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Statistical Process Control on Production: A Case Study of Some Basic Chemicals Used in Pure Water Production

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Abstract: Statistics is the art of making decisions about a process or population based on an analysis of the information contained in a sample from that population. In any production process, regardless of how well designed or carefully maintained it is, a certain amount of inherent or natural variability will always exits, Such variability like background noise. When the variability is small, we usually consider this an acceptable level of process performance or the process is within the process control. A process that is operating in the presence of assignable causes is said to be out of control. A data set collected from randomly selected packaged water producers referred to as "Pure water producers" and subjected to laboratory test of the of the level of some basic chemicals used in the production of pure water, such as pH, conductivity (µS/cm; Lead (Pb); Aluminum (Al) and Chloride (Cl). The test shows that most of the chemicals used are out of process control. This is danger to health of the consumers.

Key words: Production, process control, tweaking, tasteless, assignable causes, variability, chemicals

INTRODUCTION

Production processes must perform consistently overtime to be capable of meeting production and design requirements. Statistical process control is a methodology to monitor and benchmark a process to improve its variability, stability and capability. According to Douglas Montgomery (1985) states that Statistical methods play a vital role in quality assurance. They provide the principal means by which product is sampled, tested and evaluated and information in those data used to control and improve the production process. In any production process, regardless of how well designed or carefully maintained it is, a certain amount of natural variability will always exist. The natural variability "background noise "is the cumulative effect of many small, essentially uncontrollable causes. When the background noise of a process is relatively small, we usually consider this an acceptable level of process performance.

There is variability that usually arises from improperly adjusted machines, operator error and/or defective raw materials. Such variability is generally large when compared to the background noise. This variability that is not part of chance cause pattern is referred to "assignable causes".

Veronica and Patrick (1997) stress that control charts are among the most important tools in Statistical process control. They were developed in the 1920's by Dr. Walter Shewhart a scientist at Bell laboratories, the research arm of American Telephone and Telegraph. Statistical control can be used to:

- Monitor and reduce process variability.
- Monitor and maintain the process on target.
- Determine when a process needs "tweaking" (adjusting) and when it does not.
- Establish process stability and detect process changes so that corrective action can be taken.
- Improve quality and productivity by improving the process, which reduces product inspection, scrap and rework at the end of the line.

Background of the study: Pure water is an odourless, tasteless liquid. It has a bluish tint, which may be detected, however, only in layers of considerable pressure. Accessibility and availability of fresh clean water is a key to sustainable development and an essential element in health, food production and poverty reduction (Adekunle, 2004). However an estimated 1.2 billion people around the world lack access to safe water and close to 2.5 billion are not provided with adequate sanitation (Third World Water Forum on Water, 2003). The standard industrialized world model for delivery of safe drinking water and sanitation technology is however, not affordable in much of the developing world. Thus, given the renewed global commitments towards the Millennium Development Goals (MDG) marked for 2015, the importance and contribution of locally sourced low cost alternative drinking water schemes to sustainable access in rural and semi-urban settings of developing nations cannot be over emphasized (UNDESA, 2004).

Statutorily, portable water supply in Nigeria had been by the Government Owned Public Water Utilities (GPWU) in the past. The GPWUs provided their supply from

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conventional water treatments plants that uses water from impounded reservoirs, flowing perennial streams, lakes and deep boreholes. As the country population grows and industries increase, the supply of water by the GPWUs becomes inadequate in quality and quantity. This led to the emergence of some Privately Owned Water Enterprises (POWE) that operated side by side with the GPWUs within the water sector (Onemano and Otun, 2003).

One of the most popular POWE in Nigeria is the sachet water sold in polythene sachet otherwise called 'Pure Water'. The POWEs mainly collect their water as the end product of initially treated water supplied by the GPWUs and do little treatment such as the removal of the suspended solids to make the GPWUs water more potable. They also do some minor treatment on water from natural springs, open wells and deep boreholes. Some also collect water directly from the GPWUs kiosks and later resells them at a higher price (Onemano and Otun, 2003).

The production, marketing and consumption of sachet water have increased tremendously. There are now several brands of these type of packaged water marketed in Nigeria and other developing nations (Ogan, 1992 and Kassenga, 2007). This so called Pure Water in sachets is readily available, easy to serve and the price is affordable and finds patronage from the middle class and members of low socio-economic classes, but there are concerns about its purity. The integrity of the hygienic environment and the conditions where majority of the water in sachets are produced has also been questioned (CAMON, 2007).

We use the Statistical process control chart to monitor the production process of pure water with the assessment of some basic chemicals used in the production and process of pure water.

A control chart includes three horizontal parallel lines: a centre line, an upper control limit above it and a lower control limit below it. The centre (CL) on a control chart points are expected to cluster in the absence of an assignable cause. The centre line is usually set at average, the median, the mode or the target value of the points being plotted. The Upper Control Limit (UCL) line and the Lower Control Limit (LCL) defined a region where most observations are expected to fall. The upper and lower control limits refer to as statistical control limits or Statistical Process Control (SPC) limits reflect the natural variability of the process and are constructed in such a way that when the process is in control most of the points will falls inside the control limits in random fashion. If a point on the control charts falls above the upper limits or below the lower control limits the process is said to be out of control, and assignable causes need to be searched for eliminated.

Many control charts have a common form. Let w be an observed process characteristics that is determined from a sample, such as the sample mean (average)

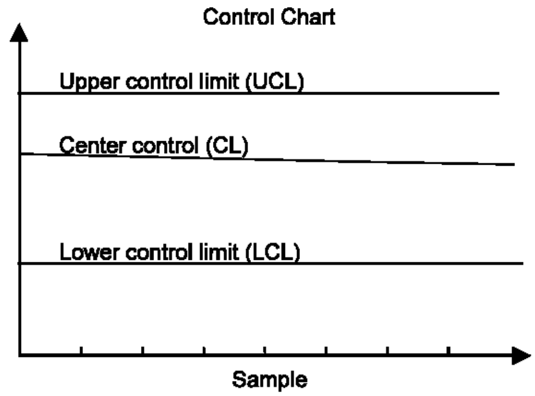

Fig. 1: A typical control chart

x-bar. Let w have a true population mean (μ) and standard deviation (σ).

The centre line, upper control limit and lower control limit have the general form:

$$UCL = \mu + k\sigma$$
$$CL = \mu$$
$$LCL = \mu - k\sigma$$

The upper and lower control limits are chosen to be a distance of K standard deviation (σ) for the mean (μ). It is customary to use k = 3, Which gives 3-sigma control limits that are standard deviation away from the centre. Research as show that if the distribution is normal, approximately 99.73% of the values production will fall between the 3-sigma control limits and 0.27% of the values of the production will fall outside the control limits giving a false alarm approximately only 27 out of 10,000 times.

Objectives of the study: The research work was aimed at ensuring that the production process is monitored to reduce variability and maintain the process target. To determine when a process needs "tweaking" (adjusting) and when it does not. To establish process stability and detect process changes so that corrective action can be taken and finally, to improve quality and productivity by improving the process, which reduces product inspection, scrap and rework at the end of the line.

MATERIALS AND METHODS

A total of hundred sachets (100) from ten different brands of the Pure water were randomly selected in Minna, Niger state which was the study area. Ten samples of each were collected direct from hawkers and wholesalers at different locations of the town which includes; motor parks, markets and other busy areas of the town. These were then transferred to the laboratory for analysis. For physical and laboratory analysis, the physical visual examination of the water samples; odour, and appearance such as colour, turbidity and presence of floating particles were all noted. While in the laboratory, each sample was subjected to both physical and chemical tests in accordance with standard methods as obtained from the American Public Health Association (APHA), 2005. The chemical tests conducted include chemical analysis of Lead (Pb), chloride (Cl), Iron (Fe) and Aluminum (Al). The physical tests carried out were those of pH and conductivity. The summary of the Raw data is as in appendix1 (Table 2).

Data analysis and interpretation: Data obtained were analyzed using means, standard deviation, standard error of mean and control charts with the use of Instat and Minitab 14 statistical software.

All the tests were conducted between January-June, 2009. The choices of the periods were as a result of the realization of the large production and consumptions of pure water during these periods. The analysis is as follows:

Table 1: Mean, standard deviation, standard error of mean of the chemicals tested in January-June, 2009

Groups	Mean	SD	SEM
pH	7.1600	0.712	0.225
Conductivity (µS/cm)	0.3610	0.1760	0.0556
Iron (Fe^{+2})	0.0870	0.1114	0.0352
Lead (Pb)	0.0340	0.0836	0.0264
Aluminum (Al)	0.0310	0.02558	0.00809
Chloride (Cl)	8.4000	3.3000	1.0400

SD = Standard deviation

SEM = Standard error of mean

From Table 1, the mean values Iron (Fe^{+2}), Aluminum (Al), Conductivity (µS/cm); Chloride (Cl) are less that maximum permitted by Standard organization of Nigerian, while, mean of the Lead (Pb) is greater than the maximum permitted by Standard Organization of Nigerian (SON) standard for portable drinking water as in appendix 1 (Table 3). This shows statistical out of process which invariably has health impact on the consumers.

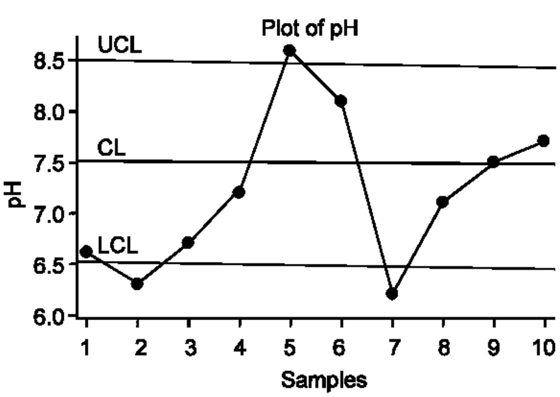

Fig. 2: The control chart for the pH

The upper control limit is 8.5 while the lower control limit is 6.5 from the statistical process chart it seen that three of the points are out of statistical process control, most of the points are at the lower control limit, which according to Veronica and Patrick (1997) when eight points fall at one side the production is out of process control. This might lead to increase of dissolution of certain metals whose concentration above normal could have detrimental health effect.

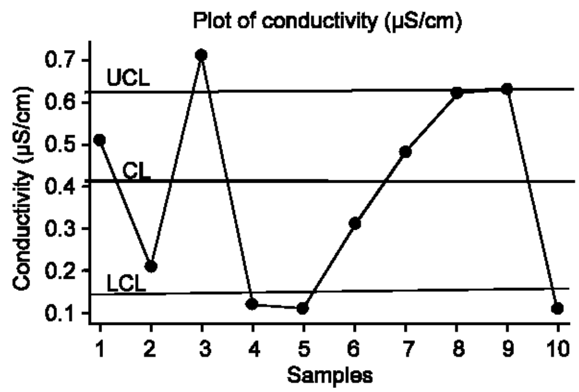

Fig. 3: Plot showing the control chart for conductivity

From the Plot above, it concord with the assertion made by Veronica and Patrick (1997), that an indicator for out of control is that if eight consecutive points are on one side of the centre line or two out of three consecutive points are outside the 2-sigma warning limits on one side of the centre line, then the productions are out of control. Thus, conductivity could be classified has been out-of-control.

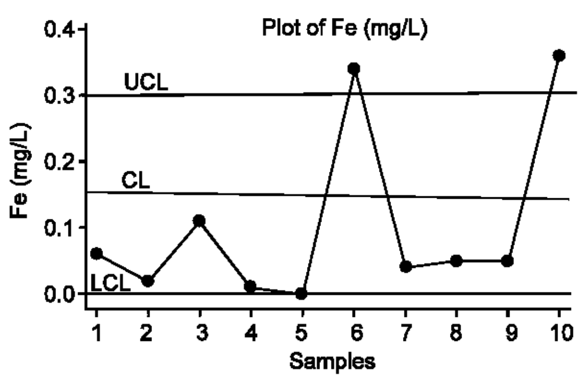

Fig. 4: Plot showing the control chart of Iron

Figure 4 shows that two of the values are out of control and looking at the plot most of the points are on one side of the center, that is , the lower limit. This could lead to water having a metallic taste and could cause stains to laundry.

Table 2: Raw Mean score of parameters analyzed for the duration of work

Sam.	pH	Cond. (µS/cm)	Fe (mg/L)	Pb (mg/L)	Al (mg/L)	Cl (mg/L)
1	6.80	0.38	0.02	0.27	0.02	11.20
2	6.40	0.24	0.01	0.00	0.06	4.33
3	7.00	0.62	0.15	0.02	0.03	4.75
4	7.20	0.13	0.03	0.00	0.03	7.96
5	8.80	0.18	0.00	0.01	0.04	15.74
6	7.20	0.38	0.24	0.00	0.04	7.34
7	6.20	0.51	0.04	0.00	0.01	8.71
8	7.10	0.61	0.03	0.00	0.08	6.80
9	7.30	0.36	0.03	0.03	0.00	9.638
10	7.60	0.20	0.32	0.01	0.00	7.53

Sam. = Samples; Cond. = Conductivity

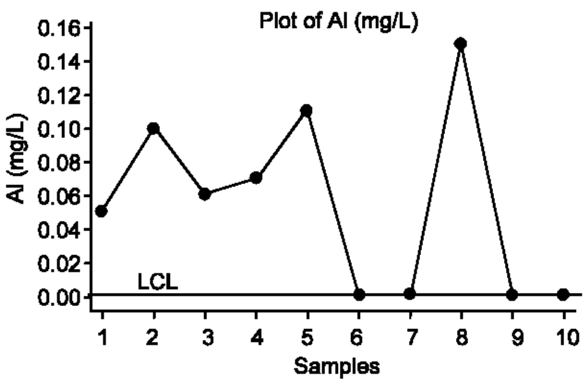

Fig. 5: Plot of the control chart for Aluminum

The range of Aluminum is between 0.00-0.0.155 mg/L which is within the acceptable limit of 0.2 mg/L.

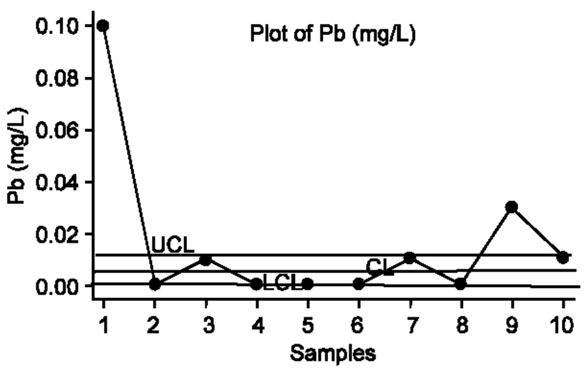

Fig. 6: Plot of control chart showing the responses for Lead (Pb)

From the figure above it was observed that the element Lead (Pb) is out of control. Given the upper control limit to be 0.01 mg/L, showing most of the points to be out of controlled, this could have deleterious health effect as lead is associated with cancer, interference with mental development and vitamin D metabolism and is also implicated in central and peripheral nervous system toxicity.

Table 3: Chemical parameters-inorganic constituents

Parameter	Unit	Maximum permitted	Health impact
Aluminum (Al)	Mg/L	0.2	Potential Neuro-degenerative disorders
Arsenic (As)	Mg/L	0.01	Cancer
Barium	Mg/L	0.7	Hypertension
Cadmium (Cd)	Mg/L	0.003	Toxic to the kidney
Chloride (Cl)	Mg/L	250	None
Chromium (Cr^{6+})	Mg/L	0.05	Cancer
Conductivity	µS/cm	1000	None
Copper (Cu^{+2})	Mg/L	1	Gastrointestinal disorder
Cyanide (CN^-)	Mg/L	0.01	Very toxic to the thyroid and the nervous system
Fluoride (F)	Mg/L	1.5	Fluorosis, skeletal tissue (bones and teeth) morbidity
Hardness (as $CaCO_3$)	Mg/L	150	None
Hydrogen sulphide (H_2S)	Mg/L	0.05	None
Iron (Fe^{+2})	Mg/L	0.3	None
Lead (Pb)	Mg/L	0.01	Cancer, interference with vitamin D metabolism, affects mental development in infants, toxic to the central and peripheral nervous systems
Magnesium (Mg^{+2})	Mg/L	0.20	Consumer acceptability
Manganese (Mn^{+2})	Mg/L	0.2	Neurological disorder

Source: Nigerian Industrial Standard (NIS) 554: 2007, Nigerian standard for drinking water quality

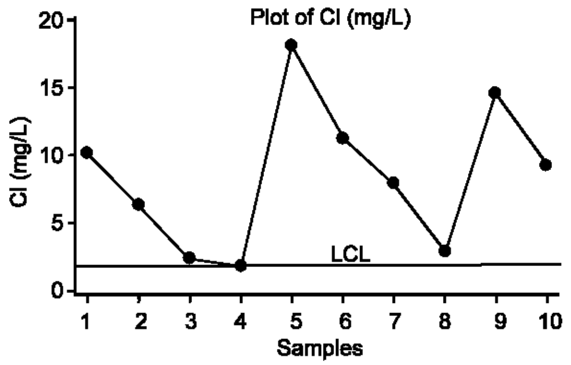

Fig. 7: Plot of control chart showing the responses for chloride

Chloride concentration in the samples has a mean range of 4.33 and 15.74 which is within the accepted limit of 250 mg/L. The range is 15.74-4.33 = 11.31.

RESULTS AND DISCUSSION

The results were compared with Nigerian Standard for Drinking Water Quality as outlined by Standard Organization of Nigeria (SON), 2007. As outlined in the table the mean pH ranges from 6.2-8.8, which indicates that some of samples are falling out of range of the normal pH of drinking water (6.5-8.5). Though, this might not have any direct effect but could lead to increase of dissolution of certain metals whose concentration above normal could have detrimental health effect.

The conductivity has a mean range of 0.13-0.62 µS/cm, while Iron has a mean range of 0.00-0.32 mg/L indication a deviation of the accepted level of 0.3 mg/L, this could lead to the water having a metallic taste and could cause stains to laundry. Lead has a mean range of 0.00-0.03 mg/L with the upper limit well above the accepted limit of 0.01 mg/L this could have deleterious have effect as lead is associated with cancer, interference with mental development and vitamin D metabolism and is also implicated in central and peripheral nervous system toxicity. Aluminum has a mean range of 0.00-0.08 mg/L which is within the accepted limit of 0.2 mg/L. Chloride concentration in the samples has a mean range of 4.33-15.74 which also within the accepted limit of 250 mg/L.

Conclusion and recommendations: Production process control chart can monitor and reduce process variability, determine when a process needs adjusting and when it does not, establish process stability and detect process changes.

As evidence from the results some of the chemicals used in the production of packaged water at times do not conform to standards led out for quality drinking water, the chemical constituents are out of process control; as such this could pose health risk to the consumers. The result also confirms other reports on the health risk of pure water.

We therefore recommend that a statistical process control chart should be plotted periodically productivity by improving the process, which the process production, scrap and rework at the end of the days production.

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