Big data analytics: A single window IoT-enabled climate variability system for all-year-round vegetable cultivation

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Abstract. Vegetables constitute a major food source with huge nutritional values as well as major source of income. The cultivation of vegetables is dictated by climate and seasonal changes across Nigeria. Edo State lies within the South of Nigeria and enjoys the two popular seasons (rainy and dry) like many other parts of the country. However, the variability in soil distribution and weather conditions across different locations is a determining factor as to the category of not just vegetables to grow but other crops. In this paper, Edo state is used as a flagship project for its diverse potentials and uniqueness in respect of known variability in soil and weather conditions. The State is divided into three geo-referenced agricultural districts. A prototype system is proposed to provide vegetable farmers with real-time information on vegetable farming requirements. The proposed system is an Internet of things (IoT)-enabled climate variability system with interfaces to popular mobile networks, existing Geographical Information System (GIS) in the State, and remote sensing stations respectively. Each geo-referenced point is a nexus to areas with similar weather variability and soil distribution. Historical data is collected from the existing GIS and a provision is made to constantly enrich the historical data with new information from the geo-referenced points including crops grown, trends in cultivation, queries from farmers, etc. The information generated from the geo-referenced locations are routed via GPS to the central analytics server in the cloud and appropriate algorithms are used to carry out data analysis for real-time prediction and messages to farmers through the Internet and Short Message Services (SMS). With this system, it is submitted that subsistent and mechanized farmers would benefit through the guidance of an analytics system thereby boosting vegetable farming regardless of the season of the year.

Keywords: IoT-enabled farming, Big data, Prototype system, Remote sensing, GIS

1. Introduction
Edo state is located in the Niger Delta in the South-South region of Nigeria [1, 2]. The state was created in 27 August 1991 from the northern part of the then Bendel State, while the southern part formed what is now known as Delta state. Edo State is located along latitude 6.6342° N and longitude 5.9304° E with an elevation above sea level of about 550 m in the north and 150 m in the south [3]. The State is elevated towards the northern part and it is covered in most areas by tropical rain forest with a humid and hot climate [4]. 80% of its land mass is covered by tropical rain forest and equatorial rain forest for the south and north respectively. The State is characterized by a humid and hot climate [4]. The soils are recognized as ferrallitic, alluvial and laterite soils for north, central and south parts respectively. Presently, the state is divided into three senatorial districts; South, Central and North respectively. The South District is inhabited by mostly the Bini speaking people occupying about 57.14% of the total population, the Central District is inhabited by mostly by the Esan speaking people occupying about 17.14% of the total population, while the North District is inhabited by mostly the Afemai (Etsako and Owan) and Igarra
(Akoko Edo) speaking people occupying about 27.73% of the total population. There are presently eighteen local
government areas in the State. To the northeast and east of the State is Kogi State, Anambra lies to the
east, Delta to the southeast and south, and Ondo to the west and northwest. The Niger River flows along the
State’s eastern boundary. The State is multi-ethnic, and comprises the Edos, Esan, Afemai, Owan, Akoko-Edo, as
well as some Ika, Okpe, Emai and Ijaw ethnicities [5, 6].

According to records from Nigerian National Bureau of Statistics (NBS) [7], the 2006 census placed the
total population of the of Edo state at 3,218,332 which comprises 1,640,461 males and 1,577,871 females.
Currently, it is believed that the population of the State is estimated at five million. The total land area of the state
is approximately 19,300 km² [7]. The map of Edo state indicating the major cities is shown in Fig. 1.

Agricultural practices began when man commenced search for food as a means of survival [8].
Indisputably, human survival is connected to food, a product of agriculture. Agricultural practices have continued
to develop from time to time due to its importance. The growing food shortage and the likely food crisis in the
near future have become a global concern. In line with calls from food and agricultural organization, the
Government of Edo State has consistently maintained its drive towards agriculture. Presently, Edo people engage
in several agricultural practices [9]. According to Omoregbee and Ekpebu [9], the major occupation of people
of the state is agriculture. They reported that various regions of the State are engaged in one agricultural practice
or the other. Agricultural practices across the State is widely based on the location owing to marked variability in
climate and soil distributions. Thus, the trends in farming and farm produce are determined by the zone and this
may be considered a limitation to a certain extent.

Climate variability monitoring is important due to roles they play in agricultural system [10, 11]. The
climate exhibit significant impact on the intrinsic structures and outlines of the environment [12, 13]. Therefore,
climate variability monitoring could be employed in policy and decision making to check the negative influence
of climate variables in the environment especially as it affects agricultural and other activities [14-22]. The
significance in presenting the ingredients of weather (weather variables) in a logical means must not be
overlooked because its knowledge is important in the management of agricultural productivity as well as
mitigation of environmental menaces [18-22]. As such, the impact of weather variations on the environment is
presently a foremost concern to many researchers [12, 14-22].

Vegetables are very vital for human health as a result of their nutritional values and one of the common
and quickest income-yielding agricultural produce [23], hence are at the centre of this study. According to Ülger
et al. [23], vegetables contain vitamins, minerals, compounds of phytochemical as well as nutritional fibre
compositions that play significant roles in our well-being. Consumption of appropriate quantities of vegetables
promote immunity of the human body against majority of chronic diseases like cancer, metabolic syndrome, diabetes, obesity, cardiovascular diseases which have become treat to human existence. The cultivation of vegetables is dictated by climate and seasonal changes across Edo State which enjoys both the rainy and dry seasons. Thus, variability in soil distribution and weather conditions across different locations play a very important function in determining the category of not just vegetables to grow but other crops. Accordingly, farmers need reliable and timely information to support their farming campaigns. Hence, in this study, a prototype system is proposed to provide vegetable farmers in Edo State with useful information on all matters relating to successful vegetable farming.

The proposed system is an IOT-enabled climate variability system with interfaces to popular mobile networks and any existing Geographical Information System (GIS) in the State or a remote sensing device. The proposed system would be beneficial to both subsistent and mechanized farmers in improving vegetable productivity regardless of the season of the year which would also translate to more food for the people of the State and beyond and income as well.

2. Materials and Methods
The approach adopted in this study is two-fold: a geographical survey, and system modelling [24].

The materials used are PC (HP Elite book 820 series laptop running Microsoft Windows 10 Operating system, Microsoft Visual Studio 2015 Ultimate), HP DL series 380(G7) server (running on Microsoft Window 12 Server, Oracle 12C), Tecno android phablet installed with geo-surveying apps.

2.1. Geographical survey
During the geographical survey, the following tasks were performed:

- Physical observation of three locations representing the three sociopolitical and agricultural districts in Edo State. The locations are three communities located within the South, Central, and North districts respectively. The three communities are Okada (South), Irukpén (Central), and Uzairue (North) respectively. These communities were selected based on ease of access as well as their geographical characteristics in each of the districts.
- Documentation of the relief and drainage, soil distribution and vegetation, and climate of the State.
- Observation of the vegetable farming trends across the three locations across the year as compared to the documented historical data.
- Selective interviews of persons with vast knowledge on vegetables across the three zones. In each zone two groups of people were interviewed: a practicing vegetable farmer and selected sellers of vegetables at a known market in the region. The information from the interview was meant to provide additional insight on the trends in vegetable farming, demand, consumption, and challenges facing vegetable farmers only and not for demographic analysis.
- Retrieving of the required weather data from the archive of the Nigeria Meteorological Agency (NiMet). This was the main concern as weather parameters such as temperature and precipitation would serve as the basis for IOT-based system modeling.
- Documentation of the services provided by Edo GIS in respect of its present and future capacity towards driving developments in agriculture across the State.

2.2. System modeling
System modelling was used to graphically articulate the various components of the IoT-driven big data analytics platform. As every big data system handles consistently growing volume of information arising from different sources such as events and users on the system, the object-based approach was employed to capture all the necessary objects including the devices that would interoperate in the platform. Data modelling was done using Visual Studio 2015 ultimate. The model defined a staging database to which data elements captured from remote sensing devices, Edo State GIS database, events, and farmers respectively are to be stored. From the staging database, the relevant data will be automatically extracted, transformed and loaded to the analytics database. From the analytics database, the predictive models (Naïve Bayes and K-means nearest neighbour algorithms) are employed to handle predictions. Fig. 2 shows the extract-transform-load (ETL) model of the system. Data sources would be categorized into two: relational and non-relational data sources. Relational data sources would include
structured data emanating from Edo State GIS. Non-relational data sources include all unstructured data such as that from remote sensing devices, farmers, and contributors (those that can make vital inputs to the system e.g. agriculturists, government agents, policy makers, etc.). Data would be automatically extracted and loaded into the staging database.

![Fig. 2: ETL Model of system](image)

2.2.1. K-means algorithm. With this clustering algorithm, n objects would be partitioned or separated into k clusters in which each object is a member of the cluster that exhibits the nearest mean. The objects are the weather variables and other relevant entities to be extracted from the analytics database. This method would produce exactly k different clusters of greatest possible distinction. The best number of clusters k leading to the greatest separation (distance) is computed from the available data. K-Means thus, minimizes the total intra-cluster variance, or the squared error function as shown by Eqn. 1

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \| x_i^{(j)} - c_j \|^2$$

Where $J$ is the objective function, $k$ is the number of clusters, $n$ is the number of cases, $x_i$ is the case $i$, $c_j$ is the centroid for the cluster.

In this study, the algorithm starts with the initialization of a sample consisting of $n$ vegetable farmers $x_1, x_2, ..., x_n$ all from the same class, and we assume that they can fall into $k$ clusters, $k < n$. Let $m_i$ be the mean of the vectors in cluster $i$. If the clusters are well separated, then a minimum-distance classifier can be used to separate them. That is, we can say that $x$ is in cluster $i$ if $\| x - m_i \|$ is the minimum of all the $k$ distances.

i. Imagine a population of farmers within a geo-referenced point, with the following class attributes: name, A, day, month, year, temperature, relative humidity where A represents the vegetable the farmers cultivate or wish to cultivate.

ii. Assume the following class decision attributes with their values:
   - Temperature(Low, Average, High)
   - Relative humidity (normal, abnormal)
   - A(carrot, ugu, cabbage, cucumber)
   - Year (varies and depends on available data)
   - Month (varies and depends on available data)
   - Day (varies)

iii. Each class attribute is a variable and each value of the variable represents a class or state for which $k$ clusters could be computed using a given sample size.
iv. Determine the number of clusters to be formed. Take any random number of the objects as the initial centroids (or the first $k$ objects in sequence) of these clusters. The number of $k$ clusters should however be dependent of the sample size of the data.

The algorithm is summarized below:

- Get training data set
- Define cluster size
- Input cluster data (sample data with class attributes and values)
- Compute initial estimates for the means $m_1, m_2, ..., m_j$

\[
\text{do} \\
\text{Until there are no changes in any mean}
\]

1. If there are no changes in any mean, stop.
2. Classify the samples into clusters using the estimated means

2.2.2. Naïve Bayes Algorithm. To predict a vegetable with a higher chance of survival under a given temperature, with the attribute domain given as: $X(\text{vegetable} = V, \text{survivalrate}=10, \text{deathrate}=90, \text{value}=25^\circ \text{C}, \text{vegetable name}=?)$; the probability for a vegetable with name $y$ with evidence $E$ would be: $P(y|E)=\frac{P(\text{temperature}= V|Y)\times P(\text{survivalrate} = 90|Y)\times P(\text{value} = 25|Y)\times P(Y)}{P(E)}$.

To predict that vegetable $Y$ could thrive on temperature $c$; the algorithm is thus:

- Define the training data set from the case data set;
- Compute the probabilities for each attribute conditional on the class value;
- Compute joint conditional probability for the attributes using the product rule;
- Neglect attribute with missing values;
- Where an attribute value does occur regularly with the class value, insert a probability of zero(0);
- Use Bayes rule to calculate the conditional probabilities for the class variable
- Compare the probabilities;
- Compute the mean and standard deviation of the set
- Return class with the highest probability
- Apply results to a testing data set

3. Discussion

3.1 Case study: fluted pumpkin, cucumber, cabbage, carrots and tomatoes

Fluted pumpkin also known as *TelfairiaOccidentalis*, is from the cucurbitace family. It is one of popular vegetables cultivated in Southern Nigeria and consumed the world over. Historically, this dioecious vegetable has been documented for its health benefits for which it is always in demand across all parts of Nigeria and beyond, is home to Southern Nigeria though currently cultivated in Ghana, Cameroun and some other tropical countries in Africa. *Ugu* (Igbo) as it is popularly called, is a perennial crop and comparatively resistant to drought when compared to other vegetables in this group. Ordinarily, *Ugu* is cultivated at the onset of the early rains. Like *Ugu*, cucumber, cabbage, carrots and tomatoes are other vegetables that are widely cultivated across the three zones though there are variations in respect of the quantities produced from the different zones in the State. They are remarkably good sources of income as their demands are high all over the year. However, the atmospheric conditions affect the cultivation of these vegetables.

3.2 Challenges of vegetable farming

Vegetables are cultivated under various climate conditions including temperate and non-temperate climates. Each of the vegetables listed is affected by the type of soil and prevailing weather conditions such as humidity, precipitation, temperature, and sunlight. Unlike other crops, *ugu*, carrots, cucumber, cabbage, and tomatoes, are very sensitive to the atmospheric elements listed above and their responses to such are easily detected through their appearance. While majority of the vegetables tend to thrive well under humid conditions with average...
temperature ranging from 20°C to 34°C, **ugu** is the most resistant crop and this accounts for its ability to survive under some extremeweather conditions.

As regard what may be termed seasonal conditions, vegetables thrive better during the early rains and some are seriously affected during the heavy rains. However, vegetables may be cultivated all-year round. A major challenge to vegetable farming throughout the year is the availability of accurate information in addition to other basic problems such as cost of acquiring farmland, fertilizers, pesticides, and labour respectively. However, it has been shown that information is central to a successful farming campaign regardless of the nature of the crop cultivated.

The profitability of vegetable farming is more during the dry season due to the fact that many local farmers only cultivate during vegetables when they are sure that the conventional atmospheric conditions would support it. However, it is interesting to note that majority of the prospective farmers are driven aback owing to their limited knowledge of best farming practices as regards vegetable farming. It is in this regard that a technological approach is needed to provide the necessary workaround against the problem posed by the season as well as the gap in the farmers’ knowledge as to what to do to sustain productivity regardless of the season or climatic changes. Accordingly, there is a need to put up a system that would not only provide a source for consistent measurement, analysis, monitoring of relevant atmospheric elements like temperature, humidity, etc. in dry and rainy season respectively but also a two-way interactive and real-time communication platform to provide prospective and active vegetable farmers with the needed information as to the necessary intervention that they need to successfully drive vegetable farming at all times during the year. An example of such intervention is what a farmer in a given location in Edo State should do to his/her vegetable farm (with the name of the cultivated vegetables e.g. carrot) within the next 24 hours. For instance, a farmer who is skeptical about a changing weather condition may query the system as to whether or not irrigation should be done to his farm perhaps to increase the soil humidity in line with the findings that application of water to the soil increases the relative humidity [25-27].

### 3.3 Atmospheric changes and vegetable farming in selected areas

In consistent with documentary evidence regarding the marked variability of atmospheric conditions across the different agricultural districts [28] in Edo State, it is restated that sunshine, rainfall, temperature, humidity are very important determinants in the cultivation of vegetables. It was also noted that Okada receives more precipitation than the other areas during rainy and dry seasons. In Irukpenu like other parts of Esan region (central district) the rainy season is often characterized by heavy rains between the month of April and October. Uzairue in the north has the lowest volume of rainfall and humidity respectively but with the highest temperature (see Fig. 3), hence cultivation of the vegetables under study is significantly reduced.
3.4 IOT-enabled Analytics and messaging system for Vegetable farmers

In proposing this system, there are basic assumptions that have been made based on field experience, Edo State GIS, and relevant technologies respectively. These assumptions have been duly stated:

- The average radiation across the various communities under study in a year is adequate for vegetable cultivation.
- The volume of rainfall differs from zone to zone. It is least in the northern part of the State (see Fig. 3).
- Average temperature varies from zone to zone. It is highest in the northern part of the State (see Fig. 3).
- The climatic and atmospheric information generated from a reference remote sensing station in each zone in addition to the historical data on the zone would be sufficient for analysis and the results from such analysis and predictions would be sufficient to provide the necessary responses to all queries/enquiries from all vegetable farmers from the communities in that given zone.
- It is assumed that 97% of vegetable farmers and sellers own a mobile phone.

With the aforesaid assumptions, it is submitted that less effort would be expended to enrol vegetable farmers and other stakeholders to the system through multi-user channels thus reducing the cost of implementation of the system. With the ongoing programs of the State government in Agricultural sector reforms, and the existing partnership the State has with Oracle Corporation, the implementation of this technology would not be a difficult task. Fig. 4 is graphical model that reflects the communication in the proposed system. The system is a variant of device-cloud implementation of IoT-driven big data analytics platform. Three channels of information exchange are provided between the stakeholders and the analytics server: short message services, mobile frontend, and through the Web.

**Fig. 4: Schematic model of the proposed system**

4. Conclusion

This paper has examined the natural endowments of Edo State as it affects the prospects of vegetable farming. The trends in practices and the challenges were duly documented. A technologically-improved solution is proposed. The solution would provide farmers across the various zones with interactive and real-time single
windowplatform for information exchange. Following the proposition, current and historical data from the different agricultural zones would be captured, stored and updated and consequently used to produce answers to queries and questions from farmers and other stakeholders on a real-time basis. Consequent upon the foregoing, this paper concludes that:

- Vital information on atmospheric conditions, cropping requirements, etc. are important to enable local farmers carry out vegetable farming regardless of the season of the year.
- A technologically-improved system that provides farmers with relevant information that would support agricultural outputs is beneficial and highly desirable.
- Big data analytics would play a significant role in boosting the economy of Edo State through vegetable farming.

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