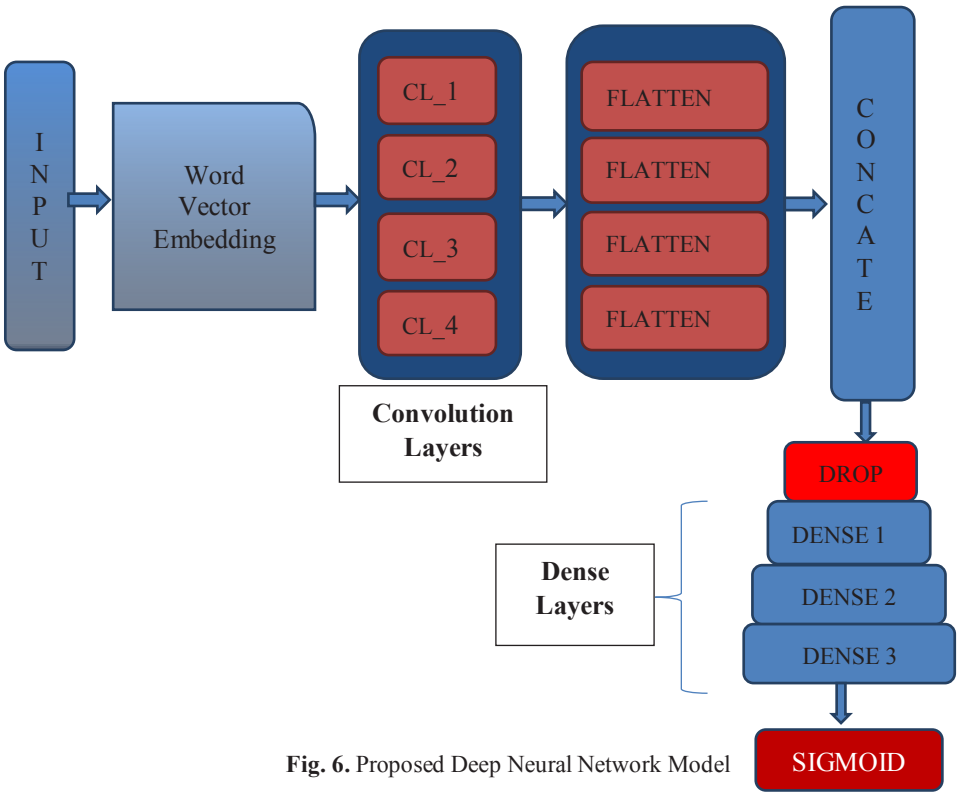

Fig. 6. Proposed Deep Neural Network Model

Table 1. Configuration of proposed DNN Model

Dimensions of Output		
Embedding	32	
	Filter Size	**Kernel Size**
CL_1	128	4
CL_2	128	6
CL_3	128	10
CL_4	128	20
	Dropout Rate	
Drop out	0.5	
	Number of Units	
Dense_1	64	
Dense_2	64	
Dense_3	64	

Each layer of the suggested model is described below**.**

Embedded Layer: This layer serves as the initial stage in Deep Neural Network models for addressing NLP tasks. Alongside tokenization, a vector output is produced by the embedding layer. The differences between word embedding and one-hot encoding (see Fig. 7, 8). The coefficients of each vector in the word embedding layer depict relationships among different characters, enhancing NLP performance by visualizing these relationships.

Convolution Layer: In the suggested paradigm, after the embedding layer, four layers of this type are employed. Each layer applies a kernel and filter to extract significant features and filter out less relevant information. The operation involves element-wise multiplication, with summaries occurring between the filters and the relevant data portions. Instead of sequential processing, parallel layers are utilized. Every layer is set up to extract characteristics by concentrating on a single window containing successive characters. Concatenation is performed after each convolutional layer's outputs have been flattened.

Concatenating layer: To make further processing easier, specifically, this layer is designed to combine properties from earlier levels. Unlike conventional concatenation methods, convolutional layers' (CLs') outputs combine with the embedding layer's outputs in this instance. The original context of the data is preserved using this method, which is essential for identifying phishing URLs.

Drop layer: During training, overfitting is avoided with the help of this regularization procedure. During training, neurons are chosen at random and turned off. These deactivated neurons are temporarily excluded during forward passes, and backward passes do not update their respective weights.

Dense layers: The suggested model is improved by adding more capabilities to extract the most important information since this layer is completely concatenated. To analyze patterns obtained from the convolutional layers, these attributes are essential.

Sigmoid layers: These utilize the sigmoid function to detect phishing URLs. The sigmoid function outputs values between 0 and 1, which are used to compute prediction probabilities in the last layers of the suggested DNN model.

t	1	0	0	0	0	0	0	0
w	0	1	0	0	0	0	0	0
i	0	0	1	0	0	0	0	0
t	0	0	0	1	0	0	0	0
t	0	0	0	0	1	0	0	0
e	0	0	0	0	0	1	0	0
r	0	0	0	0	0	0	1	0
.	.	.	.	.	.	.	-	-
.	.	.	.	.	.	.	-	-
c	0	0	0	0	0	0	0	1
o	0	0	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0

Fig. 7. Hot Encoding

t	0.13	0.85	0.76	0.12	0.14	0.26	0.75	0.62
w	0.15	0.23	0.42	0.32	0.14	0.34	0.91	0.72
i	0.37	0.65	0.72	0.32	0.61	0.42	0.32	0.41
t	0.45	0.32	0.15	0.38	0.74	0.38	0.86	0.84
t	0.94	0.32	0.18	0.37	0.67	0.52	0.65	0.74
e	0.56	0.61	0.84	0.38	0.81	0.91	0.52	0.38
r	0.85	0.32	0.17	0.45	0.37	0.64	0.49	0.38
.	-	-	-	-	-	-	-	-
.	-	-	-	-	-	-	-	-
c	0.52	0.34	0.51	0.53	0.47	0.68	0.92	0.19
o	0.37	0.65	0.72	0.32	0.61	0.42	0.32	0.41
m	0.21	0.29	0.68	0.75	0.37	0.19	0.83	0.91

Fig. 8. Word Embedding

5.2 Evaluation

In the next section, the suggested DNN model is evaluated using settings given in Table 1. The experiments were conducted on a system equipped with a GPU, minimal RAM and ROM, and a standard graphics card. The experiment included 10,234 URLs in all, 3,004 phishing URLs, and 7,234 genuine URLs. Once redundant URLs were eliminated before usage, the official repository is where the benign URLs were obtained. For training, 10% of all URLs were set aside. The accuracy measure used was the number of True Positive (TP) events. Section 6 contains specifics on the performance measures.

The proposed model achieved a True Positive (TP) accuracy of 98.13%. Other DNN-based methods for detecting phishing URLs have utilized similar structures, even when the dense and convolutional (CL) layer designs vary. As a result, the effects of these suggested layers are examined. The impact of the suggested thick layers is seen in Table 2 which is graphically represented (see Fig. 9). When the number of thick layers was first investigated, the results showed that the TP accuracy increased steadily with each new layer. When the suggested model reached the sigmoid layer, its accuracy reached its maximum of 98.13%.

Table 2 – Effect of 3- Tier Dense layer

	Accuracy
Proposed	98.13 %
1 Dense Layer	82.65 %
2 Dense Layer	84.26 %
3 Dense Layer	86. 58 %

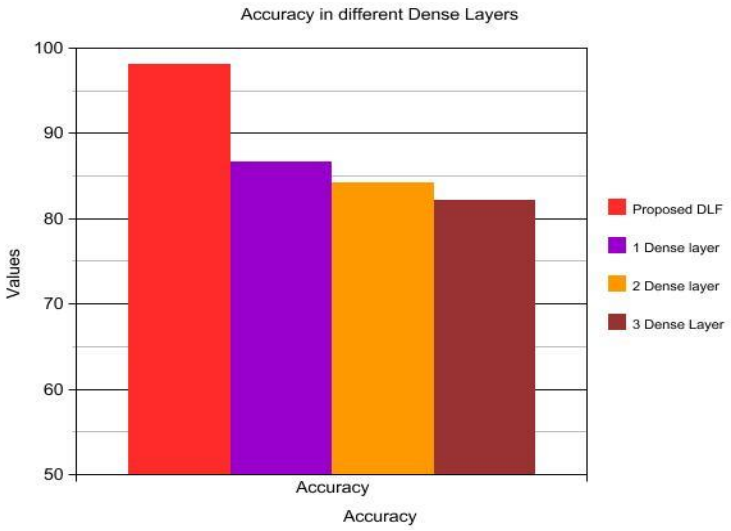

Fig. 9. Comparison of several dense layers' accuracy

The convolutional layers' effects are shown in Table 3 and represented graphically (see Fig. 10). A comparable trend indicates that the number of CL layers grows with increasing performance. In the proposed DNN model, using CL1, CL2, and CL3 resulted in incremental TP rates of 80.15%, 82.65%, and 84.21%, respectively.

Table 3. Effect of Convolutional Layers

	Accuracy
Proposed	98.13%
3 Convolutional Layer	84.21%
2 Convolutional Layer	82.65%
1 Convolutional Layer	80.15%

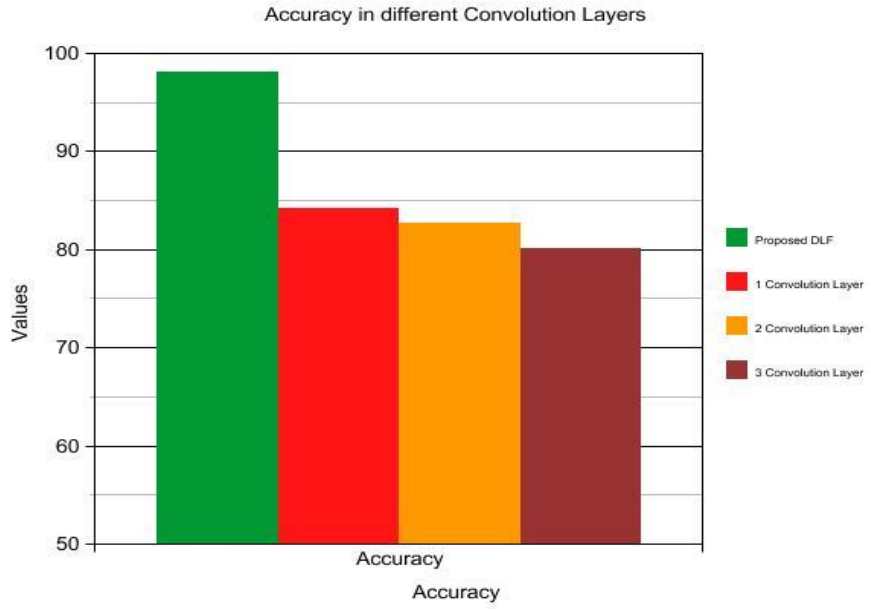

Fig. 10. Evaluation of Various Convolutional Layers' Accuracy

The proposed model also aimed to concatenate outputs from word embedding to retain unprocessed information, resulting in improved performance. Table 4 shows embedding layer outputs with and without concatenation. It shows a significant decrease in TP values when concatenation is not utilized.

Table 4. Effect of Concatenation

True Positive	
Proposed	98.13%
Without Concatenation	83.41%

5.3 Implementation with Use-Case

Performance evaluation of the proposed model, it is integrated into a low-resource device. Computational complexities are computed for assessment at every stage of the model. The execution timings for each stage, including DNN inference, tokenization, and sanitization, are shown in Table 5. Ten trials could be conducted, and the average execution times were determined. A significant amount of the overall execution time was accounted for by the inference layer, which took 105 milliseconds for each URL request. Sanitization and tokenization, on the other hand, required less than a nanosecond for each step. The overall assessment time per URL was 125 milliseconds on average, which is a noteworthy accomplishment in contexts with limited resources.

Table 5. Execution Time

Execution Time	
Data Sanitization	0.01265
Tokenization	0.195
Deep Neural Network model	124

Subsequent research included applying word- and character-level embedding to the suggested model. Throughout the embedding, the parameters stayed the same, for example, the number of convolutional and dense layers. Convolutional layer outputs were concatenated and then sent via sigmoid and dropout layers for further processing. The open-source Pi tool was used for evaluation, although it ran into an out-of-memory fault. This suggests that in contexts with limited resources, execution is not possible. This emphasizes how effective the suggested model is. In contrast, the suggested model and the model that included

embedding at the word and character levels were implemented independently. The suggested DNN model was executed in 67 milliseconds, according to the results, while the model with both embedding took 97 milliseconds. Therefore, the proposed model demonstrated 30% greater efficiency.

5.4 Comparative Analysis

The proposed model is evaluated comparatively across various parameters as outlined below:

Performance Metrics

The suggested model's overall performance is evaluated and errors are identified using statistical parameters. The following are some of the many metrics that are used in assessment. The primary assessment criteria are shown in Table 6.1.

Table 6.1: Fundamental Evaluation Metric

	Includes the condition or target object	Contains the desired item or circumstance
Tests Negative or Accepted Null Condition	True Negative	False Negative
Tests Positive or Rejected Null Condition	False Positive	True Positive

i. True Positive

A true positive is a result that is positive and rejects the null hypothesis, with the final condition being recognized as matching and accurate. A is a symbol of true positive. It has the following definition:

$$TP = n_{11} = \text{number of such individuals} \quad (1)$$

ii. True Negative

When it is said that the ultimate condition is correct and non-matching, it is considered a true negative, which is a finding that supports the null hypothesis. The symbol B stands for true negative. It has the following definition:

$$TN = n_{00} = \text{number of such individuals} \quad (2)$$

iii. False Positive

An inaccurate rejection of the null hypothesis is known as a false positive, this occurs when a positive result is reported yet the final condition is shown as matching. The letter C represents a false positive. The following is its definition:

$$FP = n_{01} = \text{number of such individuals} \quad (3)$$

iv. False Negative

The term "false negative" refers to a negative result that erroneously accepts the null hypothesis when it is said that the final condition is not matching and is incorrect. A false negative is represented by the symbol D. The following is its definition:

$$FN = n_{10} = \text{number of such individuals} \quad (4)$$

v. Recall

It assesses the model's overall performance, especially when false-negative situations are present, using a probability-based accuracy test. This is determined as

$$Recall := \frac{True\ Positive}{True\ Positive + False\ Negative} \quad (5)$$

vi. Precision

The accuracy of the model is tested using probability to show how well it performs overall when there are positive results. It is computed as

$$Precision := \frac{True\ Positive}{True\ Positive + False\ Positive} \quad (6)$$

vii. F1-Measure

The combined effect of recall and accuracy in a situation is assessed using this cumulative metric. A case's accuracy and recall ranges will determine whether the F-Measure is expressed between 0 and 1, or between 0 and 100. It is measured by

$$F1 - Measure := 2 * \frac{(R*p)}{R+P} \quad (7)$$

where p or P refers to precision and R for recall.

Table 6.2. Comparing Precision, Recall and F1-Measure.

METHODS	PRECISION	RECALL	F1-MEASURE
DLF:PUD	98.18	98.15	98.14
MFP	92.54	93.21	92.54
PCA:RF	90.21	89.26	89.25
DL:CNN	81.25	80.24	80.65
NB-LSTM	91.25	92.54	92.5
GA	80.21	81.25	80.75

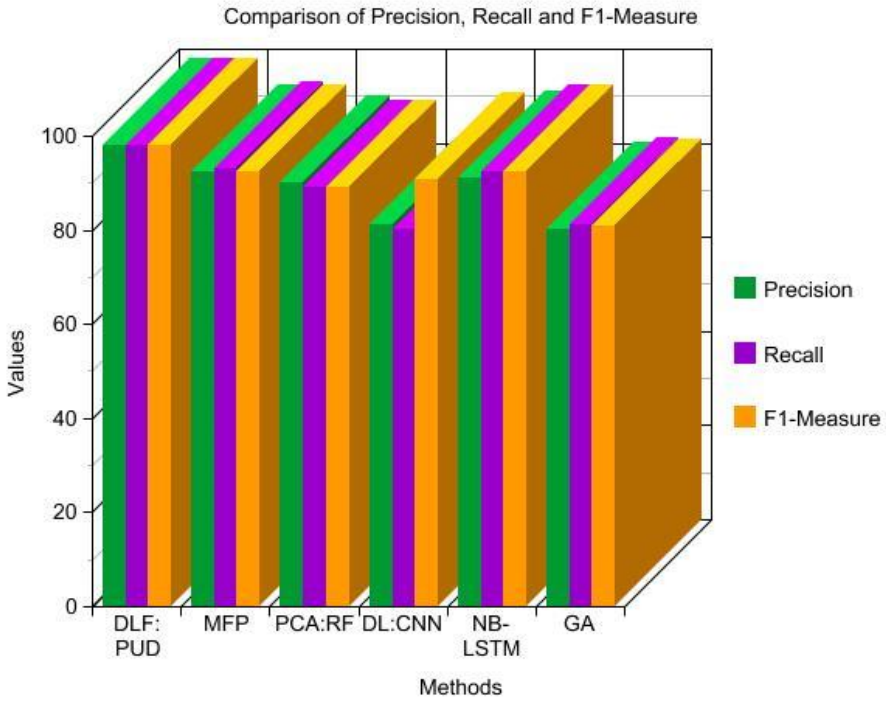

Fig. 11. Precision, F1, and Recall Comparison

Table 6.2 presents comparative data for performance metrics including Precision, Recall, and F1-Measure, as depicted graphically (see Fig. 11). The findings show that the suggested approach outperforms current approaches.

i. Accuracy

Dividing the total number of true occurrences by the total number of cases to get the overall accuracy value.

$$Accuracy := \frac{True\ Positive + True\ Negative}{True\ Positive + True\ Negative + False\ Positive + False\ Negative} \quad (8)$$

Table 6.3 presents the accuracy comparison statistics, which is graphically represented (see Fig. 12). It is observed that compared to the other approaches, the suggested method TFC: LSTM is more accurate.

Table 6.3. Accuracy Comparison

METHODS	Accuracy
DLF:PUD	98.13
MFP	92.15
PCA:RF	89.61
DL:CNN	80.12
NB-LSTM	92.50
GA	80.79

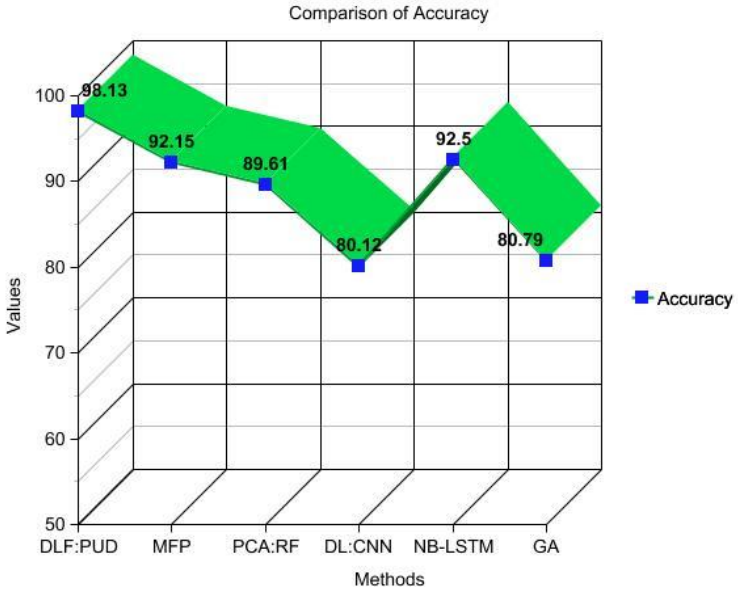

Fig. 12. Accuracy Curve

6. Conclusion

Phishing websites pose a significant cybersecurity threat that demands urgent attention from researchers. Despite numerous conventional methods proposed to address this issue, they often suffer from performance limitations, particularly in execution time due to the additional work involved in choosing features. To successfully identify phishing URLs even in resource-constrained contexts, this study develops a Deep Neural Network (DNN) model. The suggested method replaces the conventional word-level embedding with character-level embedding. Experimental evaluation demonstrated its efficiency, achieving a record-high accuracy of 98.13%. Continued assessment of the character-level embedding revealed a 30% reduction in execution time compared to traditional methods employing multiple word embedding's. Even in settings with limited resources, the outcomes were encouraging. The suggested model's future developments will concentrate on using deep learning to identify phishing websites based on online content.

References

1. Humayun, M., Niazi, M., Jhanjhi, N. et al. Cyber Security Threats and Vulnerabilities: A Systematic Mapping Study. Arab J Sci Eng 45, 3171–3189 (2020)
2. L. Liu, O. De Vel, Q. Han, J. Zhang and Y. Xiang, "Detecting and Preventing Cyber Insider Threats: A Survey," in IEEE Communications Surveys & Tutorials, vol. 20, no. 2, pp. 1397-1417, Secondquarter 2018,
3. https://www.fbi.gov/investigate/cyber
4. Jain A.K., Gupta B.B. (2018) PHISH-SAFE: URL Features-Based Phishing Detection System Using Machine Learning. In: Bokhari M., Agrawal N., Saini D. (eds) Cyber Security. Advances in Intelligent Systems and Computing, vol 729. Springer, Singapore
5. El Aassal, S. Baki, A. Das and R. M. Verma, "An In-Depth Benchmarking and Evaluation of Phishing Detection Research for Security Needs," in IEEE Access, vol. 8, pp. 22170-22192, 2020
6. Khonji, Mahmoud & Iraqi, Youssef & Jones, Andy. (2013). Phishing Detection: A Literature Survey. IEEE Communications Surveys &amp Tutorials. PP. 1-31. 10.1109/SURV.2013.032213.00009.
7. A.A. Orunsolu, A.S. Sodiya, A.T. Akinwale, A predictive model for phishing detection, Journal of King Saud University - Computer and Information Sciences, 2019
8. P. Yang, G. Zhao and P. Zeng, "Phishing Website Detection Based on Multidimensional Features Driven by Deep Learning," in IEEE Access, vol. 7, pp. 15196-15209, 2019
9. Phishing Attack Trends Re-Port-1Q, May 2018, [online] Available: https://apwg.org/resources/apwg-reports/.
10. Y. Ahmad, M. Selvakumar, A. Mohammed and A.-S. Samer, "TrustQR: A new technique for the detection of phishing attacks on QR code", Adv. Sci. Lett., vol. 22, pp. 2905-2909, Oct. 2016
11. P. Yang, G. Zhao and P. Zeng, "Phishing Website Detection Based on Multidimensional Features Driven by Deep Learning," in IEEE Access, vol. 7, pp. 15196-15209, 2019
12. Rao, R.S., Pais, A.R. Detection of phishing websites using an efficient feature-based machine learning framework. Neural Comput & Applic 31, 3851–3873 (2019)
13. Surya Srikar Sirigineedi, Jayesh Soni, and Himanshu Upadhyay. 2020. Learning-based models to detect runtime phishing activities using URLs. In Proceedings of the 2020 the 4th International Conference on Compute and Data Analysis (ICCDA 2020). Association for Computing Machinery, New York, NY, USA, 102–106
14. S. Y. Yerima and M. K. Alzaylaee, "High Accuracy Phishing Detection Based on Convolutional Neural Networks," 2020 3rd International Conference on Computer Applications & Information Security (ICCAIS), Riyadh, Saudi Arabia, 2020
15. Somesha, M., Pais, A.R., Rao, R.S. et al. Efficient deep learning techniques for the detection of phishing websites. Sadhana 45, 165 (2020)
16. Feng, F., Zhou, Q., Shen, Z. et al. The application of a novel neural network in the detection of phishing websites. J Ambient Intell Human Comput (2018)
17. W. Ali and A. A. Ahmed, "Hybrid intelligent phishing website prediction using deep neural networks with genetic algorithm-based feature selection and weighting," in IET Information Security, vol. 13, no. 6, pp. 659-669, 11 2019
18. Rao, R.S., Vaishnavi, T. & Pais, A.R. CatchPhish: detection of phishing websites by inspecting URLs. J Ambient Intell Human Comput 11, 813–825 (2020)

Identification of Factors Affecting the Overrun of Costs in Rural Road Projects: A Study Based on Sri Lanka

SWSB Dasanayaka[1], HATN Wijewardhana[2], LB Abraham[1]

Economic Section[1], School of Business, PNGUoT ,LAE, PNG
Department of Management of Technology[2]
Faculty of Business, University of Moratuwa, Sri Lanka

sarath.dasanayaka@pnguot.ac.pg, thanukanw@yahoo.com, lulu.abraham@pnguot.ac.pg

Abstract: This study focused on identifying the main factors affecting cost overruns in rural road projects and ascertaining their various economic and social implications from policy perspectives. In addition to the secondary data, a structured questionnaire was used to collect primary data from the 30 senior engineers, and interviews were carried out with many stakeholders involved in these rural road development initiatives in Sri Lanka under the iROAD project. Multiple regression, correlation analysis, and rank agreement factor methods were used to identify and check the significance and ranking of the main factors affecting phases of contract procurement and the project implementation for cost overruns in rural road development. This study found positive relationships between the awarded contract value, the engineer's estimates, and the cost of km length, and altogether 43 factors were identified and ranked by looking at their importance under the five categories: technical, economic and financial, political and regulatory management, project resources, and project implementation environment. The methodology used and the policies derived from this study can be applied to other similar projects to ascertain the factors affecting cost overruns in rural road projects and to find policy recommendations to minimize this problem in any country, specifically for South Pacific countries, including Papua New Guinea.

Keywords: Cost Overrun, Rural Roads, Project Management, Cost Estimation, Economic Development, Sri Lanka.

1. Introduction

Sri Lanka owns a very well-spread-out road network of about 119,000 km, and the current road density of Sri Lanka is 1.7 km of roads per square kilometer, a very high number when compared to its regional peers. While the road network is enough to provide accessibility to the country's entire population across the urban centers and provinces, the rural road network is not in a good motorable condition. Since about 70% of Sri Lanka's population lives in rural and peri-urban areas, the road network needs to be developed to travel within less time with efficiency. Several regional road network development projects were proposed with the view of enhancing regional connectivity and efficiency of the transport system, which will, in turn, help people to save time for productive activities [1]. The integrated road investment program was established in 2014, thereby increasing the rural population's involvement in national economic and social development. First, this integrated road investment program (iROAD - Phase I) will improve around 3000 km of rural roads in the Southern, Sabaragamuwa, Central, North Central, and North-Western Provinces and Kalutara district through 42 civil works contracts. Under the second integrated program, 3,400 kilometers (km) of rural access roads and 340 km of national roads in Eastern, Northern, Uva, and Western Provinces will be rehabilitated and improved. Some packages are already commenced, and some are still in the pre-bidding stages. Asian Development Bank (ADB) funds this project through the Multi-Tranche Financing Facility. Under the iROAD phase I, a USD 800 million loan is allocated in 6 tranches, and the Sri Lankan government contributes over 106 USD million worth of funds, and altogether 906 USD million invested in these rural roads from 2014 to 2020. The main target is to achieve project goals within the estimated budget to ensure sufficient funds are available for the completion of the whole project.

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1.1 Research Questions

1. Why do the estimated costs of the projects increase during the contract period?
2. What are the factors that affect the cost overrun in rural road projects?
3. How can the cost overrun of rural road development projects affect the economy, and what is the impact on the contractors' business involved in the contract?
4. What are the reasons behind the termination of several packages and disputes between parties after cost overruns?
5. What are the policies and strategies to overcome or control this cost overrun situation?

1.2 Research Objectives

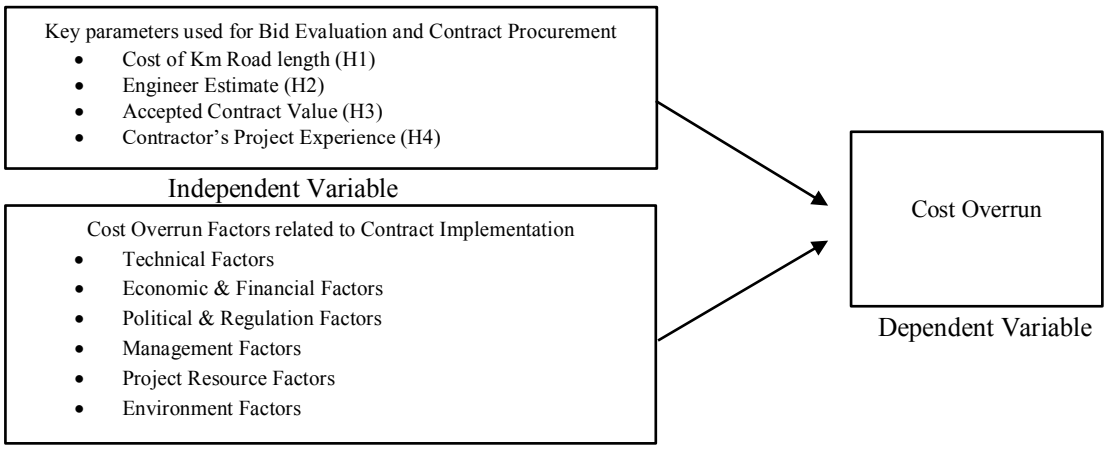
1. Identify the relationship between the cost overrun and the key parameters used in contract procurement and describe the current situation of cost overrun in rural road rehabilitation projects in Sri Lanka.
2. Identify the main factors causing cost overruns during the implementation of rural road projects in Sri Lanka.
3. Ascertain the impact of the cost overrun of rural road projects on the Sri Lankan economy and society.
4. To recommend policies and strategies to overcome the cost overrun of rural road projects to minimize economic loss to Sri Lanka.

2. Conceptual Framework and Methodology

2.1 Conceptual Framework of the Study

The development of the conceptual framework aimed to derive scientifically proven research hypotheses, and it facilitates the development of the operationalization table with all indicators and other relevant details. All these are developed based on the extensive surveyed of literature [2, 3, 4, 5, 6, 7, 8]. The main objective of the development of the conceptual framework is to show how the project's cost overrun (dependent variable) is influenced by the independent variables. The dependent variable is the cost to completion of the packages (possibility of cost overrun), which is hypothesized to be explained by the key parameters used for selecting bidders to the contracts, namely, cost of kilometer road length, engineer estimation, contractor's project experience, and accepted contract value of each package.
Figure 1 shows the conceptual framework, which illustrates the relationship of the dependent variable to the key parameters used to select bidders and other relevant factors such as technical, economic, and financial, political and regulatory, management, project resources, and the environment under the construction phase.

Fig.1 Conceptual Framework



Moreover, the study focused only on the effectiveness of the independent variable on the dependent variable. There are no measurements for the relationship between independent variables (key parameters in bid evaluation and contract procurement) and independent variables (contract implementation). This kind of mixed method was chosen to integrate quantitative data gathered directly from rural road projects and data collected through a structured questionnaire survey technique. This survey was conducted based on 43 factors identified from the literature review and grouped into six groups of factors according to their similarities in nature. This kind of mixed method is followed when there is a need to gather information from multiple perspectives of the research subject.

2.2 The Hypothesis of the Study

Hypotheses were developed to identify the impact of independent variables selected from key parameters in the evaluation criteria for selecting bidders to the contracts, namely, cost of kilometer road length, engineer estimation, contractor's project experience, and accepted contract value of each package. The null and alternative hypotheses are set as follows:

H_0 - There is no impact of independent variables on cost to completion (cost overrun).

H_1 - There is a positive relationship between the cost of kilometer road length and cost to completion (cost overrun).

H_2 - There is a positive relationship between engineer estimation and cost to completion (cost overrun).

H_3 - There is a positive relationship between accepted contract value and cost to completion (cost overrun). H_4 - There is a positive relationship between the contractor's project experience and cost to completion (cost overrun).

The impact and influence of other selected variables on the cost overrun of the rural road project in Sri Lanka were identified by including and distributing the questionnaire among engineers of i-ROAD program. The following operationalization table is prepared based on the rigorous literature survey and conceptual framework of the study to derive hypotheses.

Table. 1: Operationalization of Research Variables

Variable	Type of Variable	Indicator	Measurement	Type of Analysis
Cost of Km road length	Independent	The level of cost incurred for the km of roads.	Actual Value	Correlation
Accepted contract value	Independent	The amount of expected disbursement for a project.	Actual Value	Correlation /Regression
Contractor's project experience	Independent	The capability of the Contractor in similar kinds of projects.	Actual Value	Correlation /Regression
Engineer estimate	Independent	The level of accuracy of estimation at tendering.	Actual Value	Correlation /Regression
Technical factors	Independent	The level of impact by the technical matters.	Five-point Likert Scale	Descriptive /Rank agreement factor
Economic and financial factors	Independent	The level of impact by economic and financial matters.	Five-point Likert Scale	Descriptive /Rank agreement factor

Political and regulation factors	Independent	The level of impact by political and regulatory actions.	Five-point Likert Scale	Descriptive/Rank agreement factor
Management factors	Independent	The level of impact by managerial actions.	Five-point Likert Scale	Descriptive/Rank agreement factor
Environmental factors	Independent	The level of the impact by environmental factors.	Five-point Likert Scale	Descriptive/Rank agreement factor
Project resource factors	Independent	The level of impact by assigning project resources.	Five-point Likert Scale	Descriptive/Rank agreement factor
Cost to Completion	Dependent	Successfully completion of the project within the budget.	Scale	Correlation/Regression

Source: Authors

Collection of data through the various sources was conducted to fulfill four objectives in this study and to develop an extensive inventory of the research problems in the study; a detailed literature review was carried out from textbooks, journals, government publications, and publications by funding agencies and online resources. Primary and secondary data available in the iROAD Project are collected through the interview and directly from the database of iROAD. It is necessary to obtain an adequate data sample size that represents the target population very well. At least the sample size should be 10 % of the target population to get an accurate result [9]. It is challenging task in finding the cost overrun data for the following reasons.

a) Time consumed to generate cost overrun data (Calculation of cost to completion for initial BOQ).
b) There is no proper evidence for increasing the initial contact value until it has exceeded.
c) The officers involved in the cost estimation are hiding data on cost overrun due to government regulation, and check and balances.

On the other hand, this project is the first-ever rural road rehabilitation project implemented under the Road Development Authority (RDA) with foreign funds. The experience of cost overrun in a rural road project for RDA a new thing. The data were collected based on the availability within the project to identify the impact of cost overrun on a rural road project. To identify the current cost overrun situation, the amount of money needed to complete each project (cost to completion) will be analyzed with independent variables selected from key parameters in bid evaluation and contract procurement for determining the bidder for the contract packages. For that purpose, all the values for variables have been obtained and recorded in line with concerning contract packages. The contract packages are selected as the population, and its size is 42, and it is not a large size when it is compared to the target population in other studies. The engineers working under the integrated road investment program were selected as the data sample for the data collection to identify the reasons for cost overrun of rural road projects in Sri Lanka. According to [9], “the target population is the entire group a researcher is interested in; the group about which the researcher wishes to conclude.” The sample should be selected from at least 10% of the target population. The number of engineers working for the integrated road investment program is around 300 and 30 sample sizes were selected for the data collection with the representation of all the provinces and every group of experts for better overall results.

During the data collection period, most of the projects are completed in iROAD phase I and few contactors were demobilized. Therefore, finding participants was somewhat difficult, and the participants were selected according to availability and willingness to take part in this survey. This method is called convenience sampling, which is included in the non-probability (non-random) sampling method. The selected data collecting methods are observations and direct extracting from the document maintained in the Integrated Investment Program Offices. This method helps to collect data for analysis of relationship of key parameters in bid evaluation and contract procurement and cost overrun in the rural road projects. The analyzed results were used to identify the current situation of cost overrun in the project. This selection is the requirement to improve the accuracy of the result by using actual values obtained during the project procurement and the project implementation.

The current cost overrun situation is analyzed with respect to the independent variable selected from the contract procurement stage. The primary purpose of this analysis is to identify how much these measurable key parameters used for selecting bidder to the contract (contract procurement) impacting the cost overrun of rural road development projects. Multiple Linear Regression (MLR) model selected the following as independent variables; contractor's project experience (number of similar projects completed by the qualified bidder within the last ten years), km cost (award price divided by the total length of the project, Rs. Million/ km), accepted contract value (awarded value of the selected bidder at time of award), engineer estimate (Government estimate is the estimated total project value by the implementing agency, mainly RDA).

The primary data for 42 Contracts were collected and checked the applicability of these data for MLR estimation. The structured questionnaire was distributed and analyzed to find the factors which are mostly affected by cost overrun of rural road projects during the implementation stage. These factors were selected through the past literature and tabulated in a questionnaire form. Participants are requested to give weighed value for those factors according to the impact and frequency of happening. Then collected data in the questionnaire was analyzed using the Importance Index (I.I), Frequency Index (F.I) and Severity Index (S.I). The Severity Index formula (S.I) ranks factors of cost overruns by calculating the weighted indexes of the importance and frequency of cost overrun factors [8]. This methodology clearly mentions in appendix.

3. Data Analysis and Interpretation

This section analyzes and interpret results of statistical analysis and based on that findings and policy implications derived in substantive manner. One of the primary objective of this analysis is to identify the impact of variation of independent variables used for selecting bidder to the contract (procurement stage) for the cost overrun of rural road development projects**.** Primary data were directly collected from the Project Management Unit. Accordingly, 42 data set observations belong to 6 provinces relating to award prices (Accepted contract price), Government estimate (engineer estimation), and cost to completion, as listed in Table 2 below.

Table. 2 - Cost to Completion of Rural Road Packages

No	Package No.	Engineer Estimation (LKR Mn)	Accepted Contract Value (LKR Mn)	Km Cost (LKR Mn)	Cost to Completion (LKR Mn)	Predicted % of cost overrun (+/-)
1	G1	1,231.05	1,458.06	19.06	1550.06	6.31
2	G2	1,300.45	1,483.14	19.70	1,637.18	10.39
3	G3	1,459.50	1,733.44	19.94	1,909.32	10.15
4	H1	1,436.05	1,583.59	21.40	1,731.75	9.36
5	H2	1,070.88	1,210.33	18.46	1,430.47	18.19
6	H3	856.01	1,052.14	20.43	1,203.10	14.35

7	M1	2,132.12	2,315.35	21.86	2,735.92	18.16
8	M2	1,572.64	1,803.30	22.73	1,553.40	(13.86)
9	M3	1,078.41	1,207.60	20.19	1,188.07	(1.62)
10	KA1	1,390.40	1,756.28	18.25	1,727.77	(1.62)
11	KA2	1,460.00	1,923.67	20.71	1,777.44	(7.60)
12	KA3	1,627.70	2,096.87	22.01	1,950.32	(6.99)
13	MA1	1,260.14	1,622.37	16.65	1788.37	10.23
14	MA2	1,057.11	1,248.83	18.55	1,248.83	(0.00)
15	MA3	1,197.51	1,407.72	19.54	1,366.59	(2.92)
16	NE1	1,477.01	2,297.89	19.28	2,581.75	12.35
17	NE2	822.91	1,241.72	21.37	1,241.27	(0.04)
18	NE3	1,426.07	2,069.69	21.97	2,495.58	20.58
19	KE1	1,639.21	1,972.53	21.93	2002.35	1.51
20	KE2	1,431.01	1,817.00	18.29	2,102.50	15.71
21	KE3	1,236.18	1,632.46	19.27	1,855.51	13.66
22	R1	1,708.50	2,022.05	20.60	2,356.33	16.53
23	R2	1,782.03	2,383.99	19.43	2,465.37	3.41
24	R3	1,581.95	2,021.00	19.69	2,370.57	17.30
25	AP1	1,733.60	1,656.92	20.37	1,674.27	1.05
26	AP2	2,041.05	1,824.18	26.67	1,653.44	(9.36)
27	AP3	1,685.25	1,492.77	20.43	1,715.20	14.90
28	AP4	1,889.54	1,635.13	21.19	1,671.06	2.20
29	PO1	1,161.21	1,158.53	22.60	1,028.41	(11.23)
30	PO2	1,542.53	1,483.69	21.19	1,465.64	(1.22)
31	PO3	1,265.32	1,249.34	26.13	1,108.16	(11.30)
32	KU1	1,885.98	2,005.79	22.77	2,286.60	14.00
33	KU2	2,098.57	2,124.17	21.56	2,421.55	14.00
34	KU3	2,097.46	1,976.72	23.32	1989.56	0.65
35	KU4	2,110.87	2,091.17	22.22	2100.57	0.45
36	KU5	2,053.10	1,996.56	20.56	2000.26	0.19
37	PU1	1,677.57	1,706.32	18.15	1,688.80	(1.03)
38	PU2	1,483.27	1,463.92	19.93	1546.33	5.63
39	PU3	1,236.21	1,210.36	25.50	1321.31	9.17
40	KL1	1,931.21	1,912.47	20.54	2,107.57	10.20
41	KL2	1,976.36	1,811.35	22.21	1950.02	7.66
42	KL3	2,074.73	1,817.75	22.07	1889.23	4.48

Source: Progress report iROAD program, 2020

The multiple regression model is used to analyze the variation of a single variable (Dependent variable) based on the value of two or more variables. The variable used in this study can be categorized as follows. Independent variables are contractor's project experience (Number of similar projects completed by the qualified bidder within the last ten years), Km cost (Award price divided by the total length of the project; Rs. Million/ km), Accepted contract value; awarded value (Value of the selected bidder at time of award) and engineer estimate (Government estimate). Dependent variable is cost to completion of each package at the project completion.

The primary data for 42 contracts were collected and tabulated and checked the applicability of these data for Multiple Leaner Regression (MLR) with the above four assumptions. Accordingly, as per the result shown in Table 3 and 4, the data was analyzed in SPSS software to determine whether the above assumptions are correct for running the Multiple Leaner Regression Model. The simple correlation, tolerance value, variance increase factor (VIF), and condition index (CI) were examined in order to find the possibility of multiple relations between independent variables and the findings as shown in Table 3 and Table 4.

Table. 3 - Multiple Relation Coefficients

When the simple correlations are examined, if the correlation coefficients are higher than the value of 0.8

	B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
Constant	306451054.84	286329889.77		1.070	.291					
Eng. Estimate	-.051	.127	-.043	-.399	.692	.646	-.065	-.023	.280	3.568
Project. Exp.	867595.821	4253592.756	.013	.204	.839	-.095	.034	.012	.734	1.362
Km Cost	-22.345	12.992	-.109	-1.720	.094	-.098	-.272	-.097	.801	1.248
Contr. Value	1.191	.122	.966	9.764	.000	.931	.849	.552	.326	3.065

Dependent Variable: Cost to Completion

or Variance Increase Factor (VIF) is equal or higher than 10, there is a multiple relation between variables. According to the results obtained for coefficient of variable in Table 4 all the values are less than 0.8 and Variance Increase factor values of all variables are less than 10. Therefore, in this case, there are no multiple relations between variables.

Table. 4 - Multiple Relation Condition Index Value

Model	Factor	Eigenvalue	Condition Index	Variance Proportions				
				Constant	Engineer Estimate	Project Experience	Km Cost	Contract Value
1	1	4.452	1.000	.00	.00	.01	.00	.00
	2	.497	2.993	.00	.00	.73	.00	.00
	3	.038	10.851	.04	.11	.00	.05	.07
	4	.010	21.263	.05	.55	.23	.09	.54
	5	.003	30.332	.91	.34	.03	.85	.39

Dependent Variable: Cost to Completion

If case Condition Index (CI) is higher than 30, it is regarded that there is multiple relations between variables [10]. Obviously, the CI values less than 30, and there are no multiple relations between variables. The data set used for Multiple Linear Regression satisfied the defined assumptions and accordingly, regression analysis was done. The scatter diagrams of the dependent variable - estimated cost to completion at the end of the project, against the independent variables were developed to understand the relationship of dependent variable with respect to changing the independent variable. The scatter diagrams show the correlation coefficient of accepted contract value and engineer estimates are as 0.931 and 0.646 which consequently says that cost overrun positively correlates with these two variables. Accordingly, if the contract value and the engineer estimate are high, there is a high possibility of increasing project cost. Since

km cost and project experience have -0.098 and -0.095 correlation coefficient values, respectively, cost overrun has a negative correlation with these two variables. Therefore, if the project has a higher value for km cost and the contractor has high project experience in large projects, increasing project cost is low. Hence, it was proved that the null hypothesis could not be accepted. The conclusion of the validity of the alternative hypothesis is as follows,

H_1 - There is a **positive relationship** between the Cost of Kilometer road length and Cost to Completion (Cost Overrun)
According to the Multiple Correlation factor, the coefficient has a negative value. Accordingly, the independent variable has a negative impact. If the project has a proper suitable value for per Km cost, Cost Overrun will not happen. Therefore, this hypothesis cannot be accepted.

H_2 - There is a **positive relationship** between Engineer Estimation and Cost to Completion (Cost Overrun). According to the Multiple Correlation factor, the coefficient has a positive value and accordingly, the independent variable has a positive impact. Therefore, this hypothesis can be accepted.

H_3 - There is a **positive relationship** between Accepted contract value and Cost to Completion (Cost Overrun). The Correlation coefficient for the Accepted Contract value is 0.931 and a positive value. As described above, the Accepted Contract value has a positive relationship to the Cost to Completion and increasing of the contract value will influence the increase of Cost Overrun. This explains that the alternative hypothesis can be accepted.

H_4 - There is a **positive relationship** between the Contractor's project experience and Cost to Completion (Cost Overrun). The Correlation coefficient for the Contractor's Project Experiences value is -0.095 and it is a negative value. As described above, the Contractor's Project Experiences have a positive relationship to the Cost to Completion and have the possibility of decreasing Cost Overrun when the Contractor has the high project experience. Then it can confirm the alternative hypothesis is wrong.

ANOVA statistic test results were used to find the reliability of predicting the dependent variable and the relatively most important independent variable that could influence the dependent variable. Table 5 shows the Multiple Linear Regression analysis results related to the cost to completion of 42 rural road packages.

Table. 5 - Multiple Linear Regression Analysis Results Related to Cost to Completion

Variable	B	Beta	t	Sig.	Corr. Partial	Corr. Part
(Constant)	306451054.8		1.070	0.291		
Contractor's Project Experience	867595.821	0.013	0.204	0.839	0.034	0.012
Engineer Estimate	-0.051	-0.043	-0.399	0.692	-0.065	-0.023
Km Cost	-22.345	-0.109	-1.720	0.094	-0.272	-0.097
Contract Value	1.191	0.966	9.764	0.000	0.849	0.552
R = 0.939	R^2 = 0.882	Adjusted R^2 = 0.869		$F_{(4,42)}$ = 68.974		P = 0.00

According to the table 4.4, P-Value is very small ($p=0 < 0.05$) and less than 0.05. That means the null hypothesis can be accepted. The regression results explain that the independent variables reliably predict the dependent variable. Therefore, contractor's project experience, engineer estimate, Km cost and accepted contract value, can be used to predict the possibility of happening of cost overrun reliably. In another way, by looking at the R-value and R^2 value, the reliability of the prediction of the dependent variable can be justified. R is the 'multiple correlation coefficient and R can be used to measure the quality

of the prediction of the dependent variable. In an examination of table 4.6, the degree of predicting the dependent variable was found R = 0.939. The model's degree of explaining the variance in the dependent variable was $R^2 = 0.882$ and it is also called as the coefficient of determination. If the value of R^2 is high and it says that there is a strong linear relationship and if the R^2 value is small, it is called a weak linear relationship. By looking above two coefficient values, R^2 is 88.2% of independent variables that predict the dependent variable. It may be said that there is a strong linear relationship and the developed model predicts the dependent variable very well. Since it was found that the relationship of the independent variable to the dependent variable next step is to determine the level of effect of the independent variable. The absolute value of Beta (β) indicates the importance of the independent variable for changing the dependent variable. The variable with the highest beta value is the relatively most important independent variable in the study. On examining the contribution made by the independent variable in the model in Table 4.4, it was found that in the current situation, awarded contract value (β = 0.966) is the most important independent variable to contribute to changing the dependent variable (cost to completion). Awarded contract value was followed by Km cost, Engineer Estimation, and Contractor's project experience. The result of regression analysis shows that the beta value of the engineer estimation and contractor's project experience are 0.043 and 0.013, respectively. The absolute value shown in the result is small and explains engineer estimation and contractor's project experience have a small contribution to the model.

The questionnaire survey results describe and identify the major causes of Cost Overrun in rural road projects during the project implementation. The weighted value for effectiveness of the factor to the Cost overrun (1 – not significant, 5 – very Significant) and the weighted value for the frequency of happening of the factor (1 – not frequently, 5 – most frequently) for each cost Overrun factor are separately extracted from the response.

The total number of responses (N) in the questionnaire survey was 30, and the analysis of the questionnaire was done by using the Importance Index (I.I), the frequency Index (F.I), and the Severity Index formula (S.I), then rank the Cost Overrun factors by calculating the weighted indexes of the importance and frequency of cost overrun factors [8].

4. Classification of Cost Overrun factors

The Cost Overrun factors are grouped into several subgroups according to their similarity to find which has the higher impact on the research problems. The main six groups are namely; technical, financial and economic, management, project resource, political and regulation, and Environment as mentioned in Table 6.

Table. 6 - Groups for Factors causing Cost Overrun from previous studies

Group	Sub Group	Description	Factors (out of 43 factors)
Technical	Design	Tendering & Construction design drawing related factors	1,5,11,14,20,21,33
	Construction	Poor technical performance, changers or discrepancies that may occur during the construction period and delay in handing over the site related factors	3,14,31,37,41
	Scope	Scope, additional work and variation orders related factors	8,22,34
	Site	Site condition and site organization-related factors	7,22,39
	Experience	Decision-making in the tendering process, experience and procurement-related factors.	2,3,13
Economic and Financial	Financial Contracts	Donor policy in bidding, experience in contracts and contracts management-related factors.	28,32
	Financial Policy	Investment decisions, funding allocation and Methods of financing and payments for completed works related factors.	9,15,28,37
	Internal	Contractor management, organizational variables, Project characteristics and Client characteristics related factors	4,10,19,28

	External	Fluctuation in the money exchange rate, domination of the construction industry by foreign firms and aids, government policies (laws and regulations) and economic Instability related factors.	15,40
Political and regulation	Political situation	Unsupportive governmental policies and Governmental control and regulations related factors	15,38
Management	Estimation Process	Inaccurate or poor estimation of Original Cost, Incorrect/inappropriate methods of cost estimation and Estimating process risk	2,12,16,30,35
	Planning	Inadequate project analysis, Improper planning and scheduling and Poor planning	2,6,13
	Monitoring and Controlling	Poor site management, Poor cost control, Complexity of organizational structure of a project, absence of construction cost data and Fraudulent practices and kickbacks	9,10,17,18
	Communication	Poor coordination among the project participants and Lack of leadership knowledge	13,23,38,42,43
Project Resources	Labour	Shortage of labor and Unqualified labor	14,26
	Material	Fluctuations in the cost of building materials, The shortage in construction materials in markets and Materials problem	4,8,24,25
	Equipment	High cost of machinery and Lack of equipment	
Environment	Location	Location-related factors	43
	Weather Condition	Unpredictable weather conditions and Unsuitable climate to work	29

Source: Structured Questionnaire Survey

5. Results and Analysis of the Study

Here, 43 Cost overrun factors were included in the spread sheet and the ranking was tabulated as following Table. 7.

Table. 7 - Ranking of Cost Overrun Factors

Rank	S.No	Cost Overrun Factor	I.I	F.I	S.I
1	22	Additional Works and Variations	0.873	0.767	0.670
2	12	Inaccurate Time and Cost estimates	0.847	0.707	0.598
3	24	Fluctuation of price of material	0.780	0.733	0.572
4	32	Contractual Claims Such as extension of time with cost claims	0.800	0.707	0.565
5	30	Change of estimated quantity	0.780	0.700	0.546
6	2	Unrealistic Contract duration	0.767	0.660	0.506
7	16	Inaccurate Site Investigation	0.793	0.613	0.487
8	1	Poor design and delays in Design	0.773	0.607	0.469
9	20	Incomplete and Inaccurate Design at the time of tender	0.753	0.607	0.457

10	39	Unforeseen Ground Conditions	0.780	0.553	0.432
11	13	Delay of Decision making	0.733	0.587	0.430
12	42	Disputes	0.720	0.587	0.422
13	6	Inadequate planning and scheduling	0.727	0.573	0.417
14	7	Poor Site Management and Supervision	0.720	0.573	0.413
15	29	Effect of Weather	0.700	0.580	0.406
16	35	Omission and the errors in the BOQ	0.707	0.553	0.391
17	43	Utility Shifting	0.687	0.547	0.375
18	27	Bureaucracy in tendering method	0.667	0.553	0.369
19	25	Shortage of Material	0.647	0.560	0.362
20	9	Cash flow and financial difficulties faced by Contractor	0.633	0.567	0.359
21	18	Poor Project Management of the Contractor	0.680	0.527	0.358
22	14	Reworks	0.707	0.500	0.353
23	5	Delay preparation and approval of Drawings	0.647	0.540	0.349
24	21	Mistake and errors of Completed Design Drawings	0.687	0.507	0.348
25	11	Frequent Design Change	0.720	0.460	0.331
26	4	Late delivery of materials and equipment	0.667	0.493	0.329
27	34	Change in the scope of the project	0.667	0.487	0.324
28	10	Poor financial Control on site	0.640	0.507	0.324
29	41	Delaying Handing over site to contractor	0.633	0.500	0.317
30	31	Delay in Inspection and approvals	0.613	0.507	0.311
31	17	Inadequate monitoring and Control	0.633	0.487	0.308
32	40	High inflation rate	0.607	0.500	0.303
33	15	Finance Difficulties of Employer	0.627	0.480	0.301
34	19	Poor Contract Management of the Employer	0.607	0.493	0.299
35	3	Lack of experience	0.587	0.460	0.270
36	33	Impractical and Complicated Design	0.600	0.413	0.248
37	23	Slow information flow between parties	0.520	0.467	0.243
38	26	High Cost of Labour	0.553	0.433	0.240
39	28	Number of Construction going on same time	0.520	0.460	0.239
40	37	Delay payment to supplier / subcontractor	0.493	0.453	0.224
41	8	Change in material specification	0.500	0.380	0.190
42	38	Employer interference	0.453	0.413	0.187
43	36	Obsolete or unsuitable construction methods	0.500	0.353	0.177

Source: Structured Questionnaire Survey

The result of the analysis of questionnaire survey data by frequency index method presents in Table 8. It shows additional work and variation as the number one rank for cost overrun factor in rural road projects and followed by inaccurate time and cost estimates, fluctuation of the price of the material. Contractual claims such as extension of time with cost claims, Change of estimated quantity, unrealistic contract duration, inaccurate site investigation, poor design and delays in design, incomplete and inaccurate design at the time of tender and unforeseen ground conditions respectively.

Table. 8 - Result of Classification of Cost Overrun Factors

Group	Sub Group	Average S.I.	Rank	Group Rank
Technical	Design	0.365	9	3
	Construction	0.286	16	
	Scope	0.395	6	
	Site	0.505	2	
	Experience	0.394	7	
Economic and Financial	Financial Contracts	0.467	3	4
	Financial Policy	0.281	17	

	Internal	0.298	14	
	External	0.302	13	
Political and regulation	Political situation	0.244	18	6
Management	Estimation Process	0.506	1	1
	Planning	0.451	4	
	Monitoring and Controlling	0.337	11	
	Communication	0.331	12	
Project Resources	Labour	0.297	15	5
	Material	0.363	10	
	Equipment	0.000	19	
Environment	Location	0.375	8	2
	Weather Condition	0.406	5	

Source: Structured Questionnaire Survey

The funding agency (ADB) only allows a 15% increment of total budget allocated for each contract package, which provides a cost overrun margin for the project implementation. This study proved that the major first five factors of cost overrun are additional works and variations, inaccurate time and cost estimates, fluctuation of price of material, contractual claims such as extension of time with cost claims, and change of estimated quantity. In practical situations, most of the time above five factors caused a big impact on the total value of every contract [11]. A separate analysis carried out for Anuradhapura district but due to space problem that aspects did not include in this paper.

6. Ascertain the Impact of Cost Overrun of Rural Road Projects

This section investigates the impacts of cost overrun on rural road projects in Sri Lanka under the following headings.

6.1 Impacts to the project and stakeholders of the project

When participants were asked to explain the potential impact of Cost Overruns on rural road projects in Sri Lanka and how it would affect funding, debt resettlement, contractor activism and the country's economy, they pointed out that in rural road projects, if the cost exceeds unable to control effectively, it can lead to some of the consequences listed below.

i. Insufficient funds were available at the end of the project.

Experts have identified that the high cost of these projects is one of the reasons why there is not enough money at the end of the project. However, estimates have been prepared at the tender stage, including 20% uncertainty for physical and price variability in contract execution.
When the cost is exceeded, the estimated budget for the completion of the project also increases, but the existing fund remains the same as previously allocated. Further increase in project cost may result in insufficient funding at the end of the project, leading to failure to meet project goals and objectives defined at the outset.

ii. This may result in insufficient allocations.

At the beginning of the year, the Government of Sri Lanka allocates funds from the annual budget for the projects implemented under the Ministry of Highways. Then all the projects were allocated separate funds at the beginning of the year. Ministry of Highways has decided to put individual allocations for each road included in the projects. Since the effect of cost overrun, monthly expenditure will be increased, but financial allocation cannot normally be changed once fixed and approved in the budget. This may result in

a lack of funding for the roads and projects implemented under the Ministry of Highways. Finally, the employer may not be able to pay the monthly bills to contractors due to insufficient government financial allocations despite having a foreign fund.

iii. Contractors expected performance might experience shortcomings due to Cost Overrun. Their planned cash flow may get affected and sometimes result in implementation failures.

Contractors' performance directly depends on their cash flow. If they can achieve projected cash flow without any delay, the contractor's expected performance can also be achieved. Since the project is undergoing cost overrun, it will increase the cost to completion of the project; therefore, the required monthly cash flow will also be increased with time. That means it takes more money to complete the work scheduled to be done in the project program. High expenditure and less return will lead to the contractor's unbalance cash flow. If the contractor fails to achieve the plan cash flow and the contractor's expected performance may experience shortcomings due to the unavailability of financial capacity to complete the ongoing works [12]. Increasing required cash flow and frequent unexpected adjustments for contractor's cash flow due to Cost Overrun would sometimes result in project implementation failure.

iv. Any failure or shortcomings in achieving project targets or goals would impact the country's economy because borrowings are planned and made based on the project goals and their return.

While the project undergoes cost overrun, it would result in sort coming in to achieve the project target and goals. Project targets are mainly improving the motorable condition, reducing the travel time, and properly disbursement of the fund. According to the project's current situation, some packages were terminated and couldn't achieve project targets and goals and couldn't achieve their return with respect to the expenditure of each contract.

v. Delay in Completion of Project and curtailment of the original scope.

While the project is undergoing cost overrun, the required monthly cash flow also will be higher than the original plan with the time. That means it takes more money to complete the works scheduled to be done in the project master program. The annual turnover and working capital of many contractors are not sufficient to afford the increasing financial requirement because they depend on the line of credit to comply with financial resources as per the bidding criterion 2.3.3 of Section 3 standard bidding document [12]. Suppose the Contractor fails to provide the additional financial support to complete the project. In that case, slow progress can be observed during the latter part of the contract or under the breakeven point because they cannot make a profit for their future projects. As a result of continued slow progress, the amount of outstanding work will be increased with time and a delay in the completion of the project can happen. In many cases, the employer has decided to reduce the original scope of the contract as it is unable to provide the required additional cash flow. Pruning the original scope could have several consequences, including the loss of contractors' profits, the inability to achieve the project objectives, and the government spending the extra money to complete the incomplete scope of those projects. Therefore, this directly affects the socio-economy of the country.

vi. Terminated Contracts and Problem

- About 10% of contracts in iROAD program had to be terminated. Including one contract in the southern province, three contracts in Sabaragamuwa Province, one contract in the Central Province, five contracts in the North Western Province, and two contracts in the Kalutara District, as contractors suspended the construction works halfway without completing the full scope included in the contracts. Most of the terminated contracts are the lowest bidder and they have low rates for bill items in BOQs.
- The main reason for poor performance seems to be that their cost for construction is more than the amount they recovered through bills. That means the cost of the construction is increasing with the

time. Most of the packages were terminated due to the poor financial capability of the companies. Some investigation has found that the termination is a result of the cost overrun of the project.

- The contractors, who have completed the work, also did that by incurring substantial financial losses.

- Once the contract was terminated, preparation estimates for balance work, retendering, and the final process take 6-8 months. There is no party to maintain partially completed/uncompleted roads during that period, and roads have become unmotorable.

Excess cost is a major cause of the consequences highlighted above, and the problem of cost overruns that cause economic problems needs to be explained and answered. The participants in the interview explained how it happened and how it could be a financial problem as follows.

Participants identified that failure to execute contracts due to cost overruns would directly affect the rural economy. For example, suppose contractors have to allocate more financial resources for construction and have the less financial capacity to pay for local labor and suppliers. In that case, it is challenging to make those payments when the cost is exceeded. Delaying payment by the Contractor or Employer may result in social problems and economic problems, lowering the local peoples' living standards.

Contractors may fall into a situation of bankruptcy when limits are exceeded. A situation like this could impact the construction industry, contributing reasonably to the economic growth of the country. Another thing is that the construction will be suspended because of the termination of contracts, which may cause obstruction for the mobility of vehicles on partially completed roads. It is not only obstruction for mobility but also takes another 5 to 6 months to procure another contractor to do the balance work. Further, indirect benefits such as earning income by providing temporary accommodations, supplying food and other small businesses will be disrupted due to the uncontrollable situation described above.

7. General Discussion, Findings and Policy Recommendations

This section presents the general discussion in summary, and discusses the policies and recommendations to overcome the current situation of cost overrun in rural road projects in Sri Lanka.

- Identify the relationship between the cost overrun and the key parameters used in contract procurement and describe the current situation of cost overrun in rural road projects in Sri Lanka

The result of the regression models developed using the data collected from the database in the integrated road investment program shows cost overrun with the variation of cost of km road length, the value of engineer estimate, contract award value and contractor's project experience. The relationship between the independent variables and the dependent variable is as follows.

- Awarded contract value – Positive correlation to the cost overrun.
- Engineer estimate value – Positive correlation to the cost overrun.
- Cost of Km road length – Negative correlation to the cost overrun.
- Contractor's project experience – Negative correlation to the cost overrun.

- Awarded Contract Value

According to the scattered diagram and multiple regression analysis, the correlation coefficient of the awarded contract value is 0.931. That value indicates the awarded contract value has a strong positive correlation to the cost overrun of rural road projects in Sri Lanka. If the awarded value of a contact is high, there is a higher possibility of having a high completion cost with cost overrun.

- Engineer Estimate Value

The correlation coefficient of the engineering estimate is 0.646, which reveals that the cost overrun is positively correlated with this variable and that the engineering estimate has a moderate positive correlation to the cost overrun. This means that if the project has a high engineering estimate, there is a reasonable potential for project costs to increase. Furthermore, the estimates show some deviations from the actual values according to the observations. If the contract value is high, the possibility of happening errors is also high. That may result in high deviation and happening cost overrun.

- Cost of Km Road Length

According to the regression result, the cost of km length has a -0.098 correlation coefficient value. That means it has a weak negative or inverse correlation when two variables tend to move in opposite sides and directions from one another, such that the other variable decreases when one increases. If the cost of km road length is high, having a cost overrun is less. Compared with the contribution of Engineer estimates and the contribution of awarded contract value, the contribution of the cost of km length is significantly less for cost overrun.

- Contractor's Project Experience

The contractor's project experience has a correlation coefficient of -0.095 and the Cost Overrun is negatively correlated with this variable. This means that if the contractor has a high level of project experience in rural road projects, he is less likely to increase project costs. Because the contractor's project experience negatively correlates with cost overruns, a contractor is less likely to exceed the cost of a project with high project experience. Since the correlation coefficient value is minimal, the effect is understood to be very small.

On examining the contribution made by the independent variable in the models in Table. 5, it was found that in the current situation, awarded contract value (β=0.966) is the most important independent variable to contribute to changing dependent variable (cost to completion). It was followed by Km cost, engineer estimation, and contractor's project experience. This regression analysis in Table .5 found that the beta value of the engineer estimation and contractor's project experience are 0.043 and 0.013, respectively. That indicates engineer estimation and contractor's project experience have a small contribution to the model.

Based on multiple regression analysis, the regression equation was developed as follows,

Cost Overrun = 306,451,054.8 + 0.966 (Awarded Contract Value) – 0.109 (Km Cost) – 0.043 (Engineer Estimate) + 0.013 (Contractor's Project Experience)

- Identify the main factors causing cost overrun during the implementation of rural road projects in Sri Lanka.

The detail analysis of the questionnaire data ranking of 43 number of costs overrun factors are tabulated in Table.6. They summarized in below Table.9 based on overall index value method.

Table. 9 – The Summary of the Main Cost Overrun Factors

Rank	Cost Overrun Factor	Overall Index Value
1	Additional Works and Variations	0.670
2	Inaccurate Time and Cost estimates	0.598
3	Fluctuation of price of material	0.572
4	Contractual Claims Such as extension of time with cost claims	0.565
5	Change of estimated quantity	0.546
6	Unrealistic Contract duration	0.506
7	Inaccurate Site Investigation	0.487
8	Poor design and delays in Design	0.469
9	Incomplete and Inaccurate Design at the time of tender	0.457
10	Unforeseen Ground Conditions	0.432

Source: Structured Questionnaire Survey

This Table 9 reveals to the reader the most influencing factor for Cost Overrun is additional work and variations in rural road contracts. Inaccurate time and cost estimates are ranked as the second factor and fluctuation in price of the material is the third influencing factor of the analysis result. Other seven factors will follow, as mentioned in this Table. 9.

The factors identified as the cost overrun for rural road development projects in Sri Lanka are very much related to the errors done in the quantity calculation and design drawings done by both the employer and the contractor. As this is the first large-scale rural road development project in Sri Lanka currently in operation (iROAD project), there was not a great deal of experience, resources, and data available, and this research was completed with constraints. Furthermore, there were not many completed contracts to collect the actual data, and the data used for the research were estimated according to the current cost completion pattern. Ideally, the research should be conducted for several years and should be more focused on the actual data, not the predicted or estimated ones. Many projects were temporarily halted due to COVID-19 and the recent economic crisis. Especially many foreign-funded road projects temporarily stopped, such as iROAD in Sri Lanka. This research can be extended to other types of roads and transport infrastructure projects such as railways, seaports, air ports, and city and utility construction. This cost overrun problem is normal to all public sector projects in many countries. Especially, speed highway construction cost overruns are unbelievable in Sri Lanka and many other emerging economies, but so far not any scientific study has been undertaken on this aspect except some people's assertions and perceptions are reported by the media.

References

1. Wijekoon, B., and Attanayake, K. : Study on the cost overruns in road construction projects in Sri Lanaka (2012). Retrieved from https://docplayer.net/docview/40/21752025/ (25/08/2024).

2. Abdel-Hafeez, M., El-Attar, S., and Abdel-Hafeez, A.: Factor Leading to Cost Overrun Occurrence in Construction Projects. Journal of port said Engineering research, 20(1), 71-77 (2016).

3. Bekr, G.: Causes of delay in public construction projects in Iraq, Jordan Journal of Civil Engineering Jordan Journal of Civil Engineering, 9(2):149-162 (2015).

4. Chang, S. : Reasons for cost and schedule increase for engineering design projects. Journal of Management in Engineering, 18(1), 29–36 (2002).

5. Creedy, D. : Risk factors leading to cost overrun in the delivery of Highway construction projects, Queensland University of Technology, 1: 14-16 (2006).

6. Memon, A., Rahman, A., and Azis, A. : Preliminary Study on Causative Factors Leading to Construction Cost Overrun. International Journal of Sustainable Construction Engineering & Technology, 2(1), 57-71 (2011). Retrieved from https://www.semanticscholar.org/paper/.

7.Roachanakanan, K. : A case study of cost overruns in a Thai condominium Project Texas: A&M University.5-7, 33-35 (2015).

8. Sweis, J., Sweis, R., Rumman, A., Hussein, A., and Dahiyat, E. : Cost Overruns in Public Construction Projects: The Case of Jordan. Journal of American Science, 9(7), 134-141 (2013).

9. Easton, V. J., and McColl, J. H. (1997) Sampling, Statistics Glossary v1.1. (College of Science and Engineering). Retrieved from http://www.stats.gla.ac.uk/steps/glossary/sampling.html. (25/05/2024).

10. Uyanik, K. and Güler, N. : A Study on multiple leaner regression analysis. Procedia - Social and Behavioral Science, 106, 234-240 (2013).

11. Wijekoon, B., and Attanayake, K. : Study on the cost overruns in road construction projects in Sri Lanaka (2012). Retrieved from https://docplayer.net/docview/40/21752025/ (25/06/2024).

12. CIDA. : Guidelines for the Preparation of Bill No. 1- Preliminaries for Building Works, 2nd Ed.,. Ref. No. - CIDA/ID/04, Colombo, Sri Lanka (2018).

Appendix

The Table.7, 8 and 9 in the text (Pages 13, 14, 15 and 20) are derived through the following Rank Agreement Factor (RAF) method. The questionnaire was distributed and analyzed to find the factors which are mostly affected by cost overrun of rural road projects during the implementation stage. That factors were selected through the past literature and tabulated in a questionnaire form. Participants are requested to give weighed value for those factors according to the impact and frequency of happening. Then collected data in the questionnaire was analyzed and ranked by using Importance Index (I.I), Frequency Index (F.I) and Severity Index (S.I) formula. The ranked factors of cost overruns further analyzed by calculating the weighted indexes of the importance and frequency aspects of cost overrun factors [8].

The following equation is used to calculate I.I, F.I & S.I.

$$\text{Importance Index } (I.I) = \frac{\text{a}.n}{AN}$$

$(0 \leq \text{index} \leq 1)$,

$$\text{Frequency Index } (F.I) = \frac{\text{a}.n}{AN}$$

$(0 \leq \text{index} \leq 1)$,

$$\text{Severity Index } (S.I) = I.I\ X\ F.I$$

$(0 \leq \text{index} \leq 1)$,

Where,
a = constant that represents a weight assigned to the importance scale (ranges from 5 for extremely high impact to 1 for not significant impact).
b = constant representing a weight assigned to the frequency scale (ranges from 5 for extremely frequent to 1 for not at all frequent).
n = The frequency of each response
A = Highest weight (i.e., 5 in this case)
N = Total number of responses

Rank Agreement Factor (RAF) is used to quantify the degree of agreement in ranking between separate groups of participants. RAF denotes the average absolute differences in the rank of the factors defined as follows,

$$RAF = \left[\frac{\sum_{i=1}^{N}|R_{i1} - R_{i2}|}{N}\right]$$

Where,

$R_{i\,1}$ - For any two groups, rank of the i th item in Group 1
$R_{i\,1}$ – Rank of the i th item in Group 2
N – The number of items
j = N – i + 1.

With a maximum RAF:

$$RAF = \left[\frac{\sum_{i=1}^{N}|R_{i1} - R_{j2}|}{N}\right]$$

The Percentage Disagreement is defined as,

$$PD = \left[\frac{\sum_{i=1}^{N}|R_{i1} - R_{i2}|}{\sum_{i=1}^{N}|R_{i1} - R_{j2}|}\right] * 100$$

Then the Percentage Agreement is defined as,

$$PA = 100 - PD$$

A lower value of RAF will suggest higher agreement between any two groups, and when it becomes zero, it is called perfect agreement.

A Systematic Review of Environmental Accounting

Viswanadham Nadiminti*, Emmalize Nerius

School of Business, The Papua New Guinea University of Technology, PNG.

*Corresponding author: vishwanadham.nadiminti@pnguot.ac.pg

Abstract: Environmental accounting illustrates the economic gains and expenses commercial enterprises incur due to pollution or resource decline. Recent research on environmental accounting has attracted much attention from academics worldwide because of how important it is to use and spread this knowledge. These studies found that ecological Performance can increase brand value, decrease capital cost, and increase company value, boosting stakeholder happiness. Traditional accounting practices frequently ignore the environmental costs associated with a company's operations, such as pollution, resource depletion, and ecosystem degradation. In recent years, researchers have discovered a variety of challenges in implementing good environmental accounting, a systematic review and meta-analysis methodology are used in this study. PRISMA can group and categorize new research streams and disciplines in pertinent literature. It is essential to recognize the challenges and limitations associated with environmental accounting, including the difficulty of quantifying and evaluating environmental impacts, the lack of standardized procedures, and the requirement for the improved gathering and submitting of information systems. The study is vital because it aids companies in understanding the ecological impact by making wise decisions to enhance their reputation.

Key words: Environmental accounting, Green accounting, PRISMA model.

1. Introduction

Environmental accounting illustrates the economic gains and expenses commercial enterprises incur due to pollution or resource decline. Nevertheless, the study notes that ecological accounting is a particular account integrated into business operations rarely discussed in specific surveys. This study addresses the business cycle and operational activity that could affect changes in environmental accounting [1].

Since environmental accounting is a crucial practice for disseminating environmental accounting information to the public and draws attention to the need for accounting procedures, several academics have addressed and done a variety of research endeavors on ecological accounting, which has opened doors for significant research and conceptual advancement in the firms, policies for environmental accounting research have become more prominent in worldwide academic circles. Pressure to adopt sustainable business methods came from inside and outside the company. However, there needs to be assurance that the intrusive requirements improve the organization. The catalysts for change were pressure from audits, complaints from stakeholders, and foreign partners; because these factors were crucial to the company's reputation, they were given excellent care [2].

According to the most recent literature, research has been done on the theoretical foundations of environmental accounting and the necessary tools and techniques. Due to the disclosure of information frauds involving environmental accounting, many large-scale companies have fallen apart [3]. The discussion about whether businesses should be required to disclose information about the environment has grown over the past ten years; therefore, it is a warning to corporate organizations to raise their understanding of environmental preservation. Businesses must include environmental accounting information in their reports for their Performance and reputation. Recent research on environmental accounting has attracted much attention from academics worldwide because of how important it is to use and spread this knowledge. These studies found that ecological Performance can increase brand value, decrease capital cost, and increase company value, boosting stakeholder happiness. For the companies with a better track record. Regarding environmental Performance, the likelihood of bankruptcy was exceedingly

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low [4]. It is out that investments in enhancing an organization's Performance and its environmental responsibility toward investors have the most significant impact on reducing the cost of funding through equity for businesses, and the cost of capital effects of an organization's environmental responsibility performance is more critical in recessions than in booms. Environmentally conscious companies face fewer capital constraints [5], it has also shown that companies with better records of environmental stewardship had far fewer capital restrictions. Similarly, some ground-breaking research suggests that excellent environmental responsibility performance can lower the cost of equity financing.

1.1. Issues of the Study

1. Analyzing the results of numerous studies is challenging, making it difficult to undertake a thorough evaluation of environmental accounting.
2. There needs to be more time to conduct an in-depth assessment of the research.
3. It is challenging to conclude because there is a lack of data in fewer research areas that must comply with inclusion criteria.

1.2. Objective of the Study

The long-term objective of the research proposal is to establish excellent environmental accounting and associated business performance. Following are a few of the main goals:

1. To ascertain the variables that affect how much information is disclosed about the environment.
2. To investigate how environmental accounting affects financial achievement and business judgment.
3. To assess whether environmental accounting has a positive impact on improving the overall success of the company.

1.3. Research Questions Based on the Study

These are the following questions of the study that based on the objectives; the questions include:

1. What variables affect how much information about the environment is disclosed?
2. What effect does environmental accounting have on company earnings when making decisions?
3. What impact does environmental accounting have on how well a company performs?

1.4. Significance of the Study

Environmental accounting is valuable in that it helps businesses understand the advantages and disadvantages of their environmental impact. Traditional accounting practices frequently ignore the environmental costs associated with a company's operations, such as pollution, resource depletion, and ecosystem degradation [6].

By utilizing environmental accounting standards, businesses can more clearly understand the financial implications of their ecological effect and make better choices regarding sustainable operations. Environmental accounting facilitates the discovery of cost-saving opportunities and operational efficiency. Businesses can identify areas to reduce their environmental impact and save money [6].

Environmental accounting aids businesses in better upholding their legal commitments and maintaining environmental standards. By properly monitoring and reporting their environmental performance, businesses can ensure compliance with these regulations and lessen risks to their reputation or legal standing.

Environmental accounting is used in CSR initiatives for corporations. It enables businesses to publicly report their environmental Performance and highlight their comment on Sustainability and responsibility. This helps society achieve sustainability goals, improve business brands, and attract

environmentally conscious customers and investors [7, 8].
In general, environmental accounting is significant because it can provide a complete understanding of an organization's financial and environmental effects. It allows companies to achieve long-term economic and ecological success by enabling them to make informed decisions, recognize opportunities for cost reduction, follow regulations, and demonstrate their commitment to Sustainability [9].

1.5. Scope of the Study

EA is an emerging accounting concept with a broad range of applications, including corporate, national, international, qualitative and quantitative, positive and negative, and good and evil [10]. In the current context, everyone's concern over the environment puts pressure on management to include environmental disclosure in their financial statement. Some of the scope of ecological accounting includes;

1. Evaluation of annual environmental investment, liabilities, assets, and spending,
2. Disclosure of environmental costs, investments, and liabilities on an internal and external basis.
3. Environmental or sustainable reporting on a global scale.

1.6. Limitations of the Study

In recent years, researchers have discovered a variety of challenges in implementing good environmental accounting. These difficulties include correctly projecting future environmental expenses, choosing the best course of action, and getting businesses to see the value of environmental accounting. It is also uncertain what unique difficulties and problems various organizations may encounter while implementing ecological accounting. Further research should done into how organizations allocate staff, money, and other resources to environmental programs.

2. Literature Review

This chapter focuses on the different types of reviews of the study. The types of reviews that are to be discussed in this chapter include outcomes of the literature review and empirical review of the literature.

2.1 Outcomes of Review of Literature

Environmental accounting incorporates financial and non-financial data and evaluates the environmental Performance of both governmental and corporate institutions. This practice affects both the corporate and government levels [11].

According to Nguyen and Tran, the financial system, including banking and capital markets, has been shown in numerous studies to be a vital tool for helping businesses generate funds [9]. Environmental accounting strongly emphasizes attaining sustainable growth by keeping good ties with the community and pursuing practical preservation of the environment strategies. To explain the study's disastrous efficiency, a lag factor that represents the market's current status is included in the regression. All stakeholders, including those who are not typical shareholders, must receive economic benefits for shareholders to do this.

Numerous studies have suggested that companies' main objective should be to maximize shareholders' wealth [12, 13, 14]. Environmental practices in accounting include integrated accounting, sustainability reporting, and accountability, as well as the accounting and financial disclosure of operational activities related to environmentally friendly products while abiding by all relevant moral and legal requirements.

Deswanto and Siregar mentioned that one factor motivating managers to commit is the excellent impact of environmental sustainability practices, which tend to better and less risky risk management and are consequently tied to clients' benefit [15]. Results of Dike and Micah showed that environmental sustainability policies boost stakeholder value and are positively connected with a company's financial

Performance over the long term [16]. Environmental management executives are under corporate pressure to disclose all of their water and waste management disclosures. Some corporate organizations tend to consume large amounts of water; as a result, they require effective methods to regulate water consumption and water waste management aimed at preserving and protecting the environment to avoid unethical water efficiency.

The price that shareholders are willing to pay for the company's shares in the organization's open market determines the firm's market value. It might be challenging to value; various steps are taken, but none of the approaches are specifically described, and each reflects a different variable outcome. Investors utilize them in conjunction to have a thorough knowledge of how stocks have performed. Market and book value are the quantitative metrics most frequently used to evaluate a firm. A high firm value indicates that the company is prosperous, and as a result, the shareholders' wealth is used.

The process of publishing financial and non-financial information, known as sustainability reporting, produces reports regarding economic, social, environmental, and governance information that provide stakeholders with sufficient and comprehensive data for use in their choices. It has been concluded that environmental accounting is the best tool for modern business administration. It can demonstrate how a company's actions may affect society [17].

Businesses are forced to provide information to demonstrate their firm commitment through this indication of motivation. As opposed to this, businesses utilize the reports on "ecological washing to promote one another as better corporate citizens. In light of some negative media contacts, the concept of communicating may help to explain the justification for the autonomous reports' provision.

The signaling hypothesis can explain behavior when two distinct individuals or organizations have access to different kinds of information. The signaling concepts, on the other hand, support the idea that companies should utilize data to express their values in addressing social and environmental problems by ensuring and improving clients' awareness of how the companies are handling the issues [18].

2.2 Empirical Review of Literature

An investigation by Okpala investigated the effect of social and environmental disclosure on stock market value between 2011 and 2016 [19]. The study made use of Corporate Social and Environmental Disclosure (CSED) information gathered from the annual reports of chosen firms. The data were then analyzed using descriptive statistics and regression. The findings of the descriptive analysis revealed that the majority of the variables had minimal variability, and the average CSED score was higher than expected, indicating that the deviations from the mean were not statistically significant.

Mohammad et al., examined the connection between the profitability of publicly related companies and the disclosure of their environmental accounting reports [20]. To examine that data, the researchers combined content analysis with statistical techniques, including mean, standard deviation, and frequency. According to the study's conclusion, a strong relationship exists between business profitability and the reporting transparency index for environmental accounting.

The study looked into how publicly traded companies; financial success was affected by environmental disclosure. To acquire information, the researchers examine these businesses' annual reports and financial statements. Through a content study of the annual reports, they looked at how the corporations disclosed environmental information. They demonstrate a connection between ecological disclosures and Financial Performance using linear regression. The results showed that reporting environmental practices had a favorable and significant impact on the companies' average economic Performance. These findings led to the recommendation that companies reveal their ecological policies because doing so can help them become more successful financially.

3. Methodology

In this context, comprehensive literature reviews may help researchers identify gaps in the literature and evaluate prior work critically [7]. Improvements in the fields of study are made possible by integrating publications and identifying research gaps. Instead of focusing on progressive and repetitive research, one of the purposes of a review article is to provide researchers with fresh and intellectually stimulating ideas and suggestions for new investigations. One method of acquiring material already available in a given sector is literature reviews.

The Preferred reporting item is the acronym PRISMA. In addition to studies on environmental accounting from earlier academics, a systematic review and meta-analysis methodology are used in this study. PRISMA can group and categorize new research streams and disciplines in pertinent literature. Several databases were chosen for the systematic review, including Scopus, Science Direct, Google Scholar, and Research Gate. This section summarizes the research process, while the following subsections provide more specific information on each stage. The following section thoroughly examined the criteria for selection, the procedures in the reviewing process, data abstraction, and the analysis activities.

3.1. Resources

Sources thoroughly searched the search string utilizing Scopus, Science Direct, Google Scholar, and Research Gate for publications published between 2016 -2023. These search engines were chosen since they only displayed content from index publications, ensuring the validity and significance of each item considered. They provide a significant amount of data coverage aside from that. Science Direct and Research Gate are the most extensive electronic databases that cover many topics based on the study of environmental accounting.

3.2. Systematic Review

3.2.1 Identification

The researchers chose pertinent search terms based on previous research and also used a thesaurus with suggested synonyms related to environmental accounting, the study's topic.

Table 1 Keywords used

Database	Keywords used
1. Scopus	1.((“environmental accounting*” or “EA* and “relationship of environmental accounting and company performance*” and “green accounting*” or “effects of EA*” or “importance of EA*”))
2. Science Direct	2.((“environmental accounting*” or “EA*” and “relationship of environmental accounting and business performance*” and “ green accounting*” or “effects of EA*” or “importance of EA*))
3. Google Scholar	3. ((environmental accounting*” or "EA*" and "relationship of environmental accounting and organization performance*" and “green accounting*” or effects of EA*” or “importance of EA*"))
4. Research Gate	4.((“environmental accounting*” or “EA*” and relationship of environmental accounting and business performance*” and green accounting*” or “ effects of EA*” or “Importance of EA*”)

Source: Author’s data (2024)

3.2.2. Screening

Several inclusion and exclusion criteria are selected and cleared out before the review process. This will reduce the time scholars must spend reading hundreds of unrelated papers. Only journal papers will be chosen, indicating that perspectives from other sources eliminated to allow for an inclusive perspective. We only select articles published in English to minimize confusion and difficulty in translation. Papers published Outside the designated time frame (2016-2023), duplicate submissions, full-text submissions, and submissions unrelated to the field chosen for the study were excluded, as were submissions that were not related to environmental accounting concepts or theories, environmental costs, environmental accounting disclosures, or the relationship between environmental accounting and corporate Performance.

Table 1 Inclusion and Exclusion Criteria used for the study

Criteria	Inclusion	Exclusion
Literature type	Journal (research articles and literature review)	Book reviews, book chapters, magazine articles, conference proceeding paper
Timeline	Articles Published between the the year 2016 to 2023	Articles published outside of the time frame chosen
Language	English	Non-English
Topic Related	Articles related to environmental accounting Theories or concepts, determinants of EA, relationship between EA and Organizational Performance.	Articles that do not come under any of these titles are avoided.
Submission of papers	Full-text research papers	Duplicate and partial research papers.

Source: Author's data (2024)

3.2.3. Eligibility

Both the first and second authors finished reviewing the work. Majid recommended that the abstracts of all surviving papers be read and assessed to limit the use of a subjective assessment, and multiple investigators carry out the query string and article search activity to prevent bias [21]. This led to the retrieval of 40 articles from both Science Direct and Research Gate.

Environmental accounting, however, was only mentioned in passing by other researchers. Second, screening procedures were carried out on which of these 40 articles. There were two duplicate articles altogether removed. Thirdly, 18 articles were eliminated because they needed to meet the criteria for inclusion. With only 20 publications remaining to access and evaluate for eligibility, their titles, abstracts, and contents were carefully studied to ensure their applicability. The researchers omitted ten articles because some were from other subject areas and needed to apply to the initial requirements. Finally, there are just ten articles left to be evaluated for the study.

3.2.4 Article Extraction Process

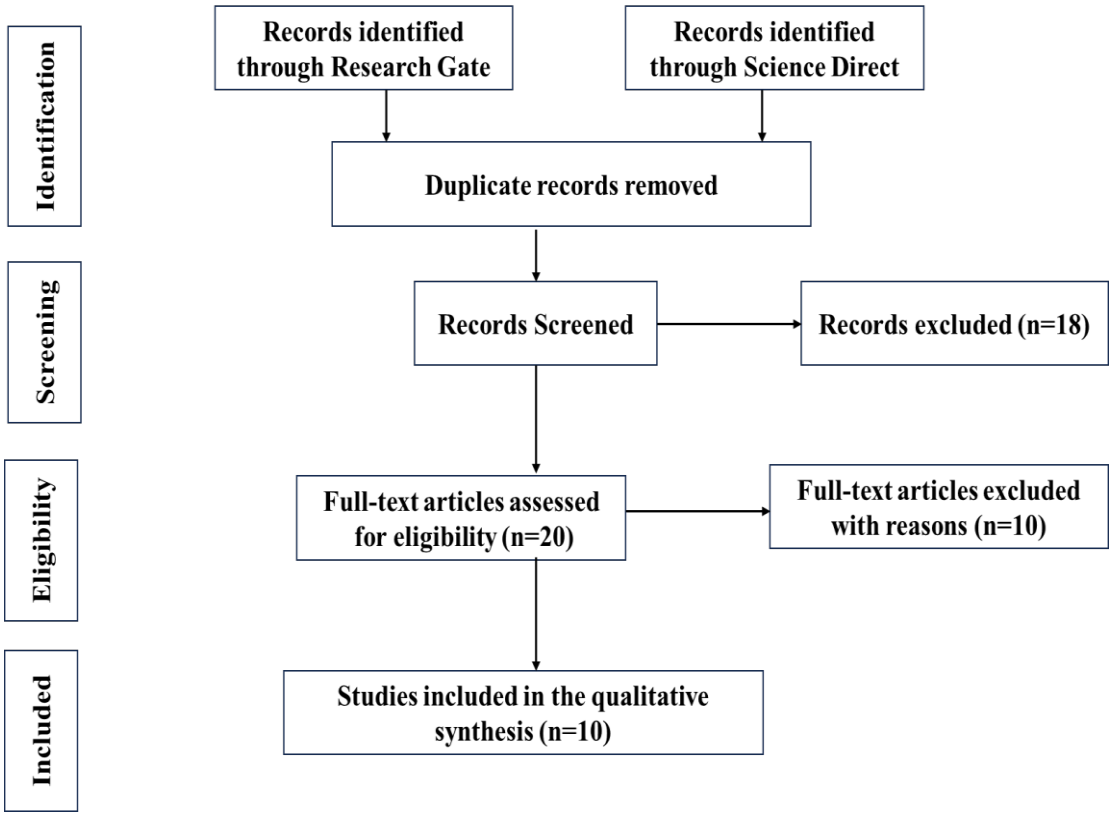

Figure 1: PRISMA flow diagram of literature search and review

3.3. Results

The study by Rounaghi, showed the importance of environmental management as a crucial factor in assessing a company's Performance [22]. It emphasized the need for collaboration among buying agents to address environmental concerns. Nowadays, businesses actively look for ways to deal with climate issues and report their efforts. In their study, Marrone, found that, according to machine learning algorithms, the use of stakeholder theory and Corporate Social Responsibility (CSR) as topics in accounting publications has increased [23].

Nicholls examined financial reporting from its nineteenth-century origins in the light of a better understanding of policy, individual preference, and how the market operates on a global scale [24]. The positive and negative aspects of evaluating social and environmental Performance should be examined. It has been argued that companies concentrate on environmental capabilities, CSR, monitoring the environment, and auditing conducted to be used to research the environmental impact [25, 26, 27]. Majid concludes that to comprehend this ongoing relationship, it should be viewed as an intellectual presence that proactively addresses environmental issues [21]. Accountability plays an essential part in providing significant and impactful solutions to social and environmental challenges rather than ignoring them. The connection between accounting and the environment is distinguished by consistency and flexibility.

4. Data Analysis

Table 2 Reviews of topics based on Environmental Accounting

Article	Author	Date
"Audit committees and financial reporting quality evidence from the UK environmental accounting disclosures."	Al-Shaer, Salama, and Toms	2017
"Environmental accounting practices: A regulatory andinternal management"	Sarah Yuliarini, Zaleha Othman, and Ku Nor Izah Ismail	2017
"Economic analysis of using green accounting and environmental accounting to identify environmental costs and sustainability indicators."	Mohamma Mahdi Rounaghi	2019
"Environmental Accounting Practices and Corporate Performance: A Study of Listed Oil and Gas companies in Nigeria"	Iliemena, Rachael O	2020
"Designing the model of factors affecting the implementation of social and environmental accounting with the ISM approach."	Tooranloo and Shahamabad	2020
"A systematic review on environmental accounting"	Haleem Athambawa, Mohamed Ismail, Mujahid Hilal, and Mohamed Cassim Abdul Nazar	2021
"Environmental Accounting practices and stakeholder value of selected listed companies in Nigeria."	Timilehin Adesanmi	(2022).
"The environmental accounting: a literature review and future direction"	Lilly Anggrayni, Alif Ilham Akbar Fatriansyah and Sofyan Tubagus	2023
"Environmental cost accounting"	Majid, Ahmed, and Al Ansari	2023
"A systematic literature review of the linkage between environmental accounting and organizational performance using Prisma guidelines"	Sony PJ, Darshan. S and M. Anbukarasi	2023

Source: Author's work (2023).

Al-Shaer sought to identify the elements affecting the volume of environmental disclosures [28]. The researchers discovered that the amount of disclosures made is unaffected by the company's number of stockholders. The discovery further strengthens the accuracy of findings across nations. It has also been believed that they have found that novel approaches are taken to resolve the contradictory demands of the narrative accounting standards regarding environmental issues [29]. Additionally, corporate governance systems, especially audit committees, have looked into the connection between environmental statements and financial disclosure using independent evidence. Yuliarini et al., show that current environmental accounting approaches represent institutions' pragmatic approach to managing complexity and thriving in a cutthroat economic climate [30]. One factor contributing to the weak patterns is the need for an appropriate conceptual framework for ecological accounting procedures, which led to a significant reliance on technical guidance from accounting standards. Standards serve as both norms and channels of interaction between institutions and authorities. Yuliarini et al., suggests a paradigm shift towards integrated systems and activities, environmental disclosure based on reliable measurement, risk mitigation via current information, investment based on dependability, and an inverse dedication to resolving environmental accounting practices [30]. An organization's maturity level may impact how well it comprehends the policies that authorities are implying, advised that future studies investigate environmental accounting practices through fieldwork to gain concrete evidence of how well businesses can adjust to external influences.

Environmental accounting is a complete tool that helps firms take ecological aspects into consideration when making decisions. Businesses can take measures that improve their profitability over the long run and their impact on the environment by accounting for costs related to the environment. This, therefore, allows them to position themselves as financial markets for industries that care about the environment, boosting shareholders' worth. Accounting for environmental factors is founded on the evolution of standards accounting principles. It entails calculating costs associated with pollution and their removal from manufacturing or services in addition to the revenues and expenses of products and services. It has been stated that the discipline of environmental accounting, also known as environmental

management accounting, is comprehensive throughout the context of accounting studies and provides internal reporting for management needs to help with capital allocation, management of expenses, and pricing. It also fulfills external purposes by revealing environmental data that is valuable to the general public and the financial sector, believes that by implementing environmental factors into the way a company operates and performs, environmental accounting seeks to strengthen the connection between the financial and Environmental Performance. Environmental accounting benefits organizations by giving decision-makers the data they need to lower costs and risks in the marketplace.

The annual reports of a few chosen corporations, corporate sustainability reports, and stock exchange fact books were used to perform the study's research [33]. The study employed an Ex-post facto research design, and straightforward linear regression was used to evaluate the data. The findings revealed that the turnover and return on capital employed significantly benefited from environmental accounting techniques and accounting, study put forth the Performance Improvement Theory (PIT), which contends that businesses should use sustainability accounting to raise their reputation and cut expenses to improve corporate Performance [33]. Overall, the study concluded that environmental accounting significantly enhances the business performance of firms that use it.

Environmental accounting is a subject that has attracted more attention in recent studies. Sayyadi et al., concentrated on the consequences of the economy, social problems have increased suffering while having few good effects [10]. However, they contend that sound accounting procedures can lessen this harm and raise awareness of environmental issues. As a result, the context of social and environmental accounting is constantly growing and changing. The study identified seven crucial elements, which might involve requirements for financial accounting, fairness in the environment, environmental transparency, corporate issues, regulations relating to the environment, financial adherence, preservation of resources, risk mitigation, and legal obligations, which affect the effective execution of both social and environmental accounting. Sayyadi et al., demonstrated that one of the contributing factors is legal obligation; however, statutory and regulatory norms determine nearly all the characteristics [10]. As a result, to make social and environmental accounting operate, legal norms must be seriously considered. Because the atmosphere plays an exceptional part in civilizations' sustainable progress, this also emphasizes improved environmental Sustainability. The adoption of the social and environmental accounting model was developed in their study as a means of avoiding its costs and losses. Sayyadi et al., also believe incorporating all known variables yields significant benefits in enhancing and improving social and environmental accounting [10]. Moreover, this is also to be the first to offer a reliable and consistent development model.

There is a dispute over the best way to measure the worth of interested parties, which has been an issue of contention. The concept of stakeholder value encompasses not only shareholders but also other stakeholders and has economic value in and of itself [32]. To solve this, Timilehin developed a model to calculate the financial value added for each stakeholder [32]. Various indices, including those for the management of water disclosure, safeguarding the environment disclosure, security precaution disclosure, social accountability disclosure, and disclosure of conformity with rules and laws, were used in the study to measure environmental accounting procedures.

Lilly stated that any relation to environmental accounting presents several concerns, concepts, theories, and measuring techniques [1].

Majid states that the ability to plan and lower environmental costs is made possible by environmental accounting, which is a valuable management tool [21]. It also helps with resource allocation, cost measurement, business decision integration, and delivering outside information. There are several systematic approaches to calculating environmental costs. The first phase emphasizes environmental reform, while the second phase acknowledges environmental costs as expenses to reduce both short-term and long-term environmental impact. According to the period and objective, environmental expenses categorized in this field of study.

By choosing an environmental accounting cost approach, the distinctive needs of each organization should be taken into account [21]. Environmental cost accounting also strives to increase organizational efficiency and high standards, and it has many institutional uses as a tool for environmental control.

Sony et al., corporate social responsibility and environmental accounting are related and represent a wise long-term investment [7]. To ensure sustainable growth, many nations have embraced environmental accounting principles. Sony et al., implied a significant favorable interaction between environmental

accounting disclosures, net earnings margin, and dividend per share [7]. On the other hand, environmental accounting disclosure and return on capital have a terrible relationship. Sony agree that the Performance of a corporation can, therefore, be improved by prioritizing ethical, environmental accounting [7]

5. Conclusion

To conclude, this paper sums up reviews of the topics related to the study of systematic reviews of environmental accounting. Environmental accounting provides insightful information into the field of environmental responsibility and the requirement that companies keep track of their ecological consequences. It also focuses on how environmental Performance impacts corporate impacts and how environmental impact is disclosed. This highlights the requirement for additional empirical research to evaluate the efficiency and effects of ecological accounting procedures.

The investigations also proved that environmental disclosures provided by corporations are unaffected by their total number of stockholders. Plus, the environment has a considerable positive impact on business Performance. Several factors that impact society and the environment are effectively implemented.

Therefore, it is essential to recognize the challenges and limitations associated with environmental accounting, including the difficulty of quantifying and evaluating environmental impacts, the lack of standardized procedures, and the requirement for the improved gathering and submitting of information systems. The topic draws attention to the advantages of environmental accounting for advancing Sustainability, spurring innovation, and improving decision-making processes. The study is vital because it aids companies in understanding the ecological impact by making wise decisions to enhance their reputation.

References

1. Lilly Anggrayni, Alif Ilham Akbar Fatriansyah, Sofyan Tubagus. :*The environment accounting: A literature review and future direction*. (2022). http://ejournal.iain-manado.ac.id/index.php/kunuz
2. Martins Mustapha Abu. : *Environmental Accounting Disclosure Practices by Companies*. (2020). http://www.abrj.org
3. Peter Boyce, Nguyen Van Du. :*Anadendrum Chlorospathum Vietnem*. (2019).
4. Fuadah, L. L., Safitri, R. H., Yuliani, Y. :Factors influencing financial performance through sustainability reporting in Indonesia. *Sriwijaya International Journal Of Dynamic Economics and Business*, 53-72 (2019).
5. Salvi, A., Petruzzella, F., Giakoumelou, A. :Does sustainability foster the cost of equity reduction? The relationship between corporate social responsibility (CSR) and riskiness worldwide. *African Journal of Business Management*, *12*(12), 381-395 (2018).
6. Md. Abdul Kaium Masud, Mohammad Sharif Hossain, Saifuddin Khan. :*Environmental Accounting concept and reporting Practices: Evidence from the Banking Sector of Bangladesh*. Retrieved 08 2023, from research gate. (2016).
7. Sony P.J, M. Anbukarasi, Darshan. S. :*A systematic review literature review of the linkage between environmental accounting and organizational performance using Prisma guidelines*. Retrieved 08 25, 2023, from Research gate. (2023).
8. Lin, K. C., Dong, X. :Corporate social responsibility engagement of financially distressed firms and their bankruptcy likelihood. *Advances in accounting*, *43*, 32-45(2018).
9. Nguyen, L., Tran, M. :Disclosure levels of environmental accounting information and financial performance: The case of Vietnam. *Management Science Letters*, *9*(4), 557-570 (2019).
10. Sayyadi Tooranloo, H., Askari Shahamabad, M.: Designing the model of factors affecting in the implementation of social and environmental accounting with the ISM approach. *International Journal of Ethics and Systems*, *36*(3), 387-410 (2020).
11. La Soa, N. :Relationship between environmental financial accounting practices and corporate financial risk: Evidence from listed companies in Vietnams Securities Market. *Asian Economic and Financial Review*, *9*(2), 285 (2019).
12. Rakiv, M., Islam, F., Rahman, R.: Environmental accounting reporting disclosure and company profitability:

A Case Study on Listed Manufacturing Companies of Bangladesh. *International Journal of Ethics in Social Sciences*, *4*(2), 21-30(2016).

13. Stefano Bresciani, S. U.: The *role of environmental management accounting knowledge management practices influences on environmental performance: mediated-moderate model.* Retrieved 09 23, 2023, from Research Gate: http://research.gate.net (2022).
14. Isono, I., Prilliadi, H. ;*Accelerating Artificial Intelligence Discussions in ASEAN: Addressing Disparities, Challenges, and Regional Policy Imperatives*. Economic Research Institute for ASEAN and East Asia. (2023).
15. Deswanto, R. B., Siregar, S. V. :The associations between environmental disclosures with financial performance, environmental performance, and firm value. *Social responsibility journal*, *14*(1), 180-193 (2018).
16. Dike, W., Micah, C. :Environmental accounting practices and sustainable development in Nigeria. *Scholars Journal of Economics, Business and Management (SJEBM)*, *5*(6), 505-512 (2018).
17. Lilly Anggrayni. :*The environmental accounting: A literature review and future direction*. Retrieved 07 30, 2023, from ResearchGate: hppt://ejournal.iain-manado.ac.id/index.php/kunuz (2022).
18. Gatimbu, K. K., Wabwire, J. M. :Effect of Corporate Environmental Disclosure on Financial Performance of Firms Listed at Nairobi Securities Exchange, Kenya. (2016).
19. Okpala, O. P., & Iredele, O. O. (2018). Corporate social and environmental disclosures and market value of listed firms in Nigeria. *Copernican Journal of Finance & Accounting*, *7*(3), 9-28.
20. Mohammad Delwar Hussain, Mohd Suberi Ab. Halim, Abul Bashar Bhuiyan. :*Environmental Accounting and Sustainable Development: An Empirical Review*. Retrieved 08 2023, from Research gate (2016).
21. Majid Ahmed Al Anssari. :*Environmental Cost Accounting: Literature Review*. Retrieved 08 29, 2023, from Science Research Journal of Economics and Business Management: http://researchgate.net (2023).
22. Rounaghi, M. M. :Economic analysis of using green accounting and environmental accounting to identify environmental costs and sustainability indicators. *International Journal of Ethics and Systems*, *35*(4), 504-512 (2019).
23. Marrone, M., Linnenluecke, M. K., Richardson, G., Smith, T. :Trends in environmental accounting research within and outside of the accounting discipline. *Accounting, Auditing & Accountability Journal*, *33*(8), 2167-2193 (2020).
24. Nicholls, J.A. :*Integrating Financial, Social and Environmental Accounting*. Retrieved 08 28, 2023, from Sustainability Accounting Management and Policy Journal: http://reseachgate.net (2020).
25. Scarpellini, S., Marín-Vinuesa, L.M., Aranda-Usón, A.Y., Portillo-Tarragona, P. :*Dynamic capabilities and EA for the circular economy in businesses*. Retrieved 08 28, 2023, from Sustainability Accounting, Management and Policy Journal, http://reseachgate.net (2020).
26. Amiolemen, O. O., Uwuigbe, U., Uwuigbe, O. R., Osiregbemhe, I. S., Opeyemi, A. :Corporate social environmental reporting and stock prices: an analysis of listed firms in Nigeria. *Investment Management & Financial Innovations*, *15*(3), 318 (2018).
27. Ezeagba, C. E., Rachael, J. A. C., & Chiamaka, U. :Environmental accounting disclosures and financial performance: A study of selected food and beverage companies in Nigeria (2006-2015). *International Journal of Academic Research in Business and Social Sciences*, *7*(9), 162-174 (2017).
28. Al-Shaer, H., Salama, A., Toms, S. :Audit committees and financial reporting quality: Evidence from UK environmental accounting disclosures. *Journal of Applied Accounting Research*, *18*(1), 2-21 (2017).
29. Bennett, N. J., Whitty, T. S., Finkbeiner, E., Pittman, J., Bassett, H., Gelcich, S., Allison, E. H : Environmental stewardship: A conceptual review and analytical framework. *Environmental management*, *61*, 597-614 (2018).
30. Yuliarini, S., Othman, Z. O., Ismaila, K. N. I. :Environmental accounting practices: A Regulatory and internal management perspective. *Journal of Economic & Financial Studies*, *5*(3), 01-11 (2017).
31. Iliemena Rachael O. : *Environmental Accounting Practices and corporate Performance: a study of listed oil and gas Companies in Nigeria*. Retrieved 08 29, 2023, from West Africa Journal of Business and Management Sciences. (2020).
32. Timilehin Dasani. :*Environmental accounting practices and stakeholder values in a national economy*. Retrieved 08 29, 2023, from Research gate: http://researchgate.net (2022).
33. Yuliarini, S., Othman, Z. O., Ismaila, K. N. I. :Environmental accounting practices: A Regulatory and internal management perspective. *Journal of Economic & Financial Studies*, *5*(3), 01-11. (2017).

Acknowledgement

IJPNGUoT embodies a significant landmark of our commitment to fostering innovation and collaboration across diverse fields of study. The journal is a culmination of hard work and dedication of several people.

We extend our heartfelt gratitude to the esteemed faculty members and researchers, who contributed their findings whose dedication and hard work have made this journal a reality. Their contributions, ranging from insightful articles to rigorous peer reviews, have been instrumental in shaping the quality of this publication. We also acknowledge the invaluable support from the Senior Executive Management, whose encouragement behind the scenes have ensured the smooth execution of this mission.

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We look forward to the continued growth and success of this publication, and to the many groundbreaking discoveries and innovations it will inspire.

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Abstract
Should be concise and presented as a paragraph, preferably less than 200 words, 150 words are preferred. This will consist of four sections, significance, background, methods, results, and conclusions which should describe the entire paper, respectively, the problem investigated, how the study was conducted, the salient findings, and what the authors conclude from the results. Discussion and citations should not be included in the abstract.

Keywords
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Introduction

This should state the reasons for doing the research and the essential background mentioned in the abstract. It should not cover either the findings or the conclusions. Introduction is normally organised 1. Significance and Motivation (based on literature review briefly) 2. Define variable and then use it 3. Normally 1-3 research questions. How to address these questions, what is your research results and Impact of your research results. How to organise your research Latin names should be *italicized*.

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Techniques and experimental procedure/s used should be described in sufficient detail to allow them to be repeated. Where appropriate, the details should include: a clear and concise account of experimental layouts; a description of treatments and general management; and a general statement about statistical analysis methods. Dates should be given for the beginning event of each experiment. The number of replications or repetitions, sample size, and population size, site characters, and subject profile are to be explained at sufficient length.

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In this section, the major findings of the study should be presented (but not discussed for some research areas). Under unavoidable circumstances, results and discussion sections could be merged and written into a single section. An assessment of experimental variability (e.g. coefficient of variation) and of the statistical significance of the results should be given. Methods used should be specified, but details of the calculations will not be necessary.

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All data must be presented with SI units (Systeme International d'Unites) and must be followed as far as possible.

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Each table should be on a separate sheet, and an indication should be given on the typescript of its preferred position in the text. Each table should be numbered in Arabic numerals, and give an appropriate title at the top of each table. Avoid presenting tables too large to print across the page: table width must not exceed 12 columns. Tables must be constructed using the table function in the office software. Manuscripts with tables created using a space bar or tab button will be returned without review. Also, authors should avoid copying and paste tables from spreadsheets. Tables may be supplied as a separate attachment with a document named after the table numbers or may be presented at the end of the references.

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This section describes the scientific or practical significance of the results and relate them to other work. The entire write-up should be based on the results presented. This section should also have a concise paragraph of conclusion/s drawn from the reported study.

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Journal article

Kyratsis, A. (2004). Talk and interaction among children and the co-construction of peer groups and peer culture. *Annual Review of Anthropology, 33*(4), 231-247.

Barford, P., & Sommers, J. (2004). Comparing probe-and router-based packet-loss measurement. *IEEE Internet Computing*, 8(5), 50-56.

Robillart, M., Schalbart, P., & Peuportier, B. (2018). Derivation of simplified control rules from an optimal strategy for electric heating in a residential building. *Journal of Building Performance Simulation,* 11(3), 294–308. doi:10.1080/19401493.2017.1349835

Books

Wells, A. (2009). Metacognitive therapy for anxiety and depression in psychology. Guilford Press.

Colclough, B., & Colclough, J. (1999). A challenge to change. Thorsons.

Book chapter

Payne, S. (1999). 'Dangerous and different': Reconstructions of madness in the 1990s and the role of mental health policy. In S. Watson & L. Doyal (Eds.), Engendering social policy (pp. 180-195). Open University Press.

Conference paper

Balakrishnan, R. (2006, March 25-26). Why aren't we using 3d user interfaces, and will we ever? [Paper presentation]. IEEE Symposium on 3D User Interfaces, Alexandria, VA. https://doi.org/10.1109/VR.2006.148.

Brown, S., & Caste, V. (2004, May). Integrated obstacle detection framework [Paper presentation]. IEEE Intelligent Vehicles Symposium, Detroit, MI..

E-journals

Vogels, A. G. C., Crone, M. R., Hoekstra, F., & Reijneveld, S. A. (2009). Comparing three short questionnaires to detect psychosocial dysfunction among primary school children: A randomized method. *BMC Public Health*, 9, 489. https://doi.org/10.1186/1471-2458-9-489

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- **Mr. Terence Kaupa**
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