

# Water Supply Security in a Drought Exposed Nairobi: Adopting a Blockchain Provenance Tracking for Informal Alternatives

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**ABSTRACT:**The paper presents the analytical stage results (partial result) for a research whose primary aim is to identify the determinants for adoption of blockchain provenance tracking system for informal water alternative's quality data in Langata sub county, Nairobi city, Kenya. The study is in two phases; analytical and participatory. The first phase is the analysis stage where indices formulae are used to estimate risk information; drought and water shortage coping cost. Drought exposure dryness factor was calculated using 57-years monthly rainfall data from Wilson Airport; Kenya Meteorological Service station number: 9136130 within the study site using Standard Precipitation Index formula. The Water Shortage Risk Index was computed using customized ratios that compared municipal, vendor and bottled water monthly bills at the household level multiplicatively. These initial analytical results will be used as the priming information to the random utility formula that has been adapted as the technology adoption model for solicitation of stated preference on water tariff change as bundled options in the second stage of study; participatory phase. The choice for status quo or a tariff change option will indicate the stated preference by a household on blockchain technology adoption from which the determining adoption factors will be identified. If the technology is adopted, it is expected that the water access cost and rising groundwater abstraction rate will both reduce which will among other benefits; bring improvement in local area water environment's health. The study is expected to be a reference for other future water security studies for other parts of Nairobi city even as it extends the use of random utility theory in the adoption of Blockchain technology literature.

**KEYWORDS:**Water security, drought exposure, blockchain provenance tracking, alternatives.

## I. INTRODUCTION

The need for consumer product's data quality tracing and tracking for confirmation of legitimacy before use is becoming ubiquitous because of health concerns. In the water security debate, drought exposure risk has popularized use of informal water alternatives more especially in urban communities within the developing nations as observed by Constantine et al. [1]. In Langata sub county located within Nairobi, the capital city of the Republic of Kenya for example, Hailu et al. [2] stated that the alternatives are a critical supplement to the intermittent municipal drinking water supplies. But, the consumers here usually have to additionally invest in the quality improvement schemes on the alternatives since they doubt their origins' quality according to Lusigi et al. [3]. Some customers also rely on bottled water for drinking purposes as was observed by Ouma et al. [4] in bottled water marketing study in Nairobi.

This concern on quality and the subsequent interventions by the consumers, do raise the households' monthly water access cost. At the same time, the number of wells, being the main source of these alternatives have significantly increased in Nairobi city as stated by Onyanacha et al. [5] which may cause a decline in water levels in the near future

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even as climate change uncertainty unfolds. This study posits that, if the alternatives' quality database can be made traceable, then fit for purpose usage will become a possibility. Equally, water resource sharing by the consumers may become a reality which may improve the local area's water environment's health. Despite this need, there is little in literature indicating any previous attempt to document provenance information for these alternatives.

The concept of provenance is about the documentation of an object's origin details as explained by authors in [6]. The word provenance is from a French word, *provenir*, which means 'to come from'. The concept was first used in the art domain to specifically provide the authenticity and ownership information on a piece of art work especially in the history books according to [7] and works of art like paintings in the words of [8]. It has since spread to many sectors including in scientific experimental works to record workflow schedules as stated by [9] and in food industry for safety assurance on food products' quality according to [10]. Since informal water alternatives have a byzantine general's problem with regards to quality doubt at the point of use coinciding with the description earlier given by Lamport et al. [11], this paper argues that adopting a Blockchain enabled provenance tracking system can offer a sustainable solution. This will be made possible through real time confirmation of the water quality status before making an order on fit for purpose basis.

Blockchain by definition is a distributed ledger technology where digital events are shared to all constituents through peer to peer network according to [12]. Blockchain technology application first began in cryptocurrency but has since spread exponentially to many areas. Blockchain runs on the internet technology backbone and is continuing to transform modern world's service industry. It is capable of storing data immutably devoid of fraudulent alterations. It operates on nodal consensus using auditable platform through shared encrypted access keys as explained by [13]. In terms of database management, Blockchain allows for making a requisition and providing instantaneous responses even as it keeps both data sets safely as transaction records without cost allowing for future confirmations, audit and retrievals as stated by [14]. The scientific data management community is already enjoying Blockchain based provenance tracking benefits according to the finding by [15].

In Langata, like in other sections of Nairobi city, households source water from multiple sources as opposed to the expected idealized municipal system. The municipal water system here is however ever intermittent due majorly to drought risk. The other supplementary sources of water include; from tankers, from vendors, from borehole operators, from kiosks and from purchased bottled water according to [2]. Drought exposure risk analysis for Kenya has been done by many scholars including the recent one by Uhe et al. [16]. Some studies like that by authors in [17] have described drought character over Kenya as being abnormal. This has made water shortage situation to rise which author [18] stated is a common challenge for most of the African countries. When the anthropologist, Hart, [19] coined the word '*informal*' as he described petty capitalism through which urban wage earners supplemented their meagre earnings to survive, little did he know that after many decades this term would later find parallel in the way urban households are coping with the perennial water shortages. Because the threat of climate change is uncertain in many ways, households' vulnerability to water shortage is widening as per concerns raised by authors in [20]. This presents a compelling need for the design of an appropriate coping mechanism as advised by scholars in [21] and [22]. It is the argument here that, when the informal water alternatives' quality is made traceable through Blockchain provenance tracking, water insecurity will reduce. This paper is to solicit for stated preference for adoption of such a system whose expected outcome is the identification of adoption factors.

The rest of the paper is organized as follows; Section II presents related work. Methodology is discussed in Section III. Section IV presents study partial results for the analytical first stage of the research. Finally, Section V presents the conclusion for this initial stage of the study.

## II. RELATED WORK

Blockchain technology adoption studies are still few. But early adoption scholars like Hassani et al. [23] have used review method to identify factors influencing its adoption process like; security and affordability. Similarly, a paper by authors in [24] had also used review approach for the construction industry in which they established the need for proof of reliability and trustworthiness of construction logbooks. In cloud platforms, the work by Tosh et al. [25] used framework analysis method and listed the need for consensus protocol. In other general technology adoption studies, like the one by workers in [26] for instance is known to have inspired a study by the author in [27] who

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synthesized some of the factors influencing technology adoption into three clusters of variables covering invention, innovation and environmental contexts. The initial technology adoption model as was coined by the author in [28] has gone through several improvements including developments of unified versions according to scholars in [29]. Each version of such models is known to have supported varying studies in the past. But because of weaknesses reported by scholars cited by authors in [30] and [31] on lack of capacity of the models to capture heterogeneous preferences, scholars like the one in [32] used discrete choice experiment (DCE) model; a random utility theory based model put together by [33] to anchor technology adoption study in transportation sector which was largely successful. This model (DCE) is credited to be able to accommodate the heterogeneity of participants' preferences. Following this reasoning, this paper has adapted the discrete choice experiment model.

Discrete choice experiment (DCE) refers to a variety of experimental design techniques, data collection and statistical procedures usually used to analyse a choice process. It is built on random utility theory which assumes that a utility has two parts; one, observable systematic component and second, a random component according to [34]. The term discrete has two meanings; firstly, a choice event must be made or not made by an individual. And secondly, the choice set contains a finite number of alternatives. DCE 's distribution function can be parametrized to accommodate varying tastes of individuals on the random variable side as explained in a study by [35]. The observable variables are obvious everyday practice choices like for water, every individual needs water on a daily basis. DCE can also be stretched to accommodate a number of hypothetical data sets. DCE is supported by many statistical software packages offering modules to run discrete choice analysis hence its popularity in the industry and academia.

This study rests on the pillars erected by one of the pioneer authors of Innovation Diffusion Theory as cited in [36] but takes into account the fact that the decision makers must be facilitated with priming information to enable them value their protective adaptation selections from the choice model carrying the option bundles. Conceptually and at the global level, the study is focused on identification of the determinants for technology adoption through the stated preferences of choices made. In this regard, the analytical phase of the study is to prepare the risk information on; drought and water shortage coping cost which are fed into the learning box during the participatory study phase. During the learning process discussions, each decision maker values the direction of coping method and finally makes a protective selection in the choice box. The choice box has bundles which include; status quo choice and varying water tariff change options.

The problem in this study therefore is; despite the usefulness of the informal water alternatives in supplementing Langata households' water needs, no attempt has been made to document their traceable quality database. This is making the water access cost to be expensive since additional quality improvement work has to be done before they are put into use. In order to solve this problem, this study aims to identify factors that will influence Blockchain provenance tracking system's adoption. At the end, it is expected that the study will contribute to the extended use of discrete choice model in promoting blockchain technology adoption in water sector.

### III. METHODOLOGY

The study uses a case study method involving deployment of indices formulae, literature search and participatory approaches. Langata is one of the seventeen sub counties of Nairobi City County, see figure 1 below. It covers 196.8km<sup>2</sup> with 176,314 residents in 52,656 households. Generally, it enjoys temperate tropical climate throughout the year.

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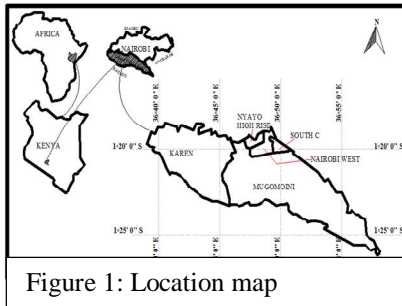


Figure 1: Location map

For drought risk quantification, the monthly rainfall data for the period 1957 to 2013 (57 years) was sourced from Wilson Airport; Kenya Meteorological Service station number: **9136130**. The Standard Precipitation formula was used to characterize drought;

$$SPI = \frac{X_i - \bar{X}}{\sigma} \quad (1)$$

Where  $X_i$  is the annual rainfall of the  $i$ -th year and  $\bar{X}$  is the mean annual rainfall over the full period. SPI values range between -2 and 2 with 0 being the turning point between wetness and dryness.

This study is interested only on dryness and the value between 0 and -1 point to a moderately dry period represented by  $\alpha$  and between -1 and -2 point to an extremely dry period represented by  $\beta$ . The ratio of extremely dry value and overall dryness value is the Dryness Hazard Factor in this study taken as Hazard Index (HI).

$$HI = \frac{\beta}{\alpha + \beta} \quad (2)$$

For coping cost risk quantification, exposure index (EI), household vulnerability ( $V_h$ ), Vulnerability Index (VI) and water shortage risk index (WSRI) are computed using the following indices formulae;

$$EI = 1 - \frac{V_p + B_p}{M_p + V_p + B_p} \quad (3), \quad V_h = \frac{V_p + B_p}{M_p + V_p + B_p} \quad (4)$$

$$VI = 1 - \frac{\sum_{i=1}^N T_{ch}}{\sum_{i=1}^N T_{th}} = 1 - \sum_{i=1}^N V_h \quad (5), \quad WSRI = HI \times EI \times VI \quad (6)$$

Where; Municipal monthly delivery cost is ( $M_p$ ), Vendor monthly delivery cost is ( $V_p$ ) and Bottled water monthly purchase cost ( $B_p$ ).

To develop a simplified explanation on the concepts of; provenance and Blockchain, the study entered the words separately into the google scholar search engine to fish out published articles which later were downloaded using their digital object identity from science hub search engine. Thereafter, simple notes were prepared which will aid learning during the participatory study stage.

For the participatory stage, a total of 382 households will form the representative sample spread within the five wards of the study site. In this study the latent class analysis model (discrete choice experiment) anchored on random utility model will be deployed which allows discrete choosing of preferences from alternatives. A decision maker,  $i$ , (from a household) therefore has to choose from  $J$  alternatives from which he / she derives a certain level of utility  $U_{ij}$  expressed as;

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (7)$$

Where  $\varepsilon_{ij}$  is unobservable unknown. Collectively, these assumptions are of extreme value type I often referred to as the independently and identically distributed (iid) conditions. While  $V_{ij}$  is the representation of the portion of the utility with linear attributes.

$$\text{Linearly } V_{ij} = \beta_{ik} X_{ijk} \quad (8)$$

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Where  $\mathbf{k}$  are the attributes for  $X_i$  alternative from  $\mathbf{j}$  alternatives and  $\mu_{ik}$  is the marginal utility derived by individual 'i' from choice X with k attributes. Now if  $y_i=j$  individual 'i' selects option j from available alternative 1 and 2, then the probability of that individual 'i' selecting j from a set of N alternatives is expressed as;

$$P(y_i = j) = \frac{\exp(\lambda V_{ij})}{\sum_{n=1}^N \exp(\lambda V_{in})} \quad (9)$$

Where  $\lambda$  is the scale parameter given by random term  $\lambda^2 = \frac{\Pi^2}{6d^2}$  related to  $\beta$  which varies across groups. Should the parameter be same, conditional logit model can be used otherwise mixed logit models is applied. It is taken that choices may be similar in a class but may be different across classes (section of the group) and this is expressed as 'c';

$$P(y_i = j/c) = \frac{\exp(\lambda \beta_{ik} X_{ijk})}{\sum_{n=1}^N \exp(\lambda \beta_{cnk} X_{ink})} \quad (10)$$

For an iterated bidding process, it is assumed that class behaviour will remain constant within the tasks expressed by;

$$P(y_i = j/c) = \frac{\exp(\lambda \beta_{ik} X_{ijkt})}{\sum_{n=1}^N \exp(\lambda \beta_{cnk} X_{inkt})} \quad (11)$$

With increasing group or class diversity, the flexibility of the latent class increases and loses distributive restrictions of mixed logit models. But this reaches a statistical limit of a certain number of class identifiable in a sample, at this point, when 'c' approaches N (respondents), then a specific focus of model becomes real beyond which the experimental design is incapacitated. If the probability of an individual 'i' within class 'c' from total classes 'C' is expressed as  $S_{ic}$  then the unconditional chance of the same individual 'i' making a series of choices across T choice sets is given by;

$$P(y_i) = \sum_{c=1}^C S_{ic} \prod P(y_{it}/c) \quad (12)$$

Each choice by 'c' is assumed to be empirical with varying criteria being in use to identify number of classes. The functional form for the utility ( $V_{ij}$ ) for individual 'i' whose taste is alternative j is expressed as;

$$V_{ij} = \beta_s SQ_j + \sum \beta_T TECH_{ij} + \alpha_{pr} PRICE_j \quad (13)$$

Where SQ is the Status Quo dummy variable and  $TECH_{ij}$  are the technology options to organize freshwater access in alternative j chosen by individual 'i'.  $PRICE_j$  is the proposed cost adjustment in percentage (%) by utility company to implement the choices upon policy formulation.  $\beta_s$  is coefficient of the status quo dummy variable,  $\beta_T$  is the vector of marginal utility and  $\alpha_{pr}$  is coefficient of price variable.

The willingness to pay (WTP) is expected to increase with the manner in which the water access system will be organized at the estate level to make it reliable in availability and quality. The shift should at the same time act to protect the water environment from degradation. Each choice will consist of three options with alternative bundles of community water management system (CWMS), plus a fourth option which is the status quo (SQ), or, 'none of these' alternatives. In the utility algorithm, the SQ dummy and its parameters will contain 'no-change' option that is unexplainable from the attributes of the alternatives and is related to individual's unique preference for change. The probability of individual membership to a class  $S_{ic}$  is framed as a function of individual characteristics ( $Z_{ki}$ ) on a multinomial logit model (MNL) expressed as;

$$S_{ic} = \frac{\exp(d_{ck} Z_{ki})}{\sum_{j=1}^c \exp(d_{jz} Z_i)} \quad (14)$$



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The variation of class membership summation according to stated preference in choice should be equal to zero expressed as;  $\sum_{j=0}^C d_{jz} = 0$ . The net-worth or maximum amount each respondent will be willing to pay for change as an attribute is a coefficient estimated under the mix logit model. And SQ dummy is a motivation to avoid radical change promoting a win-win or trade-offs for long held beliefs. The value options as part-worth is expressed as;

$$\text{Part - Worth} = \frac{-\beta_s + \beta_T}{q_{pr}} \quad (15)$$

It has been argued before in many studies that incorporating psychological factors such as behavioural attributes and beliefs in choice experiments helps in faster prediction of peoples' choices as was stated by [37]. In analysing the constructs, factor analysis will be used as a data reduction technique to come up with a composite variable to represent coping behaviour expressed as;

$$\text{BEHAV}_i = W_1 X_{1i} + W_2 X_{2i} + \dots + W_n X_{ni} \quad (16)$$

Where  $\text{BEHAV}_i$  is the estimated composite score for behavioural variable,  $W_n$ , are the factor score of regression weight and  $X_{ni}$  are the observed score for each indicator.

## IV. RESULTS

### Drought risk analysis

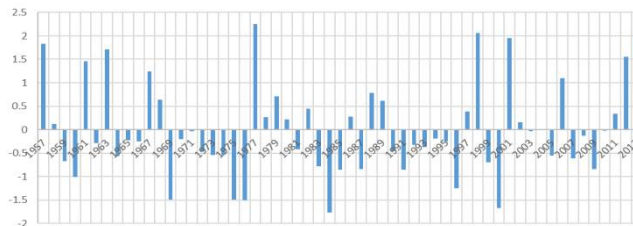


Figure 2: SPI Plots for the 57 years

The 1957-2013 rainfall data when analysed using equation 1 and 2 gave dryness hazard exposure and hazard exposure index as 0.2. Out of 57 rainfall years, 34 years were dry (59.65%) with the driest being 1985 and 2011. See the graphical plot of SPI per year in figure 2 on the left here. This confirms the Nairobi city drought exposure condition as a big concern impacting negatively on its water supply hence the

### Well digging in Langata in response to drought risk

Because of drought, boreholes are the major source for informal water alternatives being supplied by vendors in Langata. Unfortunately, only 20% of the 122 have their water fluoride level within the guideline of World Health Organization [38] in which the acceptable limit is up to 1.5mg/L, see figure 5 below. This analysis seems to confirm the earlier findings by authors in [39] for Nairobi groundwater fluoride level condition. The depths are increasing, nearly 50% have depths ranging from 300-390m as shown in figure 6. Further still, it is important to note that well digging trend is on the rise majorly in Karen ward as shown in figure 3. The digging of wells started way back in 1982 and the rate has been increasing with year 2011 recording the highest number commissioned as presented in figure 4 below.

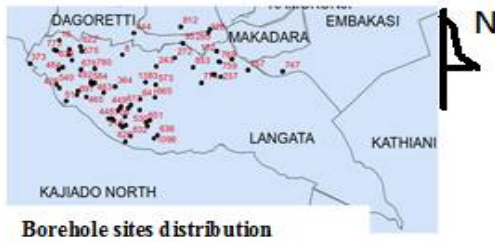
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Figure 3: Borehole distribution



Borehole sites distribution

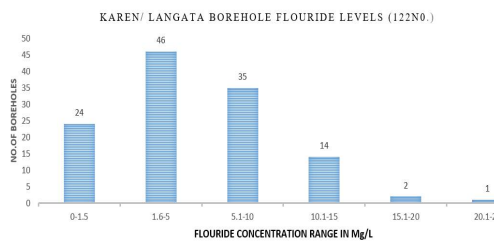


Figure 5: Fluoride levels

Figure 4: Trend of borehole digging

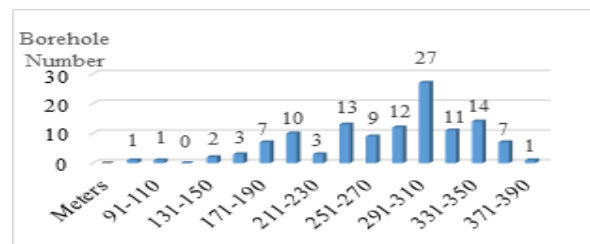
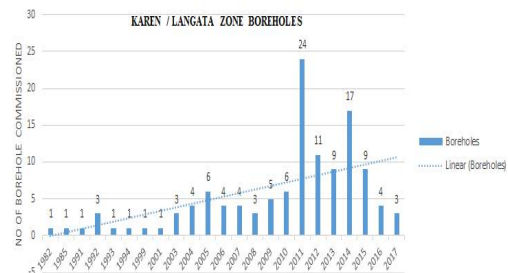


Figure 6: Borehole depths in meters

The drought of 2011 saw a total of 24 boreholes dug in Langata followed by 9 in 2012. The drought of 2014 witnessed 17 boreholes being dug see figure 4 above. This reactionary approach may result in irreversible impact on groundwater system for Nairobi and may lead to drying of rivers. This study suggests adoption of a cautious approach through transparent sharing of water of good quality. This may cause the lowering of tube-well drilling trend's gradient. Water level depths may start rising instead of the current situation where they are declining as has been warned by authors in [5]. The borehole data was sourced from Water Resource Management Authority (WaRMA) by the researchers.

### Provenance concept

In simple definition, provenance is the documentation of information about the origin of an object as given by the author in [40]. The science of provenance traces its origin in the art domain as was argued by author [7] and [8] above. Provenance has three main functions; providing authenticity, providing ownership of the object in question according to a report prepared by authors in [41]. It has in that context been able to facilitate in knowledge checking and verification according to Imran et al. [42], in replication of scientific workflows in the thinking of Kanwal et al. [43] and support to scientific research as earlier reported by authors in [9]. The food industry and open data sector have used provenance to provide trust and confidence on their products as per argument by authors in [10].

### Blockchain technology concept

When author in [44] founded the use of crypto signature for decentralized payment system it was not yet known that this was going to be the foundation on which Satoshi Nakamoto's 2008 Bitcoin virtual payment system would rest on as per authors in [45] and [46]. This happened at the height of a raging global financial crisis where value transfer without a third party intermediary was needed according to the scholar in [47]. Since then, blockchain technology has spread outside fintech world becoming one of the major globally debated topics as cited by [48] and is considered to be the fifth technology disruption for the global economy according to authors in [49] and [50].

### Blockchain provenance tracking

In provenance, blockchain is able to capture information about entities, activities and the agents in the transaction, store it and make it ready for access to constituents without cost as cited by [13]. Blockchain provenance has been used to offer a secure and immutable scientific data management according to [15].

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## Household survey results

This will come from stage two of the research which is still work in progress. However, from drought character computation in equation 2,  $\alpha$  count from SPI plot is 27 and  $\beta$  count is 7 from the same plot. Therefore, Hazard Index (HI) is 0.2 for Langata area. This means the Dryness Hazard Factor is still low but is likely to increase in the coming years ceteris parabus (if the global climate change maintains a rapid upward trend). This presents a compelling need for adaptation planning in order to be able to cope with risk of water shortage which may be witnessed.

## V. CONCLUSION

Climate change impact on water resource systems may cause a serious water shortage problem if the rate of consumption is not put in control through a provenance tracking system. The outcome expected will be that the quality of the informal alternative water will be made verifiable. In a sense it is also expected that, the well digging rate is likely to reduce if the available ones are equitably shared as common sources of water. This may eliminate a chance for declining of groundwater levels which is likely to improve water environment's health in the study area. A similar study need to be conducted for the entire Nairobi city to prepare residents to cope with future drought risk through deployment of Blockchain technology in water supply system.

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