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Numerical Assessment of Water Quality Using Quality Control - A Case Study of Idah, Kogi State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

This research seeks to apply "numerical assessment of water quality using quality control - A case study of Idah, Kogi state, Nigeria." Secondary data of 500 bags of Idah factory water produced over period of 23 days were analyzed using control chart for fraction and number defectives to monitor the proportions of defective and number of defects in the factory water. It was found using P-CHART that central line (CL), upper control limit (UCL) and lower control limit (LCL) were 0.04, 0.07, and 0.01 respectively. Similarly, the result obtained using NP-CHART in monitoring number of defects in Idah factory water production indicated that , lower control limit (LCL), central line and upper control limit (UCL) were 8, 22 and 36 respectively. In both cases all the points were within the control limits. This implies that the production process is in a state of statistical control. It was therefore, recommended that the current components of the production process should be sustained among other things.

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Keywords: Quality Control (QC); production industry; monitoring; fraction defective; charts; p-chart; NP-chart; Upper control limit (UCL); Lower control Limit (LCL); Central Line (CL); Idah.

1 Introduction

Quality control (QC) being one of the prominent activities employed to ensure a certain level of quality in a product or service has emerged as a prime engine and an important factor for any successful industry to operate in today's highly competitive business environment [1].

However, the industries in the developing countries that are problem oriented in terms of competition in the market are also adopting the concepts and techniques of quality control in the various business strategies [1].

Interestingly, business in Nigeria are beginning to realize the importance and adopting the concept of quality control to achieve excellence and effectiveness in their products and services, manufacturing industries for example are taking the lead in adopting and implementing contemporary control for optimum advantages [1].

Quality control is a topic pioneered by manufacturing sector. Nowadays, in recent time, the field has developed tremendously and its techniques, tools, concept and methodologies can be applied widely in both services and manufacturing sectors [2].

Quality control (QC) being one of the prominent activities employed to ensure a certain level of quality in a product or service has emerged as a prime engine and an important factor for any successful industry to operate in today's highly competitive business environment. Table water table in Idah being one of the industries that produces sachet water and bottle water was established on the Eve of January 2009It has three cooled room. Each of this cooled room has the capacity of taken up to 200 bags of sachet water depends on customer's patronage. Beside this, many communities within Idah depends on the company for the daily demand for water. Some of these communities are, Angwa Ayegba, Inachalo, Ega Ojuwo-Afu, Igala-ogba, Mission, Ofiji and Onye dega in Ibaji Local Government Area. It is estimated that about 20 thousand people around the aforementioned areas depends on Idah Table Water for their water needs such as drinking, and other domestics and commercial uses. Therefore, it becomes of a great importance to investigate the quality condition of their product using statistical quality control in order to create public awareness of their product quality and give advice or recommendation where necessary [1,2].

1.1 Definition of Technical Terms

i. **Quality:** Quality is relating to one or more desirable characteristics that a product or service should possess. It also has features and characteristics of a product or service that contribute to the satisfaction of customer needs, that is conformance to the requirement needs and expectation of the customer.
ii. **Quality Control:** It is a regulatory process which we measure actual quality performance or the operational techniques and the activities which sustain quality of product or service that will satisfy given needs, and the use of such techniques and activities.
iii. **Customer:** Is anyone impacted by the process.
iv. **Statistical Quality Control:** This is the collection, analysis and interpretation or the application of statistical techniques to problems associated with the quality of products and services in production industries, particularly those who produce in large quantity
v. **Quality Assurance:** Quality assurance is the system of activities whose purpose is to provide an assurance that the overall quality control is in fact being done effectively.
vi. **Defect:** A defect is a fault in an article, which is not in itself serious enough to make an article defective. It is an incidence of lack of conformity with specification.
vii. **Defective:** A defective is any article in bulk material in a sample which fails to conform to some necessary specifications. It is an incidence of non-conforming.
viii. **Specification Limit:** It is the limit of accuracy within which the dimension of a finished product must be before it can be acceptable.
ix. **Variable:** These are quality characteristics that can be expressed as numerical measures.

x. **Attribute:** This is the quality characteristics that cannot be conveniently representednumerically.
xi. **Non-Conformity:** It is the departure of quality characteristics from its intended level.

1.2 Method and Materials

This study uses secondary data obtained from a table water factory in Idah, Kogi State, Nigeria. Analysis were carried out using control chart for fraction defective, and control chart for number of defectives.

1.3 Population for the Study

Population under study is the total bags of table produce daily

1.4 Sample Size

Since the table water factory operate a special kind of operation (i.e they maintain constant production capacity). The daily production capacity for the period under review is 500 bags per day hence the population size is the same as the sample size.

2 Conceptual/Theoretical Framework

The world has undergone rapid change during the past two decades with the advent of global competition to an extent that almost every company (large or small) is touched by it in some ways. As creativity and innovation are necessary for bringing forth the change required to obtain competitive advantages, quality is the most effective factor a company or organization can use in the battle for customers/clients. To be competitive, a company must focus on quality [3].

Quality control provides philosophy and driving force for designing quality in order to delight the customers by focusing on the best value of a company's products and service. In line with the significance of quality in promoting companies and organization's product and service, the researcher reviewed the various scholar's works and findings as follows [4].

Although literature in this field statistics process control here in Nigeria has not been extensively documented according to Akinola, but as much as meeting up with the quality demand is a concern to every organization, reviewing other people's progress in this regard will not be a waste.However, doing so will be an eye opener [5].

Harris and Gahlort Suggest factors to be consider while designing the product are cost, profit policy of the company, demand, and availability of the parts [6].

Terna, Abraham and Samson Define statistical process control as a technique employed to enhance the quality and productivity of the processes and the distribution or marketing of its product [7].

Hibarkah, Setiawan and Muhammad Emphasis the need to identify what the customers' needs and requirement are and then set about meeting them forms the core of total quality approach these scholars define QC as detection and elimination of components or final product that are notup to standard [8].

Godina, JOAO and Susana define statistical process control as a powerful management method which enables quality improvement and waste elimination. This they said can be express through the customer satisfaction in relation to the products and the offered service [9].

Zulaikha opined that understanding and improving quality are key factors leading to business success, growth and enhance competitiveness [10].

Douglas viewed quality as integral part of all products including services, it is an important consumer decision criterion in selecting among competitive products [11]**.** Gupta and Guta, saw quality as aiming at the needs of the customers (present and future) [12].

Murray and larry, viewed product quality over all durability, reliability, precision, case of operation and pairs and other valued attributes. Although some of these attributes can be measured objectively from marketing point of view, but quality should measure in terms of buyer's perception [13]. Montgomery (2009) showed evidence on this issue when he defined seven stages of quality in Japan in character of increasing level of quality to include; prevention oriented, process oriented, system oriented, humanistic society, cost oriented and quality function development (QFD) [14].

According to Burr quality control is the application of all activities concerned with quality awareness in a production process [15]. Cross by saw quality primarily as a conformance to require. Burr, (1982) defined quality as the excellence at an acceptable cost. However, quality improvement has become the key factor for the success and growth of any business organization. Investment on quality improvement gives rich returns. Japan is the best example [15].

According to Deming (1950) the 'Fourteen point' that inspect product for quality after they were manufactured was unacceptable. Instead, he proposed a process known as statistical quality control (SQC) that would be used closely.

Egwuata, (2010) observed that the production process of Benue Breweries Limited, Makurdi, was under control since none of the plotted values in his work went out of control limits.

2.1 The Development of Statistical Quality Control

Quality and its management played an important role in human history according to Payam and Reza (2009), accordingly managing quality was important even for ancient civilizations.

Payam and Reza (2009), further says the industrial revolution began in the United Kingdom during the 18th century and then extended to US and the other countries. Quality has become harder to manage due to mass production. Mass production was achievable by the division of labor and the use of machinery. In such a production line, workers perform repetitive task in a cooperative way using machinery. This resulted in huge productivity gains. But the number of factors and variables affecting the quality of a product in a mass production line were also numerous when compared to the production of a single item by an artisan who did all work from start to the end. Division of labor for mass production also took away the pride of workmanship, hence quality suffered in the production line and quality monitoring became an essential activity, due to mass manufacture engineer were forced to look beyond using standardized measurements. The causes of quality variation were numerous and hence statistical method were needed for quality monitoring and assurance.

Accordingly, Prof. Water Shewhart and Harold Dodge implemented statistical methods for quality in the mid-twenties in USA. The second world war was the mean catalyst for the extensive use of statistical quality control method for improving American war time production. Certain statistical methods were classified as military secrets. Dr Kaoru Ishikawa, a well-known Japanese quality philosopher speculated that the second world war was won by quality control and by utilization ofstatistical method.

Before the year 1900 A.D, production was essentially by one-man enterprises manufacturing product such as powers, furniture, stoles etc. as the industrial revolution gained ground in Europe and the United States factories sprang up. Factory products became more complex. At this stage 'quality was inspected into product by 100% inspection'.

During the 1920s the concept of statistical quality control was developed primarily through the work water, A. Shewhart of Bell telephone laboratories. Shewhart introduced the principle of controlling quality rather than 'inspecting it into the product' and developed a statistical chart forthe control of product variation source.

In the same decade H.F. Dodge and H.A. Rooming, both of the Bell telephone laboratories, developed the area of acceptance sampling as a substitute for 100% inspection, recognition of the value of statistical quality control becomes apparent in 1942.

Deming, (1950) gave a series of lectures on statistical method to Japanese engineers and on quality responsibility to chief executive officers of the largest organization in Japan.

Joseph, (1954) made his first trip to Japan and further emphasized management's responsibility to achieve using these concepts, Japanese set quality standard for the rest of the world to follow.

This resulted in the formation of the first quality control circle in Japan by 1960 for the purpose of quality improvement using simple statistical techniques.

This circle involves the world coming together to form a standard organization known as 'International standard organization (ISO) Herold and Patrick, (1989) looked at data from 132,750 patients getting are surgery-coronary artery bypass graft, suggest rate above 50% some hospitals are consistently lower, other higher.

2.2 Dimensions of Quality

The quality of a product can be described and evaluated in several ways. It is often very important to differentiate these different dimensions of quality Ganria (1987), provide an excellent discussion of eight component or dimension of quality these are:

1. Performance (will the product do the intended job?) potential customers usually evaluate a product to determine if it will perform setting specific functions and determine how well it will perform them.
2. Reliability (how often does the product fail?) complex product such as many appliances, automobiles, airplanes will usually require some repairs over their service life.
3. Durability: (how long does the product last?) this is the effective service life of the product.

Users obviously want product that performs satisfactory over a long period of time.

4. Serviceability: (how easy is it to repair the product?) user of product are interested in how quick and economically of an item.
5. Aesthetics (what does the product look like?) this is the visual appeal of the product, often taken into account factors such as styles, color, shape, packaging alternatives and other sensory features.
6. Features (what does the product do?) usually customers associated high quality with product that have added features, those that have features beyond the basic performance ofthe competitors.
7. Perceived quality: (what is the reputation of the company or its products) in many cases customer relies on the past reputation of the company concerning quality of its products.
8. Conformance to standard (is the product made exactly as the designer intended?) we usually talk of high-quality product as one that exactly meets the requirement placed on it. For instance, how well does the hood fit on a new car? It is perfectly flushed with defender height, and is the gap exactly the same on all sides?

2.3 Variation in the Quality of Products

When articles are being mass produced, some variation in the dimension must be expected and a certain relevance limit is allowed in their specification.

Variation is inevitable in any process and this reason working limit are placed on specification which then highlights that there must be a specific limit on such variation to be permissible. Hence variation is a measure of all quality characteristic variation which is capable of providing intervalfor such variation to be permissible.

Variation is certain to occur, no matter how small in the product of a company because of this the users of product set standard of quality which product must conform if they are to be considered fitness for use. These standards specify the upper and the lower limit within which a product will be considered satisfactory. If the product falls outside the range of the specification it is consideredunfit for use.

2.4 Steps Involves in Quality Control

i. Setting standard (specification) determine the cost, safety, reliability, performs and standard for a product
ii. Appraising conformance: Design of a product or service to meet the specification by comparing the product or service to a set standard
iii. Acting when necessary: if after appraisal, it went out of control appropriate corrective measure or action is taken, otherwise no action is required
iv. Planning for improvements: Developing a continuous improvement process strategy focused on cost, performance, safety and reliability standard, there is nothing too goodthat cannot be improve upon.

There are two aspect of statistical quality control. These are process control and product or lot or acceptance inspection.

2.5 The Statistical Process Control (SPC)

Statistical process control is the methodology for monitoring and optimizing the process output mainly in terms of variability and for judging when changes are required to bring the process back to the state of control. Chandra (2001), says "SPC is a statistical tool that involves inspecting a random sample of the output from a process and deciding whether the process is producing products with characteristics that fall within a predetermine range" this strategy of control differs from the other types of SQC where the process is allowed to adopt by automatic control devices by recalibrating or readjustment of devices.

Marylyn and Robert (2007), says the foundation for statistical process control technique as quality control tool was laid by Dr. Water Shewart.

Here the variation that occur in production process may be attributed to two main causes;

2.6 Source of Data

In statistical survey, data collection is very important because it is the basis on which statistical inference are built.

Statistical data may be obtained by a researcher from various ways. Generally, different institution, organization and government establishment maintain records and reports of their activities from time to time.
These reports or records provide very useful information about the organization. Furthermore, there are other bodies whose primary activity is the collection and publication of information about the activities of other organization. Information from publication such as daily sales report, weekly summaries of transactions, annual report etc. are usually of statistical relevance to a researcher. There are two main source of data collection which includes the primary source and secondary source of data.

3 Method of Data Analysis

The analytical tools used in analyzing the data collected for this project work are control charts. A control chart is a popular statistical tool for monitoring and improving quality, originated by Walter Shewhart in 1924 for the manufacturing environment. It was later extended by W. Edward Deming to the quality improvement in all areas of an organization (a philosophy known as total quality management or TQM).

Control charts are statistical devices use to study and control variation on repetitive process. It was originated my Dr. W. Shewart (1884). The primary objective of process control is to keep a process at a stable level. The measure tool used to do this is the control chart which is a graphical method of presenting data base on sequence of samples.

A control chart is therefore a graph or variation of the response variable. Most control chart use the 3**δ** units. This mean that 99.7% of the plotted point when the process is well centered will lie within limits and 0.3% of points will lie outside. When the point falls outside the control limits, action must be taken on the basis the signal has been received indicating that the process is out of control. If, however, all point falls within the calculated limits we say the process is in state of statistical control.

The 2**δ** limits are called the warning limit the give warns of danger ahead

Example of control chart

Process Capability: This the unit of accuracy to which manufacturing process is capable of constantly working and itis mathematically $\mu \pm 3\delta$.

Specification limit is the limit of accuracy within which the dimension of a finished product must be before it can be acceptable if the process is normally distributed with mean 0 and variance 1

3.1 Uses of Control Chart

a. They are proven techniques for improving productivity. This is because a successful control chart reduced scraps and rework as a result which the productivity increase cost decrease and the production capacity increases.
b. They are effective in defect prevention this is consistent with the “do it right the first time”philosophy.
c. They give warning as to danger ahead
d. Control chart provide the information about the process capability, they provide information about the very important process parameter of their stability over time.
e. They provide diagnostics information of the pattern of point in a control chart of point in a control chart provide information of diagnostic value to an experience operator or engineer.

A control chart is characterized by three horizontal lines, a Centre line control limit to indicate the desired standard or level of the process, an upper and lower control limits, control chart can be classified into two, these include;

- Control chart for attributes and
- Control chart for variables

However, for the purpose of the project work, the control chart for attributes was used. Specifically control chart for fraction defective(p-chart) and control chart for count defective (np-chart).

3.2 Control Chart for Fraction Defectives (P-Chart)

This is the ratio of the number defectives in the population to total number of items in the population. The statistical principle underlying the control chart for fraction defective is based onthe binomial distribution.

Let the probability that any unit not conforming to specification be p and successive unit produces be independent. If a random size of n units of product is selected and if d is the number of units that are not conforming, then;

$Pr\ (d = x) = {}^{n}c_{x}\ p^{x}\ (1 - p)^{n-x}$ ……………………………………………(1)

If P is the estimate from sample P = d/n ……………………………………………….(2)

And the mean and variance of $\bar{p}$ and $\bar{\delta}^2$,

Suppose the proportion defective in the production is known or it is a standard value specified by the management. Then the control limits are given by.

$$UCL = p + 3\sqrt{\frac{p\,(1-p)}{n}}$$

CL = p

$$LCL = p - 3\sqrt{\frac{p\,(1-p)}{n}}$$

……………………………………………….(3)

The operation of these chart of taken subsequent sample of n units computing the fraction defective Pi and plotting the statistic Pi on the chart, so long as the Pi remains within the control limits and subsequence of plotting points does not exhibit any systematic non-random pattern, we will conclude that the process is in control at quality level P.

However, if the point falls outside the control limits or if a non-random pattern in the plotted point is observed, we will conclude that the process quality has shifted to a new level and the process isout of control.

If the process fraction number defective P is unknown as the case of this project work, it must be estimated from the observed data.

$Pi = \frac{di}{n}, i, = 1,2, \ldots m,$

And the average of pi = $\sum_{i-1}^{m} \frac{ni}{\mathrm{m}}$ for n

The Statistical $\bar{p}$ estimate the unknown fraction defective P, thus

$$UCL = \bar{p} + 3\ \sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}}$$

……………………………………………….(4)

C L = $\bar{p}$

$$LCL = \bar{p} - 3\ \sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}}$$

………………………………………..(5)

Note: If LCL is negative, we set it to zero (0)

3.3 Control Chart for Count Defective (Np – Chart)

The np – chart is used to evaluate process stability when counting the number or fraction defective. The np-chart is useful when it is easy to count the number of defective items and the sample size is always the same.

The formula for computation of np-chart value.

$$N\bar{p} = \frac{\sum di}{n},$$

where di is the number of defective items in the sample.

$N\bar{p}$ = CL

$$\bar{p} = \frac{n\bar{p}}{N}$$

$$UCL = n\bar{p} + 3\sqrt{n\bar{p}q} \quad \text{.......(5)}$$

$$LCL = n\bar{p} - 3\sqrt{n\bar{p}\,(1-\bar{p})} \quad \text{.......(6)}$$

3.4 Statistical Data Presentations and Analysis

Data presentation is a critical portion or part of making a proposal, report and essential demonstration for daily meeting an important presentation. The data were collected in line with defective water per 500 bags daily production.

For the period of 20 days as collected in April 2022 at Olubor table water factory off OJ eye clinic along Angwa primary school Idah below is the data.

Table 1. Tabular analysis of fraction defective for table water

Days	No. of bags per day	No. of defective (di)	Pi=di/n
1	500	14	0.028
2	500	14	0.028
3	500	35	0.07
4	500	13	0.026
5	500	35	0.07
6	500	13	0.026
7	500	25	0.05
8	500	25	0.05
9	500	12	0.024
10	500	30	0.06
11	500	35	0.07
12	500	14	0.028
13	500	25	0.05
14	500	12	0.024
15	500	35	0.07
16	500	12	0.024
17	500	12	0.024
18	500	35	0.07
19	500	25	0.05
20	500	14	0.028
Total			**0.87**

ANALYSIS

n=20

$$\sum_{i=1}^{n} \text{di} = 0.87$$

$$\bar{p} = \frac{0.87}{20}$$

=0.0435

$\bar{\rho} = 0.04$

CL=$\bar{\rho} \Longrightarrow$ 0.04

$$\text{UCL} = \bar{\rho} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{N}}$$

$$= 0.04 + 3\sqrt{\frac{0.04(1-0.04)}{500}}$$

$$= 0.04 + 3\sqrt{\frac{0.0384}{500}}$$

= 0.04 + 3 (0.008764)

= 0.04 + 0.026292

UCL = 0.07

$$\text{LCL} = \bar{\rho} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{N}}$$

$$= 0.04 - 3\sqrt{\frac{0.04(1-0.04)}{500}}$$

= 0.04 – 0.026292

LCL = 0.014

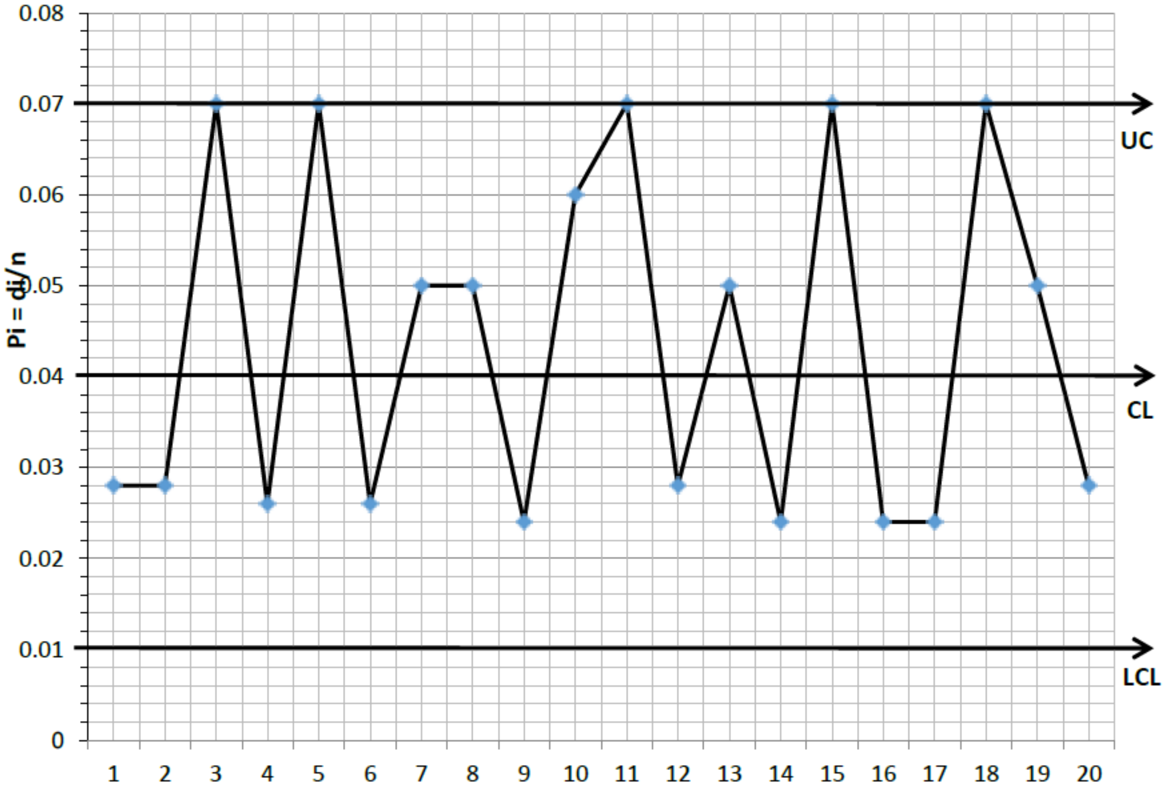

Fig. 1. Control chart for fraction defective (P-Chart)
UCL = UPPER CONTROL LIMIT
CL = CONTROL LIMIT
LCL = LOWER CONTROL LIMIT

Table 2. Tabulated data for count defective table water

Sample Number	No: of bags per days	No of Defective
1	500	14
2	500	13
3	500	14
4	500	35
5	500	35
6	500	13
7	500	25
8	500	25
9	500	12
10	500	30
11	500	35
12	500	14
13	500	25
14	500	12
15	500	35
16	500	12
17	500	12
18	500	35
19	500	25
20	500	14
Total		435

3.5 Mathematical Computation

Total number of defective = 435 $Np = \frac{\Sigma di}{n}$

Total number of defective = 435

$Np=\frac{Edi}{n}$

$NP=\frac{435}{20}$

NP=21.75

NP=22

NP=CL=21.75

$\bar{\rho}=\frac{NP}{N}$ ⟹

$\bar{\rho}=\frac{432}{500}$

CL=$\bar{\rho}$=0.04

UCL = np + 3 $\sqrt{n\rho q}$

=22 +3 $\sqrt{22(0.96)}$

=22 + 3 $\sqrt{21.12}$

=22 + 3 (4.5957)

=22 + 13.7871

UCL = 36

LCL = np – 3 $\sqrt{(1-p)}$

= 22 – 3 $\sqrt{22(0.96)}$

= 22 – 3 $\sqrt{21.12}$

= 22 – 3 (4.5957)

= 22 – 13.7871

LCL = 8.2129

LLC = 8.2

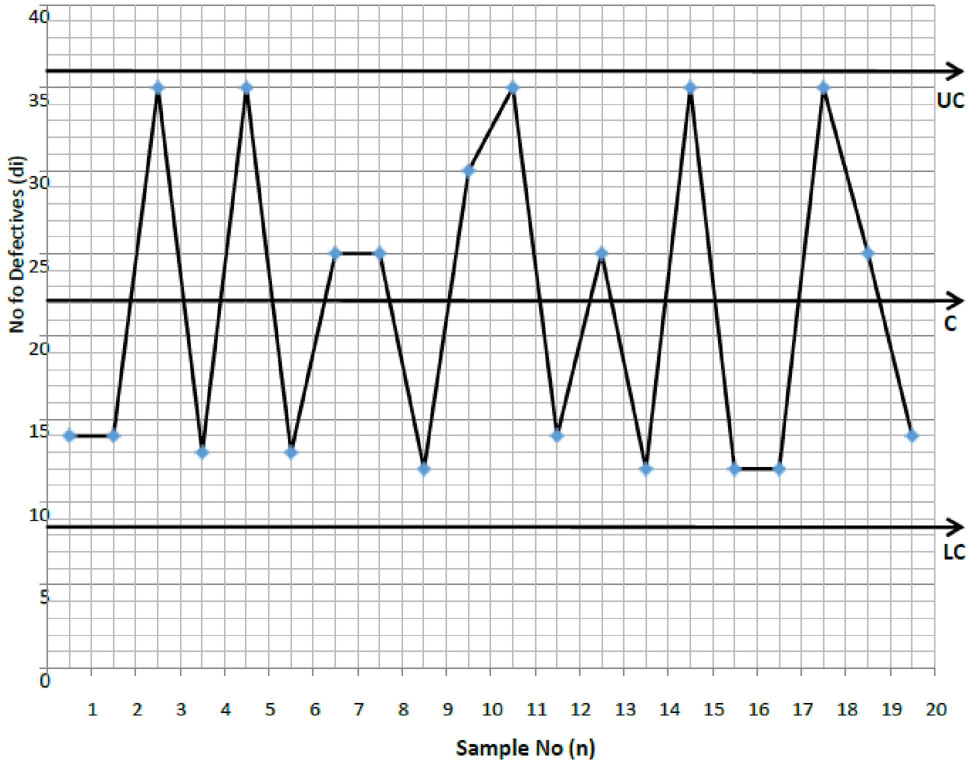

Fig. 2. Control chart for number defective (NP-Chart)
UCL = UPPER CONTROL LIMIT
CL = CONTROL LIMIT
LCL = LOWER CONTROL LIMIT

4 Interpretation of Result

Based on the techniques and tools used to analyzed the data, it is observed that production process of Olubor Table Water is in state of control.

It can be seen in all the cases of the control chart for attribute that none of the point fall outside the control limit with respect to the production process and the quality of the product itself.

5 Discussion of Findings

In the above analysis, it is obvious that although there are some defective Table water, the production process did not exceed the limits. This is an indication that the production is in state ofcontrol.

Hence, it can be said that there is no assignable cause of variation involved in the production process of Table water. As such the production process of Table water should be allowed to continue scholars like Egwuata (2010) of Benue Breweries Limited, Makurdi work agreed with this present research work when he assert that the production process of Benue Breweries Company was in a state of statistical control.

6 Conclusion

Referring to the result of the analysis showing in 5.1 i.e the control chart for fraction defective shows that all points lie within the control limit but with high concentration towards the upper control limit and the control chart for count defective, similarly shows that all points are within the control limit. The study concludes that the production process of Olubor table water isin state of statistical control.
Except that the control chart for fraction defective appears to suggest the presence of an assignable cause of variation.

Competing Interests

Authors have declared that no competing interests exist.

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