Using GIS and Statistical Approach to Model the Effect of Population Increase on Water and Public Toilet Facilities at Densely Populated Areas
A case study of Aboabo in the Kumasi Metro, Ghana.

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Abstract

The size and composition of a country's population can exert a powerful influence on her public facilities. Water and sanitation facilities are those worst affected in densely populated or fast growing population areas as a result of the fast pace of congestion coupled with increasing birth over deaths at the community levels which made population growth coupled with urbanization outpace development of sanitation infrastructure. In this paper, Geographic Information System (GIS) and a Statistical Approach have been used to develop respectively cartographic and mathematical models to help in visualising and predicting the effect of population increase on water accessibility and public toilet facilities at densely populated areas. The mathematical models correlate the population at each instance to the required number of water accessible points or standing pipes which would be able to carry it as well as the number of required public toilet facilities. The findings will inform planners and assembly members of the effects of increasing

population for proper future planning and to ensure proper infrastructural management at the community levels. The paper seeks to draw the awareness of the government, concerned groups and Non-Governmental Organizations (NGO's) to the extreme detrimental effect that the increase in population has, especially on water and sanitation facilities and how it can be managed at the community level.

Keywords: GIS, GPS, Water and sanitation facility, Statistics

Introduction

Generally, population increase has a tremendous effect on infrastructural facilities and if unchecked could put unnecessary pressure on these facilities. In developing countries, population growth coupled with urbanization has outpaced the development of sanitation infrastructure, leaving the urban poor, virtually without sanitation facilities in many countries. Of the about 2.4 billion people worldwide lacking access to basic sanitation, 80 percent are in Asia and 13 per cent in Africa (WHO & UNICEF, 2000). Ghana's sanitation infrastructure is not well developed. In Urbanised areas the urban poor tend to be concentrated in very high population density neighbourhoods of cities with growth rates of up to 4.4 per cent (UNDP, 2002). The consequences are the extreme pressures exerted on social infrastructures in these regions. Water and sanitation facilities are worst affected in these densely populated or fast growing population areas as a result of the fast pace of congestion coupled with the increasing birth over death rates at the community levels. In Ghana, little input is being made by the Government and other aiding agencies to alleviate this problem due to inadequate funding.

Aboabo, the study area located within the Kumasi metropolitan area of Ghana is a classical area of increase in population with a non corresponding increase in infrastructural facilities such as water and sanitation. The area with a population of about 22634 in 1984 had only five (5) toilet facilities. When the population increased to 34206 in 2000, only one additional public toilet facility was added. The inadequacy of these facilities coupled with their deplorable state has encouraged defecating in polythenes and littering of the surrounding consequently leading to outbreak of diseases such as cholera and diarrhoea in the area (Gandotra, 2001) .The few standing public taps hardly flow. Inhabitants traverse several meters for accessibility to water.

Many urban communities lack economies of scale for sanitation infrastructure management and do not receive support from state and federal governments. These problems are particularly severe for many developing countries. Geographical Information Systems (GIS) can improve the management of water and wastewater infrastructure in such areas (Jones, 2003).

The use of GIS applications can enable water and environmental professionals to manage allocation of the few facilities to populations as well as plan for additional location of facilities that can carry the ever increasing population with great precision. It allows queries to be done to answer questions on the number of toilet facilities that will be needed in five (5) years time (Bartam, 2005). Galley (2007) investigated how GIS can be effectively used in population management and also serve as a platform to equip Assembly-men and District Chief Executive as a tool to help them in proper planning of their community. His studies fell short of estimating the number of facilities that will be required in future years depending on say population growth. This paper, unlike other GIS applications already applied in water and sanitation, creates a model with the use of GIS to showcase the problem the existing facilities, the current population and the number of facilities that can carry the population so as to display the inadequacy of the existing. It also used mathematical models to predict the number of such facilities that will be needed at any given time in the near future. The paper has further through cartographic modelling, other than network analysis, suggested approximate positions of such facilities.

Materials and Methods

The study area is located north of Dichemso and the south of Amakom. It is also to the east of Asawasi and west to Akrom. Aboabo is bounded by a railway line from Kumasi to Tarkwa (Figure 1)

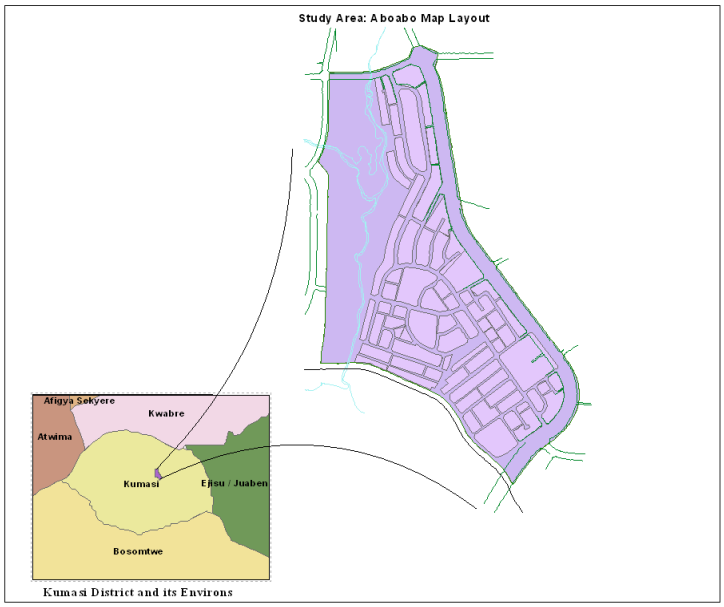

Figure 1: Map of Kumasi District showing research area.

The materials uses are:

- Town sheet of Kumasi Metropolis for projecting the study area Aboabo.
- Layout of Aboabo (study area).
- Computer and the digitizer to digitize the study area
- GPS instruments for picking the already exiting toilet and water facilities.
- Population and Census data of Aboabo
- ArcGIS software for modeling
- Minitab sofware for statistical anlysis

All existing toilet and standing pipe facilities in the study area were surveyed using a GPS instrument. These results were imputed into the digital database of Aboabo obtained from digitizing the layout map of study area. Data on the population of Aboabo was obtained from the Statistical Service department, Kumasi. Other secondary sources of data were from administered questionnaires in the community. This gave detailed information about the problems associated with using the water and toilet facilities. These data were modelled in ArcGIS for display and cartographic visualisation. The Minitab statististical software was used for mathematical model generation

Results and Discussion

Dependency of Aboabo population on various toilet facility types.

Less than 40% of the total population at Aboabo have their own private means of toilet (Figure 2). About 66% depend solely on public toilet facilities.

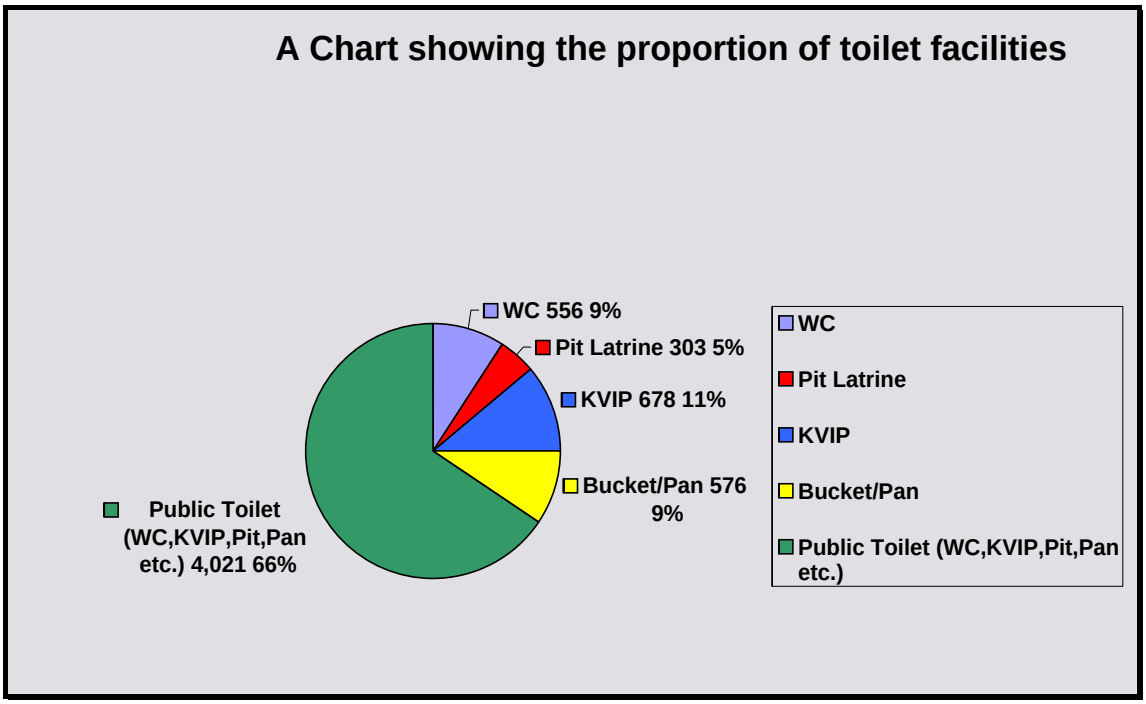

Figure 2: Chart showing dependent of the population on various toilet facilities

Population growth by years in Aboabo

Figure 3 shows the increasing trend of Population in Aboabo since 1984.

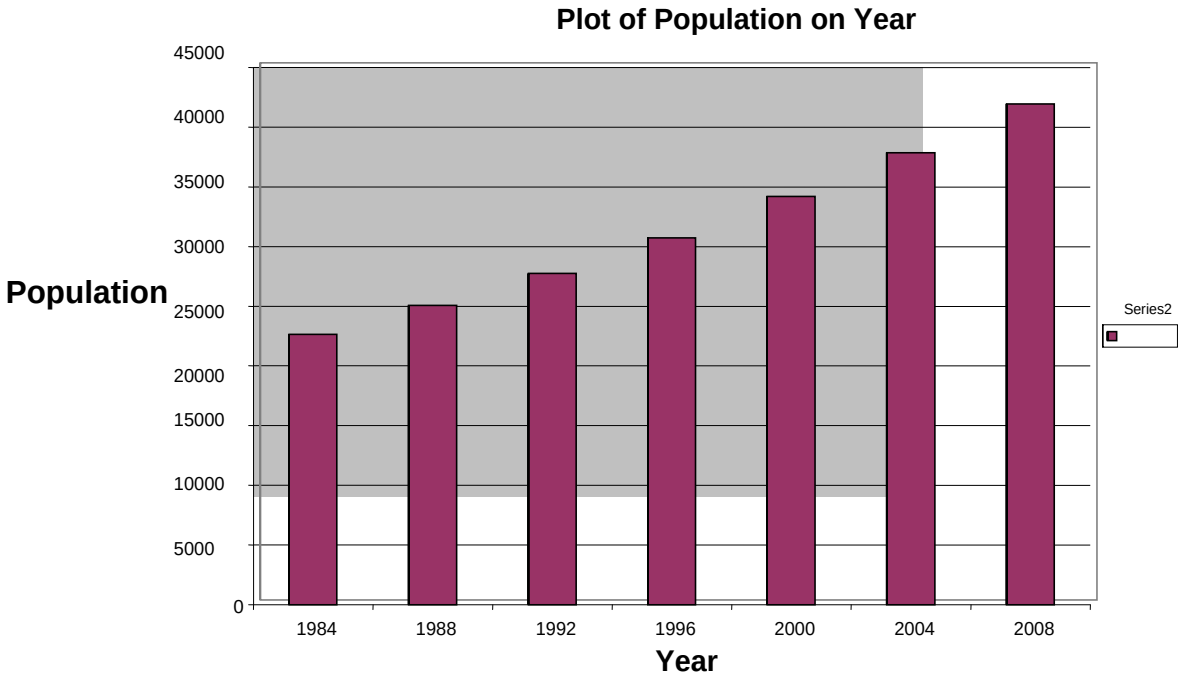

Figure 3: Plot of population against Year

Figure 4 shows the plot of available water (Av SP) and public toilet (PT) facilities against the population trend in Aboabo from the year1984 to the current year.

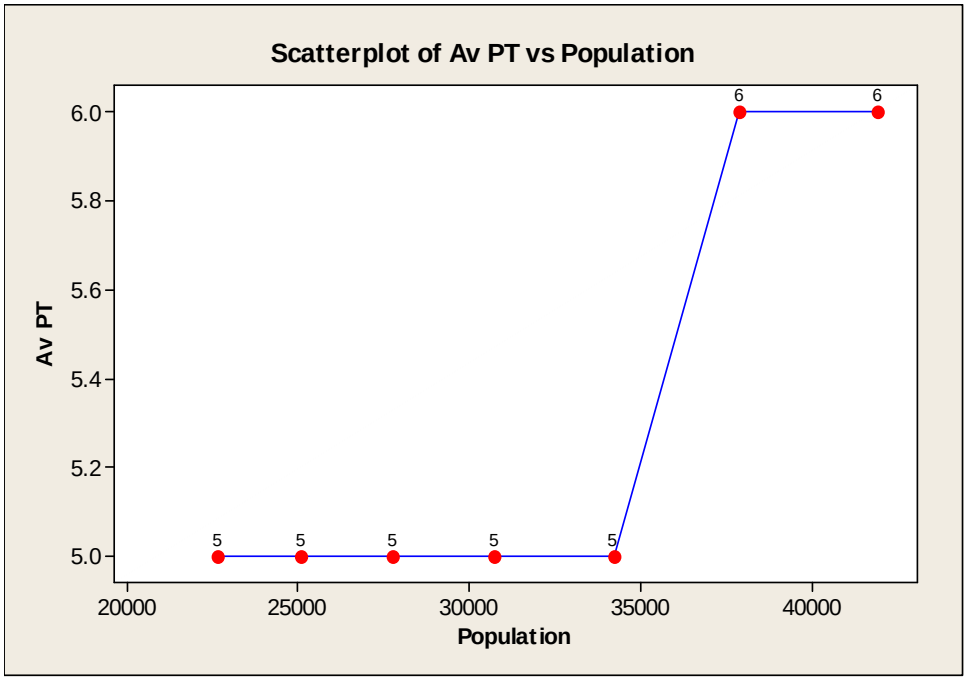

Figure 4: Plot of available water (Av SP) and public toilet (PT) facilities against the population trend in Aboabo from the year1984

Figures 5 and 6 shows the number and site location of public Toilets at Aboabo and a plot of Available Standing Pipe against Population respectively.

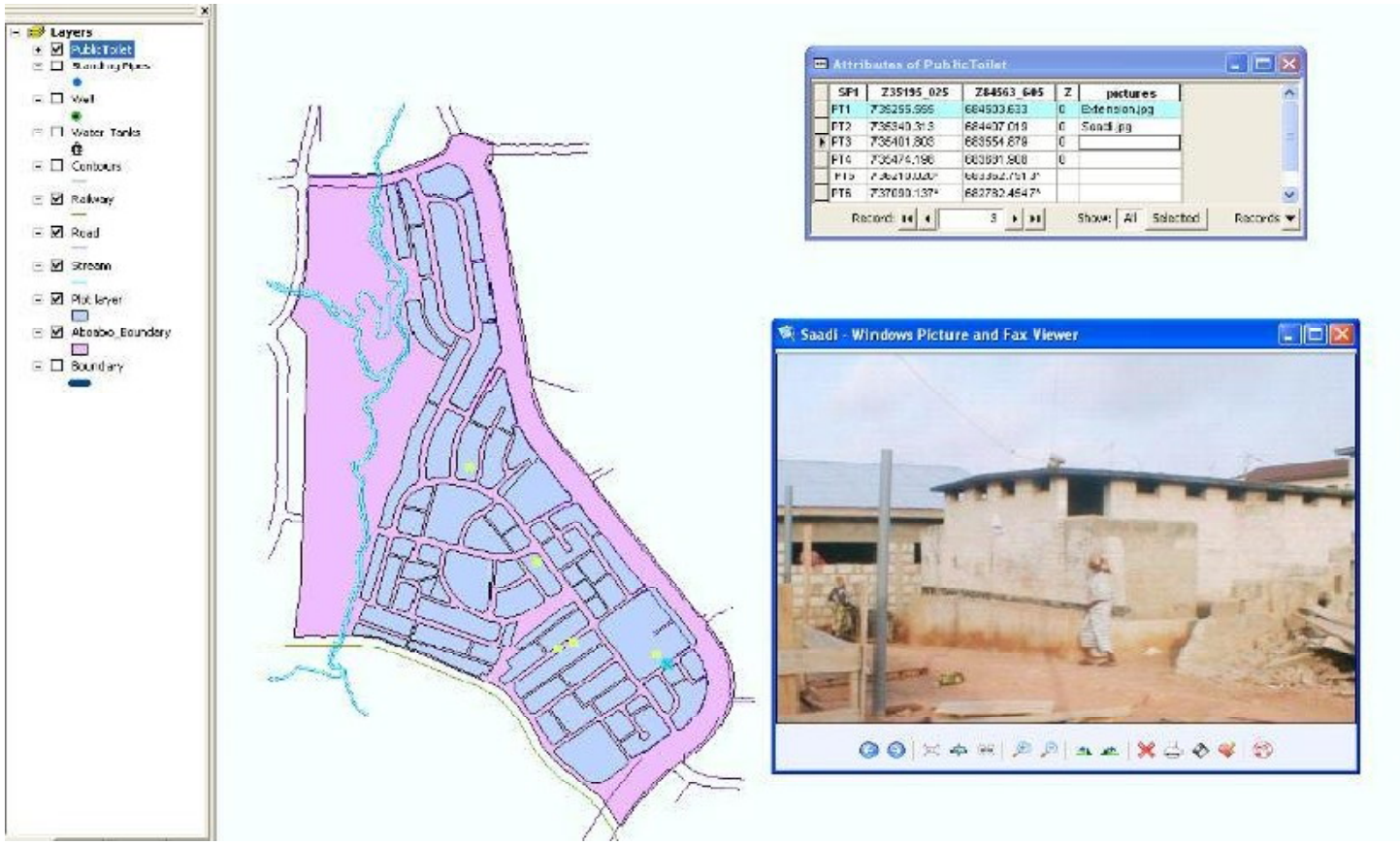

Figure 5: Number and site location of public Toilets at Aboabo

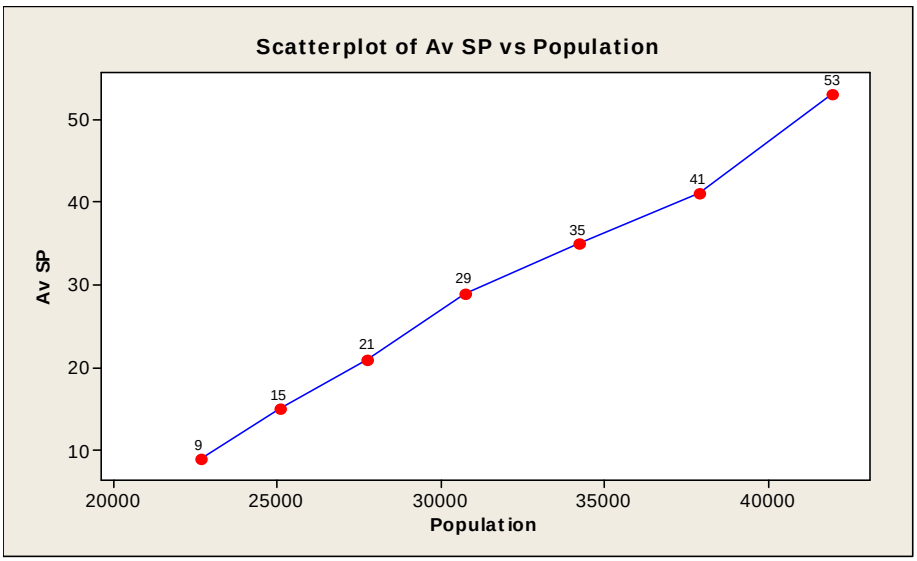

Figure 6: A plot of Available Standing Pipe against Population

Figure 7 is the Cartographic model showing the spatial locations of the existing standing pipes in different coluration corresponding to the number of the population in the scatter plot.

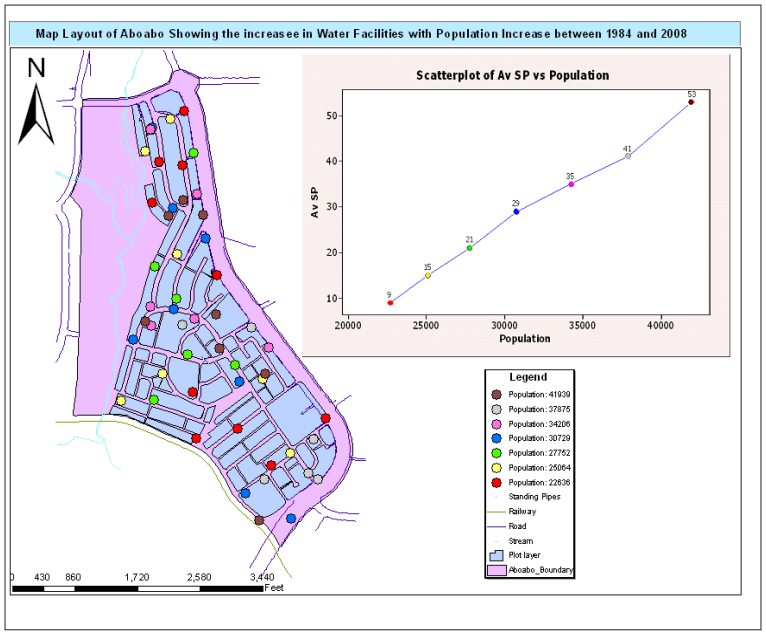

Figure 7: The Cartographic model of water facilities with population between 1984 and 2000

Regression Analysis: Available Standing Pipe (AvSP) versus Year

Figure 8 shows the fitted line plot of Available Standing Pipe against Year.

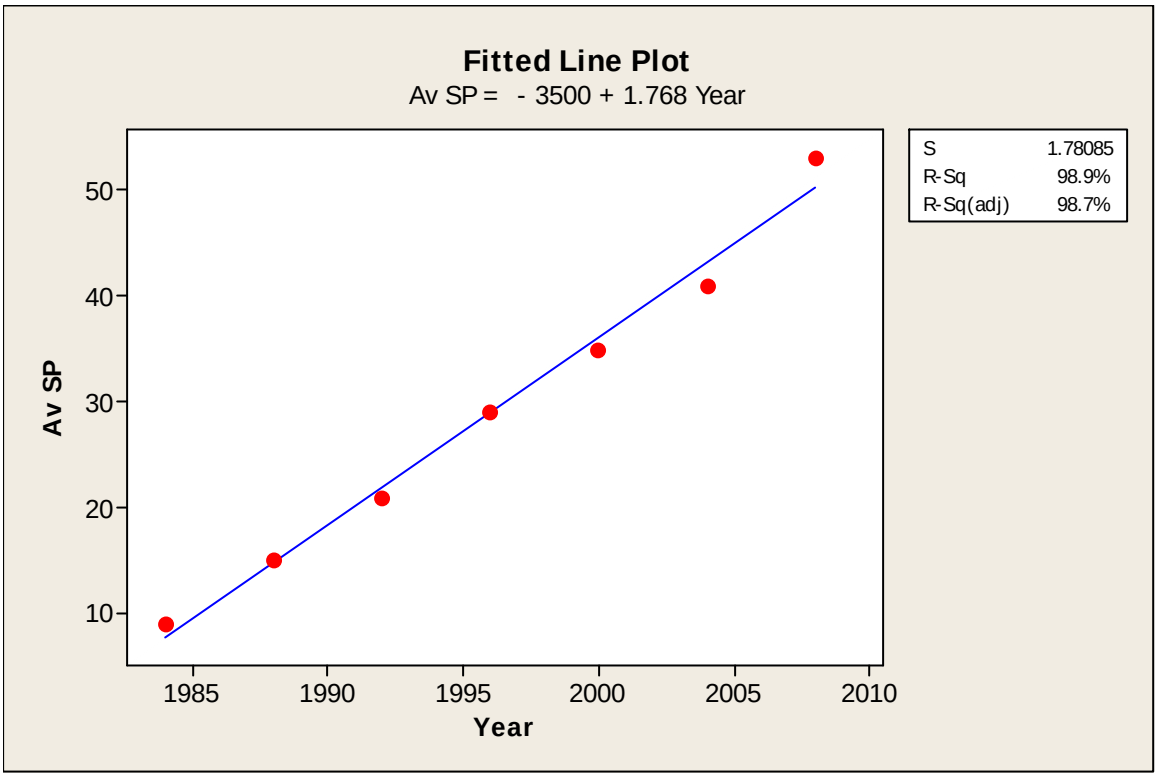

Figure 8: Fitted line plot of Available Standing Pipe against Year

The regression equation is given as:

Av SP = - 3500 + 1.768 Year

S = 1.78085 R-Sq = 98.9% R-Sq (adj) = 98.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1400.14	1400.14	441.49	0.000
Error	5	15.86	3.17		
Total	6	1416.00			

These results show a positive linear relation implying that as time progresses there has been a corresponding increase in the water facilities provided. A four year increases in years results a corresponding increase of 1.768 (approximately 2) water facilities (standing pipes) for the Aboabo community. R-sq and R-sq (adj) values of 98.9% and 98.7% resulted respectively. These indicate

that 98.9% of the variation in the available standing pipe data pertains to the year. The p-value of 0.000 also indicates that year is statistically significant since it is less than the a-level.

Regression Analysis: Available Standing Pipe (AvSP) versus Population

Figure 9 shows the fitted line plot of Available Standing Pipe against Population

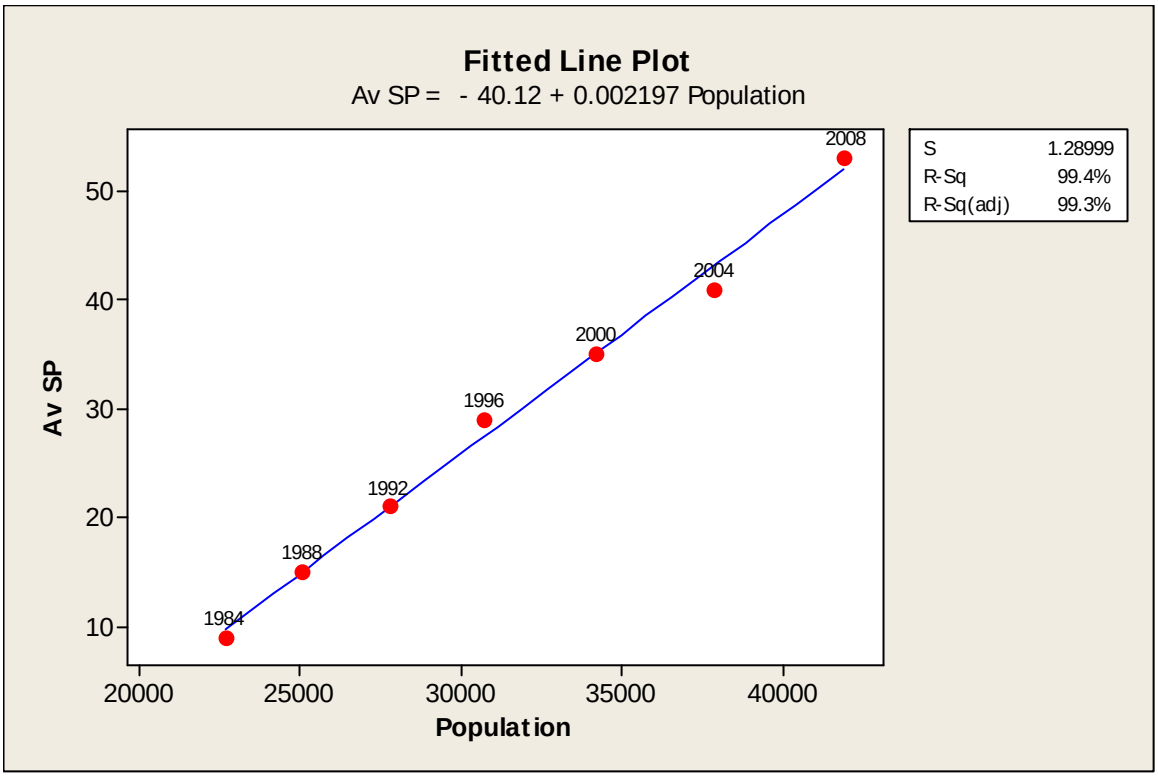

Figure 9: Fitted line plot of Available Standing Pipe against Population

The regression equation is:

Av SP = -40.1212 + 0.0021973 Population

S = 1.28999 R-Sq = 99.4 % R-Sq (adj) = 99.3 %

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1407.68	1407.68	845.920	0.000
Error	5	8.32	1.66		
Total	6	1416.00			

Again, a positive linear correlation exists. A unit increase in population results in 0.00219 increases in the available standing pipes. The R-sq, R-sq (adj) values of 99.4% and 99.3% indicates that

99.4% of the variation of the existing standing pipes data pertains to the population data. The p-value of 0.000 also indicates that year is statistically significant since it less than the a-level. Though the population data show a weaker effect on the water facility increment

Regression Analysais: Required Public Toilet (ReqPT) versus Population

Figure 10 shows the fitted line plot of Required Public Toilet against Population.

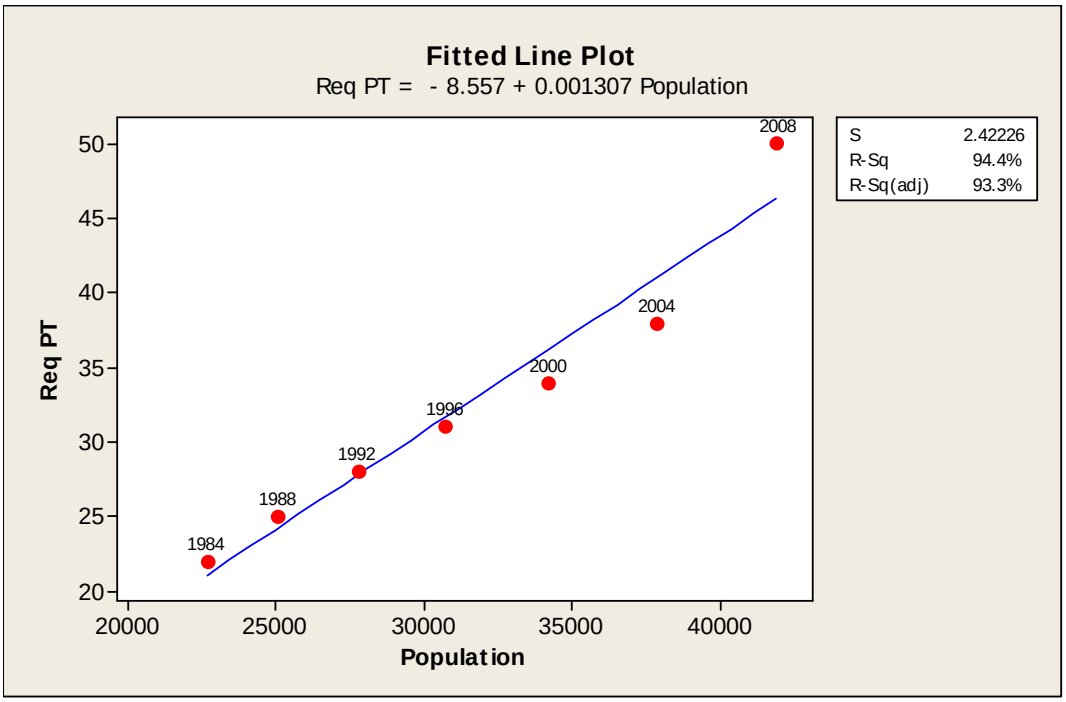

Figure 10: Fitted line plot of Required Public Toilet against Population

The regression equation is:

Req PT = - 8.557 + 0.001307 Population

S = 2.42226 R-Sq = 94.4% R-Sq (adj) = 93.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	498.377	498.377	84.94	0.000
Error	5	29.337	5.867		
Total	6	527.714			

The regression equation above indicates a positive linear relation. A unit increases in the population results 0.0013 increase in the public toilets available in the area. R-sq and R-sq (adj)

values of 94.4% and 93.3% resulted respectively were observed. These indicate that 94.4% of the variation in the available standing pipe data pertains to the population. The p-value of 0.000 indicates that the population data is statistically significant since it less than the a-level.

Regression Analysais: Required Standing Pipe (ReqSP) versus Population

Figure 11 shows the fitted line plot of Required Standing Pipe against Population.

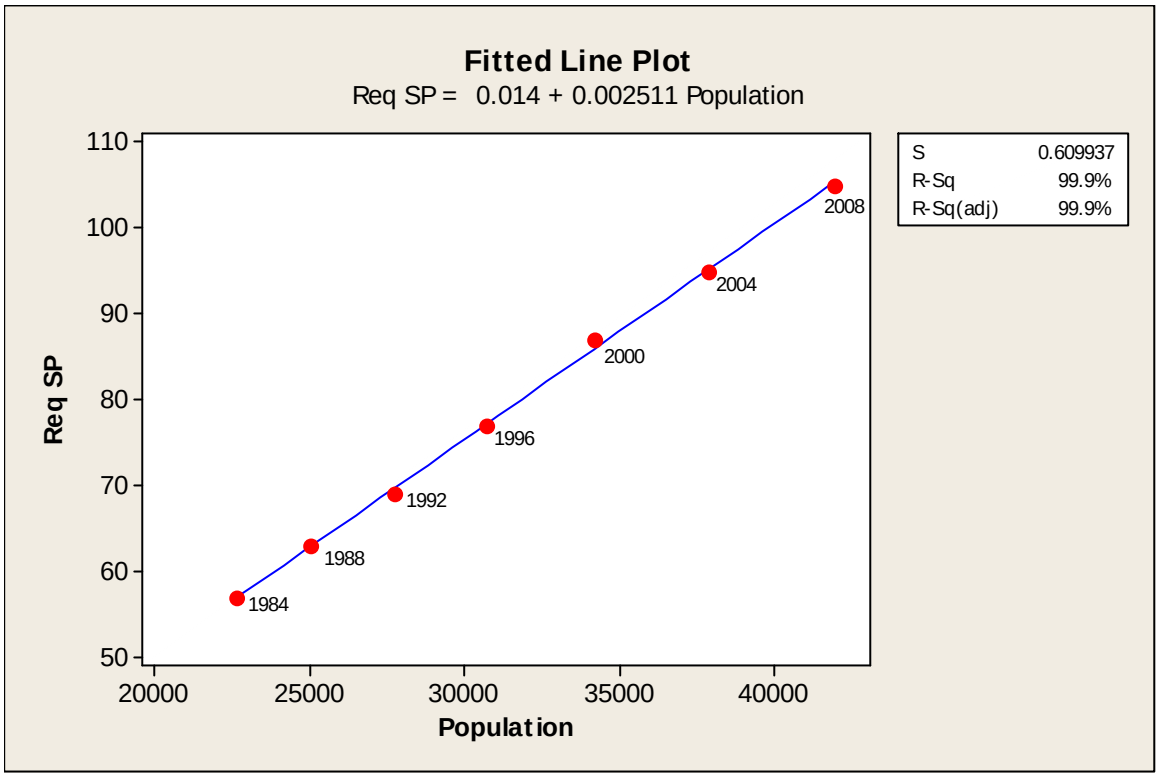

Figure 11: Fitted line plot of Required Standing Pipe against Population

The regression equation is:

Req SP = 0.014 + 0.002511 Population

S = 0.609937 R-Sq = 99.9% R-Sq (adj) = 99.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1838.14	1838.14	4940.93	0.000
Error	5	1.86	0.37		
Total	6	1840.00			

The regression analysis shown above is a positive linear correlation. A unit increase in population results in 0.0025 increases in the available standing pipes. The R-sq and R-sq (adj) values of 99.9% indicates that 99.9% of the variation of the existing standing pipes data pertains to the population data. The p-value of 0.000 less than the a-level also indicates that year is statistically significant.
Ideally according to the national development population council, one borehole or standing pipe is needed to support a population of 400. Therefore a population of 34206 needs to have about 86 number of borehole in the community as at 2000 but that was not the case.

About 105 standing pipe facilities will support a population of 41939 but as at now the existing situation are 53 standing pipes to a population of 41939. This implies that the community has a backlog of 52 water facilities they will need in order to meet the population of the community. Therefore measures need to be put in place to provide the required number of water facilities to meet the water of the needs of the community.

Also the one hole of toilet facility is required to support 50 people ideally according to NDPC. Therefore population of 41739 is to be served by 94 toilet facilities but this is not so. The existing public toilet is six (6) with a backlog of 82 which they need additional eighty-eight (88) public toilet in order to meet their needs.

From the fitted line plot of available standing pipes, available public toilet, and the fitted line plot of required standing pipe and required public toilet, it can be observed that there is a big backlog of facilities that needs to be provided. To obtain the projected required facilities for a particular population, the population is calculated as:

Growth Rate (R) Equation

$R = 1/N \text{ In } (P/P_0)$.

Where

N = Number of years

P_0 = Initial Population

P = Population at a certain period of years

Projected Population (PP)

$PP = P(1+R)^n$

n=the difference between the two years.

Required Standing Pipe

Req SP = 0.014 + 0.002511 Population

Required Public Toilet

Req PT = - 8.557 + 0.001307 Population

From the mathematical models created the number of facilities for any population or at any specific year can be calculated. Also the cartographic model will also help locate the spatial location of the facilities. Furthermore the number of facilities for a particular plot can be specified. Figure 12 shows an example of the number of standing pipes that will be required for the Aboabo community in 2015 and 2020.The number of the standing pipes for a plot has also been shown by the attributes.

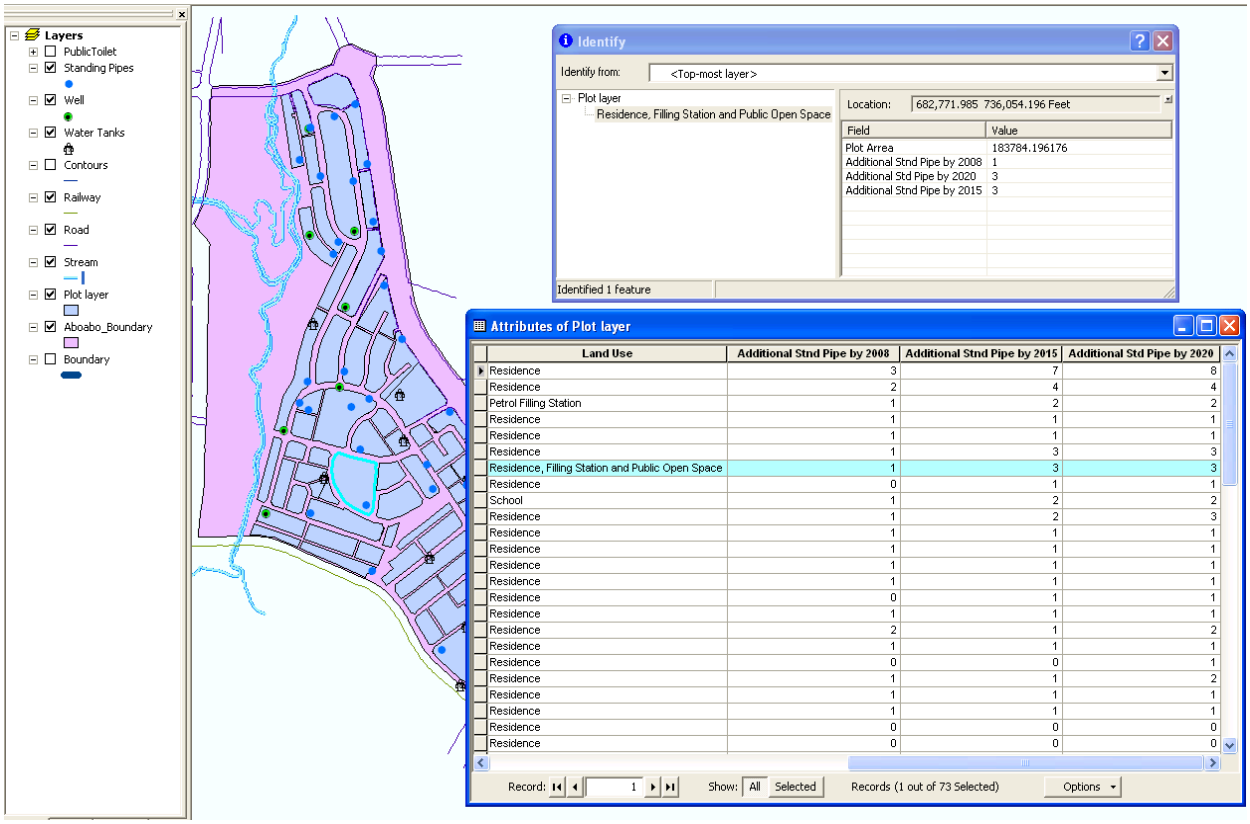

Figure 12: Locations and Attributes for various standing pipes at different years

Conclusion and Recommendations

The findings in this study show that population increase has no corresponding increase in the water and public toilet facilities consequently leading to poor quality of life of the citizenry as a whole. A model has been created to show the relationship between facilities and population and hence to estimate the number of public toilet and water facilities that a particular locality needs at a particular time with respect to its growing population. To meet the sanitation and water requirements of rapidly growing populations in order to improve the lives, condition and health of the poor it is recommended that:

- The landlords should be encouraged to build the toilet and water facilities in their houses to at least reduce the burden on the public once.
- The key to improved sanitation is a steady supply of clean water, appropriate technology, behavior change, and environment-friendly wastewater management strategies
- There is a need to strengthen the coordination and cooperation for the mobilization of both water and sanitation facilities and the wise use of such resources as well as to make increased effort to allocate more budgets for water resource management, sanitation and human settlements.
- Stricter measurements should be taken by the government to make sure that there is no haphazard building anywhere so that lands allocated for such facilities can be used appropriately.
- Government should collaborate with the chiefs, opinion leaders and those agencies in charge of land to seek their advice before selling land in order to check unauthorized sale of land.
- Residents should also consciously contribute to the maintenance of the facilities.
- The media should help publise the unhelpful effect of population increase on water and sanitation.

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