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A unified architecture framework for integrating IoT into key national infrastructure to enhance the e-government ecosystem in Rwanda.

MASTER'S THESIS

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WIRELESS INTELLIGENT SENSOR NETWORKING

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Submitted by:

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May, 2022

Declaration

I, INGABIRE Ariane, am declaring that this thesis dissertation is my genuine work and has not been submitted before in the either University of Rwanda or other higher learning institutions for academic publication or any other purpose; it's the unique result of my research. The references used for obtaining ideas about my research are from some related works or other materials indicated in the references section.

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Date: 06 April, 2022

Bonafide Certificate

This is to certify that this submitted dissertation report is the genuine work done by Mrs. INGABIRE Ariane (Reg No: 220014279), master's student at the University of Rwanda- African Center of Excellence in Internet of Things/Wireless Intelligent Sensor Networking (MSc in UR-ACEIoT/WISeNet).

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Dedication

I dedicate this dissertation to:

The almighty God

The supervisors

My lovely hubby

My kids

My parents

My siblings

My classmates and friends

Acknowledgement

First, I want to thank the Almighty God for protecting and keeping me safe during the entire academic period.

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Abstract

Internet of Things (IoT) has emerged as an enabling technology and key driver of innovation to advance e-governance and public service delivery. E-governance has considerable benefits compared to traditional governance including improved services, transparency and trust, efficiency, better accessibility of public services, sustainable community development, accountability, increased citizen participation in government activities, enhanced national information infrastructure, reduced paperwork and time spent in government institutions departments. It is in this regard that Governments are looking how to enhance e-Governance by the integration of IoT within key national infrastructures. Ultimately, this will have very large involvement with respect to policy decision making, social and economic development. The work aims to explore how to enhance e-Governance by using IoT as a way to help Governments keep track of progress and achievement of national goals. A unified architecture framework for integrating IoT into the implementation of e-Government services will be developed to have one platform for government program and services rather than having each public institution with its own way of taking decision and reporting; Elastic stack products are used to implement big data IOT solution and unstructured data with massive scaled analytics capabilities. In order to demonstrate the effectiveness of IoT solutions in the large spectrum of e-Governance domain, we will use the use case of smart air quality monitoring, smart waste collection and smart water quality monitoring in the Kigali city as this will help us perform evaluation in situations that are close to real scale and operation conditions. The objective is to design a unified architecture framework for integrating IoT in e-government for accuracy decision making. The expected results will show the benefits of IoT solution to improve e-Governance across national infrastructures domain.

Keywords: Internet of Things, e-Governance, smart air quality monitoring, smart waste collection, smart water quality monitoring, elastic stack.

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Abbreviations

AI: Artificial Intelligent

API: Application Programming Interface

CoK: City of Kigali

CSV: Comma-separated values

DED: Dubai Economic Department

Dr.: Doctor

DTU: Data Transfer unit

EDI: Electronic Data Interchange

ELK: Elasticsearch, Logstash, and Kibana

Et al.: is short for the Latin term “et al,” meaning “and others.”

G2C: Government to citizen

G2B: Government to business

G2E: Government to employee

G2G: Government to government

GSM: Global System Mobile

GoR: Government of Rwanda

GUI: Graphical user interface

HEC: High Education Council

ICT: Information & Communication Technologies

IoT: Internet of Things

IOT-WISNet: IoT-Wireless Intelligence Sensors Networking

LAN:	Local Area Network
LED:	Light Emitting Diode
MINICT:	Ministry of ICT and innovation
NICI Plan:	National Information and Communications Infrastructure Plan
NTU:	Nephelometric Turbidity Unit
ORP:	Oxidation and Reduction Potential
pH:	Potential of Hydrogen
RISA:	Rwanda Information Society Authority
RS:	Remote Sensing
RURA:	Rwanda Utilities Regulatory Authority
SMS:	Short Message Service
TCP/IP:	Transmission Control Protocol/Internet Protocol
WASAC:	Water and Sanitation Corporation
Wi-Fi:	Wireless Fidelity
WSN:	Wireless Sensor Network

Figures

CHAPTER 1: GENERAL INTRODUCTION

1.1. Introduction

The Internet of Things (IoT) is a network of devices/objects embedded with sensors, softwares connected by different means of communication technologies to exchange data. E-government can benefit these connected devices by using them to provide enough quality and real time data that is used to generate the information required for making the right decision in due time.

Electronic governance (e-governance or e-Gov) is a technology in-between governments and their citizens with regards to communication and development of policy and expressions of public with aim of using transparency in providing services [1].It is the ability of different public sectors to deliver government services and required information to citizens automatically by electronic means using less efforts and minimum costs in the right time and through Internet with the goal to achieve effectiveness and efficiency in government activities by increasing the performance of services provided to citizens, institutions, businesses, and employees .

To achieve the e-government goals some services like different infrastructure projects require to be monitored by IoT for making them more effective. Using IoT in e-Government will help decision makers in Government to monitor in real time how different national programs which in some sort interact with the environment are being putting in place (the progress) which will also help to make the right decision and deliver services at the right time based on the real time situation and specific condition as well as make a better future planning from precise data. This is for not only raising the productiveness of tasks that are conducted manually before, but also stimulate the potential for new operational methods by monitoring the information and movement about a big number of people and objects in ways that would be unrealistic when done manually [2]. The IoT technology will solve the challenge of transparency met today in monitoring and will help the e-Government to be more efficient and productive because of continuous monitoring in real time by decision makers.

IoT has different expectations including political, strategic and operational benefits which indicate that IoT enables effective and intelligent management and collaboration between divisions and domains at any level of an organization, as well as between government and its citizens [1].

In this master thesis project, we proposed a unified architecture framework for integrating IoT in Rwanda's e-government ecosystem with reference of the following 3 use cases:

- **Smart air quality monitoring**: Air quality can be defined as the concentration of various pollutants such as carbon monoxide (CO), ozone, sulphur dioxide, Particulate Matter and nitrogen dioxide [3].

  With IoT, decision makers will get real time information about the air quality and address the issue in real time which will help them to make intelligent decisions about planning, maintenance to have an environment with a clean air.

- **Smart waste collection**: a system that makes the process of waste collection more efficient and well managed by monitoring bins status in real time and take immediate action when necessary in order solve the current problem of the increasing in waste generation due to urbanization and the issue of the existing way of collecting waste in disorder without knowing if the bins are full or not. Smart waste collection or e-waste system is different from traditional ways of waste collection where trucks use to go empty the waste bins without having the information about the bins. The e-waste system uses ICT technologies to know which waste bin is full to be emptied, which optimize the waste collection direction to minimize costs [4].This system can help to automate different services regarding wastes.

- **Smart water quality monitoring**: The smart water quality monitoring, regarded as the future water quality monitoring technology, catalyzes progress in the capabilities of data collection, communication, data analysis, and early warning [5]. The smart water quality monitoring system measures different water quality parameters in automatic way for analysis like Potential Hydrogen (pH), turbidity, Oxidation and Reduction Potential (ORP), conductivity and temperature and Total Dissolved Solids (TDS) using remote sensing (RS) technology [6]. Monitoring the quality of water refers to controlling the level of physical, chemical and biological parameters that are contained in water reservoir or tank various activities to survive [7].

1.2. Background

1.2.1. What is e-government

Electronic government known as e-government (e-Gov), electronic governance, digital government or online government has various definitions depending on government priorities and strategies [8].

But most researchers and specialists chose to define e-government as a use of ICT in government to give to citizens and businesses the opportunity to collaborate and conduct businesses within the government in the help of different electronic channels such as telephones, fax, smart cards, self-service kiosks, e-mail / Internet, etc [9].

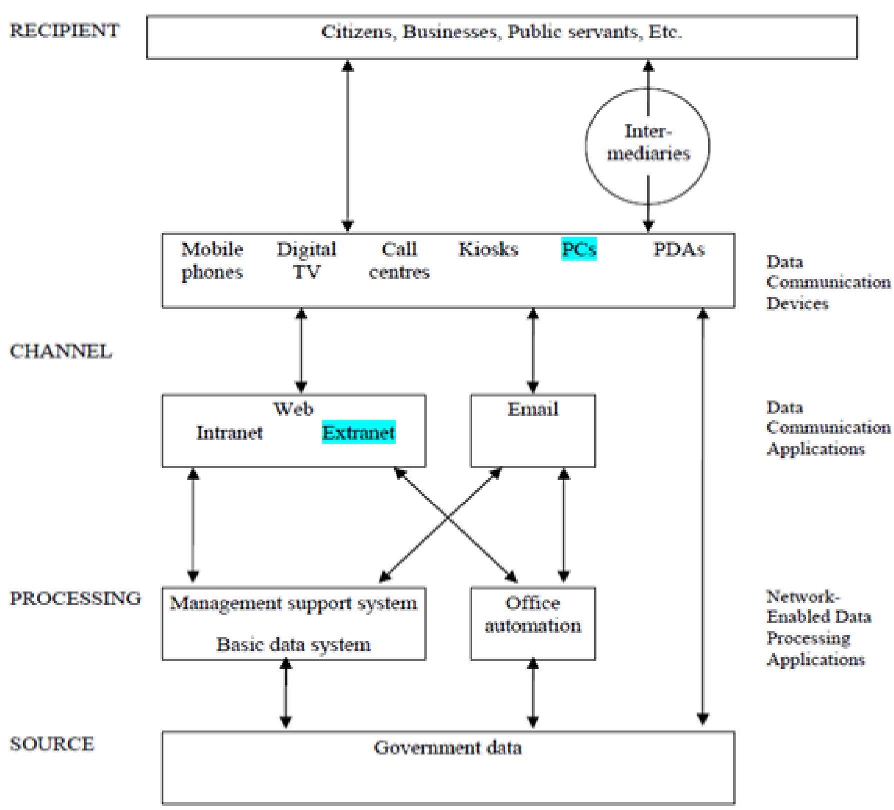

Figure 1: Architecture of e-government [10].

1.2.1.1. Components of e-government

E-government provides services to people who has authority to deal electronically with the government. These services depend to specific needs of users; this diversity brought to the development of variant types of e-government. There exist four main categories of e-government with respect to its different functions [8]:

- Government to citizen (G2C): where government interact electronically with its citizen,
- Government to business (G2B): deals with the interactions between government and different organizations for different businesses electronically,
- Government-to-government (G2G): it's about online interactions between public agencies,
- Government-to-employee (G2E): online interactions between government agencies their Employees

1.2.1.2. Why of e-government

E-government is needed because it makes the government to become transparent and provide quick and good services to citizens. There is no need to go to ask services to public institutions offices because it is enough to get them online through internet in few times which reduces cost and save time. E-government is very important as it serve as indicators of measuring the efficiency and quality of governmental work. The essential task of government is governance which means the job of regulating society and not just working with marketing and sales [9]. E-Government is the government's strong application of the information technologies achievements in daily tasks to improve efficiency, while enhancing trust and transparency to provide best services to citizens and businesses. Particularly, data-driven governance is very important for decision-making in convenient time as well as accuracy predictions [11].

1.2.2. Internet of Things (IoT)

1.2.2.1. Definition:

IoT is the interconnection of physical things (devices/objects) such as buildings, vehicles and instruments and other objects that are embedded with different technologies (electronic circuits, software, sensors and network technologies) that enables these objects to gather and interchange data. The IoT allows things to be sensed and monitored remotely through current infrastructure of network communication, which makes the need of integrating the physical world and the digital world, resulting in enhanced accuracy and efficiency [12].

The Internet of Things mark out a situation where physical objects are linked to the internet and are able to interact each other, and where each can identify itself to other objects.

Important benefits can be provided from insights that have been created by the data from these objects/devices which generate a big amount of data [1].

Internet of Things can be realized in these three approaches: things, middleware and knowledge which are makes the use of IoT only in domains of applications where these approaches intersect [13].

The figure below shows possible application domains of Internet of Things:

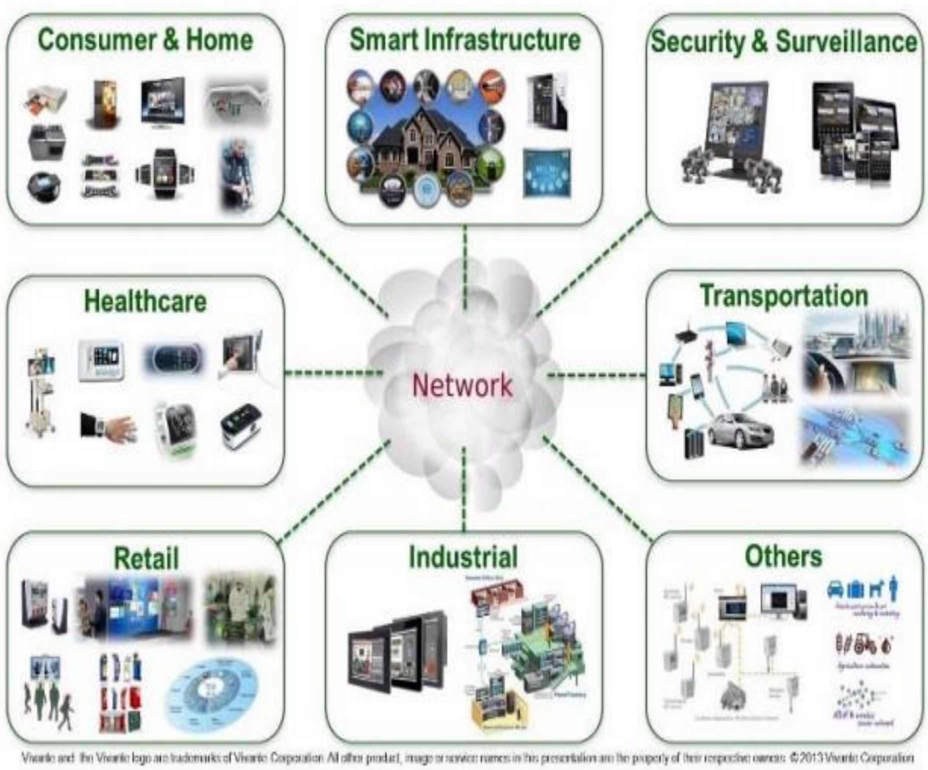

Figure 2: IoT application domains

1.2.2.2. IoT architecture

In respect of the Internet of Things, the architecture is defined as a framework that describes the: physical components, functional organization, configuration of the network, operational procedures as well as the data formats to be used [14].

To address challenges of data collection methods, heterogeneity, communication, connectivity, security, scalability, every IoT application is based on particular architecture describing how the data flows across the system [15]. There isn’t exist any architecture agreed on the Universal level; different researchers have designed different types of architectures depending on the application solution they research on. The three layers (perception, network and application layers) architecture defines the first and main idea of the Internet of Things, but it is not enough for research on IoT because researchers usually focus on improved aspects of the Internet of Things [16].

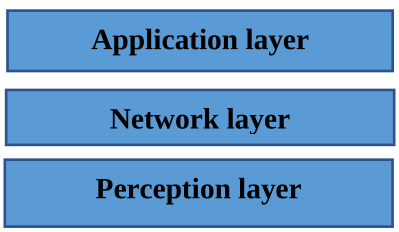

Figure 3: Three layers IoT architecture [17].

Perception layer or physical layer: it is the first and lowest layer of the architecture. It deals with the data collection from the physical environment by using different sensors and transmitters associated with the required IoT application. There are many types of perception tools associated with specific application of the IoT, including various types of sensors, transmitter. After the completion of collecting information, this layer performs the initial processing and storing the collected data or information.

Network layer or transmission layer: it transmits the information obtained from the perception layer to the upper layer (application layer) assuring the reliable communication and information exchange between the application layer and the perception layer through different network technologies, remotely or directly depending on distance and on the type of the communication technology used.

Application layer: it is the upper layer of the three-layer architecture, it analyzes and processes the information came from the perception layer and the network layer, realizing the IoT application. The application layer provides interface between IoT and users (people or system) in the combination of specific needs to achieve different IoT solutions. The IoT intelligent applications needs to be supported with other technologies such as data mining, cloud computing, middleware, etc.

Also, an IoT generic four layers architecture based on Transmission Control Protocol/Internet Protocol: TCP/IP has been illustrated: the perception layer, the network layer, the IoT platform layer and the application or business layer and associated to the IoT life cycle which is composed of four steps: capture, communicate, analyze and act to the IoT architecture [18]:

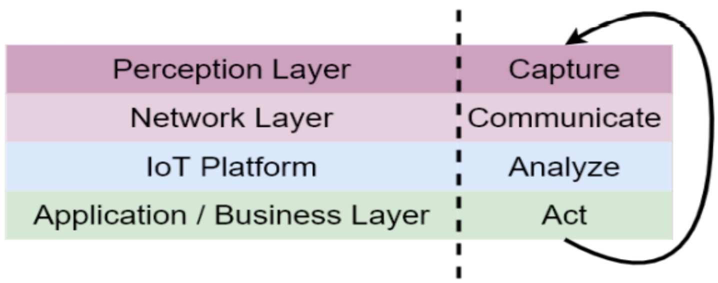

Figure 4: IoT generic architecture

The IoT generic architecture has the same three layers including in the previous basic architecture with the additional layer called IoT platform layer.

IoT platform layer: this layer is responsible of storing and analyzing the data coming from IoT devices and sends it to the dashboard to be visualized. It is at the same level as ‘’Analyzed ‘’, the fourth stage of the IoT lifecycle.

IoT lifecycle:

The IoT lifecycle has four stages:

- The first stage is ‘’*Capture*’’ refers to the way of recording a physical phenomenon and transforming it into digital qualitative or quantitative value through the Internet of Things devices that have the monitoring capabilities.

- *The second stage is ''Communicate'' c*omprises telecommunication technologies that link IoT devices and other IoT devices or between IoT devices and the central server.
- '' *Analysis''*, is the 3rd stage that aims to analyze data that from IoT devices in real time at the same time it is received or batch to accumulate the data and analyze it periodically.
- *The last stage is '' Act''* which is responsible to implements the business applications and performs actions depending on what obtained the "analysis" stage [18].

As IoT can acts in a vast range of applications, it can be integrated in e-government and be highly valuable regarding the available services beneficial to the public that it can offer to construct the innovative and smart e-government.

To achieve the goals of the e-government, it requires to have the higher determination of the whole political system to develop policies for promoting the integration of IoT in e-government to promoting socio-economic development. The way building e-government depends on resources and the level [19].

1.3. The scope of the research

The scope of our research is to design an architecture framework for integrating IoT into key national infrastructure to enhance the e-Government in Rwanda especially in Kigali city using three case studies (smart air quality monitoring, smart waste monitoring and smart water quality monitoring). Architectural aspects showing how e-government can enhanced by the IoT technology with the example of national key infrastructures were presented; Elastic stack was used to treat, visualize and explore data from various sources.

1.4. Problem Statement

Different researches have been done to show the opportunities and advantages of e-government including transparency, accountability, cost reduction, efficiency, quality of service, anticorruption, increased trust of government, network and community creation, accuracy decision making. Delivering automated and online services to citizens and ensuring connection and collaboration between citizens and government (e-service and e-citizen) are the main e-government application domains [20].

Mostly in developing countries, when it comes to services about public infrastructures (utilities) which are very important to the economy and life quality of a country, we find that managing those service, the used data is not accurate for better informed decision making because the data collection is still manual with human interaction. These services are those that can provide information one the surrounding environment like smart waste management, or services that can generate insights or changes in the state of the physical objects.

For those national programs that has a link to the environment; decision makers at national level don't have a practical, trusted and easy way to monitor the process and real the time status of how things are going on in different domains, all things are not well defined because captured data from isolated systems demands time to be combined and analyzed [1] ; there is no manner to find real time information about those national program even the accuracy of data, timing and response time is still an issue. Making open data more accessible also has an impact on the transparency, accountability and trust of governments [21].

A good information management can help authorities to identify obstacles to a well-organized government. A framework of information management is required to treat available data. This framework helps policy makers to quickly conduct useful analysis for reacting to social economic developments [9].

Decision makers need to have access to data and keep track of progress and achievement of national programs and activities in several social and economic development indicators but there is an inability of public agencies to communicate with each other and conflicting decisions among government departments [22].

Means that e-government technology can have human errors which are not recognized or controlled; currently the used manner to collect data is analog like surveys, ethnographies while when IoT is used in e-government, sensors will be used to capture data without the human intervention.

IoT generate a huge amount of "trusted" data based on, decision makers can utilize to make informed decisions after technical analysis and authentic predictions. This minimizes the period used to manage operations [1].

To solve the issue of the inaccuracy decision making and unactual data, IoT can be integrated in e-Government and using the unified framework, reports and status of activities will be always available in real time helping to save time taken in decision making as well as the cost of always going for getting data to the source; this will allow the government to improve its services that can't be delivered by disconnected systems because of real time information.

It is time to seriously consider the development and operation of an excellent government system that goes beyond the existing e-government that meets the expectations and desires of the public [23].

In comparison of traditional e-government, IoT has gained a great attention because of its capability of automation, monitoring and management, the intelligence of service, decision-making, and other services under the control of the government. Because of the IoT capability to find problems, the real time intervention helps to solve those problems in proper way preventing additional incidents; for communication and interaction, IoT helps to obtain real time feedbacks. Dealing with problems, IoT provides the capability of rapid decision-making, efficient processing. All those functionalities of IoT, the government will be able to provide scientific decision making and to deliver intelligent services [24].

1.5. Objectives

1.5.1. General objectives

Our research has the aim of advancing e-Governance in Rwanda by designing a unified architecture framework for integrating IoT into key national infrastructure where all data will be available in one command and control center rather than being scattered, helping decision makers to take accuracy decisions based on trusted data got on real time and scientific analysis during monitoring and planning for national key infrastructures which will improve transparency, quality of life of Citizens across various sectors for a smart and successful Government.

1.5.2. Specific objectives

- To design an architecture framework that integrated IoT solutions in the large spectrum of e-Governance domain
- To demonstrate the effectiveness of the suggested IoT based architecture by using a case study of smart air quality monitoring, smart waste collection and smart water quality monitoring in Kigali city
- To demonstrate the scalability of the system by allowing government institutions to integrate individual systems across various clusters mainly social, economic and

governance and to allow high level decision makers to be able to keep track of achievements and propose necessary of action in due time.

- To evaluate how the system performs in situations that are close to real scale and operation conditions

1.6. Anticipated Outputs

Outputs of this research are:

- A literature review on IoT in e-government;
- A unified architecture framework to guide the implementation of integrating IoT into key national key infrastructures.
- The use case of smart air quality monitoring, smart waste collection and smart water quality monitoring shows the effectiveness of IoT solutions in the large spectrum of e-Governance domain, by using ELK stack.
- Dashboards where decision makers and operators can interact easily and everyone can be informed or have access to necessary information in due time.

1.7. Potential impact

Applications and services that can be available in the right time and beneficial to the public keep decision makers to be always informed. This gives different opportunities and benefits to the government, citizens and business from political to operational level. Those advantages and benefits are: ensure proper oversight**,** improved predictions, intelligent analysis, transparency, informed planning with respect to management and maintenance, enforcement of regulations, improved health and safety measures, and cost reduction, improved way of delivering services and citizen empowerment [1].

The integration of IoT in e-government has the following benefits: (1) getting the public information online across the network communication; (2) Online services and interactions with citizens electronically (3) is possible to do planning and procurement electronically via the network; and (4)also an intelligent government affairs is created built on internet, which shares resources and information between departments [24].Means the decision making will be in transparent way among stakeholders based on accurate data received in real time.

1.8. Organization of this document

This research work is organized into six (6) chapters: chapter one is about the research project general introduction; the second chapter tells about literature review: some related works and gaps found. The third chapter shows the methodology used to conduct this research. The forth chapter gives the details of the architecture design where we found the proposed architecture framework. The fifth chapter is about data analysis and visualization and lastly the sixth chapter presents the conclusion and the recommendation.

CHAPTER 2: LITERATURE REVIEW

This chapter aimed to analyze in brief other researches done which are related to our ongoing research. The analysis includes what previous researchers has found, the issue they solved and solutions they proposed and the approach and methodology used as well as the results they found. Some gaps found in those previous researches have been pushing and motivating us to do the current research.

2.1. Related works

Paul Brous and Marijn Janssen [1],have identified important advantages of integrating IoT in e-government affairs that could be from the political to the operational level. IoT offers the possibilities to use sensors and access them remotely for monitoring the physical world. Additionally, stocking and analyzing recorded data it allows governments to improve and develop their services which can’t be conducted by systems on one’s own. Review literature and analyzing the data infrastructures of two case studies: Roads management data collection and water management data collection at the directorate general of public works and water management of the Netherlands. This research focused on data collection part using sensors for informed decision making. Researches didn’t show how Government can proceed to integrate IoT into those infrastructures in practical way, there is no designed architecture to follow.

Researchers in [25]proposed a unified smart city unified framework composed by three layers: secret sharing layer for controlling the physical world with IoT devices or sensors, fog computing layer which filters data from the secret sharing layer for minimizing the overload of the upper top layer, blockchain layer which is responsible of safety of data storage, it acquires data coming from fog computing layer examine it and transform it into the transaction utilizing the verification decoding phase of sharing sign. An example of mart healthcare has been used to demonstrate the effectiveness of the proposed framework. This study addresses only the data integrity issue and the proposed framework can’t be adopted by any smart city application domains.

Through [26],the study gives an overview of IoT can enhance the e-government across various application domains and controls the aspects that should be managed and considered before it can come to its entire potential. Encountered technical challenges as well as non-technical when adopting IoT in e-government have been elaborated. The analysis of IoT in e-government with respect to the application context, the foresaid challenges and the given example case study can offer beneficial insights that can interest both practitioners and researchers which can act as a place to start further researches and work in this promising domain of IoT. The adoption of IoT in e-government affairs can be highly valuable as it provides the possibility for a large range of services and applications that can be accessible and beneficial to the public. It is found that IoT based systems can be the foundation of innovative e-government. This research finds that IoT can enhance e-government by overcoming different challenges but it doesn't present an architectural design of how the implementation of IoT can be done.

Bernd W. Wirtz et al. in [27] developed an IoT framework for smart government which is composed by five layers: technology infrastructure layer, public value creation layer, public demand layer, public strategic layer, public value creation layer. Authors deliberately chose to take a broader approach that not only takes into consideration public IoT frameworks but also IoT frameworks in general and IoT business models with aim of enhancing their understanding of the public management-specific key dimensions. This is a theoretical and very complex framework.

Akemi Tokoeka Chatfield and Christopher G. Reddick, with their theoretical framework for smart government showed that smart government is a combination of digital technology and cybersecurity policies with the IoT-enabled dynamic capabilities. These dynamic capabilities that offer real time sensing and reacting can motivate the digital transformation in opening the potential of digital government into data analysis smart government able of delivering services and policies of public value and interest. Researchers used this framework to run case study analyzes of digital technology and IoT cybersecurity policies as well as the use of IoT in the following applications domains : smart cities, energy, transportation and at the U.S. federal government level federal government's IoT [28].The study focus on public policies and cybersecurity risks for explaining how the smart government performance can be realized; the used framework is extremely narrow.

To enhance e-government, Shafiq Naheed Khan et al. in [29]have designed a blockchain architecture solution of Dubai Economic Department (DED) as a case study to find out the evolution for the department of Dubai e-government by solving security, privacy, and fraud issues using blockchain technology that offers high security level. In order to found out the DED e-service level of sophistication, four stages of e-government evolution mapped its e-service strategies. Those stages are: emerging, enhanced, transactional and connected information services. Results indicate that DED has developed from the first stage of emerging services to the up to date stage of delivering connected services to the public. Here, the only blockchain technology can't be used to enhance e-government key infrastructure services, here it was used only in one department of economic, the study doesn't show how other departments can adopt this technology and how data collection is performed also it doesn't deal with the government automation.

In [22], Omar Saeed Al-Mushayt proposed a centralized management architecture for e-government information resources. It is composed by four main parts: government collective office network, big data services center, social public and research, and intelligent archives. These components use advanced technologies to improve processing, the production and the presentation of the e-government resources, including IoT, cloud computing, artificial intelligent (AI), and storage capabilities. Also, this research presents a set of deep learning technique that aims to automate various e-government affairs and propose an architecture platform of smart e-government that reinforces the development and the implementation of AI applications of e-government with the goal of utilizing accurate AI technology to advance the current position of e-government in order to reduce processing time, minimizing cost, and improving citizens' satisfaction. However, there are some challenges behind the adoption of these technologies, such as lack of specialists, trust, computational resources, and the interpretation of AI.

Cor Verdouw et al. in [30] designed an architecture framework for modelling IoT based systems in the agriculture and food domains from related existing frameworks using 19 use cases and some viewpoints including technical and business viewpoints. This framework combined viewpoints from different architectures frameworks that: (1) support smooth translations of business design to engineering models, (2) observe how things are sensed and monitored by IoT technology, (3) keep the interoperability and reuse of components and, (4) provide insights in simple and precise way, not overcharging the owner of the use case. Even if this research shows the powerful and benefits of IoT for a particular use case of agriculture by using different frameworks through different viewpoints, it is not conducted in the context of e-government.

In this thesis, the researcher has designed a unified architecture with respect to literature review of existing frameworks. Three case studies were chosen for representation other e-government key national infrastructures with the aim of having accuracy data for scientific decision making. The framework can be used as a reference architecture for IoT based system in e-government.

2.2. E-Government in Rwanda

The Republic of Rwanda has decided to put many efforts in the implementation of ICT in its all sectors for improve his economy where e-government is among the priority areas. It’s in this regards different national programs have been put in place to plan for the evolution and implementation ICT infrastructure. Those programs started by the establishment of the vision 2020 program with the aim of transforming Rwanda into a middle-income country relying on a knowledge-based. The made efforts are documented in policies and regulations documents such as the Economic Development and Poverty Reduction Strategy 2007 - 2012 (EDPRS I) and EDPRS II (2013 -2018), further acknowledged ICT as a key driver for this economic growth. Later the National Information Communication Infrastructure plan [2000 –2015]: NICI Plan I (2000-2005) aimed to put in place the fundamental legal and regulatory framework for allowing the relaxation of the sector of telecommunication and attract investors from private sectors, NICI Plan II (2006-2010) focused on accelerating infrastructure rollout including national fiber backbone and an integrated national datacenter to connect the people through increased coverage of telecommunication networks, licensing of more operators ; NICI Plan III (2011-2015] focused on expanding the benefits of increased connectivity by delivering also improved services, NICI Plan IV (2016-2020) known as the Smart Rwanda 2020 Master Plan which focus on digitalizing the government towards a 24/7 self-service, "cash-less" and "paper-less" government; with 95% of all government services are transacted [31].

The IREMBO platform is regarded as the central and a single platform for e-government in Rwanda where public services are digitalized for improving the government-to-citizens (G2C) and government-to-busines (G2B) environments [31]. Irembo is a big e-government portal currently providing access to 40 e-services from 6 different government agencies; Rwandans can access Irembo services online or via smartphone [32]. The Ministry of ICT and Innovation (MINICT) in collaboration with the Rwanda Information Society Authority (RISA) are responsible for implementing all ICT projects that can be used to enhance the social and economic domain.

CHAPTER 3: RESEARCH METHODOLOGY

Different methodologies are used to conduct this research activity and realize specific objectives: readings from different sources of documentation were conducted mainly using the internet and gathered related information to the topic of the research. Reviewing the literature of other researchers has given an overview of the actual body of knowledge, influencing us to analyze where is the gap and to be an area of focus. A multi view methodology for IoT system architecture framework approach was adopted for integrating IoT into national key infrastructure especially in case study of smart air quality monitoring, smart waste collection and smart water quality monitoring in Kigali City. Elastic stack is used to analyze and visualize data in real time.

3.1. Research area

The research area of this study is the Rwanda Government especially in City of Kigali (CoK). Rwanda’ s target is to become a middle-income with knowledge-based social-economy development; with the priority of investing in Information and Communication Technologies with the way of achieving this target. Since in 2001, there exists different ICT strategic plans for guiding the implementation of ICT initiatives. These strategic plans refer to as National Information Communication Infrastructure (NICI) plans with different versions: NICI plan I, NICI plan II, NICI plan III, and the current plan known Smart Rwanda 2020 Master Plan (SRMP) which started in 2015. In SRMP, we find two main objectives of the e-government in Rwanda : (1) to implement e-government by integrating all government services in order to enhance operational efficiency and the quality of service delivery to citizens and businesses and (2) to establish effective communication channels to enable and empower both rural and urban communities as the means to increase citizens' participation in governance .The ICT policy of the Rwanda Government focus on digital transformation for efficient government operations and service delivery [33]. For decision making**,** GoR needs to keep track of progress in several social and economic development indicators.

The researcher chose to conduct her research in City of Kigali because Kigali is the capital of Rwanda and it is where we found an increasing value of population and many government institutions. It is composed by three districts: Gasabo, Nyarugenge and Kicukiro.

Smart city has a dimension of smart government, and smart government uses smart city as an area of practice. Smart city is complimentary, part of larger smart government movement [34].

3.2. Data collection

Means of data collection are very important, they settle approaches and methodology used during the research. They show how the information has been collected, used and what it can generate. Five main means of data collection are: questions added to surveys, interviews, focus groups, observations and textual or content analysis [35]. In this thesis the methods used for collecting data includes, interviews and questionnaire.

Among the most significant source of information in a case study, we find the "interview". There exist different types of interviews: survey, open-ended interview and focused interview, and Structured. The research has to look for different sources of data to check for its authenticity [36]. In our research, the open-ended form of interview has been used where respondents are requested to comment or provide data about some cases of our concerns.

As primary data collection, face to face interview , asking questions by telephone and by emails to employees of City of Kigali in charge of infrastructure, employees of RISA in technology innovation division and to WASAC (NZOVE Branch) while reading related papers from other researchers, websites and some government records have been used as secondary data for three selected use cases (smart air quality monitoring, waste collection and water quality monitoring) because they require to be monitored on the real time basis for the safety and good health of the citizens to improve life quality. Based on the information collected through the interview made and, the current way used to monitor and manage the air pollution, waste and water are manual; an online way of monitoring is needed for getting different parameters automatically in real time to make them smart for a smart city as well as to enhance e-government.

3.3. Case studies

As a definition, a case study is a research point of view that is used to provide a comprehensively, varied understanding of a complex issue in its context of real life. It is a settled research style that is used widely in various domains, especially in social sciences [37]. It is a specific instance of a situation to used and analyzed for illustrating a principle or a thesis. Our research comprises three case studies (smart air quality monitoring, smart waste collection and the smart water quality monitoring).

3.2.1. Smart air quality monitoring

The air pollution with its rapid emission of pollutants is one of the major environment issues that affect the health of human being due to urbanization (industries, heavy transportations, etc). To provide clean air, the smart cities for their development have to control and monitor the air quality for both outdoor and indoor environments. The presence of harmful particles in the air can have long-term effects on health; WHO estimates around 7 million people die every year from air pollution-related diseases [38].

In Rwanda, Nitrogen oxides (NOX), sulphur dioxide (SO2), particulate matter (PM10, PM2:5) ozone (O3), carbon monoxide (CO), and carbon dioxide (CO2) are the major air pollutants where it is estimated that in 2012 a total of 2,227 deaths were associated to atmospheric air pollution. Acute lower respiratory infections and strokes were the major causes of death and years of life lost in Rwanda due to poor air quality [39].In our research, three gases: Ozone, CO, NO2, PM10 and PM2.5 have been taken as parameters.

.3.2. Smart waste collection

In urban areas where there is a considerable number of population, waste collection and management is one of the major issues encountered by authorities at the Government level [40]**.**To manage this overflowing garbage, we need to take correct decision [41]. Many factors play a remarkable role in making waste management challenging particular in smart cities including economic growth, a big rate of goods consumption, increase number of population, displacement of population from rural area or small cities to capital or big cities, unprofessional method of waste collection and management, absence of appropriate technologies that can be used to support the waste management [42]

In 2012, the number of population in City of Kigali was estimated to be around 1,132,686 people inhabiting an area of 730 km2 with a population density of 1551.6 inhabitants/km2. Recent studies estimated waste generation at 638 tones/day and per capita waste production at 0.57kg/day.

Municipal solid waste services are provided by private companies and cooperatives. Companies collect their fees directly from households through a door to door collection method and directly from other service users. These private entities are licensed by RURA to operate at sector level after a competitive process through public procurement processes. There are in total 15 waste collection companies operating in Kigali City covering 35 Sectors. There is a lack of concrete solution to address the cost recover.

The main issue in the waste collection is that the dust bins in the public places become full in advance just before next the time of waste collection. This leads to bad smelling because of gas concentration that may be the cause of the spreading of different in those public places [43].That's why there is a need of smart way of controlling waste in real time; the researcher based on real time monitoring the dustbin's full level and the decomposition of waste with IoT.

3.3.3. Smart water quality monitoring

Water quality is defined in three terms, such us chemical, biological and physical features of water with respect to its suitability for intended usage. Water need to monitored as it is an essential element for all living things [7]**.**

WASAC monitor the water quality by testing in laboratories with water sampling, various water quality parameters including pH, Turbidity, temperature, Iron (Fe), manganese (Mn), total coliforms, salmonella, Conductivity etc. This method used for to testify water quality is time consuming; it needs an online water quality monitoring that's helps to testify different parameters in real time in order to offer safe water to people.

For our research, we choose to monitor pH, turbidity and Cl2 parameters because they can cause many diseases to people.

3.4. Elastic stack

Elastic stack also known as ELK stack is a wide platform that aimed to create big data solutions and make it understandable. The Elastic Stack platform is composed by three main products: Elasticsearch, Logstash and Kibana. There are three steps used in the process of making sense of created big data which are: “collect”, “process” and “use”. With the purpose of succeeding to take out valuable information to stand as decision support [44].Before, the ELK stack was only about Elasticsearch, Logstash and Kibana Furthermore, another product called “Beats” turns into a fourth important component [45]:

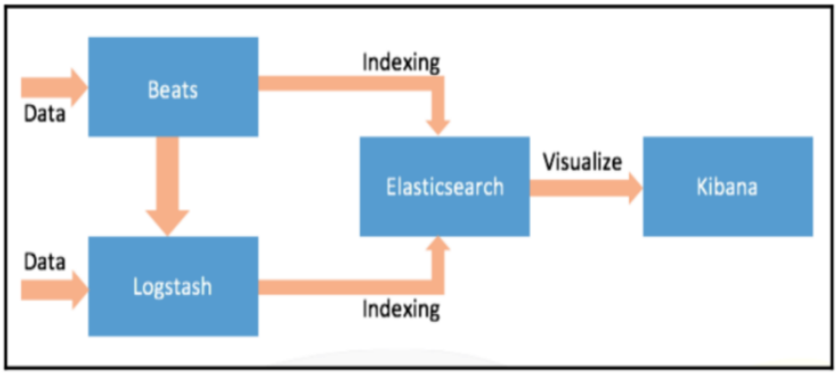

Figure 5: Elastic stack pipeline

Elasticsearch is a distributed database that stores JSON documents with the purpose of specifically searching and analyzing semi-structured data. Unlike a relational database management system, it isn’t necessary to define the types (string, number, etc.) of the data before inserting it but it is possible to define types. The underlying technology is the Apache Lucene text search engine [46].

Logstash is a "data processing pipeline" that can ingest data from several sources, transform it and send it to different consumers; Elasticsearch is one of the many consumers that can be used with Logstash [46]. Logstash supports a variety of input types and authorize to capture events from all common data sources including CSV file, TCP/UDP socket, HTTP API endpoint, Elasticsearch and many others. When outputting data, Logstash supports a large range of destination types; usually, all events are sent to Elasticsearch, but Logstash can be used also independently to save data to a CSV file, an SQL database, data analytics algorithm (i.e. Azure Machine Learning) or just show it to the console for debugging purposes. For each data source (i.e., single type of data sensor) it is required to prepare dedicated configuration file for Logstash [47].

Kibana is a web-based visualization tool that integrates with Elasticsearch to provide easy ways to navigate and visualize data, using a variety of graphs, charts and tables [46]. It provides web-based interface for search, analyze and view data stored in Elasticsearch. The main view of Kibana is divided into 4 main components: *Discover (*allows to interactively browse and analyze pure data entries*), Visualize (*provides possibility to visualize data with one of provided visualization plugins*), Dashboards* (allows to combine multiple saved Discover and Visualize results into one view) *and Management* (where all Kibana internals can be configured) [47].

Filebeat is one of the many lightweight 'data shippers' available as part of the Elastic Stack known as Beats. Beats data are single purpose and designed to be installed on the machine that generates the data without having any impact on the performance of the machine. Filebeat reads text-based log files and forwards them either directly to Elasticsearch or to Logstash [46].It is a lightweight shipper that sends data from edge devices to Logstash [47].

Elastic Stack can be deployed on premises or used as Software as a Service (SaaS) provided by external company in the cloud. The stack is currently maintained and actively supported, under open source license by the company called Elastic [47].

A broad range of Machine Learning capabilities were introduced in the Elastic Stack through the tool X-Pack. According to Elastic documentation, just by specifying the main factors which may influence stored data, the built-in machine learning functionality is able to automatically learn what is its" normal" state and identify anomalies [48].

Combining IoT and Elastic stash tools, it will overcome the challenge of management and maintenance from the IoT deployments and complexity.

CHAPTER 4: SYSTEM ARCHITECTURE

The internet of things encompasses a wide range of technologies in different domain. The use of sensors helps in making smart applications embedded with hardware. The good references are to use architecture that coexist in the internet of things by specifying the physical components, functional organization and network used to make operational, procedures as well as the format of data used in its operation [49]. From the architecture framework for the three case studies, a unified architecture has been developed to show how IoT can be integrated in e-government key infrastructure.

4.1. System architecture for Smart Air Quality monitoring

Figure 6 shows the architecture of smart air quality monitoring. Gas sensors sense data and measure the air by determining its quality. The ZigBee as high-level communication protocol used connect everything that move. The authorities responsible for air quality visualize the information on the web via LoRa gateway that helps them in the feature development of prototype and implementation.

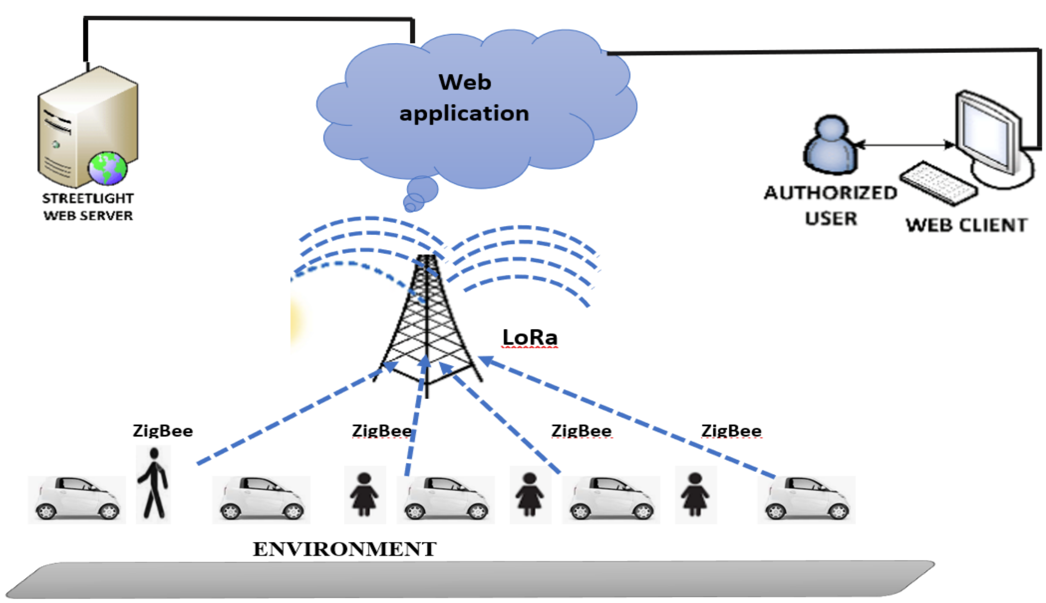

Figure 6: Smart air quality monitoring architecture

4.2. System architecture for Smart Waste Bin Monitoring

Increasing waste generation has become a significant challenge in Rwanda especially in Kigali City due to unprecedented population growth and urbanization.

This study identifies how the waste collection can become easy to be implemented, the ultrasonic sensors help the companies responsible for waste collection from its inception to the final disposal to get the status of waste bin and gas sensor helps in knowing if the waste in waste bin are decomposed or not. Both sensors help in making notification to the waste collector for making better services to the households, markets, organization and so on. The communication channel used in this case is GSM. The data are sent to the application then be processed and stored in database.

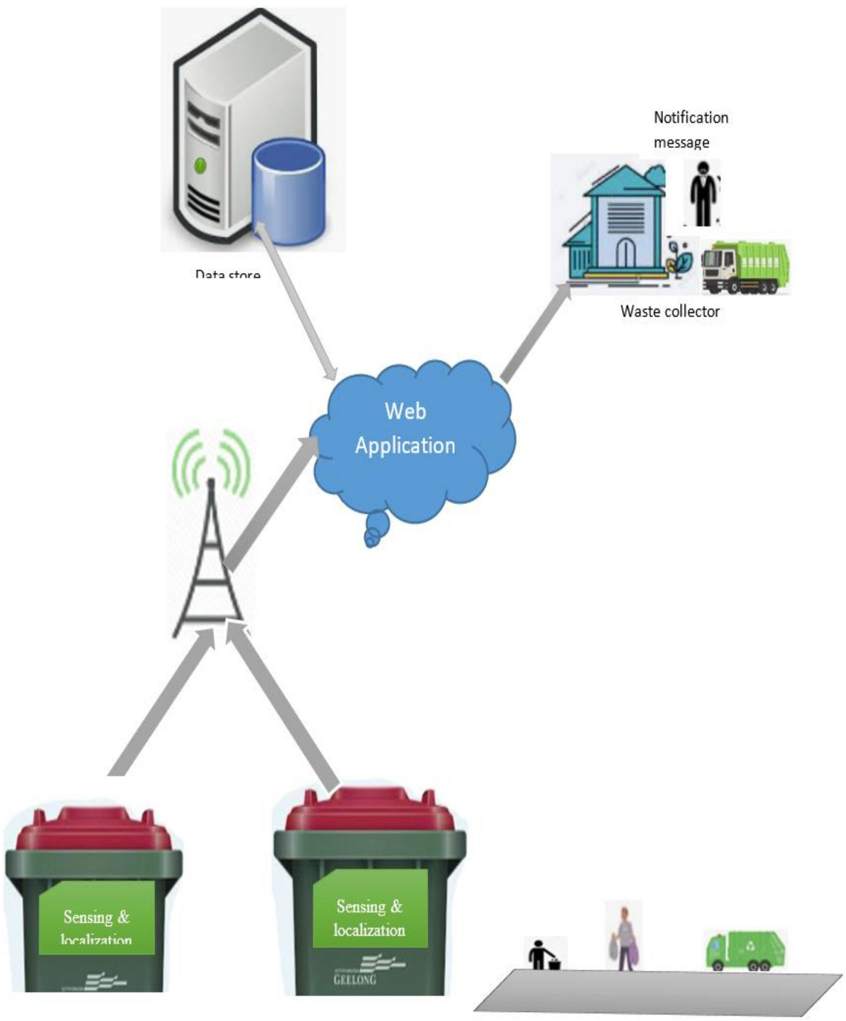

Figure 7: Smart Waste Collection Architecture

4.3. System architecture for smart water quality monitoring

Freshwater is a resource that is a gift for life of human beings on earth. Currently, drinking water facilities face new real-world problems. Due to the limited drinking water resources, the proposed studies indicate how the water can be monitored and measured. The pH measures the acidity and basicity of water; TDS measure the water by identifying objected dissolved in water and Turbidity to measure the amount of light that is scattered by the suspended solids in water. The quality of water is displayed on LCD fixed on water tank and also displayed on the application by the people.

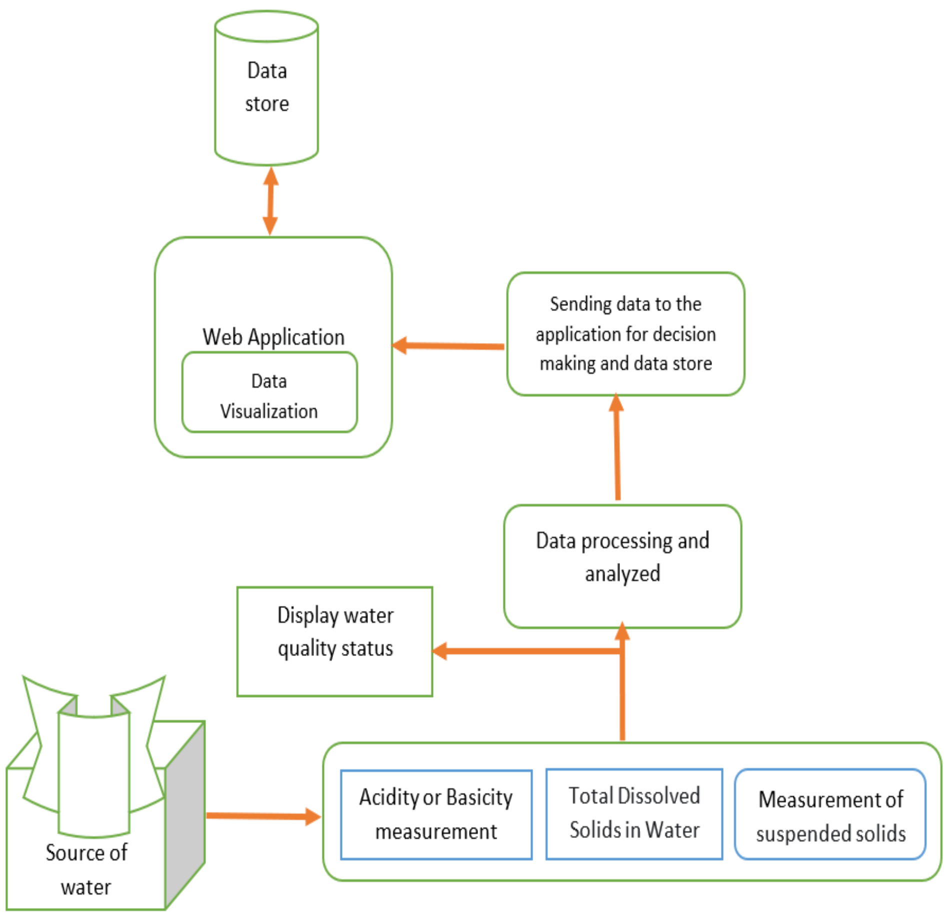

Figure 8: Water quality monitoring architecture

4.4. Proposed architecture framework

We proposed a unified architecture framework for that each public agency could adopt for every national program regarding the public infrastructures.

4.4.1. High level architecture

Integrated solution utilizing Elastic stack as a Government Business Intelligent Solution (GBIS) for creating dashboards/Reports/Analytics, Government Enterprise Service Bus (GESB) for transactions and a Hadoop Data Lake to store the data is proposed:

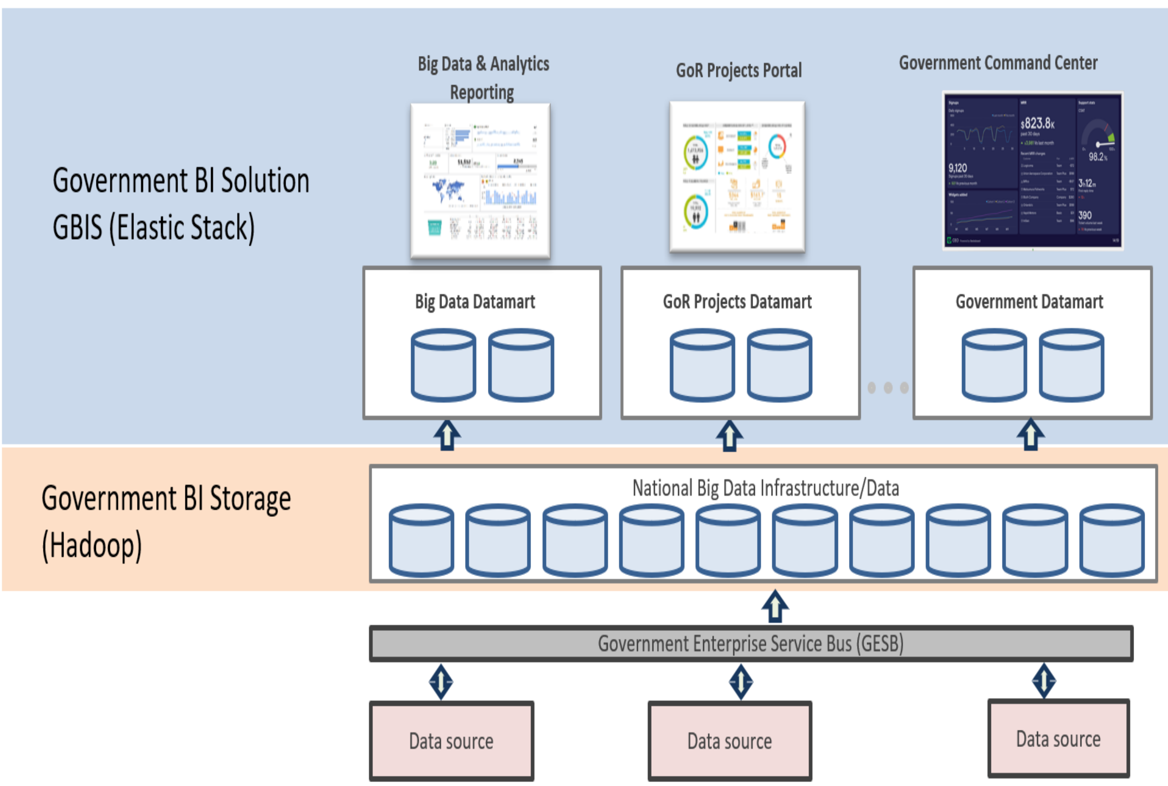

Figure9: High level architecture framework

4.4.2. Proposed unified architecture framework for integrating IoT into national key infrastructures

In this thesis, englobed architecture was proposed as indicated in Figure 9. It indicates the architecture defining how can manage air quality, water quality and waste monitoring in smart way by following the proposed four layers: perception layer, network layer, application layer and data management layer.

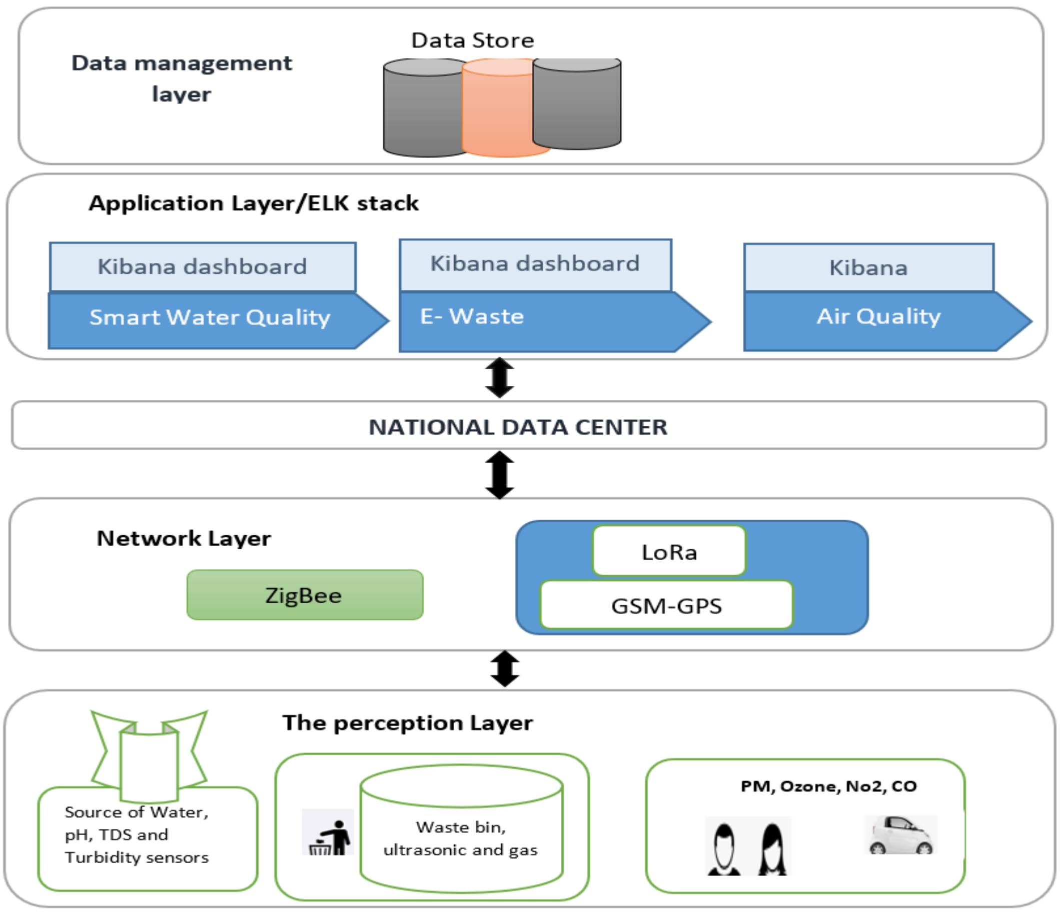

Figure 10: Proposed unified IoT Architecture framework

i. **Perception layer:** is characterized with the use of sensors such as pH, Chlore and Turbidity sensors for Smart Water Quality, Ultrasonic and Gas sensors for Smart Waste Monitoring and air quality monitoring. All these sensors are used to collect information and request information from networks.

ii. **Network layer:** is composed of networks communication like ZigBee and LoRa used for the air quality for managing and setting communication between perception layer components and network layer components, the Global Positioning System that determine precise location of waste bin. While Global System for Mobile communication, digitizes and compresses data, then sends it to the web application for being monitored and analyzed on application layer.

iii. **Application layer:** describe the interface for three applications, it determines also the visualization of data and data analytics. These applications are:

- ✓ Smart water quality management
- ✓ Smart waste bin monitoring and
- ✓ Smart air quality monitoring

We proposed Kibana for visualization and analytics

iv. **Data management layer:** stores collected and manipulated data in database for futures use or reporting. This database is linked to Kibana.

This is a proposed basic and simple architecture framework that can be help researchers, implementors and Government to understand the way IoT can be adopted to enhance the e-government to help in intelligent decision making.

The companies, the government agents, schools, public and private markets and offices are the users of such described study depending on what they are willing to do. Each part is composed of three parts such that sensing part, data storage & analyses, and data visualization & as described in the previous figures.

4.4.3. Technical Architecture

we propose Logstash for ETL (Extra/Transform/Load) from multiple source data for building data warehouse, Elasticsearch will used to create data mart and Kibana will used for creating dashboards/Reports/Analytics and intrusion detection.

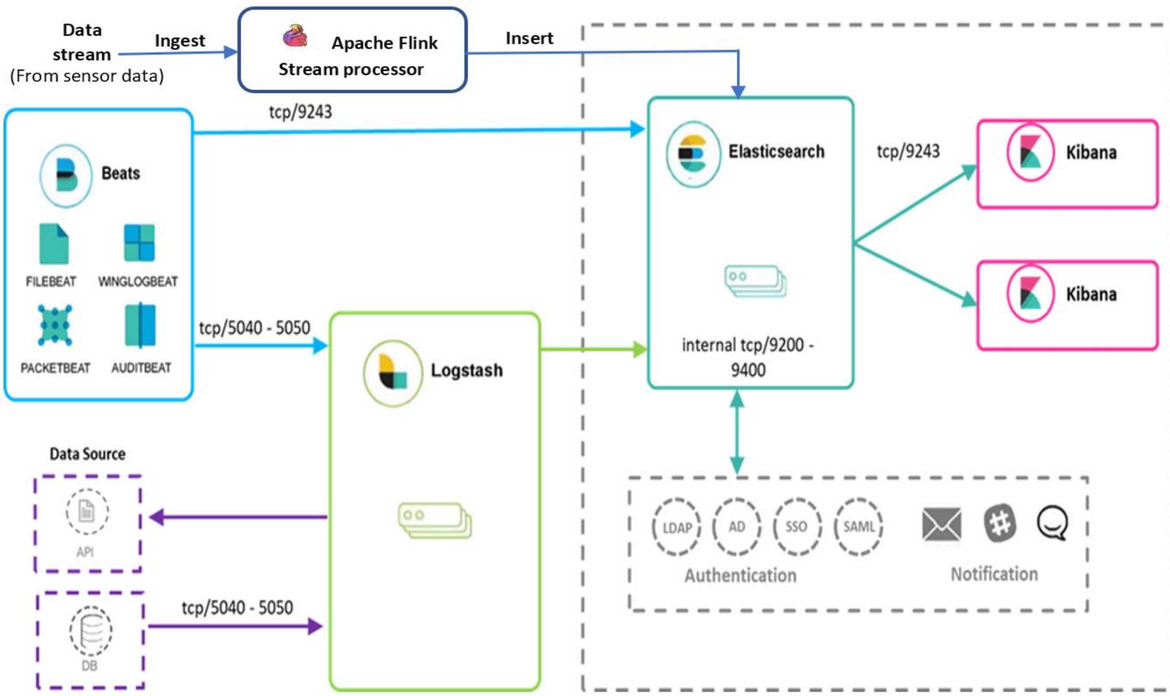

Figure 11: Technical architecture

Data source layer

There are multiple data source that need to be integrated with our framework across different institutions or departments.

Data integration layer

Logstash would access all the sub systems to get required data and performs ETL (Extra, Transform, Load) process keep track of the table and columns in the table and the complete table will be refreshed in the target table. For real time streaming data from sensors apache Flink will be used.

Data Warehouse / Data mart Layer

Once the ETL and the data stream process is completed, the data would then be stored as tables in Elasticsearch.

Dashboards & Reporting

This is for data engineering and cleansing where Kibana will used for creating dashboards/Reports/Analytics.

CHAPTER 5: DATA VISUALIZATION AND ANALYSIS

To analyze and visualize data, Kibana have been used. Kibana helps to navigate the Elastic stack and to give shape to the data. enables you to give shape to your data and navigate the Elastic Stack. Kibana is responsible of analyzing, monitoring and managing your data, controlling access and the health of your Elastic Stack agglomeration as well as finding security vulnerabilities. Kibana is for administrators, business users and analysts and it works for all types of data: structured or unstructured text, numerical data, time series data, geospatial data, logs, metrics, security events, etc.

For administrators: Kibana provides the management of Elastic Stack, from deploying the data from Elasticsearch into Kibana, and then the management of the data.

For analysts: Kibana helps to view the data on dashboards, find insights in the data, and share the findings.

For business users: Kibana helps viewing existing dashboards and to go into details.

5.1. How Kibana works

Kibana has five steps: *add data, explore, visualize, model data behavior* and *share* as shown in the figure below:

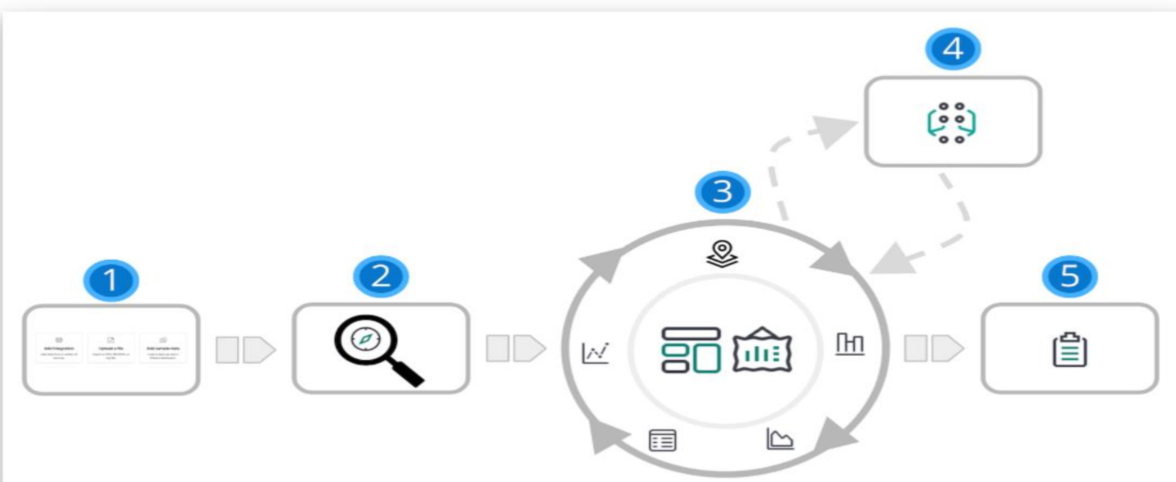

Figure 12: Steps of Kibana

1. **Add data**: You can upload data from your file, from an app or service, or upload a file that contains your data. On the Kibana home page, you find where you could add data
2. **Explore or Discover**. Rapid search and filtration of your data to get the information you wish and visualize it.
3. **Visualize**: With Kibana, many options are available for creating data visualizations using graphs with dashboard as the starting point starting.
4. **Model data behavior**: Kibana uses *Machine learning* for modelling the data behavior such as anomaly detection, classification analysis, strange behavior and regression.
5. **Share**. Kibana provides different options embedded in it to share findings such as share a link, export to PDF.

5.2. Kibana

After log in to Kibana, the home page of your space appears and you can find where to add data:

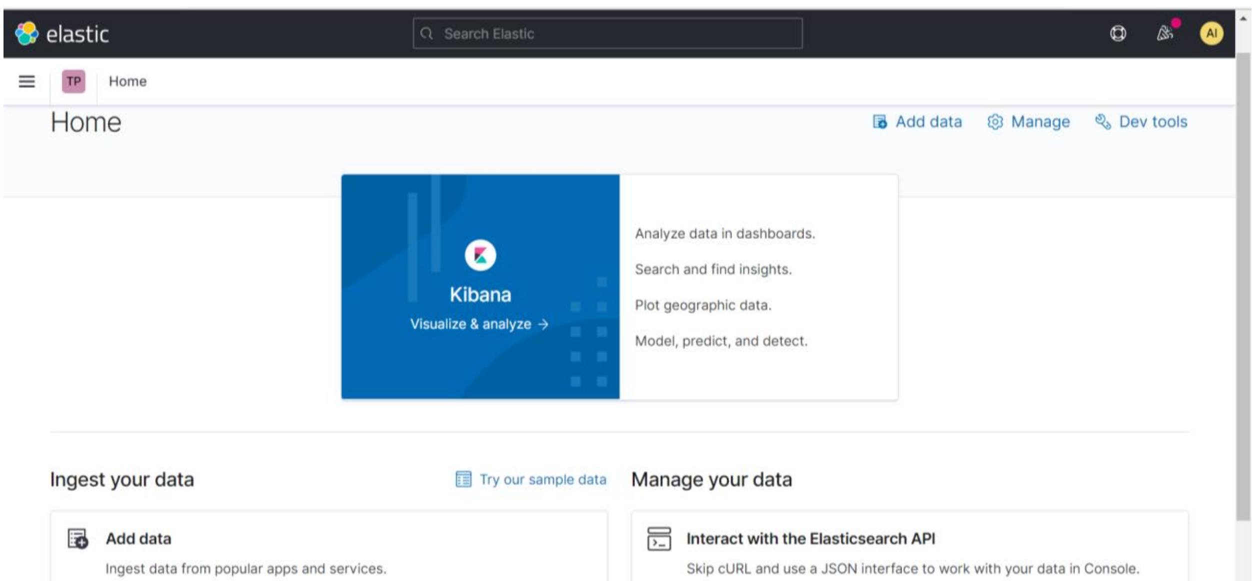

Figure 13: Kibana home page

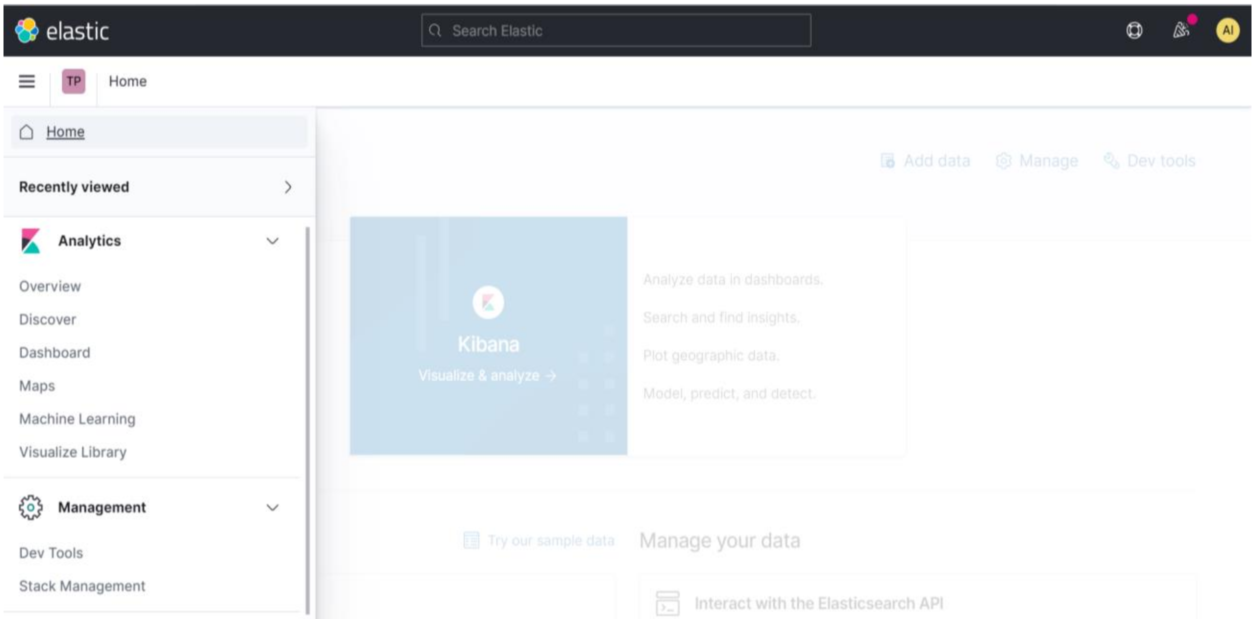

Figure 14: Kibana home menu

5.3. Analyze and visualize the case studies

By using collected data, we have selected parameters to be analyze where the purpose was to look if water to be distributed is safe for smart water quality monitoring, how bins in different markets are behaving, their collections rate for smart waste collection.

For Air quality monitoring, real time data from seven sensors deployed in different areas in Kigali have been used to monitor 4 gases and look their rate of pollution.

1. Smart air quality dashboard

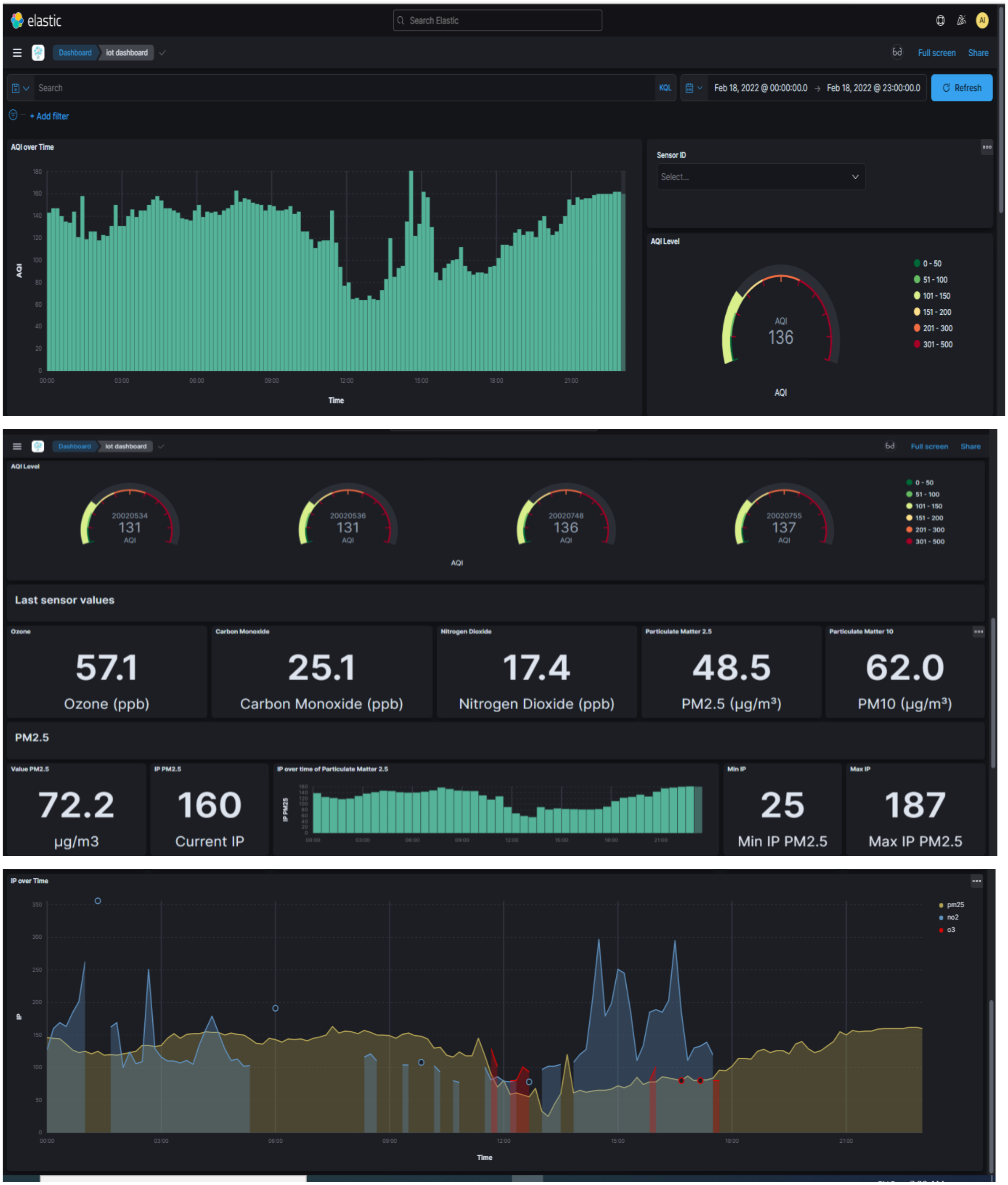

Figure 15: Smart air quality monitoring dashboards

The air quality is determined based on the index of pollutants (IP) and the air quality index (AQI) which is the index of pollutant, IP with the highest value used for reporting air quality on a daily basis to show how the air pollution can affect people health in a short period of time. It is There are six categories of AQI represented with different colors:

AQI values	Description	Colors
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151-200	Unhealthy	Red
201-300	Very Unhealthy	Purple
301-500	Hazardous	Marron

2. E-waste dashboard:

For smart waste collection, a bin at different markets is selected to measure its fill level. The bin is considered as full at the level of 80%.

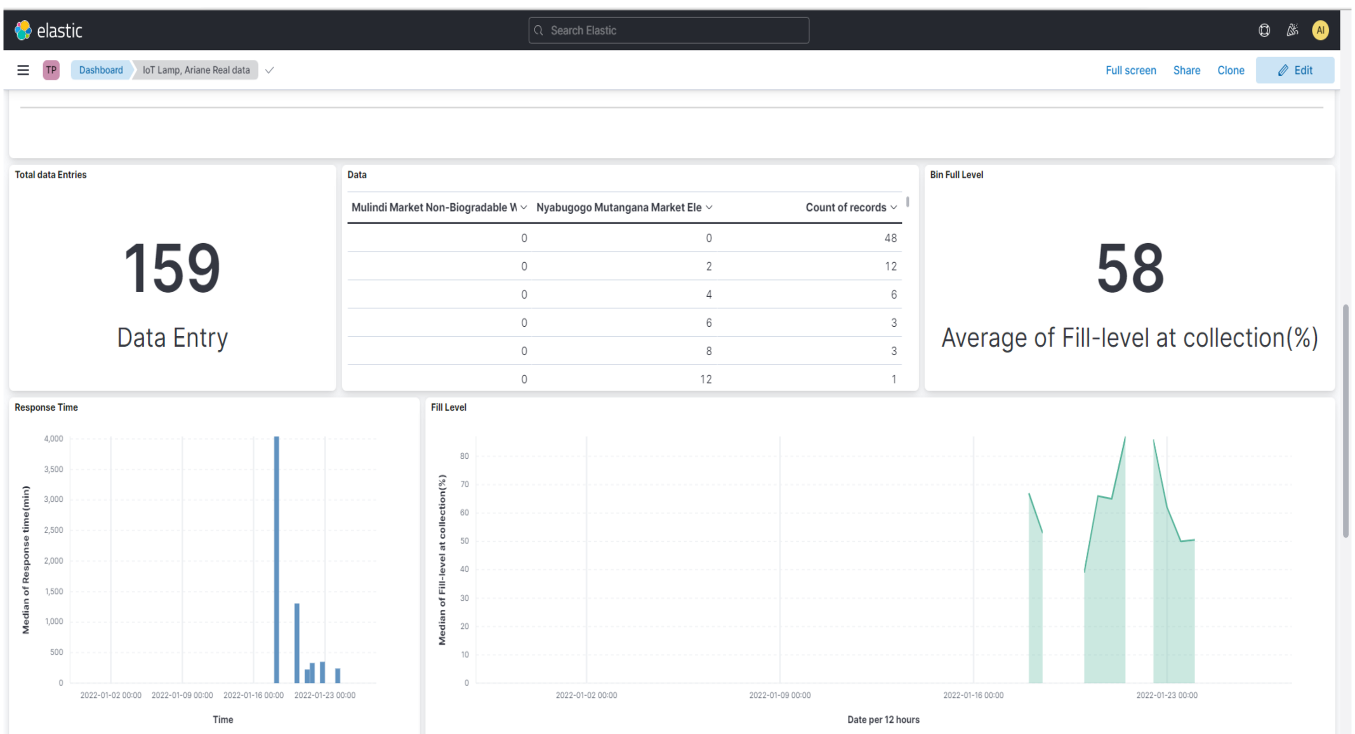

Figure 16: E-waste dashboard

3. Water quality dashboard:

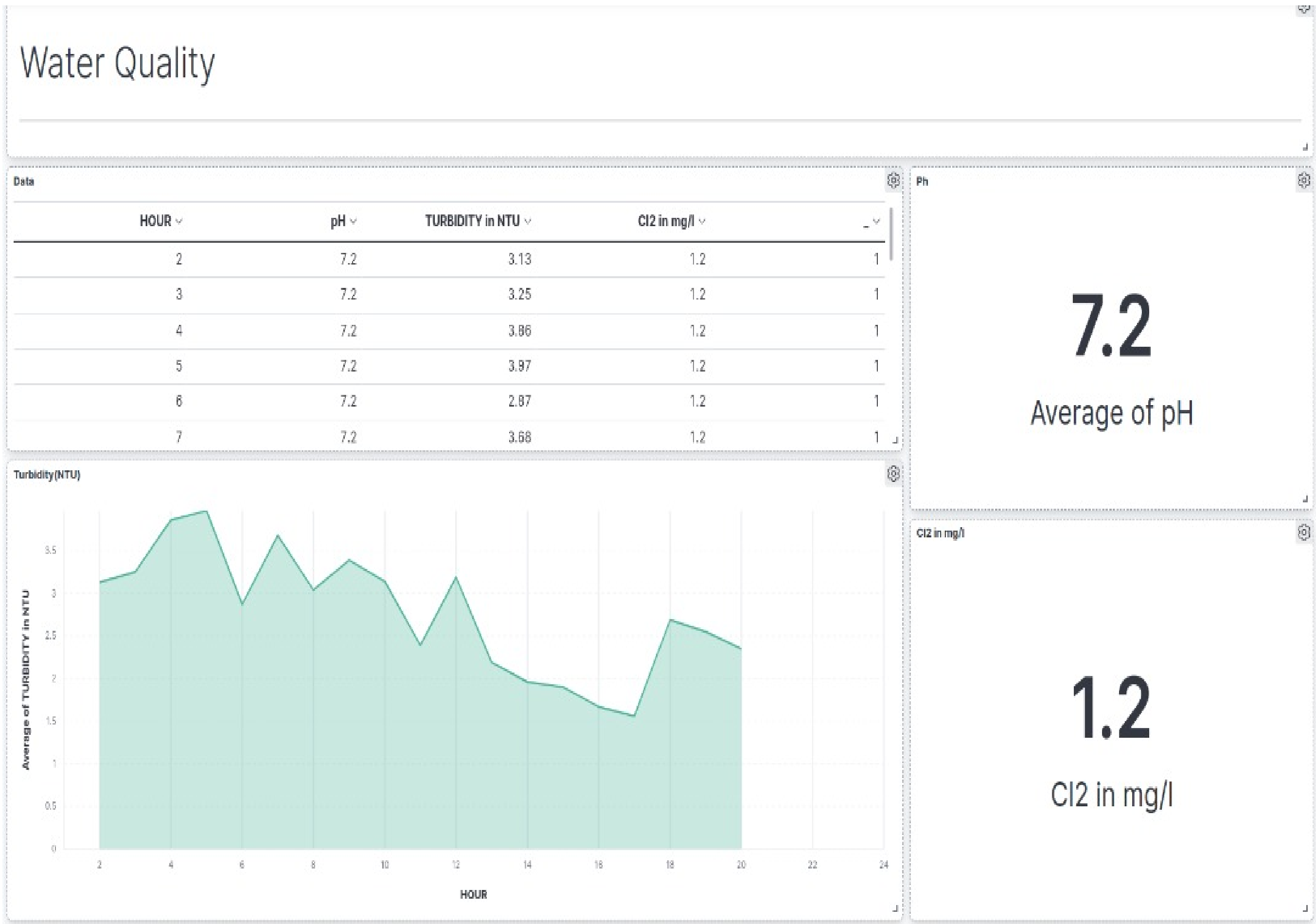

Figure17: Smart water quality dashboard

Here three parameters have been selected to be used: Turbidity, pH and Chlore (Cl2) for measuring the quality of Nzove branch of WASAC in CoK. Safe pH is between 6.5 and 8.5 above this threshold the water is alkaline while below it is considered as acid. When the turbidity is 0-5 NTU (nephelometric turbidity units), the water is safe and tolerable chlorine is up to 4mg/L.

N.B.: Dashboard can appear differently based on how you want it to be or to have, also every stakeholder has access to only what he/she has to get.

5.4. Discussion

The purpose of our research was to design a unified architecture framework the can be used to enhance the e-government in Rwanda by integration IoT into key national infrastructures.

The proposed framework is the basic architecture to be considered when enhancing e-government in developing countries by using advanced technologies for making the Government more efficient and smarter in social economic domain. This was done in the help of three case studies taken in City of Kigali and framework is designed in improved, understandable and easier way based on the basic IoT three layers architecture in order to help decision makers to keep getting informed on every time situation in different government services. The framework is composed by the data collection part where IoT sensors are used to gather data from national infrastructures and transform it in digital/electronic form that can be recognized technically for further processing, the communication part where different network technologies are used to transfer collection data in the application layer to be analyzed, processed and visualized using Elastic stack products which are powerful and able of to deal with data coming from various sources and put it in different data mart according to the specific function.

Benefits of integrating IoT in e-government are:

- Making easier the enforcement of policies and regulations
- Efficient way for collecting information from national infrastructures and to be informed about the current situation of those infrastructures in real time.
- Quick action/responses
- Improve flexibility, efficiency and effectiveness of services provided to citizens
- Safety improvement
- Efficient planning and procurement
- Improved life quality of citizens

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The integration of IoT in e-government, is very important because of IoT capabilities to gather data from the physical world using different types of sensors and transform those data to the digital world. That is why, in this research, after looking of the advantages of both the IoT and the e-government, we proposed a unified architecture framework for integrating IoT in e-government to enhance it for Government of Rwanda by utilizing three national key infrastructures which are: air quality monitoring, waste collection and water quality monitoring which are our used case studies for the purpose of having an intelligent decision making at the national level based on the real facts with genuine data get in real time for quick scientific analysis, reactions and responses. Analyzing and visualizing the collected data is performed using Kibana tool from Elastic stack platform which is a powerful product with machine learning technology. Elastic stack is capable of collecting data from different sources and sort those data for intended purpose or user. Results show that it is possible to have information of different national programs on the same dashboard in real time and being notified when it is requires.

6.1. Recommendation

6.1.1. General recommendation

For doing a good research and having a good project realization, more practical works could be performed during the period of theoretical studies to match both of them; this can contribute a lot during the final project research.

The University of Rwanda should provide on time, all tools that help students during their researches, also provide more time for final research project for better results and give opportunities to students with best selected projects to finalize and realize them in the real life what will raise the level of innovation.

6.1.2. Specific recommendations

I recommend other researchers to do further researches for improving this one by looking on other possible aspects that haven’t been considered and by also increasing the number of use cases and parameters; also looking at the implementation of our designed framework to reach to our aim of enhance the Rwanda e-government with the integration of IoT.

Next time, it will be better for researchers to go and collect data on field for improved work.

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