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# THE USE OF DIAMETER DISTIBUTIONS FOR DETERMINING OPTIMUM HOLDING LENGTH FOR *GMELINA ARBOREA* PLANTATIONS IN A NIGERIAN LOWLAND RAINFOREST

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**ABSTRACT**

Weibull Parameter models using Forest stand attributes as predictor variables were applied to partition Diameter at breast height (Dbh) into size classes (Small -< 40 cm dbh, Medium - 40–80 cm dbh and Large - > 80 cm dbh) so as to ascertain the produce /size categories of Gmelina arborea in Ukpon River Forest Reserve, Cross River State, Nigeria. The diameter distributions were projected for three management periods (5, 10 and 15 years) to determine the optimal holding length for the Gmelina plantations. An optimal holding length of 10 years was determined for the plantation when 70.6% of surviving trees (329 trees/ha) will be of timber size as against the current 1.8%. Implications of deviating from the optimal holding length were highlighted

**KEYWORDS**: Optimum holding length, Diameter distributions, Dbh, Ukpon River Forest Reserve

## INTRODUCTION

In Nigeria, large investments in *Gmelina_arborea* plantations have been made particularly to provide raw materials for pulp and paper mills (Ajayi *et al.*, 2004). The species is now being utilized for timber production as a result of failure of the mills to utilize them. These plantations have outgrown their planned maximum volume production rotation of 8 years (Akachukwu 1981; Evans, 1992). Global concern for the sustainable management of these plantations has been expressed so as to achieve many things people expect of them (ITTO, 2001; 2003). Furthermore, silvicultural management has been limited; leaving stands untended. Natural and man- made agencies such as diseases, wind and fire have superimposed their effects on the variations caused by sites, climate and management. Omoluabi *et al*, (1990) estimated the area of established plantations by 1990 to be 213,730 hectares. Of this area, *Gmelina arborea* plantations cover 83,377 hectares (41.8% of the total). Atte (1994) estimated about 10,000 ha of such plantations in Cross River State. *Gmelina arborea* plantations at Edondon in Ukpon River Forest Reserve have age range of 19 – 33 years. These plantations are currently managed for timber production. The fuel wood needs of surrounding beneficiary landlord communities are also considered in the management objective.

Clutter *et al.*, (1983) noted that if the existing stand on a particular site differs from the optimum continuing series stand, a decision problem exists. How long should the existing stand be left before it is harvested and the first stand of the continuing series established? How long should *Gmelina arborea* plantations at Edondon be left before harvesting? The Government of Cross River state wants to determine the optimum length of time to hold her *Gmelina arborea* plantations to obtain at least 300 trees of timber size (>80 cm dbh or 2.5 m girth) per hectare and steadily provide poles and fuel wood from trees of lower dbh classes. Rotation length is an important tool for forest management. It determines the tree's age; hence it largely determines the size, quantity and quality of the timber and profitability. Rotation age also affects the regulation possibilities and thereby the age distribution of the forest. Any of these factors can be the main determinant of length (Leuschner, 1984; Evans, 1992). The distribution of volume by size classes as well as the overall volume is needed as input to many forest management decisions. One widely applied technique for even-aged stands is a 'diameter distribution' modeling procedure. Diameter distribution have been found very satisfactory for describing the relative frequencies by diameter at breast height (dbh) class in unthinned stands where the underlying dbh distribution is within the range of shapes that the mathematical function can approximate. To date, diameter distribution methods have been used to quantify forest yields (Osho, 1989; Sokpon and Biaou, 2002; Ajayi, 2005).

The main objective of this study is to apply diameter distribution – based models to determine the optimum holding length for *Gmelina arborea* plantations in Ukpon River Forest Reserve, Cross River State, Nigeria. Choosing the correct rotation age for the plantations will help to obtain maximum wood volume and money yield.

## STUDY AREA

The *Gmelina arborea* plantations at Edondon are sited within Ukpon River Forest Reserve, Cross River State. The Ukpon River Forest Reserve has a total area of 12,950 hectares and managed by the Cross River State Forestry Commission. The plantation occupies about 3,757 hectares of the Forest Reserve. The Reserve falls along latitude 5.86° N and longitude 8.46° E (Forest Resource Study – CRS, 1990)

The mean annual rainfall range from 12.1 mm in January to 378 mm in August. The rain is fairly distributed throughout the months of April to October. Mean annual temperature range from 27.6° C in August to 33.1° C in February. Strong winds usually accompany the onset of dry season, which is caused by hot and dry North East wind. The mean relative humidity range from 71% in February to 90% in August (Ajayi, 2005).

The Ukpon River Forest reserves lies within the lowland rainforest with fresh water swamp at the fringes of Ukpon River and Derived Savannah north of the reserve. The structure and physiognomy of the forest is stratified with highly heterogeneous floristic composition. Recognizable tree species within the reserve includes *Ricinodendron spp., Terminalia spp., Triplochiton scleroxylon , Sterculia spp., Pterygota spp., Khaya spp. Milicia excelsa, Garcinia spp., Chrisophyllum spp., Alstonia spp., Ceiba pentandra and Pterocarpus spp.*

The main rock types are granite gneisses and quart schist with gravels and occasional rock outcrops in some areas. The soil is derived from the Eze Aku formation of precambrian series. Edondon soils are classified as Cambisol of Acid Crystalline rock (Ogar, 1994).

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The topography varies from undulating land on the south and southwestern parts of the plantation to rugged and hilly land on the North and Northeastern part of the Forest reserve. Many seasonal streams that flow northward and empty their waters into Ukpon River dissect the plantation. The access roads within the plantation are poorly developed and the existing routes are not maintained

The principal occupation of the communities around the Forest Reserve is farming. Major crops of interest are cassava (*Manihot spp.*), yams (*Discorea spp.*) cocoyams (*Cocos nucifea*) and plantains/banana (*Musa spp.*). Other crops generally seen in common production are maize (*Zea mays*), eggplants (*Solanum melongina*), okra (*Abelmoschus esculentus*), pepper (*Pipper gueneense*) and melon (*Cucumeropsis manii*). Majority of the populace from the landlord communities depend on the *Gmelina arborea* plantation for their fuel-wood supply.

## METHODS

### Data collection

Forest reserve maps were used to locate the boundaries of the plantations in the field. To allow for comparison of difference in growth performance of one stand and the other, the age series were grouped into seven age classes – 20, 22, 24, 26, 28, 30 and 32 years and each treated as a compartment - Table 1 (Okojie 1981). The compartments were coded using alphabets (A to G) and their sizes in Hectares indicated (Table 1).

Table 1: Age grouping of Unthinned *gmelina arborea* Plantation in Ukpon River Forest Reserve

| YEAR OF ESTABLISHMENT | GROUP YEAR/COMPT. | AREA (HA) | AGE (YRS) |
|---|---|---|---|
| 1971 – 1972 | 1972 (G) | 440 | 32 |
| 1973 – 1974 | 1974 (F) | 1266 | 30 |
| 1975 – 1976 | 1976 (E) | 1044 | 28 |
| 1977 – 1979 | 1978 (D) | 212 | 26 |
| 1980 – 1981 | 1980 ( C ) | 257 | 24 |
| 1982 – 1983 | 1982 (B) | 10 | 22 |
| 1984 – 1985 | 1984 (A) | 21 | 20 |
| TOTAL | 3250 | | |

### Stand Attributes and Weibull Parameter Models

Stand attributes models developed for the same plantation (Ajayi, 2005) were used to describe and project Surviving number of trees per hectare (N), Basal area per hectare (BA) and Site index (S) for 5, 10 and 15 years hence (Equations 1 - 4).

$N = 1854.250 - 35.768\ A$ ..... (1)

where,

N = Surviving number of trees per hectare (N/Ha)

A = age of stand (Yrs)

$BA = -755.362 + 1.712AHd + .940A^2 + 52.391Hd$ .. (2)

where,

BA = basal area per hectare ($m^2$/Ha)

A = age of stand (Yrs)

Hd = Average height of dominant and co-dominant trees.

$Log\ S = Log\ Hd + 6.776\ (A^{-1} - A_i^{-1})$ ..... (3)

and in all cases, $Log\ Hd = 1.735 - 6.776\ A^{-1}$ ..... (4)

where,

S = Site index (m)

Hd = Average height of dominant and co-dominant trees

A = age of stand

$A_i$ = Index age (25 years)

The projections were fitted into Weibull parameter equations developed for the plantations (Ajayi, 2005) to estimate $\alpha$, $\beta$ and $\lambda$ for the three management periods.

The Weibull parameter equations are:

$\alpha = -42.090 + 670\ S + 3.259\text{-}02\ N$ ..... (5)

$Log\ \beta = .307 + 4.581E - 02\ A$ ..... (6)

$Log\ \lambda = 2.041 - 27.769A^{-1} - 5.37E\text{-}03\ BA$ ..... (7)

where,

A = age of stand

S = site index (m)

N = number of trees per hectare (N/ha)

BA = basal area per hectare ($m^2$/ha)

$\alpha$, $\beta$ and $\lambda$ = Weibull parameters

### Number of trees/ha by Size /Dbh classes

The parameters were then fitted into the Weibull cumulative function and the probabilities for three produce/Dbh classes calculated. The categories are:

| Size Category | Produce | Dbh(cm) |
|---|---|---|
| Small | Fuel wood, fence poles Pulpwood | < 40 |
| Medium | Pulpwood/poles Match splint | 40 – 80 |
| Large | Sawn timber and veneer | > 80 |

The probability of the population in each size category was given as follows:

For **Small** category (< 40 cm Dbh),

$$P(x< 40) = 1 - \exp\left[-\left[\frac{40-\alpha}{\beta}\right]^{\lambda}\right] \quad \text{..... (8)}$$

For **Medium** category (40 – 80 m Dbh),

$$P(40< x< 80) = \exp\left[-\left[\frac{40-\alpha}{\beta}\right]^{\lambda}\right] - \exp\left[-\left[\frac{80-\alpha}{\beta}\right]^{\lambda}\right] \quad \text{... (9)}$$

For Large category (> 80 cm),

$$P(x > 80) = 1 - \left[P(x< 40) + P(40< x< 80)\right] \quad \text{..... (10)}$$

where,

$\alpha$, $\beta$ and $\lambda$ are Weibull parameters

The probability for each size class was multiplied by the projected total number of trees per hectare in each compartment and by management periods to determine the frequency for that size class.

The total number of trees per size class in a management period was calculated from:

$$N_{S_j,Y_k} = \Sigma N_{i\,(S_j,Y_k)}\, A_i \quad \ldots\ldots (11)$$

where,

$N_{S_j,Y_k}$ = total number of trees in *j*th size class and *k*th years hence

$N_{i\,(S_j,Y_k)}$ = frequency of trees per hectare in compartment *i*, *j*th size-class and *k*th years hence (N/ha).

$A_i$ = hectares in compartment i

## RESULTS

### Number of trees/ha by size categories

Table 2 shows the proportion of various size classes in *Gmelina arborea* plantations at Edondon. Of the 825 trees per hectare predicted for the plantation 393 trees/ha (47.7%) and 417 trees/ha (50.5%) fall into the small and medium categories respectively. A small proportion of 15 trees/ha representing 1.8% have attained timber size.

Table 2: predicted number of trees by size categories for *gmelina arborea* plantations at edondon (N/HA)

| COMPT. | AGE | STAND SIZE | STEMS/ HA | SMALL < 40CM | | MEDIUM 40 – 80CM | | LARGE > 80CM | | COMPT TOTAL STEM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | STEMS/ HA | TOTAL STEMS IN COMPT | STEMS/ HA | TOTAL STEMS IN COMPT. | STEMS/ HA | TOTAL STEMS IN COMPT. | |
| | (YRS) | (HA) | NN/HA | | | | | | | |
| AA | 20 | 21 | 1,125 | 958 | 20,118 | 167 | 3,507 | 0 | 0 | 23,625 |
| BB | 22 | 10 | 1,070 | 892 | 8,920 | 178 | 1,780 | 0 | 0 | 10,700 |
| CC | 24 | 257 | 1,010 | 790 | 203,030 | 220 | 56,540 | 0 | 0 | 259,570 |
| DD | 26 | 212 | 929 | 609 | 129,108 | 318 | 67,416 | 2 | 424 | 196,948 |
| EE | 28 | 1,044 | 850 | 453 | 472,932 | 393 | 410,292 | 4 | 4,176 | 887,400 |
| FF | 30 | 1,266 | 786 | 294 | 372,204 | 477 | 603,882 | 15 | 18,990 | 995,076 |
| GG | 32 | 440 | 700 | 163 | 71,720 | 481 | 211,640 | 56 | 24,640 | 308,000 |
| TOTAL | | 3,250 | | | 1,278,032 | | 1,355,057 | | 48,230 | 2,681,319 |
| PROPORTION ( % ) | | | | | 47.7 | | 50.5 | | 1.8 | 100 |
| MEAN NO. OF STEMS/HA | | | | | 393 | | 417 | | 15 | 825 |

Source: Equations 8 - 10;

$\alpha = -42.090 + 670\,S + 3.259\text{-}02\,N$;

$\text{Log}\,\beta = .307 + 4.581E - 02\,A$; and

$\text{Log}\,\lambda = 2.041 - 27.769A^{-1} - 5.37E\text{-}03\,BA$

### Projections of stand attributes and diameter distributions

Table 3 shows the projections for age, surviving number of trees per hectare, basal area per hectare and site index for 5, 10 and 15 years hence.

TABLE 3: PROJECTED STAND ATTRIBUTES FOR *GMELINA ARBOREA* PLANTATIONS AT EDONDON

| COPT | PREENT AGE (YRS) | SIZE (HA) | YEARS HENCE 5 | | | | 10 | | | | 15 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A (YRS) | N (N/HA) | BA $M^2$/HA | S (M) | A (YRS) | N (N/HA) | BA $M^2$/HA | S (M) | A (YRS) | N (N/HA) | BA $M^2$/HA | S (M) |
| A | 20 | 21 | 25 | 960 | 110.28 | 29 | 30 | 781 | 123.93 | 29 | 35 | 602 | 134.20 | 29 |
| B | 22 | 10 | 27 | 886 | 227.87 | 29 | 32 | 710 | 127.37 | 29 | 37 | 531 | 141.24 | 29 |
| C | 24 | 257 | 29 | 817 | 122.19 | 29 | 34 | 638 | 131.58 | 29 | 39 | 459 | 150.91 | 29 |
| D | 26 | 12 | 31 | 745 | 125.61 | 29 | 36 | 568 | 137.41 | 29 | 41 | 388 | 163.83 | 29 |
| E | 28 | 1044 | 33 | 674 | 129.30 | 29 | 38 | 495 | 145.68 | 29 | 43 | 316 | 180.61 | 29 |
| F | 30 | 1266 | 35 | 604 | 134.20 | 29 | 40 | 424 | 156.88 | 29 | 45 | 245 | 201.37 | 29 |
| G | 32 | 440 | 37 | 531 | 141.24 | 29 | 42 | 352 | 171.65 | 29 | 47 | 173 | 226.81 | 29 |

Source: $N = 1854.250 - 35.768\ A$;
$BA = -755.362 + 1.712AHd + .940A^2 + 52.391Hd$;
$\text{Log } S = \text{Log } Hd + 6.776\ (A^{-1} - A_i^{-1})$ ;
$A_i = 25$ years and ;
$\text{Log } Hd = 1.735 - 6.776\ A^{-1}$

These projections are very paramount to the determination of future Diameter distributions for *Gmelina arborea* plantations at Edondon. Table 4 shows the Weibull parameter estimates for projecting the diameter distribution (by size categories) for three different management periods hence (5, 10 and 15 years)

Table 5 is a summary of the projected diameter distributions for the three management periods by Dbh size-classes.

Table 4: Weibull Parameters projection for *gmelina arborea* plantations at Edondon

| YEARS HENCE | PRO- JECTED AGE (YRS) | WEIBULL PARAMETERS $\alpha$ | $\beta$ | $\lambda$ | COMPT. SIZE (HA) |
|---|---|---|---|---|---|
| 5 | 25 | 8.6264 | 28.3302 | 2.1777 | 21 |
| | 27 | 6.2147 | 34.9840 | 2.3964 | 10 |
| | 29 | 3.9660 | 43.2006 | 2.6747 | 257 |
| | 31 | 1.6195 | 53.3470 | 2.9000 | 212 |
| | 33 | 0 | 65.8764 | 3.2000 | 1044 |
| | 35 | 0 | 81.3456 | 3.3647 | 1266 |
| | 37 | 0 | 115.3187 | 3.4043 | 440 |
| 10 | 30 | 2.7928 | 48.0065 | 2.8177 | 21 |
| | 32 | 0.4789 | 59.2816 | 3.0849 | 10 |
| | 34 | 0 | 73.2048 | 3.2937 | 257 |
| | 36 | 0 | 90.3982 | 3.4021 | 212 |
| | 38 | 0 | 111.6298 | 3.3724 | 1044 |
| | 40 | 0 | 137.8479 | 3.1937 | 1266 |
| | 42 | 0 | 170.2236 | 2.8752 | 440 |
| 15 | 35 | 0 | 81.3486 | 3.3643 | 21 |
| | 37 | 0 | 100.4546 | 3.4041 | 10 |
| | 39 | 0 | 124.0481 | 3.3005 | 257 |
| | 41 | 0 | 153.1828 | 3.0472 | 212 |
| | 43 | 0 | 189.1603 | 2.6626 | 1044 |
| | 45 | 0 | 233.5877 | 2.2006 | 1266 |
| | 47 | 0 | 288.4496 | 1.7069 | 440 |

Source: $\alpha = -42.090 + 670\ S + 3.259\text{-}02\ N$
$\text{Log } \beta = .307 + 4.581E - 02\ A$
$\text{Log } \lambda = 2.041 - 27.769A^{-1} - 5.37E\text{-}03\ BA$
$N = 1854.250 - 35.768\ A$
$BA = -755.362 + 1.712AHd + .940A^2 + 52.391Hd$
$\text{Log } S = \text{Log } Hd + 6.776\ (A^{-1} - A_i^{-1})$
$\text{Log } Hd = 1.735 - 6.776\ A^{-1}$

Table 5: Projected number of trees by size categories for *gmelina arborea* Plantations at Edondon

| YEARS HENCE | PLANTATION SIZE | SMALL < 40CM | | | MEDIUM 40 – 80CM | | | LARGE > 80CM | | | TOTAL STEMS /HA | TOTAL ANNUAL ALLOWABLE CUT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | STEMS /HA | PROPORTION | ANNUAL ALLOWABLE CUT | STEMS /HA | PROPORTION | ANNUAL ALLOWABLE CUT | STEMS /HA | PROPORTION | ANNUAL ALLOWABLE CUT | | |
| | (HA) | (N/HA) | (%) | | (N/HA) | (%) | | | (%) | | (N/HA) | |
| 5 | 3250 | 113 | 17.5 | 73,601 | 350 | 54.3 | 227,481 | 182 | 28.2 | 118,190 | 645 | 419,272 |
| 10 | 3250 | 19 | 4.1 | 6,226 | 118 | 25.3 | 38,483 | 329 | 70.6 | 106,902 | 466 | 151,611 |
| 15 | 3250 | 6 | 2.2 | 645 | 19 | 6.8 | 6,177 | 253 | 91.0 | 54,851 | 278 | 61,673 |

The projections from table 5 show that *Gmelina arborea* plantations at Edondon will have a stocking of 645 trees/ha in the next 5 years. The composition will be 113 trees/ha (17.5%), 350 trees/ha (54.3%) and 182 trees/ha (28.2%) for small medium and large size categories respectively. A 10-year management period hence will produce a stocking of 466 trees per hectare with 19 trees/ha (4.1%), 118 trees/ha (25.3%) and 329 trees/ha (70.6%) for small, medium and large size categories respectively. If the plantations are to be held for 15 years, a stocking of 278 trees/ha is anticipated and this will be made up of 6 trees/ha (2.2%), 19 trees/ha (6.8%) and 253 trees/ha (91.0%) for small, medium and large size categories respectively.

## DISCUSSION

### Size categories and management options

The statistics indicate that currently, *Gmelina arborea* plantations at Edondon are mainly composed of trees of small and medium dimensions. The number of trees/ha in each size-class can be multiplied by the unit price on the tariff table to determine the money yield per hectare. This will help the Cross River State government to decide which size category to emphasize or concentrate management effort depending on demand and money yield for a particular produce category. For instance, there is a general drop in demand for small logs in Cross River State. There is also low demand for trees of medium size (poles) as most projects requiring wooden poles in the past tend to favor concrete poles now. It is a wise decision to allow a proportion of the small logs and pole sized trees to grow to timber size before harvesting. Sawn wood from Gmelina is highly valued for its unique properties. It lends itself to good finishing when used for furniture and internal decorations (Lauridsen and Kjaer, 2002)

### Holding length for Gmelina plantations at Edondon

Of the three projected management periods, 10 years tend to favor the objective of producing a minimum of 300 trees per hectare with dbh above 80cm (timber size category. The ten-year length is appropriate as it provides the wood needs of all stakeholders, which include fuel wood for landlord communities, money for the government, wood for industries and the protection of the environment (Atte, 1994) as a result of sustainable removal of different sizes over the length. Managing the plantation for a shorter period of say 5 years for instance, will produce only a small proportion of 28% in the timber size category. The 5-year length can only be considered if the State government decides to set up paper mills that will demand pulpwood. Extending rotation length to 15 years will produce less number of trees in the timber size category than 10 years (253 trees/ha) and leave little for other size categories.

## CONCLUSIONS

It is concluded that rotation lenghth determination is a useful tool for forest management. When the desired number of stems by size category is specified as part of management objective of a plantation, Weibull distribution can be applied to correctly determine the optimum holding length for maximum wood yield and profitability.

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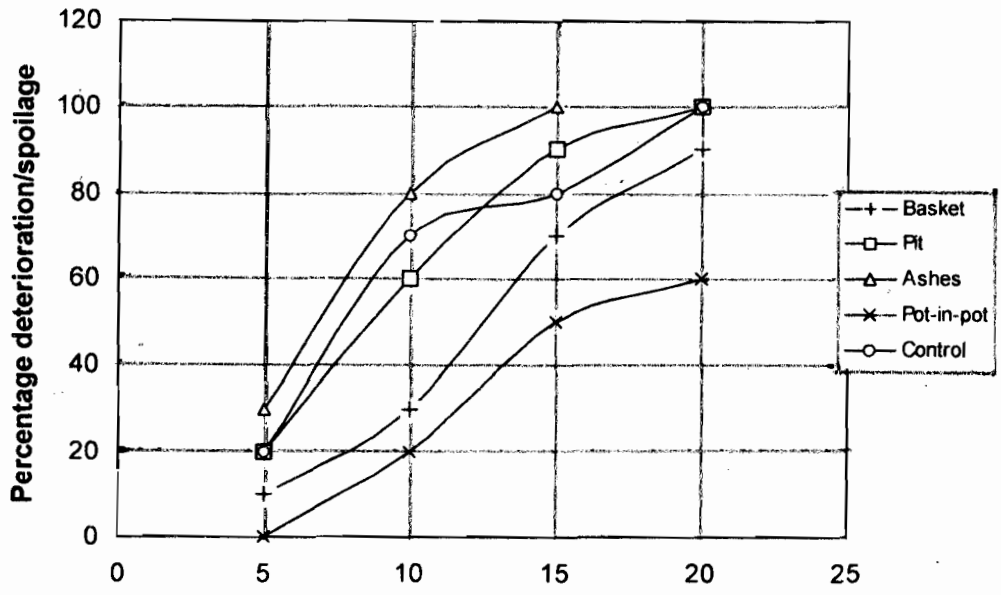


Figure 1: Deteriotion/spoilage of fresh Mango fruits stored using different starage methods

## CONCLUSION

This experiment yielded some tangible results. From the results obtained, it was observed that the efficiency of the four methods of storage viz basket, control, pit and ashes storage methods were very low compared to that of the pot-in-pot method of storing mango fruits which has high efficiency. These findings have shown that the pot-in-pot method of storing mango fruits can sustain viable fruits up to 20 days and beyond.

Pot-in-pot storage method is considered the best among the methods used and so is recommended for short-term storage and should be carried out properly especially in the rural areas where the use of conventional cool storage is a problem due to poverty and lack of electricity.

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