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Lepage-type Change-point Control Charts Applied to Monitoring Acute Mal-nutrition in Under-5 Children in Nigeria

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Abstract **Introduction:** Identification of the most affected age is an important statistical contribution to monitoring nutritional problems among children. Previous studies have demonstrated that monitoring processes' parameters (mean and variability) individually or simultaneously could provide some insights but no application has been related to monitoring proportion of wasting in under-5 children. The present study applied a nonparametric-based Lepage-type change-point (LCP) control chart to monitor the proportion of acute malnutrition in under-5 children in Nigeria. **Methods:** Data were extracted for 24,530 under-5 children with valid and complete information on date of birth, height and weight in the 2013 Nigeria Demographic and Health Survey dataset. Data were analysed using descriptive statistics including mean, standard deviation and proportion. The Shapiro-Wilk lamda was used to assess the normality of the distribution of wasting among under-5 while the LCP control chart was used for monitoring the distribution. Affter-signal diagnosis was conducted to ascertain what distributional data parameters have changed, at 5% level of significance. **Results:** Children were 23.8(±16.8) months old and mostly female (50.3%). Prevalence of wasting among under-5 was 18.4% and higher among children aged 0-55 months (24.9%). Normality test (Shapiro-Wilk: W= 0.9268; p=0.001463) suggested that the distribution of wasted children was non-normal. The LCP chart signalled a shift (abnormal rate) in the proportion of wasting at aged 24 month; while its estimated change-point was at age 21 month. After-signal diagnosis indicated the change may have occurred in both a location shift (p=0.002949) and a variability shift (p=0.03978) of the proportion of wasted children. **Conclusion:** Prevalence of wasting in the present analysis is not uniform across age groups and the LCP chart demonstrated prompt detection of shift (both in mean and variability) in the proportion of wasted under-5 children. The LCP chart could be used to monitor proportion of wasting among children to identify groups needing intervention.

Keywords: *acute malnutrition, under-5 children, Lepage-type change-point, control chart, nonparametric methods*

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1. Introduction

Malnutrition has been identified as a critical risk factor for stunted growth and poor psychosocial development in under-5 children. Although the situation has been receiving due attention in some developing countries, the trend in child malnutrition has been unabated in many countries in sub-Saharan Africa. Globally, about 45% of all child mortality are linked to malnutrition [1] while malnutrition has been associated with 54% of mortality among children in developing countries [2]. On the other hand, acute malnutrition (moderate or severe) which can be due to a low weight-for-height (wasting) is as a result of decrease in food consumption (or intake) and/or illness resulting in sudden weight loss or oedema. Acute malnutrition has been identified as a risk factor for several deadly childhood diseases including diarrhoea, Pneumonia, or other acute respiratory infections [1]. Also, it has been implicated in high mortality rate among under-5 children in sub-Saharan Africa and worldwide.

For instance, while about 55 million under-5 children suffer acute malnutrition, over 3 million of them die of malnutrition annually [3], and majority of these deaths occur among children living in sub-Saharan Africa [4,5]. Previous studies have associated increased mortality rate among under-5 to global acute malnutrition. Specifically, higher global acute malnutrition cut-points for pastoralists than agriculturalists have been reported to predict elevated under-5 mortality rate (1/10,000/day) or emergency levels (2/10,000/day) in the Horn of Africa [6].

In Nigeria, Manyike et al. [7] have previously assessed prevalence of acute malnutrition in South-east Nigeria. Their report shows the prevalence of global and severe acute malnutrition among pre-school children was 9.7% and 4.4%, respectively. In a related study conducted in communities selected from Akure South Local Government

Area (LGA) of Ondo state, Nigeria; 42% of the children (Male: 22% and Female: 20%) were affected by acute malnutrition [8]. A part from that, the Nigerian Demographic Health Survey data revealed a worrisome trend in acute malnutrition in Nigeria between 2003 and 2013. The proportion of children with acute malnutrition was 11%, 14% and 18% in 2003, 2008 and 2013 respectively [9]. These data are clear indications that acute malnutrition is a public health problem in Nigeria.

Unfortunately, there are no reliable evidence-based management strategies geared towards mitigating the impact of malnutrition among under-5 children in Nigeria (and other sub-Saharan African countries). Such strategies can inform interventions in affected group if they yield data based on validated methods that have been demonstrated to have scientific relevance and user friendliness. In the present study we employed a method that statistically assessed or monitor acute malnutrition among under-5 children using a lepage-type (LP) control chart. This method ensures an enhanced and expanded growth monitoring at community level for early detection of malnutrition among under-5 children to reduce incidence of severe cases and mortality.

2. Methods

2.1. Study Area

The study was carried out in Nigeria (a sub-Saharan Africa) with a population of over 170 million, with about 30 million under-5 children [10]. Nigeria is made up of 36 states and a Federal Capital Territory. It is grouped into six geo-political zones/regions namely: North West, North East, North Central, South East, South West and South- South.

2.2. Study Design and Population

The present analysis used the 2013 Nigeria Demographic Health and Survey, which was cross-sectional in design and involved a nationally representative sample aimed at providing population and health indicator estimates. Of 30,050 under-5 children in the 2013 NDHS subsample of households who were eligible for anthropometric measurements, about 87% of the measurements carried out were valid. The implied that valid and complete information on date of birth, height and weight were obtained on 24,530 children.

2.3. Data Extraction, Variable Definitions and Data Management

Data were extracted for the 24,530 children with valid data in the 2013 NDHS survey dataset. Specifically, in the present analysis, data were extracted on relevant variables including child age (in months), sex, mothers' wealth category, mothers' educational status, parity, birth order, delivery by caesarean section, mother's marital status, breastfeeding status, resident, region, and weight-for-height.

The following variables were recoded as indicated as follows: child age (recoded as aged 0–6 months, 6–23 months and 24–59 months), mother's wealth index (recoded as poor, middle, rich; from the five national-level wealth quintiles of poorest, poor, middle, rich and richest), mother's age (recoded into aged 15-24 years, 25-34 years and 35-49 years), total number of children ever born or parity(recoded as ≤4 children and >4 children), birth order (recoded as 1st birth, 2nd–4th birth and >4th birth). Children with weight-for-height Z-scores below minus two standard deviations (2SD) from the median of the WHO reference population are considered wasted or acutely malnourished [9]. The outcome variable (percentage of acute malnutrition) in the present analysis is the age-specific proportion of under-5 children that are acutely malnourished (wasting) in the 2013 NDHS data. Preliminary data explorations revealed minimal missing data on the extracted variables; hence, subjects with missing data were excluded from the present analysis.

2.4. Statistical Methods and Analysis

Descriptive statistics was used to assess participants' socio-economic characteristics while the Shapiro-wilk normality test was used to investigate the distribution of the percentage of acute malnutrition (outcome variable) data.

Let Y_i , be the percentage of acutely malnourished under-5 children (the outcome variable) in the 2013 NDHS data. Assuming Y_i is normally distributed and conditioned on the parameter τ, called the "change-point" which is unknown a priori. Furthermore, let the parameters μ_1 and μ_2 be the unknown in- and out-of-control means (respectively) while δ_1^2 and δ_2^2 are unknown constants describing the variability in the in- and out-of-control observations in which the process mean and variance have shifted, and τ is the change-point. The distribution of such observation can be monitored effectively using Generalized likelihood ratio (GLR) change-point control charts [11] with Y_i defined as

$$Y_i \sim \begin{cases} N(\mu_1, \delta_1^2), i \le \tau \\ N(\mu_2, \delta_2^2), i > \tau \end{cases} \quad (1)$$

where $Y_1, Y_2, ..., Y_i, ...$ are the successive observations.

However, for a non-normally distributed Y_i , Afolabi et al. [12] proposed a Lepage-type change-point control charts (LCP) for simultaneously monitoring change in location and variability parameters. The method which combines the Wilcoxon (for location) and the Mood (for variability) statistics is premised on an earlier statistical methods suggested in the literature [13]. Specifically, it supposed that the independent observations on a national or region-specific acute malnutrition data $[y_1, y_2, \cdots, y_n]$ follows a continuous cumulative distribution function $F_i(y; \mu_i, \delta_i)$, where μ_i and δ_i are the location and variability parameters respectively [12]. Assuming a shift/change in mean and/or in standard deviation of observations occurs at time τ (change-point) where μ and δ are the unknown parameters describing the location and variability inherent in the process data being monitored, the process can be modelled by:

$$Y_i \sim \begin{cases} F(y;\mu_1,\delta_1^2), i \le \tau \\ F(y;\mu_2,\delta_2^2), i > \tau \end{cases} \quad (2)$$

Shift in the location parameter occurs if $\mu_1 \neq \mu_2$ while shift in variability occurs if $\delta_1 \neq \delta_2$ and in principle, either or both of these shifts could occur in the observation process. Since sample size keeps increasing subsequent to new observation (on acute malnutrition) in a prospective surveillance study, the appropriate Lepage-type test statistic is expressed as follows:

$$LCC_{\max,n} = \max_d \left| L_{d,n} \right| \quad (3)$$

where the change-point $\tau = d$

$$L_{d,n} = \frac{12(W_S - \frac{d(n+1)}{2})^2}{d(n-d)(n+1)} + \frac{180(M_S - \frac{d(n^2-1)}{12})^2}{d(n-d)(n+1)(n^2-4)}$$

$$W_S = \sum_{i=1}^{d} R_i$$

$$M_S = \sum_{i=1}^{d} (R_i - \frac{n+1}{2})^2$$

R_i (the rank of y_i observations)

The $LCC_{max,n}$ is then plotted against sample number on a control chart. When there is a shift in the percentage of acute malnutrition, the LCP chart would issue an out-of-control signal and identify the parameter(s) that has shifted as well as the direction of the shift. Further details on the methods including the implementation strategies are well spelt-out in Afolabi et al. [12]. Applying this to a control chart provides a perspective for prospective surveillance or monitoring of health related problems like acute malnutrition, mortality etc and can on the long run informs intervention.

2.5. After-signal Diagnosis Procedures

Change-point detection implies that there has been a process shift. A primary consideration when choosing a control chart to detect and eliminate special causes should be the ability to signal quickly after a special cause occurs. It is therefore necessary to be able to point out which parameter or parameters have shifted after a signal occurs. The signalling of a process shift in location (mean) and/or in variability, however, normally poses the challenges of identifying which of the process parameters have shifted. The procedure of after-signal diagnosis would not be a problem in the face of advanced technological statistical software already developed for this task, in today's environment [14]. It is known that after a signal is raised, other plots through statistical software can easily be used when needed to help in diagnosing which parameters have changed.

Suppose that a process shift is detected at time *t*, corresponding to the value of '*d*' which maximized $LCC_{max,n}$. The accrued observations can then be partitioned into the subsets $\{Y_1,\cdots,Y_d\}$ and $\{Y_{d+1},\cdots,Y_t\}$.

A two-sample Wilcoxon-Mann-Whitney and Mood tests can then be carried out on these two subsets, and the p-values evaluated and compared. The shift is most likely to constitute a location shift or variability shift if Wilcoxon-Mann–Whitney or Mood test respectively gives the lower p-value [15]. All analyses were carried out using the R statistical package. Some basic details about the two-sample statistic tests are provided in appendix A.

2.6. Ethical Approval

Ethical approval for the parent study was obtained from Nigeria National Ethics Committee (RNEC) functioning under the Ministry of Health, Nigeria. At the point of data collection, informed consent was obtained from all study participants and all participants were free to withdraw from the study at any point without consequence [9]. All participants were made to sign written agreement form prior to the interview while all data collection activities were conducted in strict confidence. In addition, further approval was obtained from the Demographic and Health Surveys (DHS) Program, ICT International, USA prior to use of data for the present analysis.

3. Results

3.1. Distribution of wasting by Socio-economic Characteristics among Under-5 Children

Of the 24,530 under-5 children from whom valid and complete measurements were obtained, 4,506 (18.4%) had acute malnutrition (wasting). Table 1 shows that wasted children and their mother's mean age were 23.8 (16.8) months and 29.0 (7.0) years, respectively. Compared to children of aged 24-59 months, wasting was highest among children aged 0-23 months (aged 0-55 (24.9%); aged 6-23 (24.2%)).. Under-5 male children (19.3%) had a slightly higher acute malnutrition compared with under-5 female children (17.2%). Not surprising, children of poor (21.2%) mother were more wasted compared with middle (17.2%) and rich (15.6%) wealth index mothers. Wasted children whose mother's total children ever born ≤ 4 (17.9%) had the least proportion of acute malnutrition compared to those whose mother's total children ever born > 4 (19.1%). Similarly, children of birth order > 4 (20.1%) had the highest proportion of acute malnutrition compared with children of birth order 2-4 (17.1%) and 1st born (17.6%).. Surprisingly, under-5 children currently breastfeeding (21.0%) andfrom married mothers (18.5%) had the highest proportion of wasting but least being delivered by caesarean section (9.0%). In addition, as the level of mother's education increases the proportion of acute malnutrition reduces: mothers had no formal education (22.8%), primary education (16.0%), secondary (14.3%) and higher education (11.1%). Though the proportion of acute malnutrition was similar in both the rural (18.7%) and urban (17.9%) residence, the formal was slightly higher as expected. While the highest proportion of acute malnutrition was from the northern part of Nigeria (northwest region (27.3%), north east

region (19.8%) and north central region (12.24)), the least was from the southern part (south west 10.3%), %), south south (11.5%) and south east (12.1%)).

Table 1. Demographics and background characteristics of under-5 children

Characteristics	Wasting n = 4,506 (18.4%)	Total N = 24,530
Child's age		
0 -5	604 (24.9)	2430
6 – 23	1901 (24.2)	7861
24 -59	2001 (14.1)	14238
Mean±σ	23.8±16.8	28.6±17.3
Sex		
Male	2,350 (19.3)	12192
Female	2,156 (17.5)	12338
Mother wealth index		
Poor	2281 (21.2)	10759
Middle	811 (17.2)	4710
Rich	1414 (15.6)	9061
Total children ever born		
≤ 4	2,633 (17.9)	14734)
> 4	1,873 (19.1)	9796
Mean ±σ	4.4±2.7	4.3±2.5
Mother's age		
15 -24	1185 (20.5)	5779
25 -34	2190 (17.6)	12423)
35 -49	1131 (19.9)	6327
Mean ±σ	29.0±7.0	29.5±6.9
Birth order		
1st born	794 (17.1)	4640
2nd to 4th	1990 (17.6)	11327
> 4th	1722 (20.1)	8563
Delivery by Caesarean section		
Yes	47 (9.0)	523
No	4418 (18.6)	23731
Current marital status		
Yes	4362 (18.5)	23589
No	143 (15.2)	940
Currently breastfeeding		
No	1578 (14.9)	10582
Yes	2928 (21.0)	13948
Mother highest education		
No education	2,589 (22.8)	11376)
Primary	790 (16.0)	4932)
Secondary	959 (14.3)	6721
Higher Education	167 (11.1)	1500
Residence		
Urban	1,619 (17.9)	9066
Rural	2,887 (18.7)	15464
Region		
North Central	440 (12.4)	3562
North East	808 (19.8)	4086
North West	2,326 (27.3)	8505
South East	277 (12.1)	2283
South South	272 (11.5)	2372
South West	383 (10.3)	3722

3.2. Normality Test for the Proportion of Acute Malnutrition

Figure 1 graphically depicts that the data set distribution does not follow a normal distribution. Collaborating this, Shapiro-Wilk Normality test statistic: W=0.9268(p=0.001463) confirms that there was sufficient evidence to conclude that the distribution of under-5 wasted children of 2013NDHS dataset has not been drawn from a normal population.

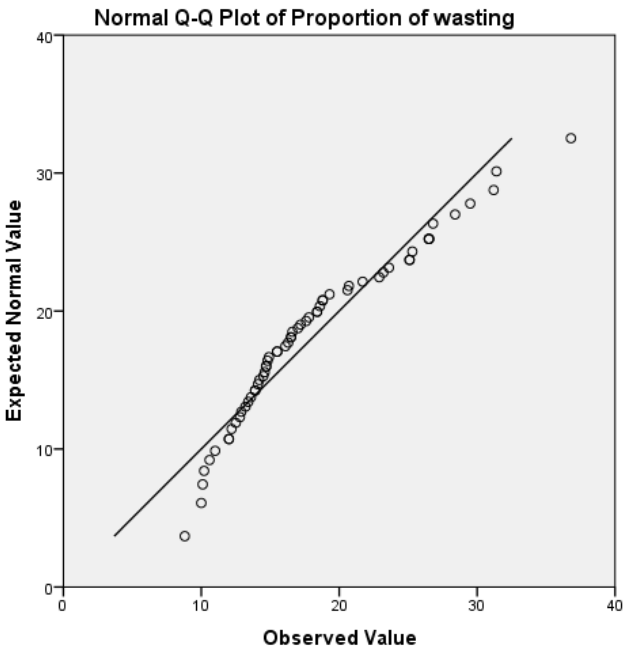

Figure 1. Q-Q plot showing of proportion of acute malnutrition

3.3. Application of LCP Chart to the Proportion of Acute Malnutrition Under-5 Children

Figure 2a & Figure 2b show the results of applying nonparametric-based LCP control chart to the proportion of acute malnourished under-5 children from 2013 NDHS dataset. The Figure 2a displays the change-point statistic along with its control limit. The estimated change-point, along with the epoch at which the maximised test statistic (LCC_{max}) exceeds the control limit, is shown in the figure 2b. The LCP chart signalled a shift in under-5 children's nutritional status, as measured by acute malnutrition, at aged 24 month; while its estimated change-point was at age 21 month.

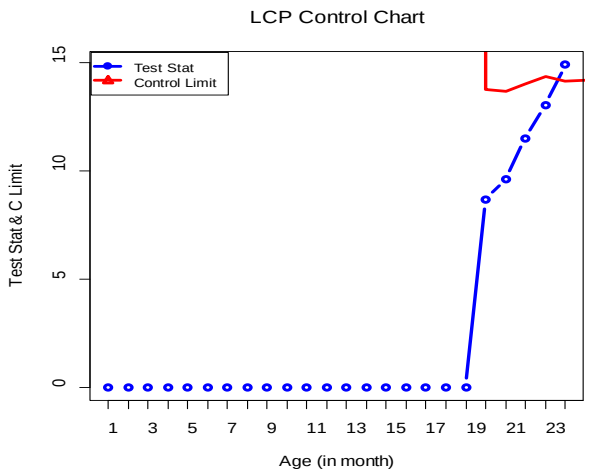

Figure 2a. LCP nonparametric-based chart on acute malnutrition of under-5 children

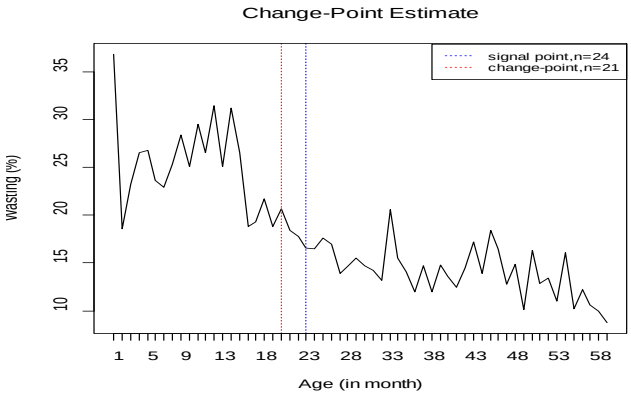

Figure 2b. LCP estimated change-point, along with its detection time of acute malnutrition of under-5 children nutritional status

3.4. After-Signal Diagnosis to Determine if There is Shift Location or Variability

A shift signalled by LCP is an indication of either shift in mean, in variance or in both. Hence, it is important for after-signal diagnosis to be carried out on the pre- and post-shift data segments of the proportion of wasted under-5 children by age (month). The summary statistics in Table 2 confirms that the signal may have resulted in both a mean shift (p=0.002949) and a variability shift (p=0.03978) of children's nutritional status as measured by acute malnutrition (wasting). Graphically, this is corroborated by a box plot for pre and post-shift segments in Figure 3.

Table 2. Summary statistics of pre-shift and post-shift segments of wasted under-5 children

	Pre-Shift (Segment 1)	Post-Shift (Segment 2)	2-sample test statistic (p-value)
Mean	25.07201	17.33677	W = 76 (0.002949)
Standard deviation	4.747507	0.910598	Z = -2.056 (0.03978)

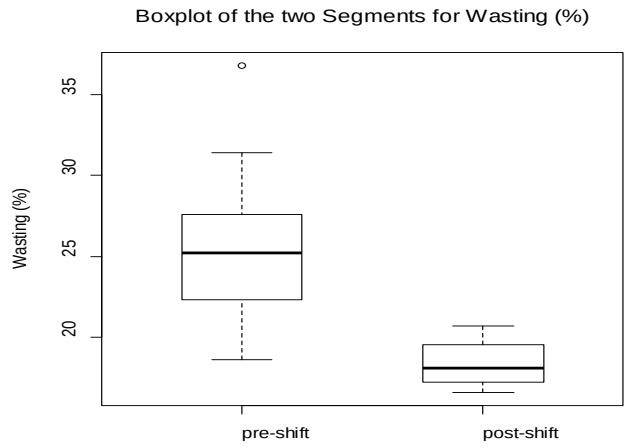

Figure 3. A box plot comparing the pre-shift and post-shift segments of shift in acute malnutrition of under-5 children nutritional status

4. Discussion

In the present study, we applied a nonparametric-based Lepage-type change-point control (LCP) chart to monitor acute malnutrition of under-5 children in Nigeria using data from the 2013 NDHS dataset. Although most recent NDHS reported an improvement in the nutritional status of children in Nigeria over the last decade, the extent of wasting has been worse with an increased proportion from 11% (year 2003) to 18% (year 2013). This increase may not have occurred exactly in 2013. The departure might have commenced undetected at a much earlier time. The beauty of the Lepage-type change-point control (LCP) chart lies in its ability to detect the exact point when a process has changed [12]. This will simplify the search for and identification of the special cause of the change in any other parameter/phenomenon of interest. Following a control chart signal, an estimate of the process change-point would be useful for policy and planning of interventions that would reduce the burden of malnutrition. Application of such monitoring tool therefore becomes necessary for early detection of acute malnutrition among under-5 children in Nigeria.

Socio-demographic status of the under-5 children showed that majority of the children were between 24-59 months, from the North West geo-political zone, lived in rural areas, had at most four siblings, of birth order 2-4, of poor and uneducated mother. Acute malnutrition is more prevalent in children aged 0-5 months and 6-23 months compared to children aged 24-59 months. This is an indication of malnutrition resulting in acute weight loss, which hinders child's development in the early two years of a child's life.

Of course, in addition to inability to request for food when hungry, children aged 0-5 months benefit from exclusive breast feeding than any other food or food supplements. Unfortunately, the practice of exclusive breast feeding in this setting has been reported to be very low [16]. Previous literature, based on recommended infant and young child feeding practices, have shown that majority of children less than 6 months old were not exclusively breast fed, and that over 90% of children age 6-23 months were fed inappropriately (NPC & ICT, 2014). Similarly, Vitta et al. [17] reported that children less than aged 6 months had low rates of exclusive breastfeeding and only 38.4% aged 6-23 months were fed with a minimum acceptable diet. Of recent, Akombi et al. [18] also confirmed the high prevalence of malnutrition in children aged 0-23 months in a study conducted in Nigeria. In their study, more than 18% of the children (aged 0-23 months old) were acutely malnourished while 9% were severely wasted. On the other hand, in a related study conducted among preschool children in Hawassa zuria (a suburb of Addis Ababa), Ethiopia, 36% of children aged 48-60 months were acutely malnourished compared to prevalence of 28% among children aged 36-60 months old [19]. The reason for this reversed situations in Ethiopia was unclear, it is likely that the limitation of coverage and nearness to the capital city must have influenced the results reported by [19].

A part from that, the distribution of wasted children by age was confirmed to be non-normal. This is necessary in order to justify the use of the LCP nonparametric-based approach to monitor the acute malnutrition of under-5 children. It was found that, though the signalling of a reduction in the prevalence of wasted children was at 24th month, the prevalence reduction actually commenced at

age 21st month. This finding which coincided with other reported prevalence of wasting [17,18] is an indication that the LCP gave clear indications of the true situations of children in this age group. Such clarity is essential for effective policy and planning of interventions. Besides, a shift in both the mean and variability of the distribution of wasted children emphasised the necessity to keep a check on the current state of the accuracy (central tendency) and precision (spread) of the distribution of the data. Previous literatures have also supported the idea of monitoring both the process mean and variability [11,20] with the use of a single control chart [21] such LCP chart.

In conclusion, prevalence rate of wasting among under-five as revealed by this analysis is high. The LCP demonstrated prompt detection of shift (both in mean and variability) in the proportion of wasted under-5 children that is not normally distributed. The point at which LCP signalled and its estimated change-point would help reduce to a large extent, the burden of wasting in under-5 children and can guide necessary policy and interventions directed towards ameliorating the situation. Since the distributions of similar data are usually unclear, we recommend that LCP control chart be used in monitoring such situations.

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Appendix

Wilcoxon-Mann-Whitney test statistic

Suppose $\{Y_1,\cdots,Y_d\}$ and $\{Y_{d+1},\cdots,Y_t\}$ are independent random samples. We wish to test

$$H_0:\mu_I=\mu_{II} \quad \text{versus} \quad H_0:\mu_I\neq\mu_{II}$$

Let $R_1<R_2<\cdots<R_d$ be the combined samples ranks of the first segment, $\{Y_1,\cdots,Y_d\}$ observations in increasing order of magnitude. The Wilcoxon-Mann-Whitney rank test statistic for testing null hypothesis is defined as,

$$W=\sum_{i=1}^{d}R_i.$$

The mean and variance of the statistic *W* is given as:

$$E(W)=\frac{d(t+1)}{2} \text{ and } Var(W)=\frac{d(t-d)(d+1)}{12}$$

The normalised statistic *W* is thus expressed as:

$$WM=\frac{W-d(t+1)/2}{\sqrt{d(t-d)(d+1)/12}}$$

The p-values for the Wilcoxon-Mann-Whitney test are based on the sampling distribution of the rank sum statistic *W* when the null hypothesis (no difference in distributions) is true. Wilcoxon-Mann-Whitney is implemented in R function as “wilcox.test". The process is thereafter considered to have shifted in location parameter given a lower p-value < α, pre-specified level of significance.

Mood test statistic

The Mood statistic is used to test for a change in scale between two samples. Unlike the Wilcoxon-Mann-Whitney, the Mood test assesses the extent at which the ranks of the observations deviate from their expected value.

Suppose $\{Y_1,\cdots,Y_d\}$ and $\{Y_{d+1},\cdots,Y_t\}$ are independent random samples. We wish to test

$$H_0:\sigma_I=\sigma_{II} \text{ versus } H_0:\sigma_I\neq\sigma_{II}$$

Let $R_1<R_2<\cdots<R_d$ be the combined samples ranks of the first segment, $\{Y_1,\cdots,Y_d\}$ observations in increasing order of magnitude. Then, the Mood test statistic for testing null hypothesis is defined as:

$$M=\sum_{i=1}^{d}(R_i-\frac{t+1}{2})^2$$

The mean and variance of the statistic *M* is given as:

$$E(W)=\frac{d(t^2-1)}{12} \text{ and } Var(W)=\frac{d(t-d)(t+1)(t^2-4)}{180}.$$

The normalised statistic *M* is thus expressed as:

$$MD=\frac{M-d(t^2-1)/12}{\sqrt{d(t-d)(t+1)(t^2-4)/180}}$$

The null distribution of M is needed to obtain the critical values and the p-value. Mood is implemented in R function as “mood.test". The process is thereafter considered to have shifted given a lower p-value < α, pre-specified level of significance.