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# Ecological (Eco) Friendly Pit Latrine Development for Northern Nigeria

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**Abstract:- The pit latrine developed in the early 20th century to control the outbreak of infection and pollution because of improper human excreta disposal. Pit latrine continues to develop to satisfy the users need for over a millennium. Although a large proportion of Northern Nigerian population practice open defecation, an estimated 70million Northerners rely on pit latrines to defecate. Studies shows the moistures discharged by pit latrine contaminate the groundwater or water sources. Based on quantitative vulnerability, the pit hole microbial and chemical discharges may pollute the water sources of about 48.5million Northerners, thereby necessitate the development of ecological friendly pit hole. Two chambers eco-friendly and costless pit hole is developed using fixed and random effect modelling with new lining techniques described as a minimum requirement standard for Northern Nigeria. Study recommended further studies on the possibility of generating electricity using human excreta biogas in Nigeria.**

***Keywords:-*** *Pit Latrine Design, Groundwater Contamination, On-Site Sanitation, Northern Nigeria, Nigeria.*

## I. INTRODUCTION

Inadequate supply of quality water and measure to promote adequate sanitation and good hygiene behaviour remain the major global concern and top in the Sustainable Development Goal (SDG) agenda. About 4.0% and 5.7% of all deaths and disabilities are caused by poor hygiene, inadequate sanitation and of access to clean and potable water [1]. Report indicated that about 80% of death and illnesses are linked to the poor sanitation (Water Project, 2016) improper disposal of the human excreta. Although many efforts have been made to increase people with sustainable access to potable water and good sanitation & hygiene, the world health organisation (WHO) and UNICEF report [2] and The UNICEF water, sanitation and hygiene (WASH) report [3], recorded the substantial progress in the MDGs global access to clean and safe water targets; meeting up with the targets five years before the target date of 2015, while adequate sanitation remains unattainable especially the sub-Saharan African countries failed to meet up with both adequate water supply and sanitation target 2015. However, efficient sewer system or sewerage is a key factor to achieving adequate sanitation in the region, thus, preventing major diseases and infection associated with inadequate sanitation and poor hygiene, and improving economic stability dignity and immediate environment protection [4].

In most of the sub-Saharan African countries, human excreta disposal remained the major sanitary issue in the region (Gokcekus et al. 2020) [5], especially Northern Nigerian where over 60% [5] of the population rely on pit latrine for defecation due to the lack of the proper sewer system or sewerage in the region. Pit latrine an onsite-sanitation facility consists of a hole in the ground to accumulate human excreta lined with concrete, concrete bricks, etc. [6] covered with slabs or floor. They further explained, pit latrines are made from all types of construction materials depending on the user's preference; available materials at the locations and financial status of the user. The ground hole that accumulates faecal sludge, is 3m height minimum and 1m wide [6] covered with the slab with 0.25m dropping hole [7]. The pit latrine varies in type depending on the user's preference and financial status.

The pit latrine developed as a result of the early 20th century diseases and infection outbreak, and pollutions' widespread associated with improper human excreta disposal that consumed many lives [8]. The outbreak was successfully controlled with human excreta disposal programs [9] by constructing pit latrines. The early 20th century's pit latrine design and construction involved the basic pit latrine design components such as ground hole with slab or floor and a drop hole covers the ground hole [10-11]. Then evolved to borehole (or simple) latrine which was developed in the Dutch East Indies with 300mm-500mm cross-sectional diameter [8]. Pit latrine design continues to improve to address insects and odour associated with a simple pit latrine. The most improved pit latrine developed after simple latrine was South African 1940s' reed odourless earth closet (ROEC) [12]. During the 1970s, Blair or ventilated improved latrine (VIP) was introduced in Zimbabwe. This pit latrine was improved in Ghana to what we called Kumasi ventilated improved pit (KVIP) [13-14] and subsequently ventilated improved double pit (VIDP) known as revised improved closet II (REC II) developed in [15-16]. Furthermore, SanPlat, the costless and innovative design was introduced in Mozambique 1979 [17]. The pit latrine design and techniques continue to evolve to address issues associated with pit latrines such as environment and environmental resources contamination, thus, putting human and other living organism lives at stake

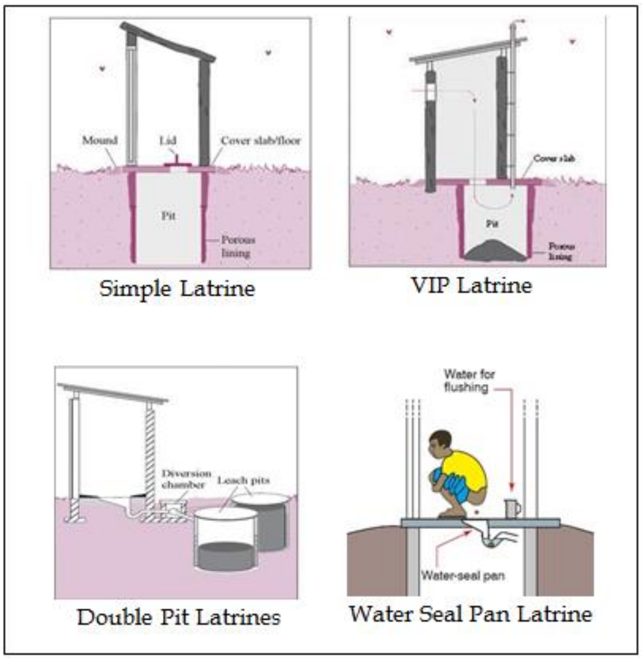


Fig 1:- Map of Nigeria Showing the Northern Region [18]

SanPlant considered being most improved pit latrine for its ability to retain the smells and odours within the pit hole [17], unlike VIP which is less effective in controlling pit latrine smells and odours thereby attract insect if it's inadequately constructed [19-22, 8] even if it's adequately constructed, it less effective in controlling mosquitos [22]. Therefore, SanPlant should be modified and improved to be sustainable or ecologically friendly.

The irregular, improper and squalid settlements in Northern Nigeria as a result of the increase in population and absence of building law enforcement made excreta collection difficult in the region [5]. However, onsite sanitation facilities have remained the viable option for this setting excreta disposal. According to Gokcekus et al [5], the human excreta disposal in this nature are of two types, improve and unimproved excreta disposal. However, both improved and unimproved onsite sanitary facilities appeared to pose danger by contaminating the environment and environmental resources [5]. Although many studies showed that pit latrine is still evolving; improving and modifying to satisfy users satisfaction level by mitigating odours and smells, and insect nuisance, however, no study found on new sitting techniques effective with a view to preventing contaminant discharge from bottom pit latrine to the groundwater and harvesting the biogas emanated human excreta inside the pit hole [5]. As a result of that, Gokcekus et al. [5] suggested that pit latrine future modification and improvement should be sustainable and environmentally friendly this include, feeling rate, materials to prevent contaminant discharge, harvest the greenhouse gases emanated by faecal sludge in the pit latrine, and treatment and collection for safe environmental disposal or end-use. Therefore, this research intends to use an integrated approach to develop a minimum pit latrine design and sitting standard requirement for Northern Nigeria.

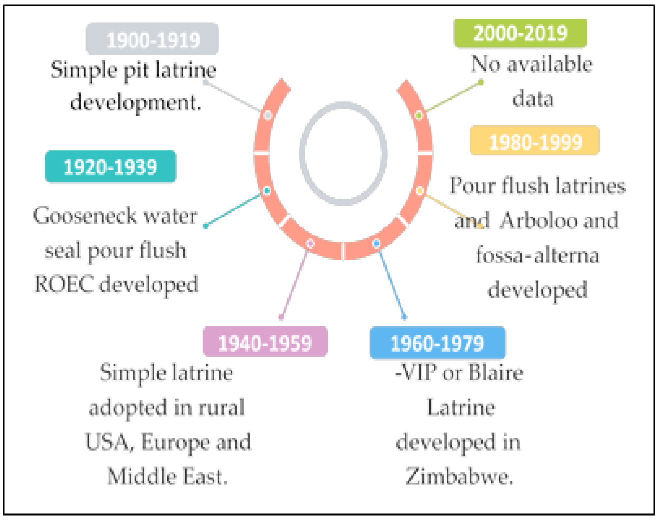


Fig 2:- Pit Latrine Evolution and Development

## II. PIT LATRINE

Although open defecation and cat method; burying human faecal in shallow holes [8] has long been practising in Northern Nigeria, the National Survey Finding Report [23] indicates that the large proportion of the people in the region use pit latrine to dispose of their excreta (Figure 5). Most of those pit latrines are inadequately and improperly designed and sited thereby, contaminating the environment and environmental resources, thus putting people of the region at stake; vulnerable to infections and pollution associated with improper excreta disposal.

Northern Nigeria the defunct British Protectorate of Northern Nigeria (Figure 3) was an autonomous region within Nigeria bordered with Niger, Cameroon, Chad and the Benin Republic. The region is comprised of 3 geopolitical zones (Figure 4), 19 Northern states and Abuja, Federal Capital Territory (Figure 3). National Nutrition and Health Survey-NNHS [24] estimated the region population at about 108.5million constituting 59.4% of the whole country's population

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Fig 3:- Map of Nigeria Showing the Northern Region [25]

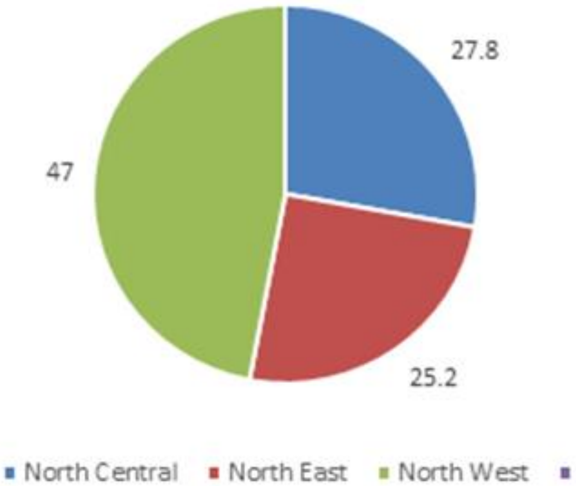

Fig 4:- Northern Geo-Political Zone Population Distribution

To asses, understand and determine the different pit latrine structural design features and qualities in Northern Nigeria and health risk imposing on the users and populace around them, established survey data were utilized to estimate the average number of people in the region who a) use pit latrine to defecate, e) use unimproved water sources, and f) are susceptible to get infected by contaminated water. Based on the Multiple Indicator Cluster Survey for 2016-2017 of the National Survey Finding Report [23] indicates that 64.03% of the region population rely on pit latrine to defecate (Figure 7).

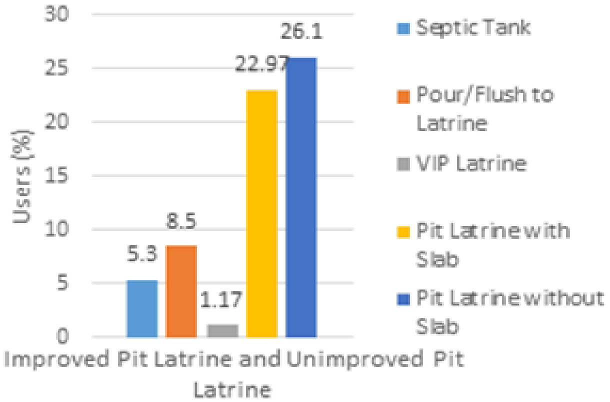

Fig 5:- Variable Pit Latrine Use for Defecation in Northern Nigeria [6]

Based on the National Survey Finding Report [23] Northern Nigeria's average pit latrine usage data (Figure 5), the average total of both improved and unimproved pit latrines users (PU) in the region estimated by using a fixed-effects statistical modelling method approach (Equation 1). Where PU is pit latrine users proportion (%), U is average users while P is the total population of the region.

$$PU = \sum U \quad (1)$$

$$U = (\sum(PU)(P)/100 \quad (2)$$

There is concern that pit latrine microbial and chemical contaminants' discharged to the groundwater [26] and other water sources may cause harm to human health. Water sources contamination by a faecal contaminant is evident, many studies established the groundwater quality in relation to pit latrine [27-36]. Moreover, the studies conducted in the region also established the groundwater contamination in relation to pit latrine, Amadi and Aminu [37] discovered total and coliform and faecal coliforms and Northwestern state of Katsina and Mbonu and Ibrahim-Yusuf [38] established nitrate groundwater quality in the preliminary survey in North Central zone.

It estimated that more than 40% of Northern Nigerians are exposed to the possibility of being infected from borne water diseases [6] as this percentage rely on unimproved water sources (Figure 6) which are susceptible to contamination. Widespread of bone water in the region is evident. Gokcekus et al. [5] estimated about 161,865 cholera cases in Northern Nigeria between 1991-2018 (Figure 7), other endemic diseases or infections such as polio etc., and diseases and infections which are uncommon continue to surface in the region are generally associated with poor sanitation conditions especially excreta disposal which contaminates the drinking water and lack of health sensitization and awareness programs [5].

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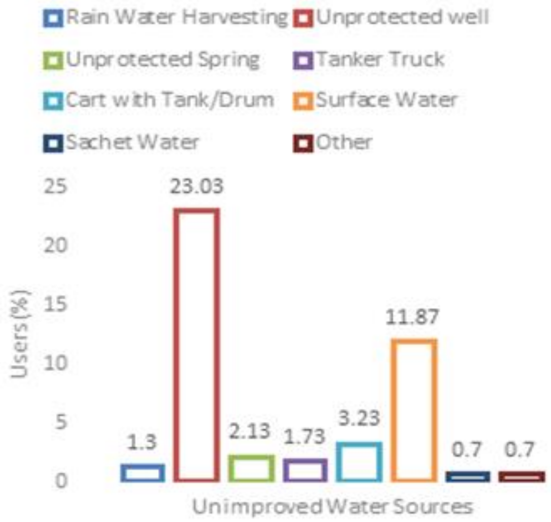


Fig 6:- Variable Unimproved Water Sources in the Region [5].

The average quantitative vulnerability (QV) was estimated using fixed-effect statistical modelling (Equation 3). Where UWU (%) is the percentage of average unimproved water users. This is to estimate the number of people who are vulnerable to bone water infections in the region.

$$QV = \sum U \quad (3)$$

$$U = (\sum(UWU\%)(P))/100 \quad (4)$$

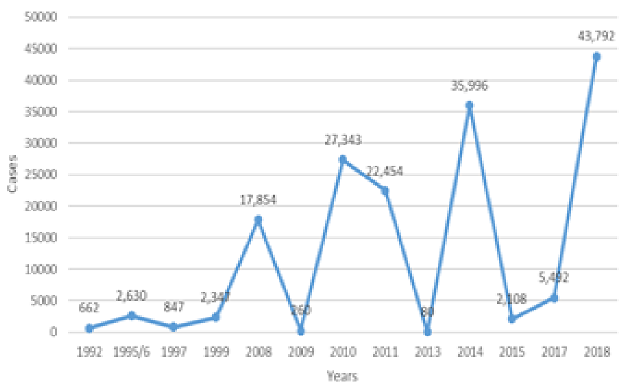


Fig 7:- Cholera Cases in Northern Nigeria between 1991-2018 [5].

## III. APPROACH

Pit latrine developed to last long according to the general rules, the longer the pit latrine last, the lower the cost and greater the social benefits. However, the anthropogenic emission to the larger extent and groundwater contamination is least regarded. To enable Northern Nigeria with proper human excreta disposal which is more important than proving portable water as its eliminates or minimize environmental and environmental resource contamination [25] the Northern Nigerian table water depth was evaluated by Gokcekus, et al [5] the study found variation in hydrological formation in the region, thus, it's impossible to suggest the minimum vertical distance between the bottom of a pit latrine and water table for the entire region. Therefore, new design and siting techniques needed. In this approach, engineering design and combining several in-depth qualitative methodologies will be utilized to develop an environmental friendly pit latrine. This method has been chosen to obtain information and to draw a logical conclusion on the development of sustainable and ecological friendly pit latrine in Northern Nigeria. However, the research will give priority to the pit hole (Figure 8) because that is where excreta are retained in and all activities and processes are carried out such as FS accumulation, anthropogenic emission and discharge.

This section is divided into two parts. In the first part, the fixed and random effect statistical analysis and the Buswell equation [39] will be utilized to determine the annual average pit hole size or capacity (PS). In the second part, new sitting techniques and lining materials will be described.

### *A. Average Annual Pit Hole (PS)*

Pit hole size depends on the filling rate which also depends on FS accumulation rate [6] ranges between 40-90 litre/capita/year [40, 9]. Studies extensively indicate that there is no actual pit latrine filling rate varies between 1-30 years or more [41-46, 40, 22] which ascribed to the number of users and factors such as flushing water and rubbish disposing into the pit latrine [47-48] which sometimes includes non-degradable materials [49]. Furthermore, human bio-waste is one of the biogas sources [8], according to Emetere and Pindar [50] the biogas productions in pit latrine is higher than in water closet (WC) due to the anaerobic and aerobic decomposition processes; solid excreta decomposition into pieces by water dissolution [8]. These processes especially the anaerobic process considered as pit latrine other filling factors [9, 48, 51] because gases are released to the atmosphere, and microbial and minerals compound are drained into the ground [8] thereby, reducing the significant volume of pit latrine [40, 9-10, 52-53]. Therefore, determining a pit hole size depends on pit hole content and biogas harvesting. The pit hole should comprise two (2) chambers, digester chamber and biogas chamber as described in Figure 5.

In determining PS per household (Equation 5), average annual digester chamber size (DC) and average annual biogas chamber size (BC) are estimated the process is described in Figure (8).

### *B. Digester Chamber Size (DC)*

In estimating the DC, the data on average daily excreta (urine and faeces) and flushing water rate per gram and litre per person, and Northern Nigerian average household members. The information on the DC filling components are given in Table 1

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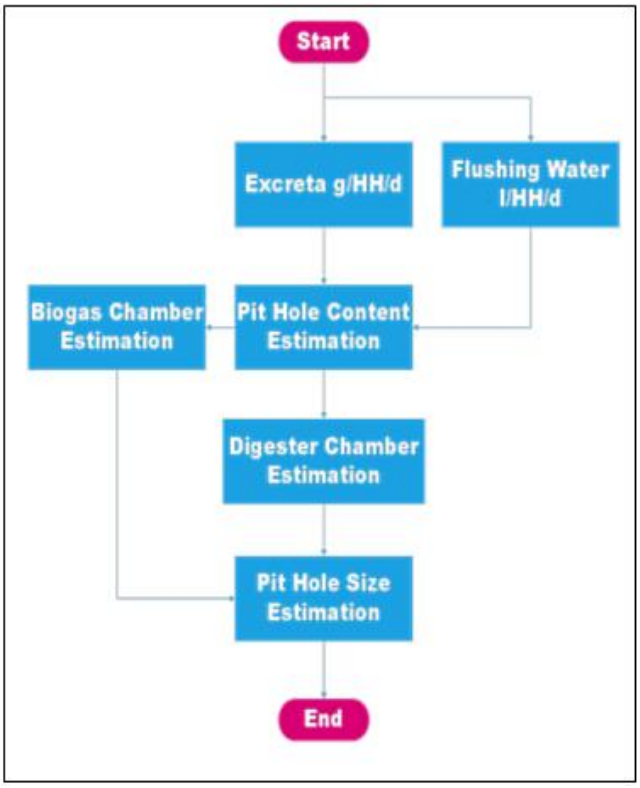


Fig 8:- Annual Average Pit Hole Size

| Components | Amount | |
|---|---|---|
| Urine | 1,200 gram/capita/day [54] | $0.00145 m^3$ |
| Feces | 250 gram/capita/day [55] | |
| Average Household | 5.5 (Mean) [56] | 5.5 |
| Flushing Water | 30 litre/flushing/capita/day [57] | $0.03 m^3$ |

Table 1:- Pit Hole Filling Components

The DC is estimated using Equation 6, where EX is average daily excreta per person, FW is average daily flushing water per person, HH average Northern Nigerian household members and yr is 365 days.

$$DC = \big((EX)(HH)\big)(yr) + \big((FW)(HH)\big)(yr) \qquad (6)$$

*C. Biogas Chamber Size (BC)*

The BC size is based on the average amount of biogas emanated by excreta per annum which depends on the human excreta component [58]. The component (Table 2) shown a great capacity of emanating biogas [59]. The biogas emanated per kilogram of human faeces is greater or equal to that of animal manure with up to 70% methane content [60]. This is because human excreta have biogas optimum pH of about 7.3 [61]. Therefore, harvesting biogas; long noted greenhouse gases emanated by pit latrine [8] and new detected 198 volatile gases [62] is a viable option to significantly reduce the anthropogenic emissions

| Component | Unit | Amount |
|---|---|---|
| Wet Excreta (Feces) Per Person Per Day | g/c/d | 250 [55] |
| Nitrogen | g/c/d | 0.3 [63] |
| Total Phosphorus (TP) | g/c/d | 0.5 [64] |
| Total Potassium (TK) | g/c/d | 0.7 [64] |
| Water Content | % | 65 [39] |
| Solid Content (TS) | % | 35 [39] |
| pH | - | 7-9 [39] |
| Carbon (%C) | % | 24 [39] |
| Carbon Biodegraded (%CB) | % | 70 [39] |
| Buswell Methane ($\%CH_4$) | % | 53 [39] |
| Mol of Gas at STP | Litre | 22.4 [39] |

Table 2:- Human Excreta Content

Although, there are numbers of equations used to estimate the biogas such as Hashimoto model [65], Bousier equation [66], Buswell equation [39, 55], Bouille and Bubois equation [67], Executive Board-CDM equation [68] and Vedrenne equation [69]. However, the current study utilises Buswell equation [39, 55] to estimate the methane biogas emanated by anaerobic decomposition of organic substances of chemical composition C450H2050O950N12S1 [55], [39].

$$C_cH_hO_oN_nS_s + 1/4(4c-h-2o+3n+2s)H_2O = 1/8(4c+h-2o-3n-2s)CH_4 + 1/8\,(4c-h+2o+3n+2s)CO_2 + nNH_3 + sH_2S \qquad (7)$$

The amount of the methane biogas estimation using theoretical Buswell parameters depends on the average daily excreta (faeces) per household dry matters (DM) which expressed in Equation (8), where FC is average faeces per household:

$$DM = (FC)(HH)(TS) \qquad (8)$$

The Bank [39] estimation procedures where he estimated the volume of methane by determining the weight of carbon (WC) (Equation 9), the weight of carbon degraded (WCB) (Equation 10) then the weight of methane carbon (CH4-C) (Equation 11. The conversion of CH4-C to biogas (WCH4) is expressed in Equations (12):

$$WC = (DM)(\%C) \qquad (9)$$

$$WCB = (WC)(\%CB) \qquad (10)$$

$$CH4 - C = (WCB)(\%CH4) \qquad (11)$$

$$WCH4 = (CH4 - C)(MMCH4/MMC) \qquad (12)$$

At standard temperature and pressure (STP), the average daily volume of biogas in litre and the cubic meter are expressed in Equations 13 and Equation 14 respectively:

$$VCH4\, lt = (mol\, CH4)(22.4) \quad (13)$$

$$VCH4 = VCH4\, lt/1000 \quad (14)$$

The BC size or capacity is estimated using Equation 15:

$$BC = (VCH4)(yr) \quad (15)$$

*D. Lining and Lining Materials*

The basic need for pit hole lining depends on the type of pit latrine; users' preference and financial status, and soil condition; firm or loose. The pit hole is lined with any material that is strong and durable enough to support the structure to prevent it from collapse and to ensure that it will last long. The common pit hole lining materials include stone, burnt bricks, masonry blocks or termite resistant timber. However, preventing microbial and chemical discharge to groundwater is less considered, even septic tank which is watertight compacted discharged microbial and chemical to the group, thus, contaminating the groundwater. Therefore, the pit hole should be constructed to avoid groundwater contamination. Water table depth parameter should be considered according to Graham, et al. [28] before constructing any pit hole; pit hole and groundwater proximity and safety should be evaluated. Many efforts have been made to establish a pit latrine minimum design standard [5] to mitigate anthropogenic emission and groundwater contamination, however, vertical distances between the bottom of a pit latrine and water table depth, depending on the topography and subsurface condition, the vertical distances vary between 3m-50m [34, 70-75] and between 10m-30m [28].

Northern Nigerian hydrogeological formations were investigated by Gokcekus, et al. [5] and their study revealed the variation of water table depth in the region ranged between 0m-40m. Moreover, the gradual rising of groundwater levels as a result of climate changes which is limiting the vertical safe separation between the water table and bottom of pit latrine make it impractical to achieve a minimum uniform vertical safe distance between the bottom of pit hole and highest water table for the entire region. However, new siting techniques including lining and material materials will be developed to achieve an ecological friendly pit latrine.

## IV. RESULT

*A. Pit Latrine Usage in Northern Nigeria*

The average pit latrine users (ΣU) in Northern Nigeria is estimated in Table 3 based on the Northern Nigerian pit latrines usage proportion (Figure 5). Based on the 5.5 average Northern Nigerian household members, about 12.73million household in the region is estimated to use pit latrine for defecation.

| Pit Latrine Types | PU(%) | P | U |
|---|---|---|---|
| Septic tank | 5.3 | 108,491,992 | 5750075.58 |
| Flush to Pit latrine | 8.5 | | 9221819.32 |
| Ventilated Improved Pit Latrine | 1.17 | | 1269356.31 |
| Pit Latrine with Slab | 22.97 | | 24920610.6 |
| Pit Latrine without Slab/Open Slab | 26.1 | | 28316409.9 |
| ΣU | | 69,478,271.7 | |

Table 3:- Estimated Pit Latrine Average Users In Northern Nigeria

*B. Pit Hole Size*

A pit hole size of a minimum of one-year filling rate which comprises of two chambers, digester and biogas chambers is determined (Table 4) based on the pit latrine filling component (Table 1) and amount of biogas emanated annually.

| **The Average Annual Digester Chamber Size (DC) Estimation** | | | | | | |
|---|---|---|---|---|---|---|
| **EX ($cm^3$)** | | **FW ($cm^3$)** | | **HH** | **Yr (days)** | |
| 0.00145 | | 0.03 | | 5.5 | 365 | |
| DC ($cm^3$) | | | | 63.145 | | |
| **The Average Biogas Chamber Size (BC) Estimation** | | | | | | |
| **DM** | **WC** | **WCB** | **$CH_4$-C** | **$CH_4$** | **$VCH_4$** | **$VCH_4$** |
| Kg | | | | | lt | $cm^3$ |
| 0.49 | 0.12 | 0.084 | 0.0445 | 0.06 | 83 | 0.083 |
| BC ($cm^3$) | | | | 30.30 | | |
| PS ($cm^3$) | | | | 93.445 | | |

Table 4:- The Average Annual Pit Hole Size (PS)

*C. Pit Hole Sitting*

Based on the variation of Northern Nigerian hydrological formation and rising of groundwater level which limits the vertical safe separation between the bottom of a pit latrine and water table, the study described a new pit hole method includes new lining techniques and lining materials in Figure 9 and 10 for the region entirely intending to prevent contaminants discharged from the pit hole. In both Figure 9 and 10, impervious barriers are used to prevent moisture or solvent discharges from pit latrine to contaminate the groundwater.

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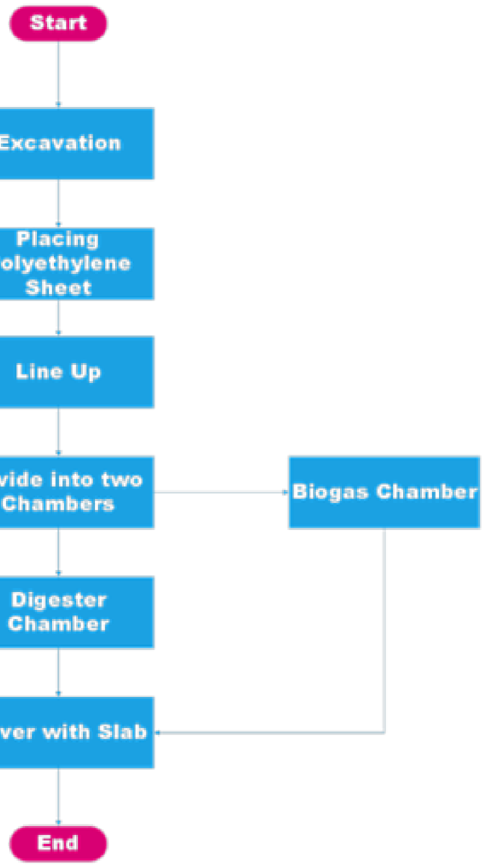


Fig 9:- Pit Hole Setting Techniques 1

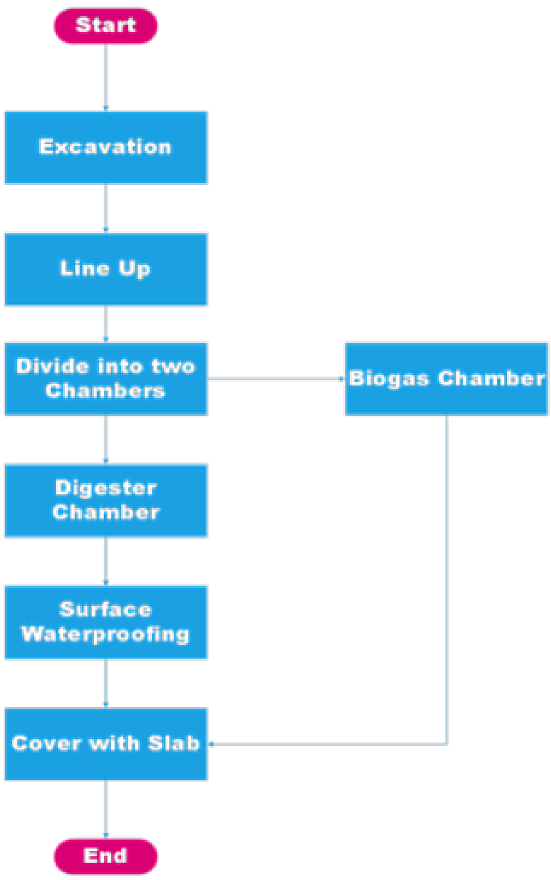


Fig 10:- Pit Hole Setting Techniques 2

## V. DISCUSSION

The Northern Nigerian all types of pit latrine users are estimated at 70 million people (Table 3) corresponding to the 12.73 million households based on the 5.5 Northern Nigerian average households and this number is expected to increase as over 30million people practice open defecation in the region. Studies extensively established groundwater microbial and chemical qualities in relation to a pit latrine. Based on quantitative vulnerability (QV), the pit hole microbial and chemical discharges may pollute the unimproved water sources of approximately 48.6million (Table 4) people in the region, thereby, making them vulnerable to bone water infection. QV necessitate the need for the environmental friendly pit hole.

Based on the Northern Nigerian average household and average excreta per capita per year, flushing water per capita per year and average annual biogas emanated by wet excreta, a minimum one-year pit hole is estimated at 90.50m3 (Table 5) comprise of 2 chambers, DC and BC. Both are estimated at 60.145m3 (Table 5) and 30.30m3 (Table 5) respectively. The minimum pit hole development or sitting method which includes lining materials and new lining technique are described different ways (Figure 9 and 10) with a view to anthropogenic control or mitigation. Figure 9 described the use of polyethylene sheet which is placed in pit hole after the excavation before the lineup this is to prevent pit hole moisture from draining to the ground to contaminate the groundwater. Polyethylene sheet is widely used in construction also used in Nigeria for foundation mostly in the swampy area to protect the building against dampness while Figure 10 described cementation and bituminous (asphalt) coating waterproofing techniques, both are common and easier waterproofing method, easy to mix and get from suppliers. Asphalt considered to be essential and economical for the pit digester chamber waterproofing as it will not be exposed to sunlight, the asphalt becomes very brittle when exposed to sunlight.

## VI. CONCLUSION

The sitting standard for Northern Nigeria is described in Figure 9 and 10 with a view to anthropogenic discharge or emission control or mitigation. Both impervious barrier material suggested are common and widely used as waterproofing materials and they are less expensive. The minimum one-year life span pit hole design requirement based on the statistical analysis and Buswell equation is estimated at 90.50m3 comprises of 60.145m3 digester chamber and biogas chamber. On the other, based on the estimated 12.73 million residences that use pit latrine for defecation in Northern Nigeria an average 385.72cm3 biogas to be harvested annually if all residence adopted this proposed ecological friendly pit latrine, this number is expected to increase as the use of pit latrines are on the rise. The quantity of methane to be harvested annually present a great energy potential for the region and the country at large. Therefore, further study is needed for the possibility of generating electricity using human excreta biogas and its economic potential.

## REFERENCES

[1]. World Health Organisation. Unsafe drinking water, sanitation and waste management. 2019 Retrieved September 13, 2020, from https://www.who.int/sustainable-development/cities/health-risks/water-sanitation/en/

[2]. World Health Organisation (WHO) and UNICEF Report. Progress on Drinking Water and Sanitation. 2014 Retrieved September 13, 2020 from: https://www.unicef.org/publications/files/JMP_report_2014_webEng.pdf.

[3]. UNICEF Annual Result Report. Water, Sanitation and Hygiene. 2015 Retrieved January 1, 2020 from: https://www.unicef.org/wash/files/WASH_2015_Report.pdf.

[4]. Collignon B and Vezine M. Independent Water and Sanitation Providers in Africans Cities. Washington, DC: World Bank, Water Sanitation Program. 2000

[5]. Hüseyin Gokçekuş, Yousseuf Kassem, Nura Yunusa, Muhammad Khidre Musa, Serah Onuh John, Sayyadilkhair Usman, Muktar Sabiu Yahuza and Sadiq Mahmoud Ahmad. Study on Pit Latrine Minimum Design Requirement and Considerations in Northern Nigeria. International Journal of Scientific & Technology Research, ISSN 2277-8616. 2020, Vol (9), Issue (04).

[6]. Tilley, E.; Ulrich, L.; Lüthi, C.; Reymond, Ph.; Zurbrügg, C. Compendium of Sanitation Systems and Technologies (2nd ed.). Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag). 2014, ISBN 978-3-906484-57-0.

[7]. World Health Organisation. A Guide to the Development of on-site Sanitation. 1992, Retrieved December 25, 2019 from https://www.who.int/docstore/water_sanitation_health/onsitesan/ch04.htm.

[8]. Anne Nakagiri, Charles B. Niwagaba, Philip M. Nyenje, Robinah N. Kulabako, John B. Tumuhairwe and Frank Kansiime. Are pit latrines in urban areas of SubSaharan Africa performing? A review of usage, filling, insects and odour nuisances. BMC Public Health. 2016, 16:120.

[9]. Wagner EG, Lanoix JN. Excreta disposal for rural areas and small communities. 1958

[10]. Cotton A, Franceys R, Pickford J, Saywell D. On-Plot Sanitation in lowincome urban communities. A review of literature. Loughborough: WEDC Loughborough Univ. of Technology. 1995

[11]. Kalbermatten JM, Julius DS, Gunnerson CG, Mara DD, Mundial B. Appropriate sanitation alternatives; a planning and design manual, vol. 2: Baltimore, USA, John Hopkins University Press; 1982.

[12]. Rybczynski W, Polprasert C, McGarry M. Low-cost technology options for sanitation. A state-of-the-art review and annotated bibliography. Ottawa: IDRC. 1978

[13]. Saywell D, Hunt C. Sanitation programmes revisited. Loughborough, UK: WEDC, Loughborough University. 1999

[14]. Thrift C. Sanitation policy in Ghana: Key factors and the potential for ecological sanitation solutions. Stockholm: Stockholm Environment Institute. 2007

[15]. Winblad U, Kilama W. Sanitation without water. Revised and enlarged edition. London: Macmillan Education. 1985

[16]. Van Nostrand J, Wilson JG. Rural ventilated improved pit latrines: a field manual for Botswana. Technical Advisory Group technical note; no. 8. In. Washington, DC: World Bank. 1983

[17]. Solsona F. The South African Sanplat. An alternative low-cost pit latrine system for rural and peri-urban areas. Technical guide. South Africa: CSIR Pretoria. 1995

[18]. François Brikké and Maarten Bredero. Linking technology choice with operation and maintenance in the context of community water supply and sanitation. World Health Organization and IRC Water and Sanitation Centre Geneva, Switzerland. 2003

[19]. Cotton, A.P. & Saywell, D. On-plot sanitation in low-income urban communities: guidelines for selection, Loughborough: Water, Engineering and Development Centre. 1998

[20]. Nakagiri A, Kulabako RN, Nyenje PM, Tumuhairwe JB, Niwagaba CB, Kansiime F. Performance of pit latrines in urban poor areas: a case of Kampala, Uganda. Habitat Int. 2015, 49, 529–37

[21]. Dumpert JW. Performance Evaluation of VIP Latrines in the Upper West Region of Ghana. In Houghton, Michigan: MSc Thesis Michigan Technological University. 2008

[22]. Morgan PR, Mara DD, Mundial B.. Ventilated improved pit-latrines: recent development in Zimbabwe (Technical Note No. 2) vol. 3. In. Washington, D.C: World Bank. 1982

[23]. National Survey Finding Report, February. The fifth round Multiple Indicator Cluster Survey (MICS5), Multiple Indicator Cluster Survey 2016-17. 2018

[24]. National Nutrition and Health Survey (NNHS). Report on the Nutrition and Health Situation of Nigeria. 2018

[25]. Fanen Terdoo, Olalekan Adekola. Assessing the role of climate-smart agriculture in combating climate change, desertification and improving rural livelihood in Northern Nigeria. African journal of agricultural research. 2014, 9(15):1180-1191

[26]. Fredrick Owino Gudda, Wilkister Nyaora Moturi, Omondi Steve Oduor, Edward Wanee Muchiri and Jeroen Ensink. Pit latrine fill-up rates: variation determinants and public health implications in informal settlements, Nakuru-Kenya BMC Public Health. . 2019, (19)(68).

[27]. Feachem RG, Bradley DJ, Garelick H, Mara DD. Sanitation and Disease: Health Aspects of Excreta and Wastewater Management. New York: John Wiley & Sons Ltd. 1983

[28]. Jay P. Graham and Matthew L. Polizzotto. Pit Latrines and Their Impacts on Groundwater Quality: A Systematic Review. Environmental Health Perspectives. 2013, 121(5).

[29]. Pujari PR, Padmakar C, Labhasetwar PK, Mahore P, Ganguly AK.. Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings--a case study from India. Environ Monit Assess. 2012, 184(1), 251-63.

[30]. Vinger B, Hlophe M, Selvaratnam M. Relationship between nitrogenous pollution of borehole waters and distances separating them from pit latrines and fertilized fields. Life Sci J. . 2019, 9(1), 402–407.

[31]. Banerjee G. Underground pollution travel from leach pits of on-site sanitation facilities: a case study. Clean Technol Environ Policy. 2011, 13(3), 489–497

[32]. Verheyen J, Timmen-Wego M, Laudien R, Boussaad I, Sen S, Koc A, Uesbeck A, Mazou F, Pfister H. Detection of adenoviruses and rotaviruses in drinking water sources used in rural areas of Benin, West Africa. Appl Environ Microbiol. 2009, 75(9), 2798-801.

[33]. Ophori, D. Groundwater Quality in Shallow Domestic Water Wells, Ughelli, Nigeria. 2006, Retrieved December 2, 2019, from http://www.iseg.giees.uncc.edu/abuja2006/Abstracts/Abstract_ID_284.

[34]. Dzwairo B, Hoko Z, Love D, Guzha E. Assessment of the impacts of pit latrines on groundwater quality in rural areas: a case study from Marondera district, Zimbabwe. Phys Chem Earth. 2006, 31(15–16), 779–788.

[35]. Zingoni E, Love D, Magadza C, Moyce W, Musiwa K. Effects of a semi-formal urban settlement on groundwater quality Epworth (Zimbabwe): case study and groundwater quality zoning. Phys Chem Earth. 2005, 30(11–16), 680–688.

[36]. Adelana, S. M. A. & Olasehinde, P. I. High nitrate in water supply in Nigeria: implications for human health. Water Resources. 2003, 14, 1–11.

[37]. Amadi, A. N., Okoye, N. O., Alabi, A. D., Aminu Tukur and Angwa, E. M., Quality assessment of soil and groundwater near Kaduna Refinery and Petrochemical Company, Northwest Nigeria. Journal of Scientific Research & Reports. 2014, 3(6), 884-893.

[38]. Mbonu, M. & Ibrahim-Yusuf, A. I. Groundwater quality in the Basement Complex region of north-central Nigeria – A preliminary survey of nitrate concentration. Water Resources1994, 5, 16–21.

[39]. C. Banks. Anaerobic digestion and energy. 2014, Available: http://www.valorgas.soton.ac.uk/Pub_docs/JyU%20SS%202011/CB%204.pdf.

[40]. Franceys R, Pickford J, Reed R. A guide to the development of on-site sanitation. London: World Health Organisation; 1992.

[41]. Appiah-Effah E, Nyarko KB, Gyasi SF, Awuah E. Faecal sludge management in low income areas: a case study of three districts in the Ashanti region of Ghana. J Water Sanit Hyg Dev. 2014, 4(2), 189–99.

[42]. Adubofour K, Obiri-Danso K, Quansah C. Sanitation survey of two urban slum Muslim communities in the Kumasi metropolis, Ghana. Environ Urban. 2013, 25(1), 189–207.

[43]. Still DA, Foxon K. Tackling the challenges of full pit latrines. Volume 2: How fast do pit toilets fill up? A scientific understanding of sludge build up and accumulation in pit latrines. In., vol. 2. South Africa: Water Research Commission (WRC). 2012

[44]. Günther I, Horst A, Lüthi C, Mosler H-J, Niwagaba CB, Tumwebaze IK. Where do Kampala's poor "go"?-Urban sanitation conditions in Kampala's lowincome areas. 2011

[45]. Kulabako RN, Nalubega M, Wozei E, Thunvik R. Environmental health practices, constraints and possible interventions in peri-urban settlements in developing countries - a review of Kampala, Uganda. Int J Environ Health Res. 2010, 20(4), 231–57.

[46]. Pickford J. Low-Cost Sanitation. A survey of practical experience. London: ITDG Publishing. 2006

[47]. Still DA, Foxon K. Tackling the challenges of full pit latrines. Volume 1: Understanding sludge accumulation in VIPs and strategies for emptying full pits In., vol. 1. South Africa: Water Research Commission (WRC). 2012

[48]. Buckley CA, Foxon KM, Brouckaert CJ, Rodda N, Nwaneri CF, Balboni E, et al. Scientific support for the design and operation of ventilated improved pit latrines (VIPS) and the efficacy of pit latrine addtives. In. South Africa: Water Research Commission (WRC). 2008

[49]. Brouckaert C, Foxon K, Wood K. Modelling the filling rate of pit latrines. Water SA. 2013, 39(4), 555–62.

[50]. M.E. Emetere and H. Pindar Processing Human Biogas Using Drying Agent. IOP Conf. Ser.: Earth Environ. Sci. 2019, 331 012050.

[51]. Chaggu EJ. Sustainable Environmental Protection Using Modified PitLatrines. In. Netherlands: Ph.D thesis: Sectie Milieutechnologie; Wageningen University. 2004

[52]. Bakare, B. F. Scientific and management support for ventilated improved pit latrines (VIP) sludge content. PhD Thesis, University of KwaZulu Natal (UKZN), Durban, South Africa. 2014

[53]. M.A. Lopez Zavala ; N. Funamizu ; T. Takakuwa. Onsite wastewater differential treatment system: modeling approach. Water Sci Technol. 2002, 46 (6-7), 317–324.

[54]. See Del Porto D, Steinfeld C. The Composting Toilet System Book, Center for Ecological Pollution Prevention, Concord, Mass.; Drangert J-O, Bew J, Winblad U, 1997. Ecological sanitation: Proceedings from Sida Sanitation Workshop, Balingsholm, Sweden. 1999

[55]. C. Rose, A. Panken, B. Jeferson, and E. Cartmell. The Characteristics of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. Critical Reviews in Environmental Science and Technology. 2015, 45:1827-1879.

ISSN No:-2456-2165

[56]. Household Population and Housing Characteristics. Retrieved, March 23, 2020 from: https://dhsprogram.com/pubs/pdf/FR148/02Chapter02.pdf.
[57]. Estimated Water Consumption in the World per Appliance and Sector, International Water consumption data table, Wastewater Gardens Information Sheet. Retrieved, March 23, 2020 from: http://www.wastewatergardens.com/pdf/WWG_InfoSheet_InternationalWaterConsump.pdf
[58]. E. v. Münch. Characteristics of urine, faeces and greywater. 2014. Available: http://pakresponse.info/LinkClick.aspx?fileticket=lyNIwWxUlxQ%3D&tabid=92&mid=743.
[59]. M. N. Suyitno and Dharmanto, Teknologi Biogas : Pembuatan, Operasional, dan Pemanfaatan. Yogyakarta: Graha Ilmu, 2010.
[60]. E. Y. Febrianto and S. Priyono, "Studi Pemanfaatan Feses (Kotoran Manusia) sebagai Bahan Baku Alternatif Energi Terbarukan," TELAAH Jurnal Ilmu Pengetahuan dan Teknologi. 2012, vol. 30, pp. 19-24.
[61]. P. S. E. Haq and E. S. Soedjono. Potensi Lumpur Tinja Manusia Sebagai penghasil Biogas (In Bahasa). Available: http://digilib.its.ac.id/public/ITS-Undergraduate-11072-Paper.pdf
[62]. [62] Lin J, Aoll J, Niclass Y, Velazco MI, Wünsche L, Pika J, et al. Qualitative and Quantitative Analysis of Volatile Constituents from Latrines: Supporting Information. Environ Sci Technol. 2013, 47(14), 7876–82.
[63]. Vinner˚as, B., Palmquist, H., Balm´er, P., and J¨onsson, H. The characteristics of household wastewater and biodegradable solid waste—A proposal for new Swedish design values. Urban Water Journal. 2006, 3(1), 3–11.
[64]. Meinzinger, F., and Oldenburg, M. Characteristics of source-separated household wastewater flows: A statistical assessment. Water Science and Technology. 2009, 59(9), 1785–1791.
[65]. B. T. Nijaguna, Biogaz Technologies. Principal, I S S Academy Of Technical Education, Bangalore, Karnataka, India.: New Age Internacional publishers, 2002.
[66]. H. Boursier, "Etude et modélisation des processus biologiques aux cours du traitement aérobie du lisier en vue d'une optimisation du procédé," Thèse Ingénieur Génie de l'Environnement, Ecole des Mines de Nantes, 2003.
[67]. E. Bouille and V. Dubois. Traitement, épuration et valorisation des effluents d'une fromageri. 2014. Available: http://hmf.enseeiht.fr/travaux/CD0405/beiere/4/html/binome3/dim_inst.htm
[68]. E. Board-CDM, "Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories," 2008.
[69]. F. Vedrenne, "Etude des processus de dégradation anaérobie et de production de méthane au cours du stockage des lisiers," Thè se Science de l'environnement, ENSA de Renne, 2007.
[70]. CABI. Communicable Disease Epidemiology and Control: A Global Perspective. 2015, p. 52. ISBN 9780851990743.
[71]. Banks D, Karnachuk OV, Parnachev VP, Holden W, Frengstad B. Groundwater contamination from rural pit latrines: examples from Siberia and Kosova. J Chartered Inst Water Environ Manage. 2002, 16(2), 147–152.
[72]. Chidavaenzi M, Bradley M, Jere M, Nhandara C. Pit latrine effluent infiltration into groundwater: The Epworth case study. Schriften Ver Wasser Boden Lufthyg. 2000, 105, 171–177.
[73]. Chidavaenzi M, Jere M, Bradley M. Pit latrine effluent infiltration into groundwater. In: Proceedings of the 23rd WEDC Conference, Durban, South Africa. 1997. Available: http://wedc.lboro.ac.uk/resources/conference/23/Chidavae.pdf
[74]. Kligler IJ. New York: Rockefeller Institute for Medical Research. Investigation on Soil Pollution and the Relation on the Various Types of Privies to the Spread of Intestinal Infections. 1921
[75]. Dyer BR. Studies of groundwater pollution in an alkaline alluvium soil. Ind J Med Res. 1941, 29(4), 867–877.