UNIVERSITY OF NAIROBI

COLLEGE OF BIOLOGICAL AND PHYSICAL SCIENCES

SCHOOL OF COMPUTING AND INFORMATICS

USE OF BLOCKCHAIN TO DIGITIZE LAND RECORDS AND TRACK LAND TRANSFER TRANSACTIONS IN KENYA

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A research project report submitted in partial fulfilment of the requirement for the award of Masters of Science in Distributed Computing Technology of the University of Nairobi.

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DECLARATION

This research project is my original work and to the best of my knowledge has not been submitted for any other award in any university

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This report has been submitted for examination with my approval.

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DEDICATION

I dedicate this work to my parents who introduced me to education, my wife for support, my son and daughters for their love.

ABSTRACT

Land transactions have been marred by illegal, unauthorized and untraceable actions globally and locally in Kenya. This has led to huge loses when same parcel is allocated to multiple owners or to wrong owner. To help curb the menace in land transactions, governments are digitizing the physical records used historically. Whereas, most attempts are using the traditional approach of a centralized land management system controlled by one body, there are ongoing projects and pilots to use decentralized systems to manage land records and transactions. Blockchain being at the heart of distributed ledgers, it can be used to solve the issues faced in land transactions.

The objective of the research was to investigate existing vulnerabilities in land records and transactions, hence propose a solution using blockchain. The research was focused on land registries and actors interacting to effect various land transactions. Physical and phone interviews were conducted with several actors in land transactions, there was a review of documents used in land transactions.

The research revealed existence of vulnerabilities in land records as presently stored and nature of transactions conducted. The application developed using distributed ledgers shows how blockchain can be used to enhance integrity, security and traceability of land transactions. The main limitation of the research was selecting a subset of actors in the land sector and therefore may not cover all vulnerabilities in land transactions.

The research conclusion showed the main land transactions that are vulnerable and how they are exploited by unscrupulous persons. The application developed shows how blockchain can solve most of the vulnerabilities. This research project sought to show blockchain can be used to track land transactions by various actors like: land registrars, buyers, sellers, banks and surveyors. This would solve the current pain points facing the actors in land transactions.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
API	Application Programming Interface
CA	Certificate Authority
DLT	Distributed Ledger Technology
HSM	Hardware Security Module
IBM	International Business Machine
IS	Information System
MSP	Membership Service Provider
SDK	Software Development Kit

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CHAPTER ONE: INTRODUCTION

1.1 Background

Land records in Kenya within general boundaries are mainly in physical files located in district land registries. Any transfer involves the access of the physical files and changes added in the records. The attempt to digitize the records has proposed use of a centralized system to keep the land records and track all transfers affected.

According to Rizwan et al. (2020), there is need to develop a distributed system that will accelerate land registration processes in addition to making it easy for actors like sellers, buyers, financial institutions and government officials to transact by storing all transactions in the transfer of ownership. They further explained the system should implement blockchain to ensure all transactions committed during the process of transferring ownership are transparent, traceable and immutable.

Using blockchain, the transactions are immutable and stored in a distributed ledger hence decreasing cases of fraud in the transfer process. Implementing smart contacts concept of blockchain technology, we can automatically trigger events like transfer of funds from buyer to seller only after verification of all documents and successful transfer of land ownership (Rizwan et al., 2020).

1.2 Problem Statement

The process of transferring land is characterized by a long period of time to effect changes. Secondly it's prone to fraud where unscrupulous workers and citizens collude to make illegal transfers of innocent landowners' parcels. Innocent buyers are also conned most of the time into buying public land, road reserves and unauthorized parcels.

As explained by Collindres et al. (2019), on average it takes about 6 processes, 22 days and total fees of 5.7% of the property's values in order to get it transferred. Further in the study, Collindres et al. (2019) established commercial disputes emanating from land transfer takes an average of 920 days to resolve from the instant a legal action is filed in court until effective payment is made; the cost in court fees and attorney fees, represents around 35.2% of the total claim.

1.3 Objectives

General Objective

The general objective is to develop a system using distributed ledger technology to store land records and implement blockchain to track all transactions of land transfer.

Specific Objectives

I. Find out main challenges and vulnerabilities in land transactions in Kenya.
II. Use distributed ledgers to digitize land records in Kenya as opposed to centralized systems controlled by one office.
III. Develop an application using blockchain for land transactions.
IV. Develop Application programming Interface (API) that can be used for land transactions.
V. Test the system and API to validate functionality.

1.4 Research Questions

I. Which are the main challenges and vulnerabilities in land transactions in Kenya?
II. Which land transactions are common in Kenya?
III. Which blockchain platform is the best to digitize land transactions?
IV. What kind of interface would stakeholders require for interacting with the system?

1.5 Significance of the research

In their research, Rizwan et al. (2020) show that land is a high-valued asset hence it is very important to have correct records which pinpoint the current owner and provide the proof that he is indeed the legitimate owner. They enumerated some of the reasons to have a fool proof system for land records:

I. protect owner's rights
II. prevent sale frauds
III. make sure ownership is transferred correctly to new ownership
IV. resolve disputes

This research was aimed at giving solutions to painful processes in the current system of keeping land records and managing transfers. They include:

I. Unauthorized transfers of land without consent of the legitimate owner can be eliminated.
II. Transfers of public and community land to individuals can be curbed.
III. Non-repudiation of land registry officers doing illegal transfers. The cryptographic record include digital signature of the land officer authorizing all new records and transfers hence he/she cannot refute to have committed.

1.5 Scope

The scope of this research is limited to district land registries in Kenya currently used to store land records for rural areas for the respective districts. The study sought to establish the main challenges encountered by users in those land registries. Since operations are standard, based on the findings from the land registries used in the study, the research end product is an application that used Distributed Ledger Technology to solve the issues highlighted.

1.6 Nature of the End Product

According to Oates (2006), researchers in IS and computing want to solve a problem by developing a computer-based product. If they develop a computer product to do something in a new way, then it is research.

The research aimed at developing a computing system using distributed ledger technology to digitize land records in Kenya and use block chain to track transfer of land transactions. According to Glaser (2017), by using blockchain technology in land registry it would be possible to resolve many problems that are characterized by a typical centralized system of storing land ownership records. The decentralization of records and control coupled by the immutable nature of blockchain avails an opportunity to build systems that are 'trustless', collaborative and multi-sided. The following technologies have been used:

I. **Front end:** HTML, CSS, JAVASCRIPT
II. **Backend:** PHP, Node Js
III. **Database:** PostgreSQL
IV. **Server:** Linux
V. **Blockchain framework:** Hyperledger Fabric

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, the research dives into literature about land records in Kenya, common land transactions and vulnerabilities and current status of digitizing land records. The research then explores how distributed ledgers function and suitable blockchain platform that can be used to digitize land records and transactions. There is also review of existing work by other researchers on how blockchain can be used to solve problems in real life especially on transfer of value like property ownership.

2.2 History of Land Records in Kenya

The survey of Kenya was established in 1903 under the colonial government. Land registries were established across the country in 1970s and later in 2000 the District Land registries were formed. The 2010 constitution introduced the community land management policy. The Ministry of Lands was merged with Housing and Urban Development in 2013.

Land records for all towns or urban areas referred to as fixed boundaries or cadastral maps are stored at National Titling Centre in Kenya's capital Nairobi. Land records for rural areas referred to as general boundaries are stored at the District Land Registries.

2.2.1 Status of Land Digitization in Kenya

The government of Kenya has embarked on a program to digitize the land records in Kenya. The project dubbed Ardhisasa, was launched in April 2021 after three years of development since 2018. The Land Management Information System has started with land records in Nairobi with plans for rollout to Nairobi Metropolitan which includes neighbouring counties of Kiambu, Machakos and Kajiado with eventual rollout in entire country. Ardhisasa is a centralized system controlled from National Geospatial data centre.

2.2.2 Common Land Transactions in Kenya

This research established land transactions in Kenya are categorized into five main areas and different services fall under those categories. Land registration has the following services: caution, charge, lease, replacement of title, restriction, search, stamp duty and transfer. Services offered under land administration include: subdivision, extension of lease, change of user, consent, lease preparation, extension of user and renewal of lease. The category of survey and mapping has the following services: subdivision, amalgamation, extension of lease and re-survey. Other categories include physical planning and valuation with services such as: certificate of compliance, asset valuation, estate administration and arbitration.

2.2.3 Main challenges and vulnerabilities in Land transactions

The research probed further to establish the most vulnerable land transactions. The following transactions were found to have more challenges and cause pain to stakeholders:

Search is done by filling the provided form, attaching required legal documents and paying the stipulated search fee. Upon submission, the land registry officer accesses the physical file for the land parcel and fills the details on the submitted form. The applicant later collects the search results within a period of 1 day to 3 days based on traffic of the land registry. The main pain with the search is relatively longer period of time taken and relying on physical forms which can be manipulated.

Transfer is done under several conditions such as purchase, inheritance or government allocation. The owner submits KRA PIN Certificate, National ID card copy, passport photos and duly filled forms. The entire process usually takes different path based on reason for transfer. For example in case of sale, the seller must also submit legal documents. The main challenge currently is possibility of double allocation which is usually noticed late.

Stamp Duty is paid to the government when there is transfer of ownership. Valuation is conducted and the owner then pays the fee based on the stipulated percentage of land value. The main challenge is evasion since there is no proper tracking of all transfers done.

Charge and Discharge is usually done by financial institutions like banks when a land owner wishes to use the land parcel as collateral for loan. The main challenge with this transaction is when land owners manage to charge same parcel with more than one financial institution.

Caution and Caveat are restrictions placed by land owners to stop any transactions for the parcel of land. The research found out the transaction is vulnerable when caution is removed without their consent and transactions like transfers are done.

2.2.4 Land Acts in Kenya

According to Kenya laws in The Land Act (2012), the jurisdiction of land in Kenya territory falls under three acts of parliament. Anjarwalla and Khana (2012) summarizes the land acts as follows:

The new land acts enacted by Kenya parliament following 2010 constitution:

I. Land Registration Act, 2012
II. Land Act, 2012
III. National Land Commission Act, 2012

Important highlights by Anjarwalla and Khana (2012) about changes put forward by new land acts entail:

I. To have a single registration system and one Land Registry
II. Change of format of land documents
III. Creation of 3 categories of land: public land, community land and private land
IV. Land and Environment Court

2.3 Overview of Distributed Ledger Technology (DLT)

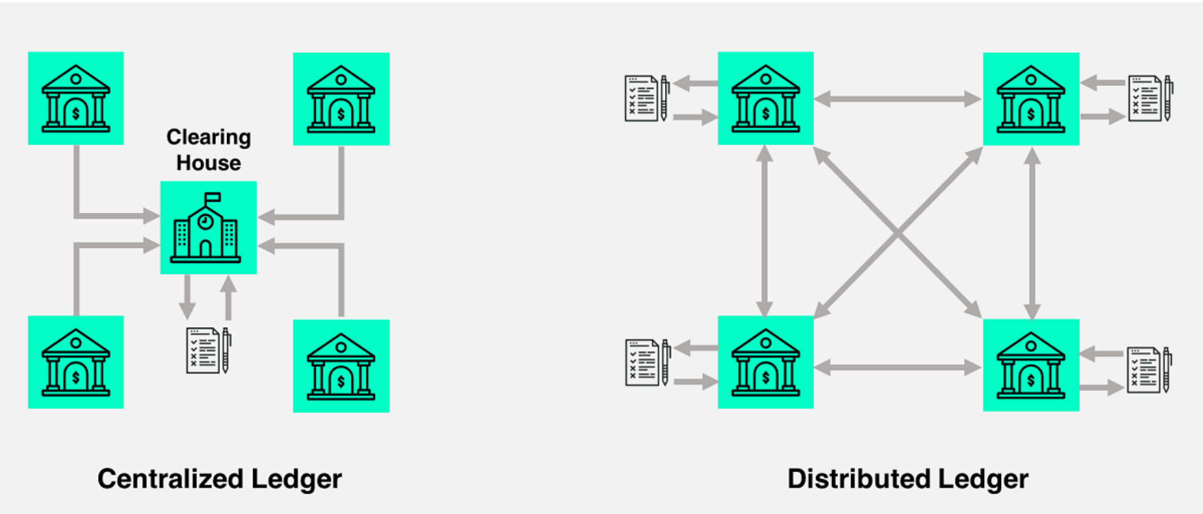


Figure 1 - Centralized Ledger vs Distributed Ledger. Source (Beedham, 2018)

According to (Beedham, 2018), a distributed ledger consists of a database that exists in several locations and usually controlled by multiple participants; whereas a centralized database is stored in a single location and it's controlled by one party. This means the biggest weakness of a centralised database is the existence of single point of failure. On the other hand, the main advantage of a distributed ledger is the decentralization of storage and control hence no single party has authority to process, verify or validate transactions and add blocks. Distributed ledger technology is being used by enterprises to verify transactions during data exchange. The different nodes participating in the blockchain use installed smart contract to validate transactions using consensus protocol and the block is only added after consensus has been reached. Each block stored is timestamped, assigned unique identifier and it is connected to the next block using cryptographic signature. The blockchain technology hence provides immutable storage of records and transaction that are verifiable and traceable.

2.3.1 Classification of Distributed Ledgers

Distributed ledgers have been categorised by Hileman and Rauchs (2017) based on level of access. Based on **read access** which refers to which actors can access and see transactions stored in the distributed ledger network we have **public** where anybody can access and see all transactions in the ledger and **private** where only selected parties can access and see transactions in the distributed ledger. Based on write access which refers to who can make changes in the distributed ledger like committing transactions we have **permissionless** where anyone can participate in consensus process of approving transactions added to the distributed ledger (the only limit may be resources such as computing powered required). In **permissioned** only the selected participants can make changes to the distributed ledger by committing transactions.

2.3.2 How Blockchain Technology works

Blockchain at its core uses Distributed Ledger Technology (DLT). DLTs are classified as highlighted above based on level of access. The two broad categories are: **public permisioneless** also referred to as **open DLTs** such as Bitcon and Ethereum which are technically open to anyone for read and write access. For **private permissioned** also referred to as **closed DLTs**, they exist in entities that know each other such as commercial banks (Vos, 2017) and only allowed participants can access the distributed ledger for read and write such as **Hyperledger Fabric**.

In the blockchain environment, information is stored in a distributed mode across computers commonly referred to as nodes and blocks are added by way of consensus among the participating nodes. As explained by Vos (2017), blockchain is a peer to peer decentralized system with no central decision-making method hence a dynamic and predetermined method of reaching agreement referred to as consensus has to be in place instead of a central entity of authority. The commonly used types of consensus are: proof of stake and proof of work. In proof of work, the consensus method involves solving of a complex computational problem and reward given to first computer usually referred to as miner by being allowed to add a block to the blockchain. According to (Yaga et al., 2018), the proof of stake model uses the amount of interest and control a participant has as a determining factor to add new blocks. Therefore, users with more stake are more likely to produce new blocks.

2.3.3 Blockchain Technology for Land Registry

Traditional use of centralized system for land registration to store records, process and track transaction has had many problems which can be addressed by blockchain technology. The resulting distributed ledger provides storage of ownership records in a manner which is immutable, auditable, verifiable and traceable(Glaser, 2017). Any attempt to alter land transactions like changing ownership would result in change of the cryptographic signature that had been calculated and connected to following blocks hence easily noticeable as they appear like new entries in the ledger therefore it is tamper proof (Lemieux 2016). As stated by (Benbunan-Fich & Castellanos, 2018), blockchain technology allows definition of smart contracts, verification and validation of new transactions submitted by use of distributed consensus mechanism for adding new blocks and use of cryptography to ensure there is security. To secure the data stored in the blockchain, it is published in an encrypted form by assigning each block a cryptographic unique fingerprint in the immutable and distributed ledger (Nakamoto, 2008). The data stored in the distributed ledger is protected from alterations, and from malfunction of the system hence critical records of data are secured in the blockchain by “proof of existence” (Lemieux 2016).

The most appealing characteristic of the blockchain is its immutable nature. Each block is joined to the preceding block by a cryptographic signature which contains hashed information of the former block (Lewis, 2016). In contrast to an ordinary ledger that stores enumerated records which are not linked in any way, in blockchain each stored block has a hash representing content of preceding block. Therefore, it is mathematically impossible to alter the content of a block without altering the whole chain of blocks. Any attempts to tamper with any block would be easily noticeable by other nodes (Vos, 2017).

2.3.4 Smart Contracts

Smart contracts are programs stored in a blockchain that are only executed when pre-set conditions are met. They are used to automatically execute an agreement so that all participants can be sure of the result, without any involvement of an intermediary or loss of time. In addition, they enable automating workflows and triggering the next action when the set conditions are met.

Smart contracts function by using conditional statements like: “if, else, switch” that are written into code in the blockchain. The network of nodes executes the actions when pre-set conditions have been fulfilled and validated. These actions could include sending notification, transferring ownership, or issuing a certificate. The blockchain is only updated when the transaction is committed successfully. Therefore, the transaction cannot be changed, and only participants with permission can see the results in the blockchain.

The participants in the blockchain must agree on the rules to use to determine how transactions are verified satisfactorily. The smart contracts can be programmed by developers and submitted to the network for approval by the participants.

Benefits of Smart Contracts

Security: Transaction records in the blockchain are encrypted hence making them very hard to hack. In addition, because every record is joined to the preceding and following records in the distributed ledger, any hacker would have to change the whole chain to alter a single record.

Speed, efficiency and accuracy: The smart contract is executed immediately the predetermined sets of conditions are met. Since smart contracts are automated, there are no physical documents required during processing and no time is spent reconciling errors from manual records.

Trust and transparency: Since there is no involvement of third party, and records of transactions are shared across participants in an encrypted format, information cannot be altered.

2.4 Existing Work

2.4.1 Related Work Globally

Research conducted by Benbunan-Fich and Castellanos (2018) explored two country instances of land records digitization by using blockchain technology. The instances were in Honduras and Georgia where examination was done on how technical, social-political issues and IS readiness of public institutions to adopt emerging technologies such as blockchain influence uptake of proposed solutions. Both countries partnered with organizations offering blockchain technology but one case was more successful than the other one. In Honduras the implementation of land registry digitization using blockchain stalled mainly due to lack of political support despite support from organizations like World Bank. The project was started and stalled but it illustrated blockchain can be used to resolve traditional problems ailing the country's land records and transactions especially in transfer of ownership. In contrast, the implementation of blockchain in Georgia's land registry was very successful due to political goodwill, existence of blockchain technology and willingness to adopt the technology to resolve problems in the land registry. Both cases illustrated blockchain can be adopted in any country to digitize land records and trace all transactions if implemented properly and supported by all participants

Land Registry in Honduras

According to Lemieux (2016), Honduras had made attempts to upgrade the manual land registry by digitizing records using a centralized database; however they failed due to problems such corruption leading to alteration of records without authorization and creation of duplicate titles. As a result of those problems, an idea was born to digitize the country's land registry using blockchain which would provide distributed tamper-proof database. Honduras was one of the pioneers globally to evaluate the innovation of using blockchain technology to digitize their land registry and that attempt to increase transparency resulted in increased positive image of the country (Collindres et al., 2016).

Land Registry in Georgia

In Georgia, the process of selling, buying and transferring land was long and tedious. To verify any land transaction, sellers or buyers had to visit a public registry and pay a uniform or expedited fee to verify the transaction. The manual procedure was slow-moving and susceptible to bribery (Benbunan-Fich & Castellanos, 2018). According to (Heider & Connelly 2016), the government implemented blockchain to digitize public land registry in 2016, and as a result, Georgia improved global ranking for ease of registering a property.

Sweden

The Swedish government national mapping, land registration and cadastral authority was among the pioneer government agencies to test use of blockchain technology in digitizing land records and conducting change of property ownership. The government agency partnered with a telecommunication firm and blockchain technology company to develop a blockchain-based system for conducting land transactions (*Swedish Mapping Authority Pioneering Blockchain-Based Real Estate Sales | Nasdaq*, n.d.). They tested different ways to store records of property transfer transactions in a blockchain. In 2016, the blockchain experiment of digitizing land records concluded the second phase of testing. In 2017, the testing incorporated developing of blockchain-based smart contracts to automate transactions.

2.4.2 Locally in Kenya

Social Tenure Domain Model (STDM) was a pilot conducted in Kenya by Pamoja Trust (PT) in collaboration with UN HABITAT. They involved Technical University of Kenya (TU-K) in implementing the pilot project. The project entailed evaluating a system that could be used to capture land records in informal settlements like mapping and ownership information. The system also involved government agencies and academia who gave input on how it could be improved to actualize the dream of digitizing land records in Kenya(*Social Tenure Domain Model (STDM) Piloting in Kenya*, 2015).

The taskforce on distributed ledgers technology (DLT) and artificial intelligence (AI) in 2019 chaired by Professor Bitange Ndemo listed improvement of land titling as an emerging area of blockchain application by improving security. The taskforce on DLT and AI (2019), elaborated that blockchain can provide a secure mechanism to transfer property ownership and can eliminate corruption and land fraud in Kenya’s land management agencies. The following was recommended by the taskforce:

I. Digitizing all land records throughout the country.
II. Leverage on Blockchain in creating digital land records which are immutable hence increased transparency of land transactions.

III. Review and amend the land titles regimes to formulate guidelines for electronic land titling.

IV. Conduct public awareness campaigns in Kenya to train Land officials and Land practitioners regarding the blockchain technology.

2.5 Gaps Identification

Many countries including Kenya have a government entity in charge of land registration which mainly entails ownership and transfer of land rights records. The records provide true source to validate legitimate ownership when conducting transactions and helps to prevent fraud. In cases where out-dated land registry is used, the system results in delays when verifying ownership, transactions taking relatively longer and possibility of land misappropriation (Dobhal and Regan 2016).

Ways Blockchain can Improve Land Administration

Some of the challenges in land administration that can be addressed by blockchain include:

2.5.1 Corruption in the Land Sector

The land sector corruption cases can be considered to be prevalent and without fruitful means of control. (*Corruption in the Land Sector*, 2013). Due to lack of transparency in flow of information, it allows the elite to fabricate opportunities for corruption. While centralized systems have so far been used to digitize and improve access to information and increase transparency, blockchain can offer additional advantages over existing centralized systems. Due to its immutable nature, once a transaction has been processed, it cannot be removed from the blockchain thus creating secure records which are tamper-proof. Any alteration to an existing record or transaction would make the hash value or unique identification of the tampered block inconsistent with other blocks in the chain (Vos, 2017).

According to Berke (2017), a private blockchain can be developed in a way that participants have view-access to anonymous parameters of transactions like time thus providing an extra layer of security even on public blockchain. In addition to transparency and accountability of peer-to-peer validation; this approach would give a blockchain-based land registry the main advantages of a public blockchain such as quick traceability, error detection and correction, and increased security. Therefore, this adds a clear advantage over existing systems using centralized records which can be altered without being noticed. Consequently, if utilized appropriately, blockchain has the ability to enhance transparency and decrease corruption in the land sector (Vos, 2017).

2.5.2 Cybersecurity

It is estimated that in most countries, up to 75% of the country's wealth exists in the form of real estate or land (Byamugisha, 1999). Land is also an important factor of production that contributes to growth of the economy. Therefore, as land registration systems and records are being digitized, cybersecurity becomes very important with respect to protecting people's ownership of land as one of the most valuable asset. When a country's digital systems are attacked, it poses a threat that land information could be hacked into and maliciously manipulated. Blockchain technology can offer an additional layer of security through its immutable nature and the merits that records generally cannot be tampered with (Vos, 2017).

2.5.3 Disaster Recovery

The distributed nature of blockchain offers the advantage of disaster recovery of land records in land registration (Vos, 2017). When a disaster strikes like natural calamity (earthquakes, floods), fires or wars, the servers storing the land records would be at risk of being damaged hence loss of data or require physical guarding to avoid intrusion and manipulation. The inherent nature of blockchain's ability to distribute or spread data over all engaged nodes decreases the threat of losing the data. In the event a disaster happens, blockchain would enable data recovery from other nodes with the same ledger hence operations would not be affected as opposed to centralized systems.

2.5.4 Property Rights of Women and Vulnerable Groups

Blockchain can enable "multisignature" transactions where multiple users' private keys are needed to finalize a particular transaction. This can create remarkable advantages for the property rights of women and other vulnerable groups (Vos, 2017). By requiring private keys of all owners of the parcel of land to make transfer transaction, blockchain will safeguard rights of women in marginalised communities which are patriarchal denying them properties.

2.6 Linking Existing work with this research

In Kenya, the Ministry of Lands and Physical Planning has embarked on first phase where it is digitizing land records in Nairobi and big cities. The digitization is using a centralized system at the National Geospatial data centre. In the second phase, the Ministry of Lands is planning to digitize land records in the general boundaries stored in District Land registries. This research and application developed has shown more security can be added to the digitization of land records by using blockchain technology. By implementing blockchain technology, not only efficiency of land search and transfer will be increased but also security of the transfer process since details of one block will be connected to the next block in a cryptographic hash.

2.7 Conceptual Model

Users: Registered users when authenticated can submit transactions. A consensus mechanism authorizes transactions to be added to the blockchain.

Graphical User Interface: it can be used by different users to interact with the system for example search, place caveats and transfer transactions

APIs: authorized nodes interact with the system via APIs for queries and transactions.

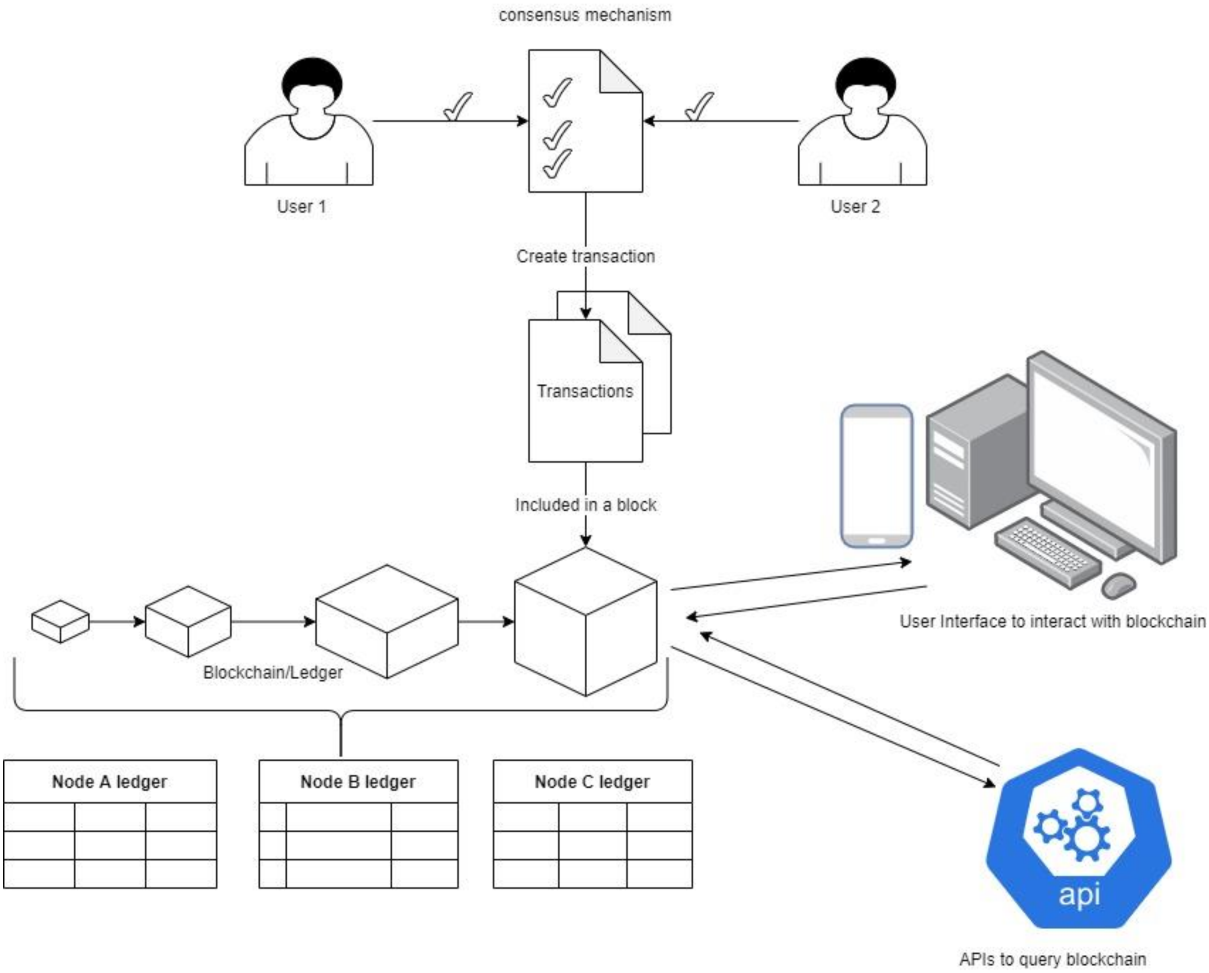


Figure 2 - Conceptual Model

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction and Methodological Approach

The research used applied research methodology. In applied research, the aim is finding a solution for an actual problem facing a society or an business organisation (Kothari, 2004). The reason it used applied research is because there is a computing system that has been developed implementing blockchain in digitizing land records and track transfer transactions.

The study also used qualitative research approach. According to Kothari (2004), qualitative research, is concerned with qualitative phenomenon, which is involving quality or kind. The main reason the research used qualitative approach is because sampled participants gave data that guided the nature of the computing solution. In addition, most of the data collected was in format of textual information and thus was analysed using the qualitative research methodology. According to Gounder (2004), when it comes to dealing with smaller amount of data, more focused samples of participants, qualitative research approach proves that calibre of data collected and analysed is of crucial importance but "size doesn't matter." Qualitative research is an extremely subjective research discipline, aimed at looking beyond the proportions to gain an understanding of feelings, impressions and views of the participants.

3.2 Delphi Research Method

The Delphi methodology is a research pattern, usually regarded a qualitative method, which was designed to predict workable solutions to problems where data was missing or insufficient. The goal "is to obtain the most dependable consensus of opinion from a category of experts" (Dalkey & Helmer, 1963) as to the best feasible remedies to the problem.

The research used guiding principles of Delphi technique which include:

I. Participants involved in the research are experts in their respective fields for example surveyors and blockchain developers.
II. Participants were unnamed. They did not recognize the other participants giving information.
III. The research used a series of iterations where information was returned to the participants for review.

IV. The Delphi methodology is a “consensus” research method. The target of the research was to approach an agreement amid the expert group as to future “best” solution.

3.3 Participants and Sample Size

Participants

According to Oates (2006), a research should consider 6Ps of research which are: participants, products, purpose, process, paradigm and presentation. It is important to consider how participants should act or be managed during the research. The participants as summarised by Oates (2006) includes:

I. The people directly involved in the research for example interviewees, people observed, participants filling questionnaires or supplying documents
II. Colleagues if it is a research team;
III. Members of the academic body who explore, evaluate and learn from the research work;
IV. System users who may be interested, use or be affected by any computing product developed.

The research involved the following participants:

Registered Surveyors: they gave information of the land registries records, processes and transactions. The surveyors interviewed highlighted the main challenges in land registries and the most vulnerable land transactions. The research also got data on the current status of digitization of land records and how blockchain can be used to address the existing gaps.

Land Selling companies: their interaction with land registries, buyers and sellers contributed data to this research. The participants provided data on common land transactions in Kenya and the most vulnerable transactions causing pain.

Blockchain experts, developers, researchers: these participants provided data on blockchain platforms. The factors to be considered when choosing blockchain platform for the application was as a result of data collected from them.

Land sellers and buyers: gave information on their interaction with land transactions. They gave information on most vulnerable transactions and how technology can be used to resolve the pain points.

Bankers: provided information on charge and discharge transactions.

Cybersecurity professional: input on securing web application and APIs developed to illustrate blockchain in land transactions.

Sample Size

According to Kothari (2004), when field studies are conducted in practical life, the respondents chosen should be illustrative of the total population as possible in order to produce true representation and results.

To select the sample size when using Delphi research method, Delbecq et al. (1976) noted that "With an analogous group of people, about ten to fifteen research participants might be sufficient" (p. 89). This research iterated during data collection by engaging the participants until there was no new knowledge added by engaging more new participants. The research engaged eleven participants.

The sample size was based on recommendation of Kothari (2004) that the proportion of participants sampled should neither be excessively huge, nor too tiny rather it should be optimum. By being optimum, the sample fulfils the requirements of efficiency, representativeness, dependability and flexibility. Non-probability sampling procedure was used to ensure all categories were represented. Due to the small sample size, non-probability sampling ensured representation of the whole universe.

3.4 Data Collection

According to Kothari (2004), the mission of data collection starts after a research problem has been determined and research plan drawn. While choosing the methods of data collection to be deployed in the study, the researcher should consider two types of data: primary and secondary. Primary is collected afresh and for the first time, therefor happens to be original in character. On the other hand, secondary data usually are already collected by other researchers and have been passed through the statistical process.

Primary Data

There are several ways of getting primary data, particularly in surveys and descriptive researches. Common ones include: observation, interview and through questionnaires, Kothari (2004).

This research used the following methods to collect primary data.

Observations

In the observation technique, the information is sought by researcher's own direct observation without inquiring from the respondent (Kothari, 2004). Researchers usually engage observation as a data collection method to discern what people actually do, rather than what they say they do when asked. Mainly observation involves looking, but it at times involves senses other than sight such as: hearing, smelling and touching (Oates, 2006). This research involved visiting a district land registry to observe how records are kept, how the transactions involving buyers and sellers are conducted, the role and conduct of middlemen and government land officers.

As enumerated by Kothari (2004), the edge of observation as a data collection method includes:

i. When observation is done accurately, subjective bias is eliminated.
ii. It enables collection of real-time information i.e. what is currently happening as opposed to past behaviors or future attitudes and intentions of participants.
iii. Observation allows the research to collect data without requiring active participation of the participant in contrast to other methods like interviews or filling questionnaires.

Interviews

An interview is a distinct type of conversation between people. Normally, the interviewer has the purpose for conducting the interview so as to gain information from the interviewee(s). Usually, the discussion is structured by the researcher to allow collecting information on target areas or subjects. The discussion topics do not occur arbitrarily or randomly but on selected particular agenda (Oates, 2006).

This research entailed interviewing participants to get data from them. Interview participants were drawn from categories of all envisioned stakeholders listed under participants of this research. The reason for choosing interviews to get data for this research is due to the advantages highlighted by Oates (2006) which includes:

i. Allowed collection of detailed information.
ii. Enabled asking questions that were complex which needed to be different for specific people.
iii. Allowed exploring feeling, experiences and passions that couldn't easily be observed or described via pre-defined questionnaire feedback.
iv. Allowed investigating delicate issues, or privileged details, that respondents could not be willing to pen down.

Secondary Data

Secondary data refers to information that is already obtainable i.e. the information which has already been collected and analysed by another researcher. Sources include: publications by local governments, publications by foreign governments or international bodies and their subsidiary organisations, technical journals, reports and publications of various associations (Kothari, 2004). Examination of existing documents was deployed as a technique of secondary data collection. The various documents used in land transactions were scrutinized and provided guidance on the application developed illustrating use of blockchain in land transactions.

Documents

According to Oates (2006), documents used as source of research data can be divide into: existing documents and researcher-created documents. This research involved collecting all documents used for registering land, conducting searches and making transfer of ownership.

3.5 Data Analysis Methods and Validations

Data Analysis

According to Kothari (2004), data after collection has to be refined and analysed in line with the laid down procedure for the purpose at the time of developing the research plan. This is crucial for a scientific study and for ensuring that we have all relevant data for making envisioned similarities and analysis. All qualitative data collected from primary sources was comprehensively arranged to facilitate analysis. It involved data editing, coding, classification and tabulation (Kothari, 2004).

Editing: This involved inspecting the data collected from the interviews to detect any omissions and errors so that they could be corrected. This ensured the data was accurate and consistent.

Coding: Similar data was assigned codes for classification or identification.

Classification: Data was arranged into categories according to similarities and differences identified.

Tabulation: Data collected was listed systematically for easier analysis.

Data Validation

Validity is demonstrating whether the instrument content is measuring what it is supposed to measure (Mugenda & Mugenda, 2003). For this research, data collected from respondents in interviews was analysed against the existing documents to determine its correctness and if it's acceptable.

3.6 Application Development

After analysis of the data collected the most common and vulnerable transactions were selected to be used in the application developed. Analysis of data collected from blockchain experts showed private permissioned blockchain platform would be the best for developing an application in the case of digitizing land records and transactions.

3.6.1 Application Overview

The application uses IBM blockchain platform on the backend. The server applications use Node.js Hyperledger Fabric SDK to connect to the network. The client application is developed using: HTML, CSS, JavaScript, PHP and PostgreSQL.

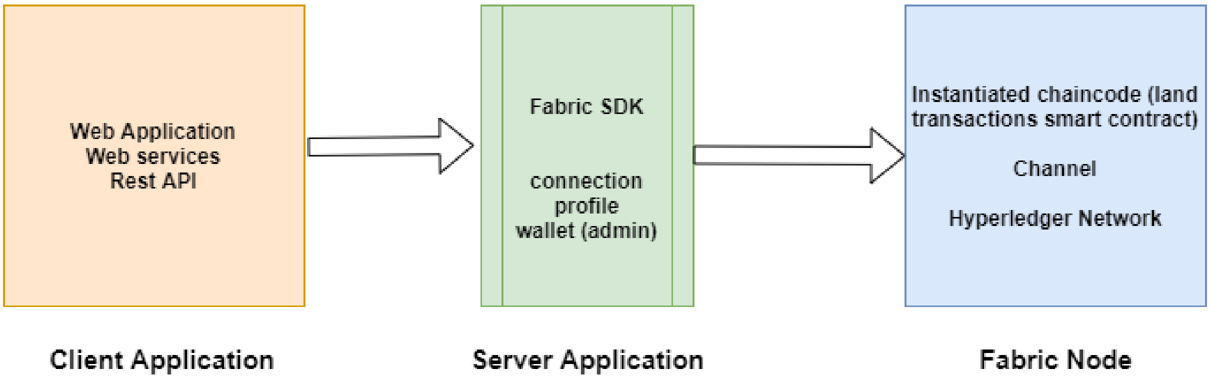


Figure 3 - Application overview

IBM blockchain uses Hyperledger fabric and has the following components:

Certificate Authorities: Each organization that joins the consortium must use a certificate authority to generate public and private keys for identifying all players in the blockchain which entails: nodes, administrators and applications.

Organizations: each organization forms a membership service provider (MSP) where users and nodes are registered.

Nodes: An organization must have at least one node which stores the ledger and participates in approving transactions submitted.

Ordering Service: This is a special node that orders the transactions which have been approved and timestamped so that they can be appended in the ledger.

Channel: For nodes to communicate, they must join the channel. Nodes in the channel discover other nodes which approve the transactions submitted.

Smart contract: Also referred to as chaincode in IBM Hyperledger platform. Once a chaincode has been committed and approved by member organizations in the consortium, it cannot be altered. The smart contract automatically approves transactions which meet the set conditions and rejects transactions which do not meet set conditions.

Administrators: Each organization must register at least one administrator with their CA. The administrator is issued with certificate which is downloaded and used by the application to connect to the blockchain network using Hyperledger Fabric SDK. The certificate can be stored in Hardware Security Module (HSM) in production but in development it can be stored in filesystem.

3.6.2 Sample Network

A sample IBM Hyperledger Platform network has several organizations. Each organization must use CA to register members, have at least one peer, administrator(s), form an MSP which joins the consortium. The peers/nodes join a channel so that they can communicate. An ordering service adds a timestamp to the transactions which are appended to the blockchain.

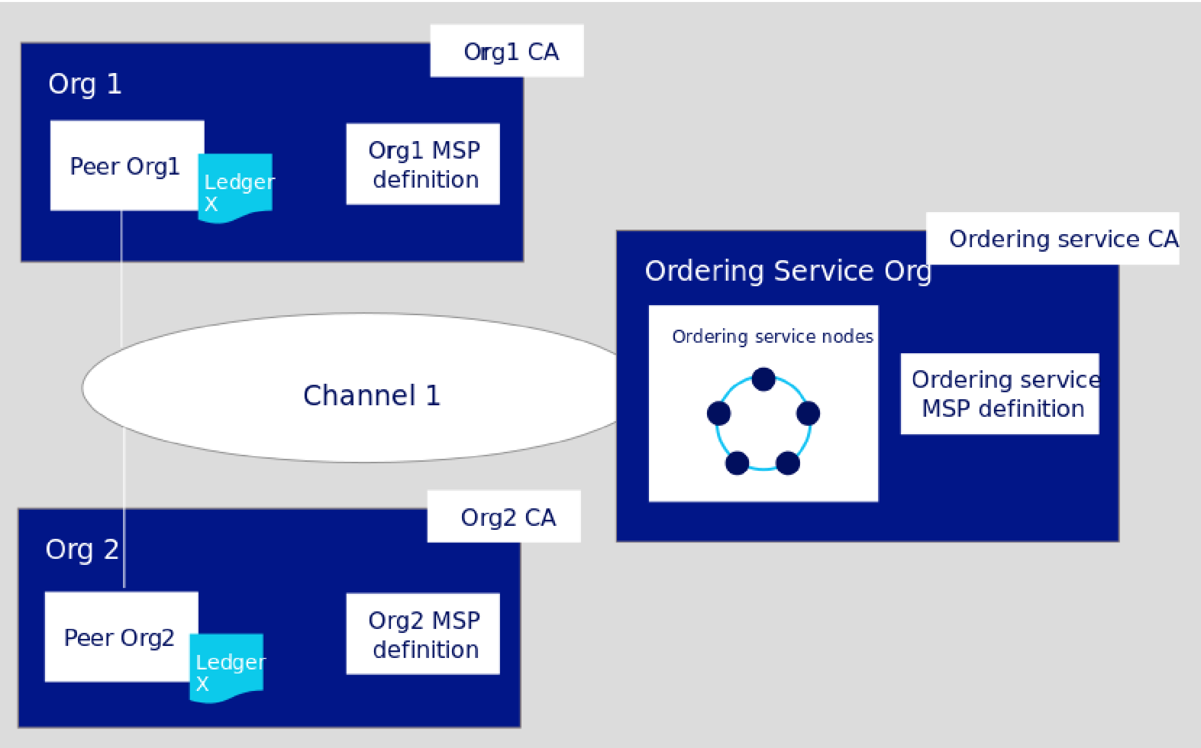


Figure 4 - Hyperledger Fabric sample network (source: IBM)

3.6.3 Smart Contract Deployment

The application used Node.js to develop smart contract. All conditions for application transactions were defined in the smart contract and packaged. The package was submitted on the channel with the member organizations. The organization submitting the smart contract proposed and other organizations approved so that the smart contract could be used. One organization in the channel is required to commit the smart contract once the approval threshold defined is met for example 3 out of 4 organizations.

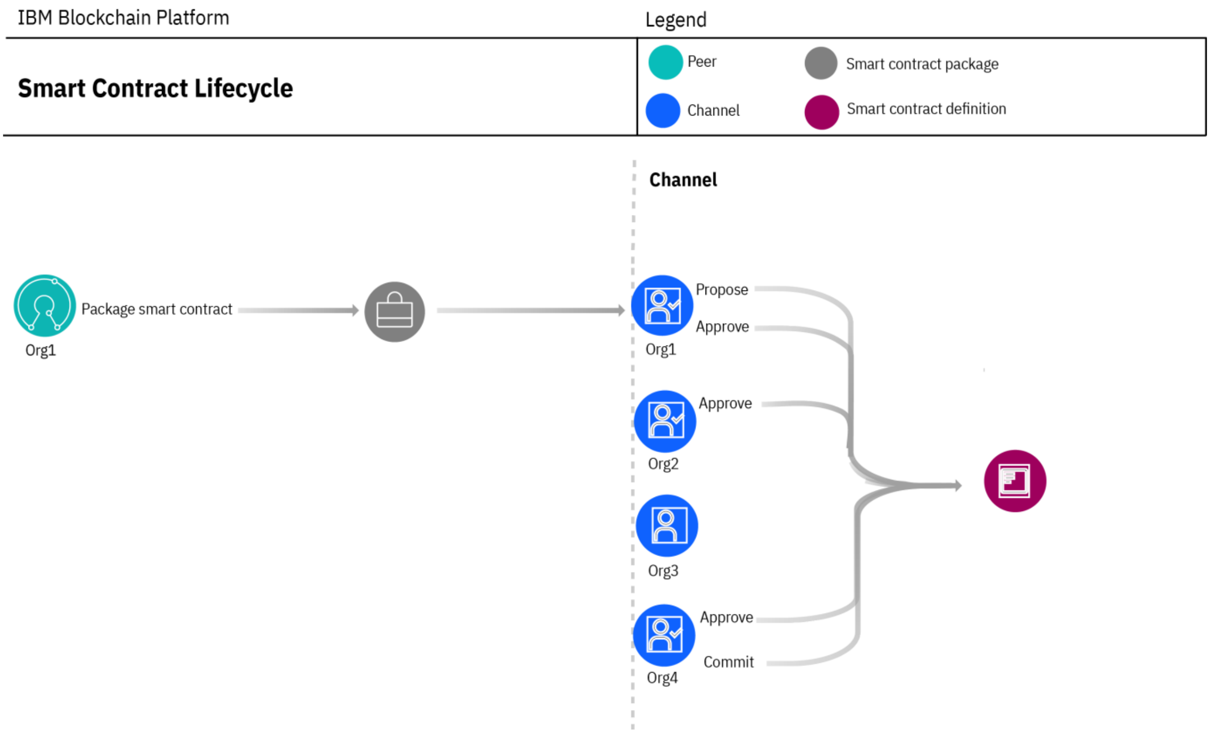


Figure 5 - Smart contract Lifecycle (Source: IBM)

3.6.4 Submitting Transactions to Blockchain Network

Each application connecting to the blockchain network downloads network discovery configuration file. The file has connection details to all members of the network. When the application submits a transaction, it is broadcasted to all nodes/peers in the network. If the transaction is approved, the ordering service assigns it a timestamp and appends it in the ledger.

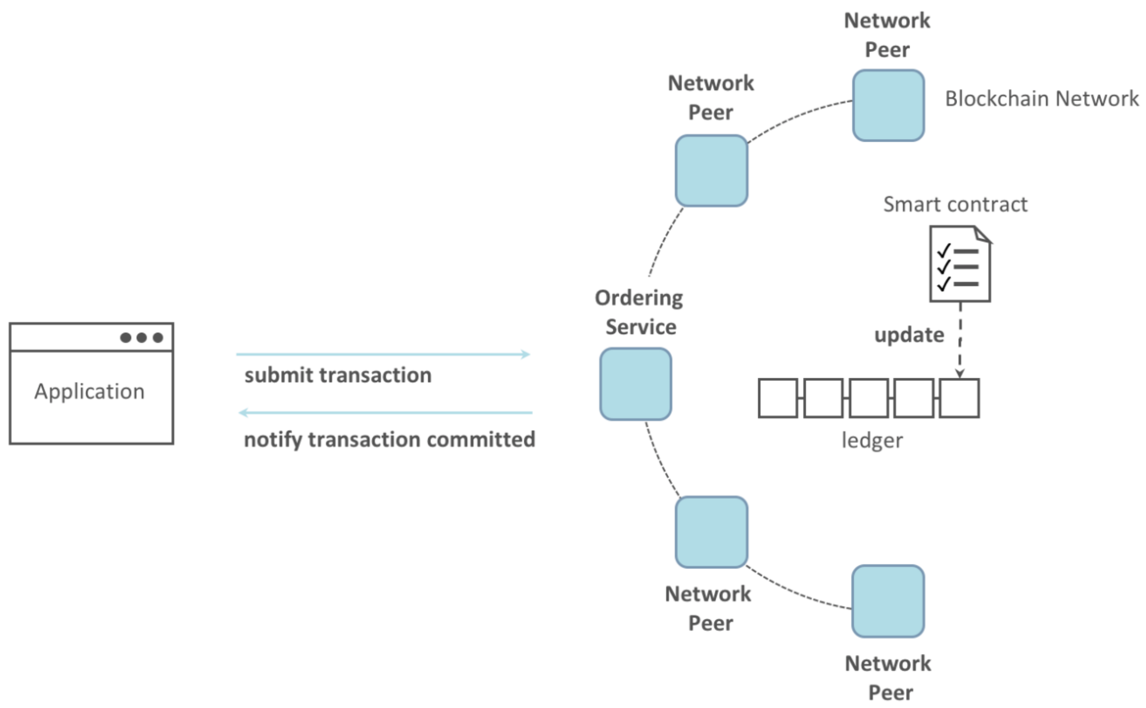


Figure 6 - Updating the ledger (source: IBM)

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Common Land Transactions in Kenya

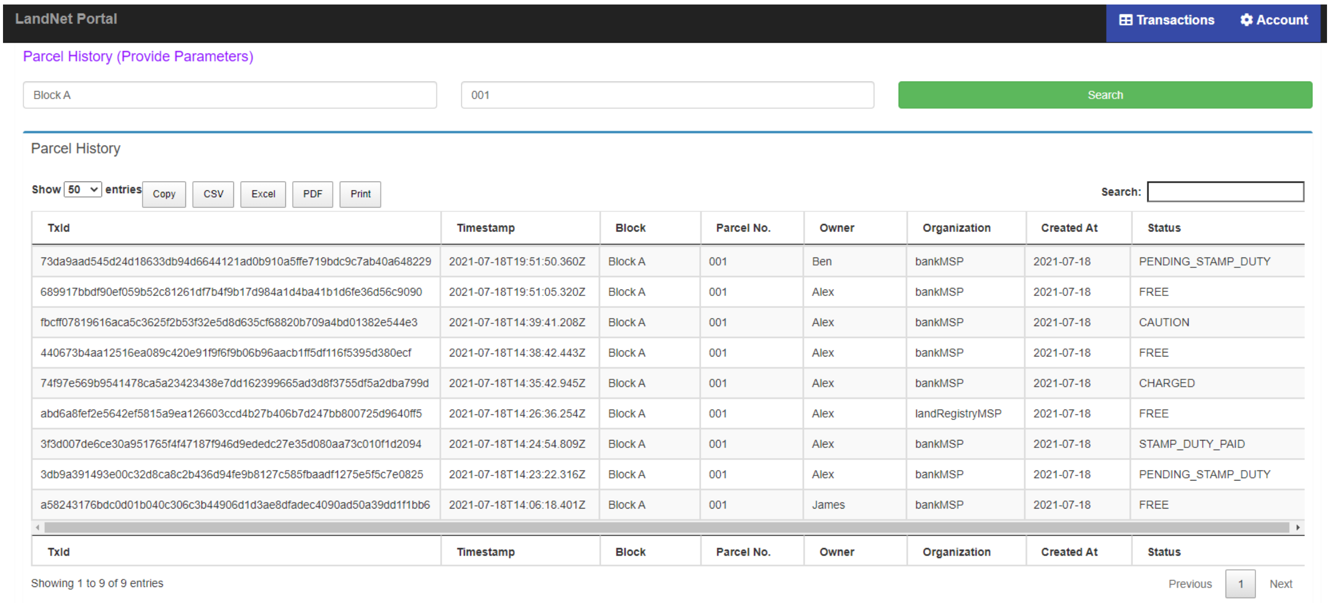
Some of the common transactions which featured in the research include: subdivision of land to create new parcels, transfers, search transactions, caveats, charges and discharge.

4.2 Web Application Testing

The web application frontend was developed using HTML, CSS and JavaScript. The backend used PHP to serve webpages and PostgreSQL database for storing data such as system users.

4.2.1 Search Transaction

The web application has provided user interface to query the history of a parcel of land. The returned data from the blockchain is displayed on a table showing unique id for each transaction, timestamp, owner and the status of the parcel.



TxId	Timestamp	Block	Parcel No.	Owner	Organization	Created At	Status
73da9aad545d24d18633db94d6644121ad0b910a5ffe719bdc9c7ab40a648229	2021-07-18T19:51:50.360Z	Block A	001	Ben	bankMSP	2021-07-18	PENDING_STAMP_DUTY
689917bbdf90ef059b52c81261df7b4f9b17d984a1d4ba41b1d6fe36d56c9090	2021-07-18T19:51:05.320Z	Block A	001	Alex	bankMSP	2021-07-18	FREE
fbcff07819616aca5c3625f2b53f32e5d8d635cf68820b709a4bd01382e544e3	2021-07-18T14:39:41.208Z	Block A	001	Alex	bankMSP	2021-07-18	CAUTION
440673b4aa12516ea089c420e91f9f6f9b06b96aacb1ff5df116f5395d380ecf	2021-07-18T14:38:42.443Z	Block A	001	Alex	bankMSP	2021-07-18	FREE
74f97e569b9541478ca5a23423438e7dd162399665ad3d8f3755df5a2dba799d	2021-07-18T14:35:42.945Z	Block A	001	Alex	bankMSP	2021-07-18	CHARGED
abd6a8fef2e5642ef5815a9ea126603ccd4b27b406b7d247bb800725d9640ff5	2021-07-18T14:26:36.254Z	Block A	001	Alex	landRegistryMSP	2021-07-18	FREE
3f3d007de6ce30a951765f4f47187f946d9ededc27e35d080aa73c010f1d2094	2021-07-18T14:24:54.809Z	Block A	001	Alex	bankMSP	2021-07-18	STAMP_DUTY_PAID
3db9a391493e00c32d8ca8c2b436d94fe9b8127c585fbaadf1275e5f5c7e0825	2021-07-18T14:23:22.316Z	Block A	001	Alex	bankMSP	2021-07-18	PENDING_STAMP_DUTY
a58243176bdc0d01b040c306c3b44906d1d3ae8dfadec4090ad50a39dd1f1bb6	2021-07-18T14:06:18.401Z	Block A	001	James	bankMSP	2021-07-18	FREE
TxId	Timestamp	Block	Parcel No.	Owner	Organization	Created At	Status

Figure 7 - Search land parcel history

4.2.2 Transfer Transaction

The Web application has provided interface to initiate transfer of land parcel from current owner to a new owner. The provided parameters are submitted to the blockchain for validation. If the parcel meets all conditions for transfer, the transaction is added to the blockchain and status updated.

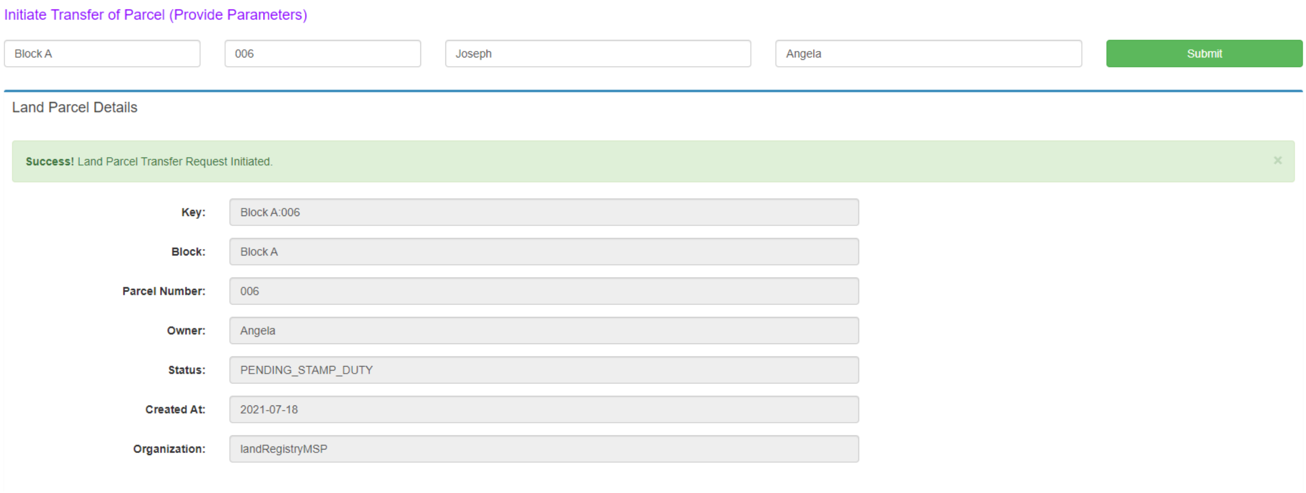


Figure 8 - Initiate land parcel transfer (successful)

If any anomaly is noticed like: the current owner is not the legitimate owner or the parcel has any encumbrances (existing charge, caveat or unpaid legal fees), then the transfer is rejected.

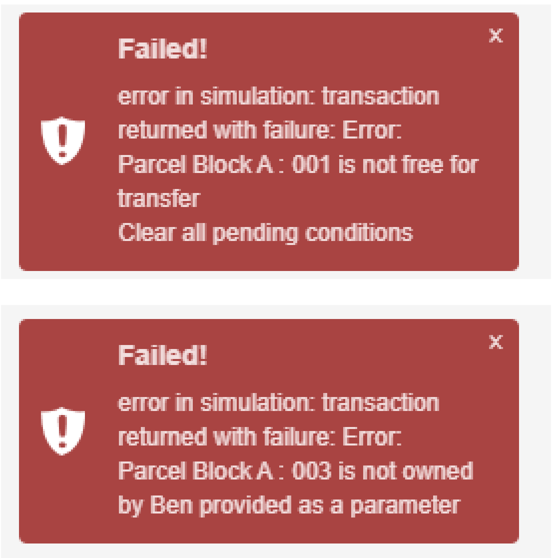


Figure 9 - Land parcel transfer failed due to encumbrances

4.3 API Testing

The API developed was tested using postman application. The restful API returns JSON which can be consumed by applications of integrating organizations.

4.3.1 Search

The API can be used to search parcel history. The returned JSON has history of the land parcel from the date it was created till current date. Every transaction has unique transaction Id, timestamp and data about the transaction.

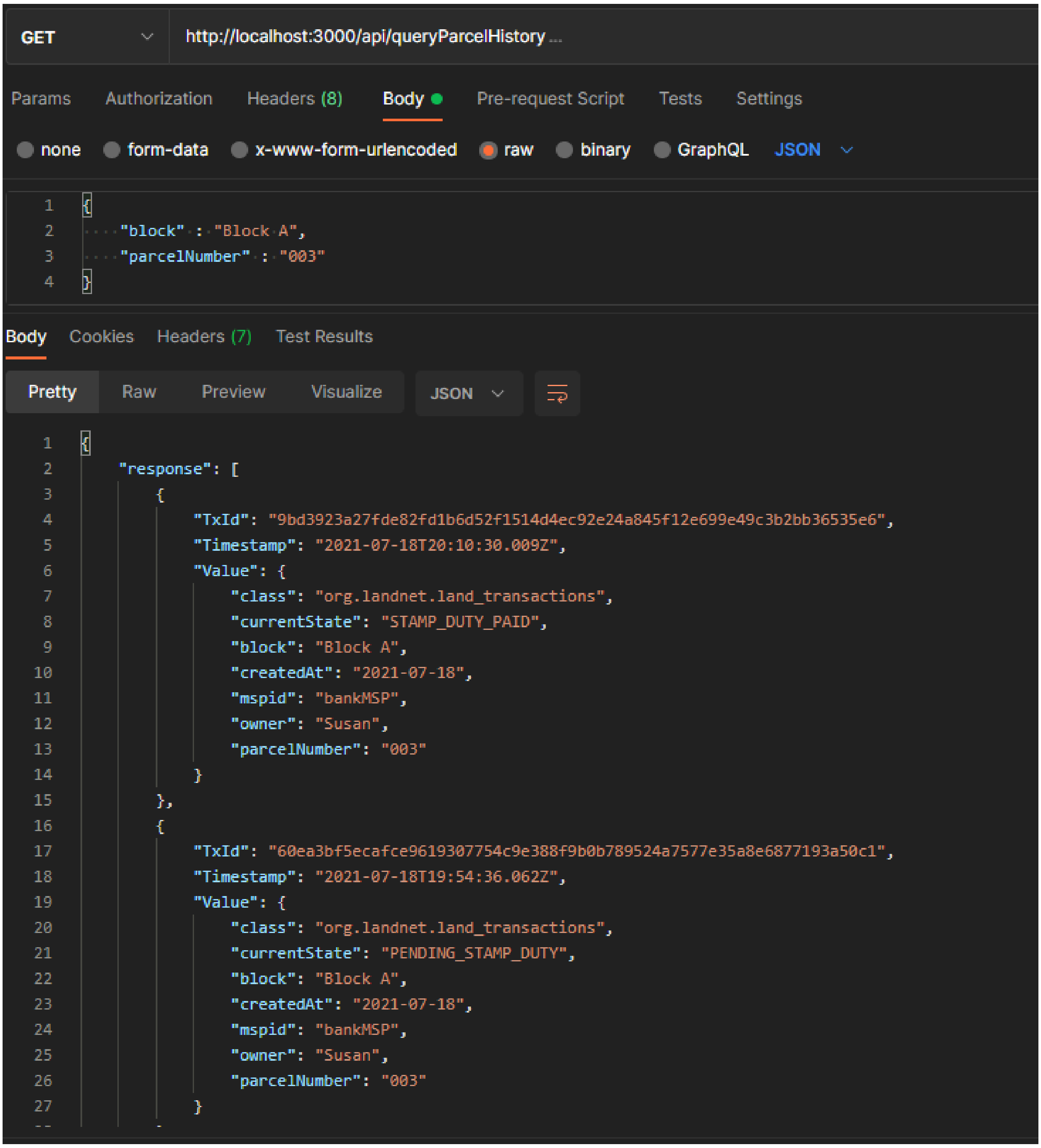


Figure 10 -Search of land parcel history via API

4.3.2 Charge Requests

A financial institution accepting land parcel as collateral for loan offered can use the API to submit a charge request on the parcel. The parcel cannot be transferred or have another transaction until the same financial institution discharge the parcel.

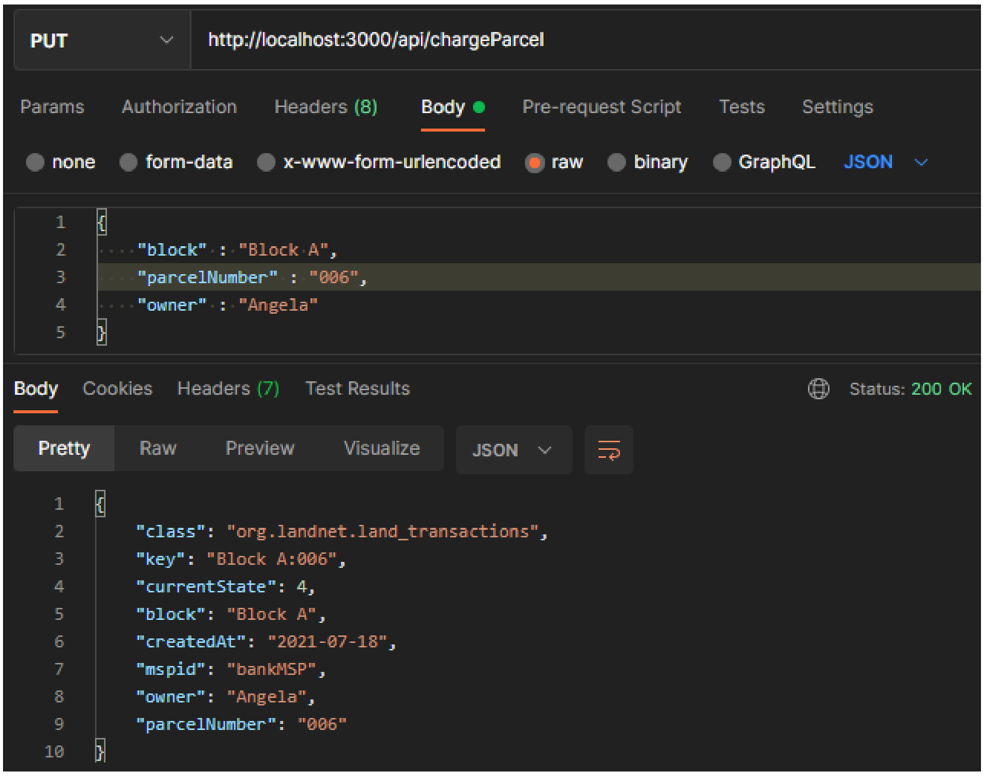


Figure 11- Successful charge request on a land parcel via API

4.3.3 Add Caution/Caveat

The API can be used to add caution on the land parcel to stop all transactions like transfer and charging. Once the caution request is submitted to the blockchain, all transactions are barred until the caution is removed.

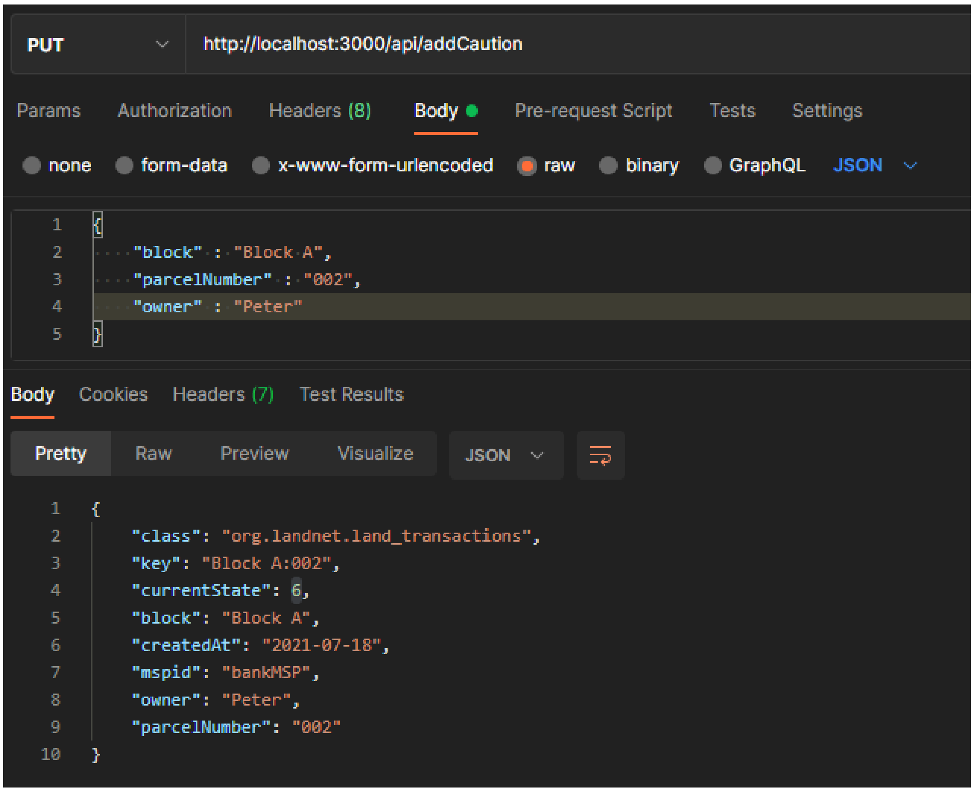


Figure 12 - Add caution to land parcel via API

4.2 Vulnerabilities in Land Transactions

From the interviews conducted, after analyzing the data, this research established some of the vulnerabilities in land transactions include: illegal transfers of land parcels, double spending for example charging of a parcel by banks, ignored caveats and lack of traceability of user actions. By using blockchain, the application developed illustrates the vulnerabilities can be addressed for instance: double allocation is barred, transactions on a land parcel with encumbrances are also barred.

4.3 Factors to Consider for Blockchain Platform

The blockchain experts interviewed listed the following as main factors to consider when choosing blockchain platform for a project:

Status of development: the community backing the blockchain platform should be actively developing. Continuous development ensures bugs are fixed and security vulnerabilities addressed.

Nature of the blockchain: public, permissioned or private blockchain network. The nature of land records and transactions requires participants to be registered and authorized nodes to approve transactions. Private permissioned blockchain platform best suits this goal.

Programming languages supported to ensure developers can use SDKs to connect applications to the blockchain platform.

Popularity and reputation of the blockchain platform based on the companies using the blockchain and nature of solutions developed

Consensus protocol used: Proof of Work, Proof of Stake, Proof of Burn. For land transactions, it is preferable to choose a blockchain platform that uses proof of stake as consensus protocol to approve transaction in the blockchain.

Support of Smart contracts is crucial for a blockchain platform. This ensures automatic approval of transactions which meet set conditions.

Scalability: the blockchain platform should grow to accommodate increasing number of transactions and participants in the network.

After analyzing the feedback from blockchain developers, Hyperledger Fabric platform was chosen for the application. It is a private permissioned blockchain platform supported by large corporations like IBM.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

This chapter summarizes the findings based on research questions. Conclusions are drawn and recommendations for future studies given.

5.1 Summary of Findings

Main challenges and vulnerabilities in land transactions in Kenya.

The main challenges in land transactions from the research were: double spending for example allocation of same parcel to multiple buyers, charging with multiple institutions. Time factor was also found to be an issue where transactions take relatively longer in the current system.

The best blockchain platform to digitize land records

The research project entailed application development using distributed ledgers on IBM Hyperledger Fabric blockchain platform which is private permissioned. The blockchain network allows multiple organizations to join channels which allow discovery of peers. The channel has installed smart contract to automatically approve or reject transactions. Each organization can add nodes or peers which store a copy of the ledger and approve submitted transactions. Each organization is affiliated to a certificate authority for issuing public and private keys to all actors in the network.

Different interfaces that stakeholders can use to interact with the blockchain system.

The blockchain network was developed on IBM blockchain platform. The application server to interact with the blockchain was developed using Node Js SDK for Hyperledger Fabric. The client web application used HTML, CSS and JavaScript.

A restful API has been developed using Node Js Express server. The API communicates with the blockchain platform for various transactions such as search parcel history, charge, discharge and caveats.

The web application and restful APIs have been tested and they are communicating with Hyperledger Fabric blockchain network via Node Js SDK. Transactions can be committed to the network and updates done on the distributed ledgers. Querying the blockchain responds with history of all transactions for the land parcel.

5.2 Conclusion

The research found out the issues bedevilling land transactions can be alleviated using technology particularly blockchain. The application developed to simulate land transactions on blockchain has shown that Kenya land registries can use blockchain to solve the issues ailing them.

5.3 Limitations of Study

The research involved selected participants in the lands and blockchain areas. For land records and transactions, challenges and vulnerabilities may not have been exhausted. There may also be more factors that should be considered when choosing a blockchain platform for a project to digitize land transactions.

5.4 Recommendation for Future Studies

There is need for more researchers to simulate how blockchain can be used to solve problems in land transactions in Kenya. The technology may be used in near future to actualize the dream of digitizing all land records and transactions in Kenya.

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