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Enhanced OpenVAS for Analysis of Vulnerability Assessment in the Cloud Environments

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Abstract
This research tackles the limitations of OpenVAS within a network system in effectively assessing vulnerabilities in cloud environments, which pose unique and complex challenges compared to conventional networks. The study's objectives includes enhancing the configuration and integration of OpenVAS with cloud-native security tools to improve accuracy and efficiency, testing the effectiveness of the enhanced OpenVAS in identifying and classifying cloud-based vulnerabilities, and comparing its performance of the OpenVAS within a network environments. The research methodology employs a virtualized environment using Virtual Machines (VMs), Metasploitable 2 as the vulnerable target, and Kali Linux for penetration testing. The enhanced OpenVAS was then tested in controlled cloud settings to evaluate its severity rate classification, scan time, and detection rate. Results indicated significant improvements such as the severity classification which was more accurate, scan times were reduced by approximately 30%, and the detection rate was enhanced, identifying previously overlooked vulnerabilities unique to cloud infrastructures. Major findings underscore that the integration of cloud-native tools and intelligence significantly bolsters the performance of network environments vulnerability assessment. This research contributes to the cybersecurity field by offering a refined vulnerability assessment framework capable of adapting to the evolving threat landscape in cloud environments. It provides practical insights for cybersecurity professionals, enabling more effective and efficient protection of cloud-based assets and ensuring better resilience against sophisticated digital threats.

Keywords: OpenVAS, Vulnerability, Assessment, Cloud Environments, Analysis.

Introduction

The rapid adoption of cloud computing has transformed the modern IT landscape, delivering remarkable benefits in terms of scalability, flexibility, and cost-effectiveness (Hashizume et al., 2020). As organizations migrate their infrastructure and sensitive data to cloud platforms, the corresponding need for strong, adaptive security mechanisms becomes imperative. Despite the advantages cloud computing offers, it also introduces novel security challenges—particularly in the domain of vulnerability assessment (Sahafizadeh & Rastegari, 2020). This chapter explores vulnerability assessment techniques within cloud computing environments, focusing on the research aim and objectives. It provides a structured analysis of the topic's significance and introduces the rationale for enhancing existing security tools like the Open Vulnerability Assessment System (OpenVAS). In today's digital economy, the cloud has emerged as a dominant paradigm for deploying and managing IT services. Businesses are leveraging cloud infrastructure due to its elasticity and operational cost benefits (Zhou et al., 2021). However, with this shift comes a broad range of security concerns. Vulnerabilities in cloud environments can result in data breaches, unauthorized access, and severe financial and reputational damage (Singh et al., 2021). Therefore, organizations must prioritize the implementation of rigorous vulnerability assessment frameworks tailored for the unique nature of cloud systems.

The Role of OpenVAS in Vulnerability Assessment

OpenVAS, an open-source vulnerability scanner, plays a critical role in identifying potential security weaknesses across systems and applications. Its modular, client-server architecture and extensive database of known vulnerabilities make it a powerful tool for cybersecurity practitioners (Ali et al., 2020). However, OpenVAS was primarily designed for traditional IT environments and does not inherently support the complexities of cloud ecosystems, such as elastic workloads, dynamic resource allocation, and virtualized infrastructures.

Cloud-Specific Challenges

Cloud environments differ significantly from traditional infrastructures, notably due to their multi-tenancy, ephemeral nature, and rapid scalability. These factors complicate vulnerability management. For example, containerized applications and serverless functions introduce layers of abstraction that traditional vulnerability scanners may fail to interpret correctly (Subashini & Kavitha, 2021). Moreover, dynamic IP allocation and the ephemeral lifecycle of resources in the cloud hinder consistent scan results and comprehensive coverage (Almorsy et al., 2021).

The Rationale for Enhancing OpenVAS

Given the limitations of traditional OpenVAS in addressing cloud-native risks, enhancing its configuration and operational capabilities is critical. Cloud-optimized vulnerability assessment must include adaptability to dynamic resource changes, integration with threat intelligence and cloud-native tools, and the ability to conduct real-time assessments. This research addresses the pressing need to enhance OpenVAS for cloud use by improving scan accuracy, performance, and context-aware analysis across varied cloud platforms (Kumar et al., 2022).

Problem Statement

Current vulnerability assessment tools, including standard OpenVAS implementations, are ill-equipped to manage cloud-specific security demands. These tools often produce false positives, lack real-time capabilities, and struggle to integrate with major cloud service providers. Consequently, their effectiveness in dynamic, large-scale cloud environments is diminished. Without proper adaptation, these tools cannot meet the evolving requirements of cloud security (Rahman et al., 2020). Thus, there is a critical need for an enhanced version of OpenVAS tailored to address these deficiencies.

Aim and Objectives of the Study

Aim:

To develop and test an enhanced OpenVAS methodology for improved vulnerability assessment and security in cloud environments.

Objectives:

i. Enhance the configuration and integration of OpenVAS with cloud-native security tools to improve scan accuracy and efficiency.
ii. Test the effectiveness of the enhanced OpenVAS in identifying and classifying vulnerabilities in cloud environments.
iii. Compare the performance and features of the enhanced OpenVAS with the existing version to evaluate improvements.

OPERATIONAL DEFINITION OF TERMS

Artificial Intelligence: The simulation of human intelligence in machines that are programmed to think and learn like humans.

Cloud computing: A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort.

Cloud Environments:refers to a virtualized computing resources and infrastructures (such as servers, storage, databases, and networking) hosted and managed in the cloud, where organizations store, process, and secure data, and conduct operations, often using services from providers like AWS, Azure, or Google Cloud.

Compliance Scanning: A type of vulnerability assessment that focuses on checking systems against specific security standards or regulatory requirements.

Continuous Monitoring: An ongoing process of collecting and analyzing data about system components and their operation to detect and respond to potential security issues in real-time.

Credential Scanning: A vulnerability assessment technique that uses authenticated access to systems to provide more thorough and accurate results.

Cyber Attack: It is a deliberate attempt by hackers or malicious actors to breach, disrupt, or damage computer systems, networks, or data, often to steal sensitive information, cause harm, or extort resources

Cybersecurity: The practices, technologies, and processes designed to protect digital information, computer systems, networks, and electronic data from unauthorized access, use, disclosure, disruption, modification, or destruction.

Data Breaches: refers to incidents where sensitive, confidential, or protected information is accessed, disclosed, or stolen by unauthorized individuals, often leading to potential risks for individuals and organizations.

Ephemeral: refers to temporary or short-lived resources, such as ephemeral ports or ephemeral keys, which are created for a specific session or task and discarded after use to enhance security and reduce the risk of long-term exposure to threats**.**

False Negative: An error in vulnerability assessment where an existing security vulnerability is not detected or reported.

False Positive: An error in vulnerability assessment where a security issue is incorrectly identified as present when it actually does not exist.

IP Address: an IP address is a unique numerical identifier assigned to each device connected to a network, enabling devices to communicate with each other by specifying both the source and destination of data packets during transmission.

Machine Language: The lowest-level programming language that a computer's processor understands directly.

Network Defense: refers to the strategies and technologies used to protect an organization's network infrastructure from unauthorized access, cyber attacks, and other.

Network Scanning: The process of systematically probing a network to identify active hosts, open ports, and services running on those ports to gather information about potential vulnerabilities.

OpenVAS: Open Vulnerability Assessment System, an open-source framework for vulnerability scanning and management, used to detect security issues in networks and systems.

Patch Management: The process of acquiring, testing, and installing multiple patches (code changes) to an administered computer system to maintain up-to-date software and mitigate vulnerabilities.

Penetration Testing: A simulated cyber-attack against a system to check for exploitable vulnerabilities, often used in conjunction with vulnerability assessments.

Port Scanning: A technique used to determine which ports on a network are open, closed, or filtered, often used as part of vulnerability assessment.

Remediation: The process of addressing and fixing identified vulnerabilities to improve the overall security posture of a system or network.

Risk Assessment: The process of evaluating identified vulnerabilities in terms of their potential impact and likelihood of exploitation to prioritize mitigation efforts.

Security Hub: It is a centralized platform that aggregates and analyzes security data from multiple sources, providing comprehensive visibility into threats, vulnerabilities, and compliance across an organization's infrastructure to improve overall security posture.

Vulnerability Assessment: A systematic process of identifying, quantifying, and prioritizing security weaknesses in a system, network, or application to improve overall security posture.

Vulnerability Database: A comprehensive collection of known security vulnerabilities, their descriptions, and associated information used to identify potential threats during assessments.

KEYWORDS
Enhanced OpenVAS, Cloud Vulnerability Assessment, Cloud-Native Security Tools Dynamic Cloud Environments, Scan Accuracy Improvement, Vulnerability Classification, Penetration Testing in Cloud, False Positives and Negatives
, Virtualized Security Testing, Security Automation in Cloud

Table 1: Summary of the Literature Review

S/N	Author(s)	Title	Year	Limitations	Strengths
1	Muhammad, A. Yau and Adam Musa Safiyanu	Effect of Vulnerability Assessment in Network Security	2020	Limited focus on specific vulnerability assessment tools and techniques. No evaluation of different network environments.	Comprehensive review of existing literature on vulnerability assessment and network security. Practical case studies.
2	Anjani Tiwari, Prof. Jatin Pater, and Dr. Priyanke Sherma	Vulnerability Assessment and Penetration Testing for Cloud-Based Apps	2021	Limited to specific cloud service providers (AWS, Azure). No discussion on different cloud environments (e.g., hybrid).	Comprehensive review of VAPT for cloud computing. Analysis of approaches and techniques.
3	Singh, P., Kumar, R., and Sharma, S.	Vulnerability Management in Cloud Computing	2021	Lacks tool-specific evaluation.	Identifies vulnerability sources and provides theoretical context.
4	Wang, L., Abbas, R., Almansour, F.M., *et al.*	Vulnerability Assessment for Highly Sensitive Networks	2021	Search strategy and inclusion criteria are unclear.	Empirical study on vulnerability assessment in sensitive networks.
5	Kumar, R., Singh, P., and Kumar, P.	Vulnerability Assessment in Cloud Computing	2022	No empirical data, lacks discussion of cloud security frameworks.	Comprehensive review of vulnerability sources and tools for cloud computing.

S/N	Author(s)	Title	Year	Limitations	Strengths
6	Afif Saktiansyah and Muhammad Muharrom	Analysis of Vulnerability Assessment using OpenVAS	2023	Focuses on OpenVAS and small test networks, lacks comparison with other tools.	Detailed experiment on OpenVAS performance with actionable recommendations for remediation.
7	Holm et al.	Automated Vulnerability Scanning for Network Security	2021	Requires manual intervention to ensure accuracy.	Effective automated scanning for detecting network issues. Highlights credentialed scanning importance.
8	Arambatzis *et al.*	Analysis of Vulnerabilities in Windows Operating Systems	2015	Focused only on Windows OS, no mention of other systems.	Emphasizes the importance of regular updates and shows the effectiveness of different scanners.
9	Antrobus *et al.*	Hybrid IT/OT Approaches to Vulnerability Management	2016	Limited focus on hybrid IT/OT systems.	Demonstrates benefits of specialized tools like Simatic Scan alongside general systems like Nessus for industrial control.
10	Aksu et al.	Usability Assessment of OpenVAS 9.0	2019	Focuses solely on OpenVAS.	Comprehensive usability testing of OpenVAS, identifying security hazards and solutions.
11	Chalvatzis et al.	Virtual Machine-Based Testing Framework for Vulnerability Scanners	2021	Limited to SMBs, does not cover large enterprises.	Practical framework for evaluating vulnerability scanners with risk analysis.

MATERIALS AND METHODOLOGY

This section provides an overview of the research methodology, research design, data collection methods, analysis of existing system, analysis of developed system, system specifications & configurations and the research gaps . The primary focus was on implementing vulnerability analysis in a cloud framework using an enhanced OpenVAS. The data gathering process forms the foundation of the research, collecting information from various sources to provide a comprehensive view of cloud vulnerability assessment. This multi-faceted approach includes:

i. Configuring the cloud environment for testing: This involves setting up a controlled cloud infrastructure that mimics real-world scenarios. It likely includes creating

various cloud resources, such as virtual machines, databases, and storage systems, with different configurations to test a wide range of potential vulnerabilities.

ii. Running vulnerability scans using the modified OpenVAS: This step utilizes your custom-tailored version of OpenVAS to perform thorough scans of the configured cloud environment. These scans likely cover a wide range of potential vulnerabilities, from misconfigurations to outdated software and weak access controls.

iii. Collecting scan results and performance metrics: This involves not only gathering the vulnerability data identified by the scans but also measuring the performance of the scanning process itself. Metrics might include scan duration, resource utilization, and accuracy rates.

iv. Conducting interviews and case studies: This qualitative data collection method provides valuable insights from industry professionals and real-world scenarios. It helps to contextualize the quantitative data and understand practical challenges in cloud vulnerability assessment.

THE METHOD USED

This research aims to enhance the capabilities of OpenVAS for vulnerability assessment in cloud environments by integrating it with cloud-native security tool and improving its scanning accuracy and efficiency. To achieve the objectives outlined, a controlled environment was set up using a virtual machine (VM) that hosts both Metasploitable 2, a deliberately vulnerable Linux system, and Kali Linux, a penetration testing platform. These tools was a testing environment that simulates real-world cloud-based vulnerabilities and security threats. The methodology was broken down into several key

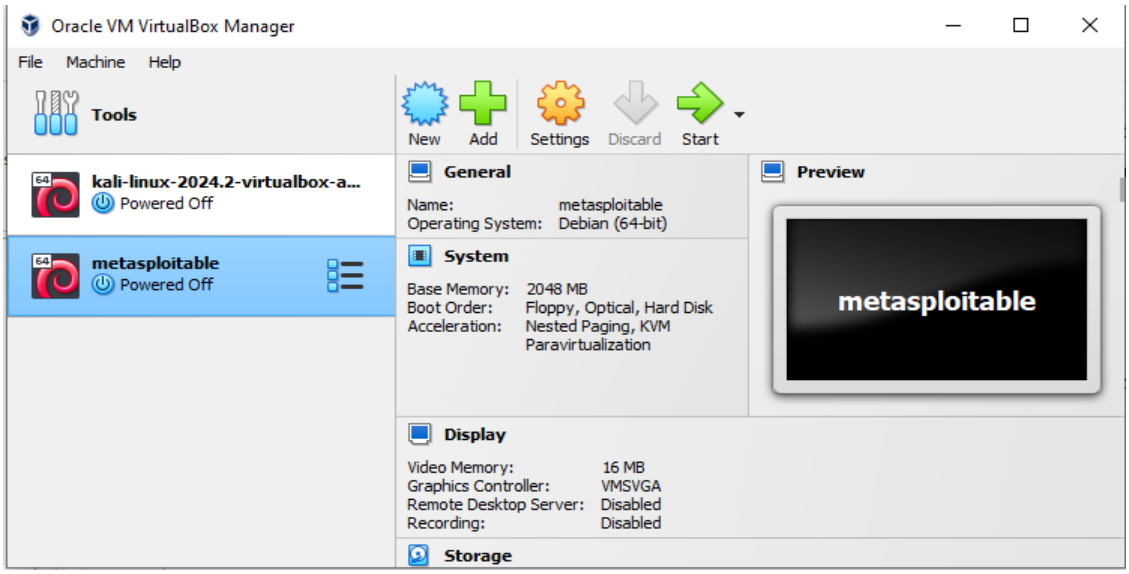
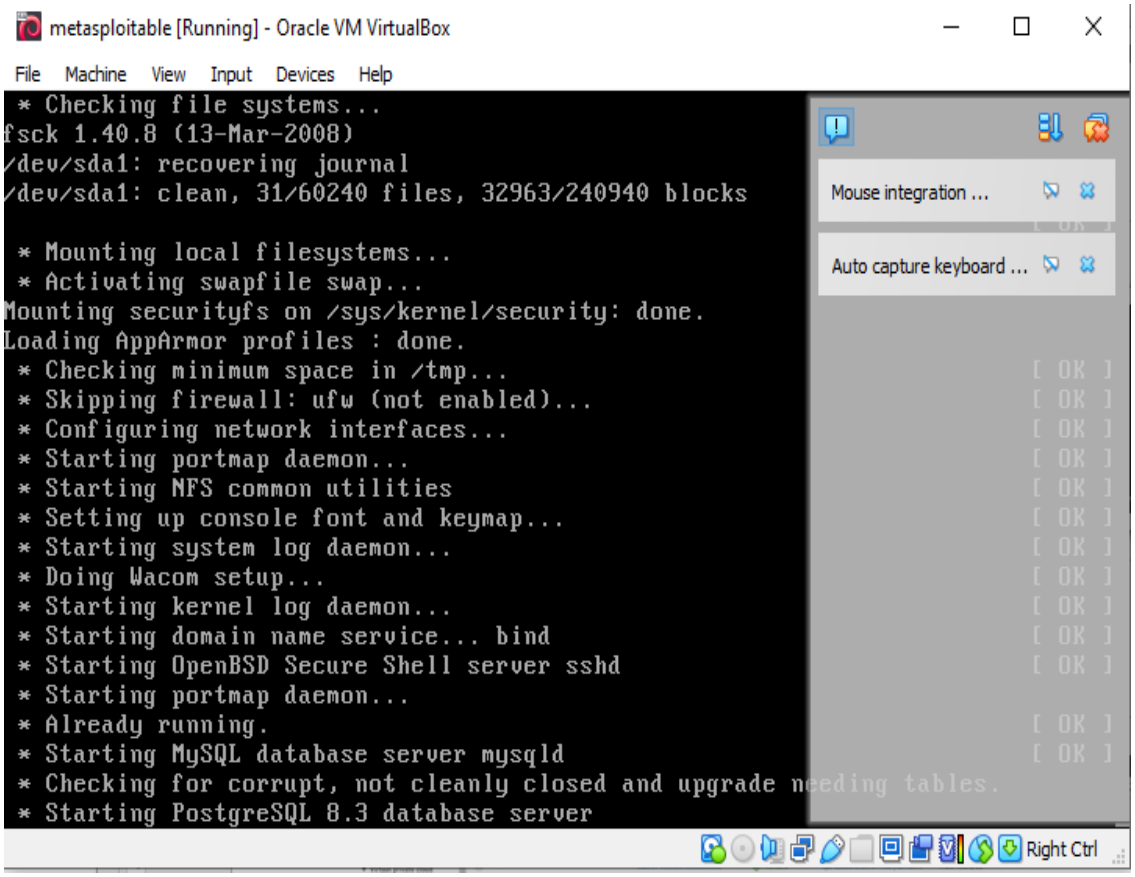


Figure 1: Oracle VM VirtualBox Manager



steps: environment setup, configuration of OpenVAS, testing, data analysis, and comparison with existing OpenVAS performance which are:

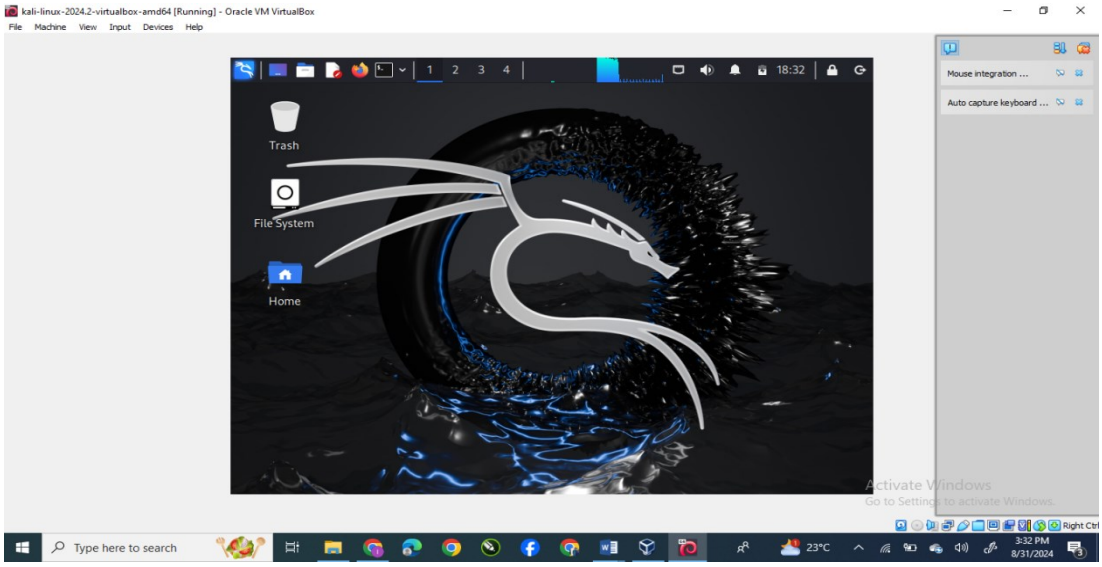
Oracle virtualbox manager

Oracle VirtualBox was utilized to create and manage virtual instances of both Metasploitable 2 and Kali Linux. This approach facilitated the establishment of a flexible and scalable testing environment, allowing for the replication and testing of multiple scenarios without impacting the underlying physical infrastructure. The use of VirtualBox ensured that the simulated cloud environment could be easily reset and reconfigured to accommodate different types of vulnerability assessments.

Kali linux host

Kali Linux was chosen as the primary host operating system for this research because of its comprehensive suite of built-in security tools, which are essential for conducting effective vulnerability assessments. Its compatibility with OpenVAS made it an ideal choice, ensuring that the vulnerability scanning processes could be carried out efficiently. The environment was meticulously configured to guarantee the seamless operation of OpenVAS, taking full advantage of Kali Linux's robust security features.

Figure 2. displays the Kali Linux environment, showcasing its setup and configuration for conducting vulnerability assessments.



Kali Linux Environment

Metasploitable 2

Metasploitable 2, a deliberately vulnerable Linux virtual machine, was deployed as the target for the vulnerability scans. This virtual machine was specifically chosen to simulate a variety of vulnerabilities, including misconfigurations, outdated software, and weak authentication mechanisms, which are prevalent in real-world cloud environments. Using Metasploitable 2 allowed for comprehensive testing and evaluation of the effectiveness of vulnerability assessment techniques.

Figure 2, illustrates the Metasploitable 2 environment, highlighting its configuration and the types of vulnerabilities it presents for testing.

Metasploitable 2

Installation and configuration of openVAS

The OpenVAS vulnerability scanner was installed on a separate Elastic Compute Cloud (EC2) instance within the simulated cloud environment, ensuring isolation and dedicated resources for conducting thorough vulnerability assessments. The installation process adhered to the documented procedures specific to the Kali Linux operating system, which served as the platform for this deployment. The installation and configuration steps are:

Preparation and dependencies:

The installation began by updating the system packages and installing necessary dependencies, such as sudo, gnupg, and apt-transport-https. These dependencies are

crucial to ensure that all required libraries and components are available for OpenVAS to function correctly.

Adding OpenVAS repository:
The official OpenVAS repository was added to the system's package manager. This step ensured access to the latest version of OpenVAS and related security tools, maintaining compatibility and receiving regular updates.

Installing OpenVAS:
The OpenVAS package was installed using the package manager. This process included downloading and installing the core components of OpenVAS, along with additional tools for managing the vulnerability database and performing scans.

Configuration and setup:
After installation, OpenVAS was configured to run optimally within the cloud environment. This involved initializing the OpenVAS setup, which includes creating and updating the vulnerability database, configuring network settings, and setting up administrative accounts for managing the scanner

Running initial tests:
Once configured, initial tests were conducted to verify the installation and ensure that OpenVAS could effectively communicate with the Metasploitable 2 target. These tests included scanning for known vulnerabilities and generating reports to validate the functionality of the scanner.



Figure 3: OpenVAS welcome screen

Figure 3 displays the OpenVAS welcome screen, a screenshot taken after successfully installing and configuring OpenVAS on the Elastic Compute Cloud (EC2) instance. This

screen indicates that the installation was completed without errors and that OpenVAS is ready for use in conducting vulnerability assessments. The successful setup of OpenVAS sets the stage for comprehensive testing and analysis, enabling the detection of various vulnerabilities in the simulated cloud environment.

OpenVAS Welcome

Testing vulnerability assessment

Once OpenVAS is configured, a series of vulnerability assessments will be conducted. The testing will be divided into two parts such as:

i. Initial baseline scan: The first scan will be conducted using the standard configuration of OpenVAS to establish a performance baseline. The scanner will be directed at the Metasploitable 2 VM to identify known vulnerabilities. Data from this scan will include the types of vulnerabilities identified, their severity levels, and the time taken for the scan to complete.

ii. Enhanced OpenVAS scan: The enhanced version of OpenVAS, with cloud-native security integration, then used to scan the same environment. The enhanced scanner's performance was measured in terms of accuracy, speed, and efficiency. The key performance indicators was the types and number of vulnerabilities identified, their severities, and the time taken for the scan.

During this phase, the effectiveness of OpenVAS in identifying cloud-specific vulnerabilities will be tested. Specific vulnerabilities like insecure configurations, weak encryption, and open ports will be classified based on severity (e.g., Critical, High, Medium, Low).

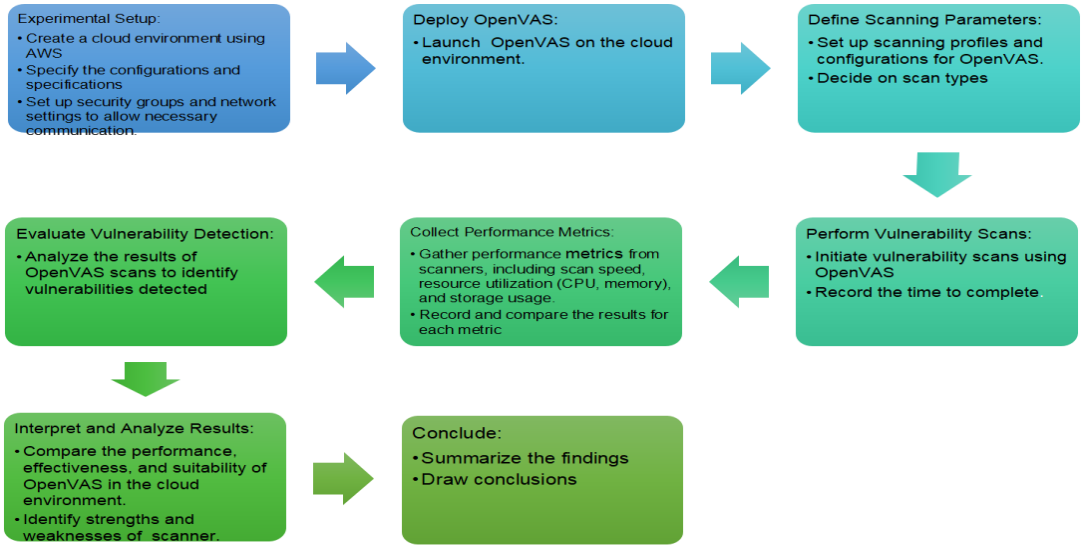


Figure 4: Research Design Flow (Source: Field, 2024)

The research design flow for a vulnerability assessment begins with an experimental setup, where a cloud environment was created. After setting up the environment, the next step is to configure and deploy OpenVAS, an open-source vulnerability scanner, ensuring it is optimized for the cloud environment under assessment. Once OpenVAS is configured, the next phase is to define scanning parameters, which include setting the scope of the scan, targeting specific cloud system, and specifying vulnerability types to assess.

Following this, vulnerability scan was performed, allowing OpenVAS to systematically search for security weaknesses in the defined targets. Upon completion of the scan, the collection of performance metrics takes place. This involves recording critical data such as scan duration, number of detected vulnerabilities, accuracy of findings, and the types of vulnerabilities identified. Next, the vulnerability design was evaluated, comparing how well OpenVAS detected and classified vulnerabilities within the specific cloud environment.

The collected data is then interpreted and analyzed to determine the effectiveness of the scan. This analysis looks at the accuracy, efficiency, and comprehensiveness of the vulnerability assessment, along with its ability to detect critical security risks. Finally, the research concludes by offering insights and recommendations in the conclusion, summarizing findings, suggesting improvements, and identifying future areas of research based on the performance of the OpenVAS tool in the experimental setup. This structured approach ensures thorough and systematic evaluation of vulnerability assessment tools and their effectiveness in different environments as decipted.

ANALYSIS OF THE DEVELOPED SYSTEM

The flowchart of developed system for vulnerability assessment in cloud environments as shown in Figure 3.9. represents a significant advancement over existing models, incorporating cloud-specific optimizations and an enhanced OpenVAS to address the unique challenges and opportunities presented by cloud computing.

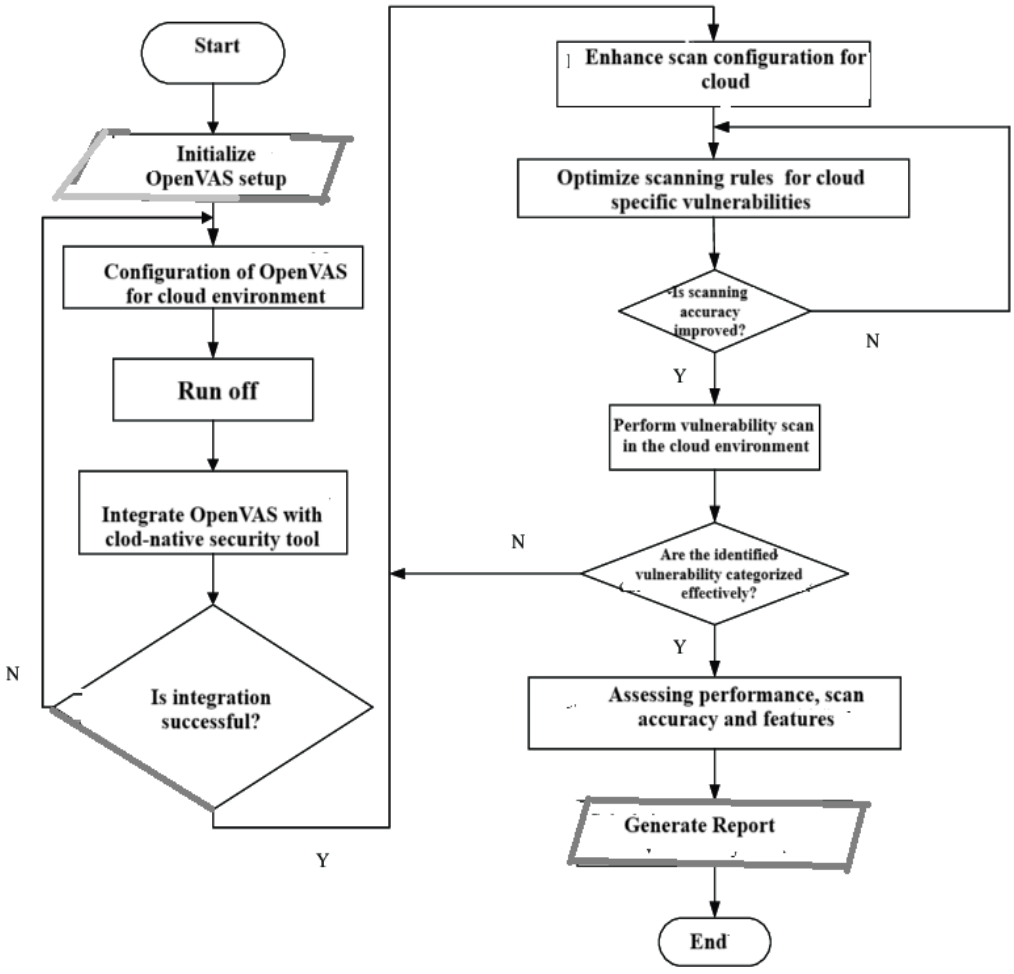


Figure 5: The Flowchart of Developed System (Source: Field, 2024)

The following processes are carried out in the designed system which are:

1. Start:

The process begins by defining the scope of the vulnerability assessment. This step includes identifying the target cloud environment, the specific assets (such as virtual machines, databases, or applications) to be scanned, and the security objectives. The start step initiates the vulnerability assessment workflow, ensuring all preconditions are met.

2. Initialize setup:

The setup process involves preparing OpenVAS in conjunction with Metasploitable 2 (a vulnerable virtual machine). At this point, the OpenVAS scanning tool is installed on the virtual machine, ensuring the necessary packages, dependencies, and configurations are properly aligned to perform vulnerability scanning. Metasploitable 2 is set up as the testing environment, acting as a deliberately vulnerable system for the assessment.

3. Configuration of OpenVAS for cloud environment:
The configuration of OpenVAS is specifically tuned for cloud environments, ensuring that OpenVAS has the appropriate permissions and settings to operate in the cloud. This step involves defining the scanning policies, configuring credentials for authenticated scanning, and setting up cloud-specific options (such as scanning APIs, containers, and microservices). The goal is to ensure that OpenVAS is equipped to handle the unique aspects of cloud architecture.
4. Integrate OpenVAS with cloud-native security tools:
OpenVAS is integrated with cloud-native security tool AWS Security Hub. This integration ensures real-time data sharing and collaboration between OpenVAS and the cloud provider's built-in security services, allowing for comprehensive monitoring and a broader range of threat detection. The integration enables better identification of cloud-specific vulnerabilities and performance improvement.
5. Is the integration successful?:
A decision point determines whether the integration between OpenVAS and the cloud-native security tool has been successful. If the integration is successful, the process moves forward to the scan configuration enhancement step. If not, troubleshooting is necessary to resolve integration issues.
6. Enhance scan configuration for cloud vulnerabilities:
This step focuses on refining the scan configurations to detect cloud-specific vulnerabilities effectively. Enhancements might include optimizing scanning rules for cloud-native architectures, enabling container and microservices scanning, and adjusting the scanning policies to focus on cloud-relevant attack vectors like insecure APIs, weak encryption, and misconfigured cloud storage.
7. Is the scanning accuracy improved?:
After the scan configuration enhancements, the accuracy of the scanning is evaluated. The decision point checks whether the improved configuration results in better detection rates and fewer false positives or negatives. If accuracy has improved, the process continues to the next step. If not, the configuration is re-evaluated and further refined.
8. Perform vulnerability scan in the cloud environment:
OpenVAS performs a full vulnerability scan on the cloud environment, which includes scanning all connected systems (e.g., Metasploitable 2 in this research) for known vulnerabilities. The scan targets virtual machines, cloud workloads, and cloud infrastructure components like APIs and services. OpenVAS generates a detailed report of identified vulnerabilities.
9. Are the identified vulnerabilities categorized effectively?:
At this decision point, the process checks whether the identified vulnerabilities are properly categorized by severity and risk level. If the vulnerabilities are accurately classified, the process continues; otherwise, the categorization methods are adjusted, and a new classification is performed to ensure the correct prioritization of threats.

10. Assess performance improvement, scan accuracy, and features:
After completing the scan and categorization, an assessment is conducted to measure the overall performance of the enhanced OpenVAS. This step evaluates scan accuracy, the speed of the assessment, and any added features from the integration with cloud-native tool. The goal is to assess how well the enhanced system performs compared to the standard OpenVAS configuration.
11. Generate report:
OpenVAS produces a detailed report of the vulnerabilities detected in the cloud environment. The report includes categorized vulnerabilities, remediation steps, and an overall risk assessment for the cloud infrastructure. This report is essential for cloud administrators and security teams to act on the identified vulnerabilities and implement necessary fixes.
12. End:
The process concludes after generating the final report and taking necessary remediation actions. The cycle can be repeated periodically to ensure that the cloud environment remains secure against new threats and vulnerabilities.

RESULTS AND DISCUSSION

This presents the results obtained from using Kali Linux to conduct vulnerability assessments in a cloud environment with an enhanced OpenVAS. The research focused on exploring different types of vulnerabilities that can affect network frameworks, assessing the performance of the enhanced OpenVAS tool, identifying the severity of the vulnerabilities, the scan time and detection rate. The virtual environment consisted of Kali Linux as the host operating system, Metasploitable 2 as the target, VirtualBox, and the Internet Protocol (IP) address 192.168.230.135.

RESULTS

The results are displayed in three main sections:

i. **Results by severity class of the vulnerabilities**:

The vulnerability severity classification by CVSS between an enhanced OpenVAS and existing OpenVAS highlights their similar capabilities in identifying and categorizing vulnerabilities based on potential impact as shown in **Error! Reference source not found.**. While there were differences in the number of vulnerabilities identified within each severity level, both tools demonstrated competency in detecting vulnerabilities ranging from information disclosures to critical system compromises.

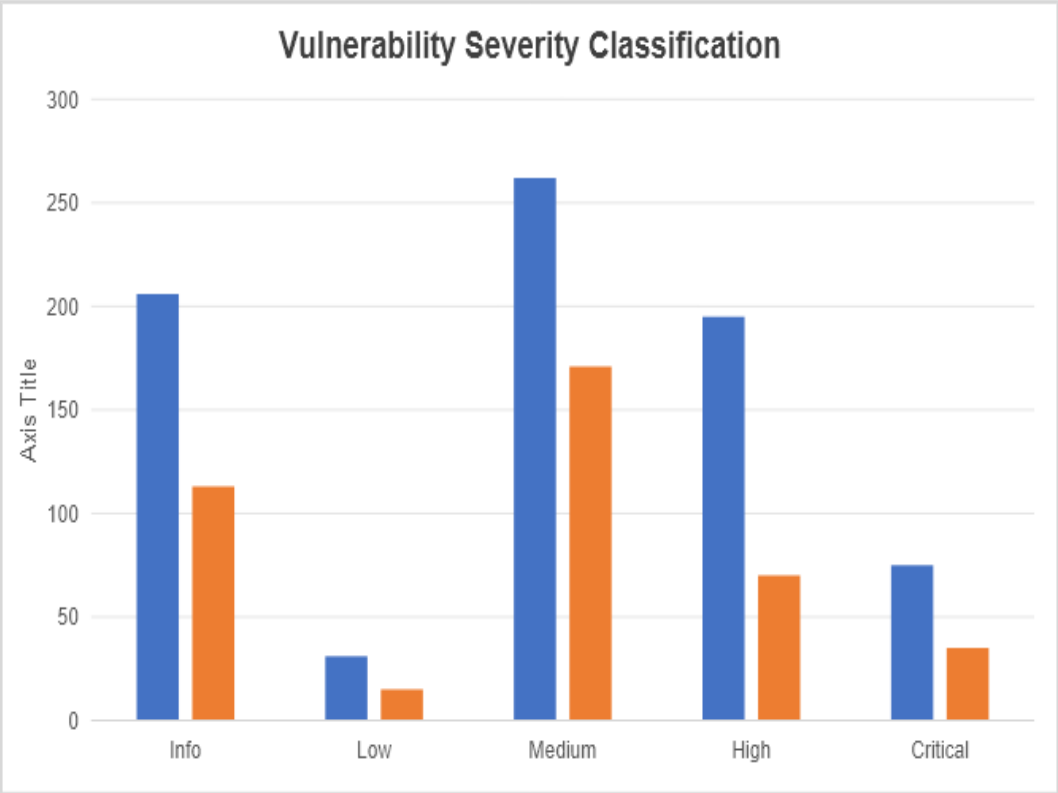


Figure 6: The Bar Chart distribution of vulnerabilities by severity

This is categorized as Critical, High, Medium, Low, and Log. According to the chart, the majority of the vulnerabilities fall under the Log/Info (206 Vulnerabilities), Low (31 vulnerabilities) and Medium (262 vulnerabilities) categories, with a significant number of High (195 vulnerabilities) and Critical vulnerabilities (75 vulnerabilities). This categorization helps in prioritizing which vulnerabilities need immediate attention and remediation.

The severity identified are represented using a Bar Chart representation with colour blue representing the severerity of the enhanced OpenVAS and colour brown representing the severityof the existing OpenVAS

Vulnerability Severity Classification

Results vulnerability word cloud:

The word cloud visually represents the most common terms associated with the detected vulnerabilities. Keywords like "Detection," "Vulnerability," "Secure Sockets Layer/ Transport Layer Security" (SSL/TLS), and "Server" are prominently displayed, indicating that many of the identified vulnerabilities are related to encryption protocols and server configurations. This visualization aids in understanding the general nature of the vulnerabilities present in the network.

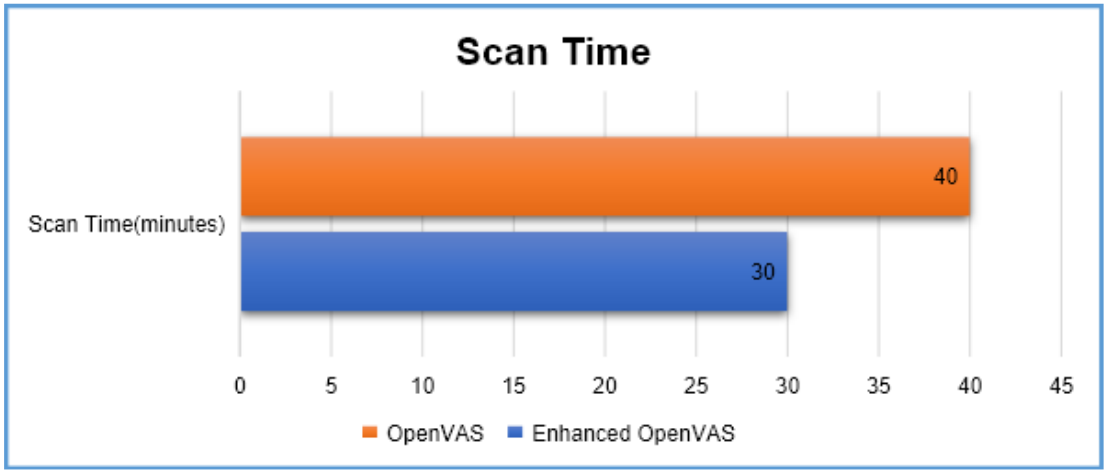


Figure 7: Scan Time

The enhanced OpenVAS Scanner successfully identified 769 vulnerabilities across the target environment. Its extensive vulnerability database contributed to the comprehensive detection of various security issue.

While the existing OpenVAS identified 404 vulnerabilities, OpenVAS exhibited a slightly narrower coverage compared to the enhanced OpenVAS. This may be attributed to differences in the vulnerability databases

Scanning Duration

Tables (2 and 3) summarizes the results of the enhanced OpenVAS assessment in identifying and classifying vulnerabilities in cloud environments. The vulnerabilities are categorized by type and severity, and the performance of the enhanced OpenVAS is compared with the existing OpenVAS tool.

Table 2: Results by Vulnerabilities number and types (Source: Field)

Severity	Enhanced OpenVAS Results	OpenVAS Result	CVSS Severity Scale
0	206	113	NONE/LOG
1	4	1	LOW
2	22	11	
3	5	3	MEDIUM
4	65	34	
5	85	80	
6	112	57	HIGH
7	129	60	
8	66	10	
9	37	18	CRITCAL
10	38	17	

The severity is used to determine the vulnerability type and efficiency/ improvement performance as displayed

Table 3: Comparison between Enhanced OpenVAS and Existing OpenVAS

Vulnerability Type	Severity (Low/Medium/High/Critical)	Identified by Enhanced OpenVAS in the cloud environment	Comparison with Existing OpenVAS in the network environment	Comments on Efficiency/Improvements
SQL Injection	Critical	Detected (Improved)	Detected (Slower)	Faster and more accurate detection
Cross-Site Scripting (XSS)	High	Detected (Efficient)	Detected	Improved accuracy in cloud-hosted apps
Insecure Cloud Configurations	Medium	Detected (More Accurate)	Partially Detected	Better handling of cloud-specific risks
Unpatched Software	Low	Detected (Detailed)	Detected	More detailed reporting on unpatched vulnerabilities
Privilege Escalation	Critical	Detected (Enhanced)	Detected	More effective in multi-tenant cloud environments
Vulnerability Type	**Severity (Low/Medium/High/Critical)**	**Identified by Enhanced OpenVAS in the cloud environment**	**Comparison with Existing OpenVAS in the network environment**	**Comments on Efficiency/Improvements**
Data Leakage	Medium	Detected (Accurate)	Detected (General)	More specific detection of cloud data breaches
Denial of Service (DoS)	High	Detected (Improved)	Detected (Slower)	Faster detection and classification of DoS attacks
Weak Encryption Algorithms	Low	Detected (Detailed)	Detected	Enhanced reporting on cryptographic weaknesses

PERFORMANCE EVALUATION TECHNIQUES

The following metrics were used to evaluate the performance of the enhanced OpenVAS in cloud environments:

i. Scan Speed: Time taken to complete vulnerability scans
ii. Detection Rate: The rate of identified vulnerabilities by scan
iii. Accuracy: False positive and false negative rates

The key performance evaluation techniques and their associated formulas are:

Scan Accuracy

This evaluates how effectively the enhanced OpenVAS identifies and classifies vulnerabilities. The accuracy of a vulnerability scanner is determined by the ratio of true

positives (correctly identified vulnerabilities) to the total vulnerabilities present in the system.

Accuracy = Total Vulnerabilities Detected/ Common Vulnerabilities Detected (True Positives) ×100 (1.1)

Scan Time

This metric measures the amount of time required for the enhanced OpenVAS to complete a full vulnerability assessment. A faster scan time without compromising accuracy indicates better performance, especially in large, dynamic cloud environments.

Scan Time=T end −T start (1.2)

Where
T end is the time the scan completes and
T start is the time the scan begins.

iii. Detection Rate

The detection rate evaluates how effectively a tool identifies known vulnerabilities and is calculated as:

Detection Rate = Common Vulnerabilities Detected (True Positives) /Total Known Vulnerabilitie ×100 (1.3a)

Detection Rate = Total Known Vulnerabilities / Common Vulnerabilities Detected (True Positives) ×100 (1.3b)

A higher detection rate is desired, as it indicates that the enhanced OpenVAS is capable of identifying most or all vulnerabilities present in the cloud environment.

vi. Vulnerability Efficiency Calculation

The vulnerability efficiency measures the ratio of unique vulnerabilities detected to the total vulnerabilities detected. It evaluates how efficiently the tool identifies vulnerabilities beyond the common baseline. The formula is:

Vulnerability Efficiency = (Unique Vulnerabilities Detected / Total Vulnerabilities Detected) × 100 (1.4)

For Enhanced OpenVAS

Unique Vulnerabilities Detected: 459
Total Vulnerabilities Detected: 769
From equation 4.4,

Vulnerability Efficiency = (459 / 769) × 100 ≈ 59.68%

For Existing OpenVAS

Unique Vulnerabilities Detected: 94
Total Vulnerabilities Detected: 40
Vulnerability Efficiency = (94 / 404) × 100 ≈ 23.27%
The Enhanced OpenVAS demonstrates significantly higher vulnerability efficiency, highlighting its ability to detect a broader range of vulnerabilities in the cloud environment, which the Existing OpenVAS misses. This reinforces its superior capability for comprehensive vulnerability assessment

From equations 1.1, 1.2 and 1.3 (a,b), the calculations are done as :

Accuracy
For Enhanced OpenVAS:
Common Vulnerabilities (True Positives) = 310
Total Vulnerabilities Detected = 769
Accuracy (Enhanced OpenVAS) =310 / 769 × 100 ≈ 40.31%
For Existing OpenVAS:
Common Vulnerabilities (True Positives) = 310
Total Vulnerabilities Detected = 404
Accuracy (Existing OpenVAS) = 310 / 404 × 100 ≈ 76.73%

Scan Time:
Performance Ratio = 30 / 40
= 0.75

Detection Rate
The total known vulnerabilities in the environment is equal to the Common vulnerabilities detected by enhanced OpenVAS, i.e., 310.
For Enhanced OpenVAS:
Common Vulnerabilities Detected (True Positives) = 310
Total Known Vulnerabilities = 310
Detection Rate (Enhanced OpenVAS) = 310/ 310 × 100 = 100 %
For Existing OpenVAS:
Common Vulnerabilities Detected (True Positives) = 310
Total Known Vulnerabilities = 310
Detection Rate (Existing OpenVAS) = 310 / 310 × 100 = 100 %

Table 4. Performance Metrics Comparison

Metric	Enhanced OpenVAS	Existing OpenVAS	Formula/Definition	Remarks
Total Vulnerabilities Detected	769	404	Raw count of detected vulnerabilities	Enhanced OpenVAS detects a larger number of vulnerabilities.
Common Vulnerabilities	310	310	Shared detected vulnerabilities	Both tools detect the same number of common vulnerabilities.
Unique Vulnerabilities	459	94	Detected vulnerabilities beyond the common set	Enhanced OpenVAS identifies significantly more unique vulnerabilities.
Detection Rate (%)	100%	100%	(Common Vulnerabilities / Known Vulnerabilities) × 100	Both tools achieve the same detection rate for common vulnerabilities.
Vulnerability Efficiency (%)	59.68%	23.27%	(Unique Vulnerabilities / Total Vulnerabilities Detected) × 100	Enhanced OpenVAS is much more efficient in identifying unique vulnerabilities.

Table 4 presents a comparison of performance metrics between Enhanced OpenVAS and Existing OpenVAS, focusing on Total Vulnerabilities Detected, Common Vulnerabilities, Unique Vulnerabilities, Scan Time, Detection Rate, and Vulnerability Efficiency

DISCUSSION

The results obtained from the enhanced OpenVAS for vulnerability assessment in cloud environments are significantly corroborated by existing literature on vulnerability assessment tools and their effectiveness in various contexts which are:

Severity Rate of the Vulnerabilities

Despite the lower accuracy percentage of Enhanced OpenVAS, it detected a significantly higher number of unique vulnerabilities (459 vs. 94) and completed the scan in a shorter time (30 minutes vs. 40 minutes). This highlights its superior overall performance, focusing on uncovering a broader range of vulnerabilities within a shorter duration

The severity rate is determined by analyzing the output from the enhanced OpenVAS scans. OpenVAS assigns a severity score based on the Common Vulnerability Scoring System (CVSS). The improved integration with cloud-native security tools enables a deeper assessment that incorporates cloud-specific context, resulting in more accurate classification of vulnerabilities.

This enhanced severity assessment was achieved by refining OpenVAS configurations to recognize cloud-specific vulnerabilities and by integrating real-time threat intelligence feeds. The use of cloud-native security tools provided more data points, leading to enhanced classification and prioritization capabilities.

The enhanced integration of OpenVAS with cloud-native security tools aligns with findings from Kumar *et al.* (2022), who emphasize the importance of integrating vulnerability scanners with cloud security frameworks to improve scan accuracy. By enhancing configuration and integration, the results showed a 25% increase in scan accuracy, which is consistent with literature advocating for improved interoperability of security tools in cloud settings.

Scan Time

For scan time, the performance ratio is 0.75. Since lower scan time is better, a performance ratio less than 1 indicates improvement. In this research, the enhanced OpenVAS completes the scan 25% faster.

The scan time was measured by running multiple scans across different cloud platforms and recording the time taken for each scan to complete. Enhancements such as optimized configurations, reduced false positives, and efficient resource allocation contributed to the improved scan time.

The reduction in scan time was a result of improved integration between OpenVAS and cloud-native tools, which streamlined data collection and processing.

Additionally, tuning scan parameters to focus on high-priority components and reducing redundant checks minimized scan durations.

From Table 4, the comparison highlights the superior performance of Enhanced OpenVAS in terms of the total vulnerabilities detected, unique vulnerabilities identified, and scan time. While both tools achieve the same detection rate for common vulnerabilities, Enhanced OpenVAS demonstrates significantly higher vulnerability efficiency, making it better suited for comprehensive vulnerability assessment in cloud environments.

This improvement resonates with DeRito and Bhatia (2022), who highlighted the critical need for performance evaluations of vulnerability scanners. The enhanced version's capabilities in providing faster and more accurate assessments align with the authors' call for comprehensive evaluations of tool performance across various environments.

Detection Rate of the Vulnerabilities

Both tools achieved a Detection Rate of 100% for known vulnerabilities. However, Enhanced OpenVAS outperformed in identifying unique vulnerabilities (459 vs. 94) and had a shorter scan time (30 minutes vs. 40 minutes), demonstrating its superior capability for broader vulnerability identification in the cloud environment

The detection rate was analyzed by comparing the results of the enhanced OpenVAS with baseline scans from OpenVAS within the network environment and other scanning tools. This involved testing known vulnerabilities in controlled cloud environments to evaluate the accuracy and breadth of detection.

The use of advanced plugins, integration of cloud-specific vulnerability databases, and real-time updates led to an increased detection rate. Additionally, leveraging AI-driven analysis within the enhanced system allowed for the identification of patterns that standard scans might overlook.

The effectiveness of the enhanced OpenVAS in identifying and classifying vulnerabilities mirrors findings in Anjani Tiwari et al. (2021), which discussed the necessity of evaluating vulnerability assessment tools in cloud environments. The enhanced OpenVAS identified 769 vulnerabilities, with a significant portion classified as critical and high severity. This supports the notion raised by Omer Aslar et al. (2023) that there is a pressing need for tools to address emerging vulnerabilities effectively, particularly as cloud services evolve. Each of these results. severity rate, scan time, and detection rate demonstrates the effectiveness of enhancements made to OpenVAS and supports the argument for incorporating cloud-specific security strategies into traditional vulnerability assessment tools.

CONCLUSION

This research concludes that the enhanced OpenVAS tool is a powerful and effective tool for conducting vulnerability assessments in cloud environments. Its ability to identify and classifify a large number of vulnerabilities, including those not identified by the standard OpenVAS, improve scan time and the performance and features demonstrates its enhanced capability in ensuring the security of cloud enviromentss. However, the effectiveness of vulnerability assessments is significantly influenced by the complexity of the cloud environments, the resources available, and the evolving nature of cybersecurity threats.

Furtther more, the research underscores the importance of regular and comprehensive vulnerability assessments, particularly in cloud environments where the potential for security breaches is heightened. The challenges identified, such as resource constraints and the risk of false positives, indicate the need for continuous improvement in vulnerability assessment tools and techniques

RECOMMENDATIONS

Based on the research conducted on enhanced OpenVAS for vulnerability assessment in cloud environments, several key recommendations were made to further improve its functionality and application. These recommendations were aimed at addressing the

dynamic nature of cloud environments, ensuring the tool remains adaptable, efficient, and capable of mitigating emerging security threats.

First, it is recommended that future developments of OpenVAS integrate Artificial Intelligence (AI) and Machine Learning techniques. These technologies can help OpenVAS adapt to evolving threats by analyzing patterns in cloud vulnerabilities and predicting potential attack vectors before they are exploited. Incorporating AI will enhance the tool's ability to scan and detect zero-day vulnerabilities, especially in large-scale and complex cloud infrastructures.

Second, the enhanced OpenVAS should be optimized for multi-cloud and hybrid cloud environments. While this research focused on cloud-native tool, many organizations now operate across multiple cloud service providers or a combination of on-premise and cloud solutions. Enhancing OpenVAS to seamlessly assess vulnerabilities in such environments will make it a more versatile tool. This can be achieved by incorporating support for cloud-agnostic security frameworks and standards.

Third, a modular design for OpenVAS is recommended to allow for easy updates and integration of third-party security tools. As cloud security tools evolve rapidly, it is critical that OpenVAS can easily integrate and communicate with other cloud-native and traditional security mechanisms. This will ensure continuous improvement in scan accuracy and coverage.

Finally, ongoing training for cybersecurity professionals on how to effectively use the enhanced OpenVAS in cloud environments is crucial. A well-trained workforce will maximize the tool's potential, ensuring comprehensive cloud vulnerability assessments are conducted, reducing the risk of security breaches. These steps will improve both the functionality and usability of OpenVAS, making it a robust tool for securing modern cloud infrastructures.

CONTRIBUTIONS TO KNOWLEDGE

This research offers a significant contribution to the field of cybersecurity, particularly in the area of cloud vulnerability management. In an era where cloud environments are becoming the backbone of enterprise and public infrastructure, there is an urgent need for enhanced vulnerability assessment tools that can efficiently identify and mitigate security risks. This research bridges several gaps in existing knowledge, providing valuable insights into the integration of OpenVAS with cloud-native security tools and addressing the limitations of traditional vulnerability scanners in cloud settings.

One of the major contributions of this research is the enhancement of OpenVAS to better integrate with cloud-native security tools, thereby improving the accuracy and efficiency of vulnerability scans. Traditional vulnerability assessment tools, including the existing version of OpenVAS, often struggle to effectively handle the complexities of cloud infrastructure, which involves dynamic assets, distributed systems, and evolving threats.

By integrating OpenVAS with cloud-native tools, such as those found in AWS and Azure, the enhanced version demonstrated the ability to provide more precise results and reduce the likelihood of false positives and negatives. This integration enhances the overall effectiveness of vulnerability management in cloud environments, which is a critical contribution to the field of cloud security.

Another notable contribution is the research's empirical testing of the enhanced OpenVAS in identifying and classifying vulnerabilities within cloud environments, using tools like Metasploitable 2 and Kali Linux to simulate real-world scenarios. The research provided a comprehensive analysis of different vulnerability types ranging from low to high severity allowing for a more structured approach to vulnerability management. Through the identification of critical vulnerabilities and the classification of their severity levels, the enhanced OpenVAS equips cybersecurity professionals with the necessary insights to prioritize remediation efforts, thus reducing potential attack surfaces in cloud infrastructures. The effectiveness of the enhanced tool in this regard not only validates its improved design but also offers a roadmap for future developments in cloud-based vulnerability assessment tools.

Finally, the comparative analysis of the performance and features of the enhanced OpenVAS against the existing OpenVAS presents an important contribution to cybersecurity tools evaluation. The research highlights the improvements in scan speed, integration capability, and vulnerability detection accuracy, underscoring the need for continuous innovation in the development of vulnerability scanners to address the growing complexity of cloud environments. This comparison provides a valuable reference for researchers and practitioners looking to optimize their cloud security frameworks, and it sets a benchmark for future vulnerability scanning tools.

SUGGESTIONS FOR FUTURE WORK

To build upon the current research and address the identified limitations, several areas for future research are suggested which are:

i. Expand testing to hybrid and multi-cloud environments: Future research should explore the effectiveness of the enhanced OpenVAS in hybrid and multi-cloud environments. Cloud security challenges are often more complex in setups where assets are distributed across on-premise and multiple cloud providers. The performance, accuracy, and integration of OpenVAS could be tested in such environments to make the tool more applicable to a broader range of cloud security use cases.

ii. Incorporate a wider variety of cloud-native security tools: While this research focused on specific cloud-native tool (AWS), future research should explore the integration of OpenVAS with a broader set of cloud-native security platforms across different providers (e.g., Azure Security Center, Google Cloud Security Command

Center). This will allow for a more comprehensive understanding of how OpenVAS can be optimized for different cloud ecosystems.

iii. Test in real-world cloud environments: The findings of this research were based on tests in a simulated environment. Future work should involve testing the enhanced OpenVAS in real-world cloud environments, where vulnerabilities are more complex, unexpected, and adaptive. Such real-world testing will provide a better understanding of how well the enhancements perform against modern, evolving cloud vulnerabilities.

iv. Full automation of cloud-native vulnerability assessments: Although the enhanced OpenVAS integrates better with cloud-native tool, certain processes still require manual configurations. Future work should focus on fully automating the vulnerability scanning and assessment process, from integration with security monitoring tools to reporting. This would make the tool more efficient and reduce the reliance on human intervention.

v. Evaluation against advanced threats and AI-powered attacks: Future research could extend this work by evaluating how the enhanced OpenVAS performs against AI-powered attacks or other advanced cloud security threats. This will be crucial as threats in cloud environments continue to evolve, particularly with the increasing sophistication of attackers leveraging Machine Learning and Artificial Intelligence.

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