International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Predictive Logistic Modelling for Sustainable Portable Water Supply in Ghana

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Abstract: ***One of the primary goals of World Health Organization (WHO) and its member states is that all people, whatever their stage of development and their social and economic conditions should have the right to access adequate supply of safe drinking water. Water of course is essential for the survival of humans, animals and plants. A significant proportion of the world's population use potable water for drinking, cooking, personal and home hygiene. However, the quality and the quantity of fresh water supply is deteriorating globally as a result of rapid urbanization, population growth and industrialization. This paper seeks to focus on how to predict and supply portable water to every household in Ghana by 2050taking into account the water source at Weija and Bonsa in Greater Accra Region and Western Region respectively. A Mathematical model was formulated to estimate the required quantity of water needed to be produced based on the population density. In order to sustain its production, the developed model was used to predict the population of Ghana for the next 30 years using Logistic Growth Model. Results show that,in2010, when the actual population of Ghana was 25, 574, 719 million, the predicted population was 19,918,781 with a demand for water as 3452587065 and 2,689,035,435litres respectively.Thus, in 2030 it is predicted that the population of Ghana is expected to increase to 27,589,274 million with a domestic demand of 3,724,551,990 litres which indicates that as the population growth increases the demand for portable water increases exponentially hence affecting the quality of portable water to be supplied due to treatment cost. Thus, it is suggested that Government as well as stakeholders should continue to intensify the educational campaign against illegal mining activities along the water bodies in Ghana to save lives and minimise cost and constant supply of portable water.***

Keywords: Portable water, Weija, Bonsa, Galamsey, Logistic Growth Model, Population

1. Introduction

Water, a basic necessity of life constitutes approximately 75% of the earth landmass. Many have lived without food but none survived without water, thus water is life. One of the primary goals of World Health Organization (WHO) and its member states is that "all people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water" [1].Water is literally, the source of life on earth. It covers about two-thirds of the Earth's landmass. A significant proportion of the world's population use potable water for drinking, cooking, personal and home hygiene (Anon., 2004). Water is also used for irrigation.

It is estimated that 31 countries, accounting for fewer than 8% of the world's population face chronic fresh water shortage. The quality and the quantity of fresh water supply is deteriorating globally as a result of rapid urbanization coupled with population growth and industrialization. Moreover, there has been a growing concern and much public outcry with respect to the safety and aesthetic qualities of potable water supplies nationwide. High quality water is defined as water that contains no pathogenic organism and is free from biological forms. Thus, it is very clear and colourless, and has no objection regarding its taste and odor. However, portable water released into the distribution system becomes contaminated during its passage through pipes, open reservoirs, standpipes and storage tanks. Bacteria enter the distribution system through failure to disinfect water or maintenance of adequate disinfection residual, low pipeline water pressure, intermittent service, excessive network leakages, corrosion of parts, and inadequate sewage disposal.

Water supply is the process of self-provision or provision of water of various qualities to different users by third parties in the water industry commonly a public utility company. In Ghana about 88% of the urban population have access to at least basic drinking water. According to the Ghana Multiple Indicator Cluster Survey of 2011, urban dwellers are more likely to have access to safe drinking water than the rural dwellers at 91% and 69%, respectively. Consequently, dependency on unsafe water sources is higher in rural areas due to illegal mining activities along water bodies.

The share of non-functional supply systems in Ghana is estimated at almost one third, with many others operating substantially below designed capacity. Moreover, domestic water supply competes with a rising demand for water by the expanding industry and agriculture sectors. Studies have also revealed that 32% out of 2.5 million residents in the Northern part of Ghana lack access to improved water sources and often resort to contaminated drinking-water. Thus, in northern Ghana report indicates that, one in ten children die before their fifth birthday due to some water-related illnesses. According to WHO and UNICEF.[1], sources of water in Ghana were /are classified as improved and unimproved. The improved water sources include household with pipe-borne water, boreholes, protected dug wells and springs, and public standpipes whilst the unimproved water sources were identified as Rivers and ponds, unprotected Well, Vendor-provided water, Tanker truck water and Bottled and Sachet water

According to research findings, one quarter of the residents in Accra receive a continuous water supply and approximately 30% are provided water for 12 hours each day, for five days in a week. Another 35% are supplied for two days each week. The remaining 10% who mainly live on the outskirts of the capital are completely without access to pipe-borne water.[3] According to another source, the situation is even worse: In February 2008 some communities within the Accra-Tema metropolis were served either once in a week, once in a fortnight or once in a month.[20] The continuity of water supply in rural areas especially, the Northern part of Ghana are less frequent, and are forced to fetch their own water from a variety of water sources depending on location such as Tube wells or boreholes, protected dug, well Rainwater collection, Water tank truck, Cart with small tank and Surface water sources such as rivers, dams, lakes and ponds.[2]

However, the lack of clean drinking water supply is a severe public health concern since it contributes to 70% of diseases. In addition, widespread use of drinking sachets water due to lack of available potable water has also led to increased plastic pollution, often polluting water bodies, choking stormwater drains and causing death of livestock.[3] The country's gold mining industry has also polluted about 60% of Ghana's waters bodies. As a result of unclean water about 1,000 children under five years old in Ghana die each year from diarrhea, caused by polluted water. Consequently, households without access to clean water are forced to use less reliable and hygienic sources, and often pay more.[4]

1.1 Sources of Water in Ghana

Ghana is well endowed with water resources. The Volta Riverbasin system, consisting of the Oti, Daka, Pru, Sene, and Afram rivers as well as the White and Black Volta rivers, covers about 70% of the country area[5]. Another 22% parts of Ghana is covered by the southwestern river system watershed comprising the Bia, Tano, Ankobra, and Pra rivers. The coastal river system watershed, comprising the Ochi-Nawuka, Ochi Amissah, Ayensu, Densu and Tordzie rivers, covers the remaining 8% of Ghana. Most of these water bodies have been polluted by illegal mining activities, see figures 1and 2 [6].

Furthermore, if a plan, method, or system is sustainable, it can be continued at the same level of activity or pace without harming its efficiency and the people affected by it [7]. Therefore, the question ‘How would you supply water and sustain the water supply to every household in Ghana?[8] requires of us to look at the processes involved in the provision of clean useable water to every home in Ghana and the means to continue to maintain the provision of the portable water.

However, with most of our water bodies polluted, how would the agencies supply water and sustain the water supply to every household in Ghana in/ for the next 12 years?’ [9] Thus, this study is tasked to identify processes involved in the provision of clean useable water to every home in Ghana and its sustainability.

Figure 1: Galamsey threatening water supply in Ghana (W/R- GWCL)

Figure 2: Galamsey- Polluted PRA River (Citi news)

Figure 3: A source of water available for treatment (river Densu)

1.2 Access to water

Water is produced as a result of the chemical reaction between hydrogen and oxygen molecules. It is known that 75 percent of the earth's volume constitutes water and of the earth's 1360 million cubic meters of water, 97 percent is in the oceans. Three –quarters of the fresh water is in glaciers and icebergs, another fifth is ground water and less than 1 percent is in lakes and rivers. Almost two-thirds of the renewable freshwater provided by annual rainfall over land evaporates. Much of the rainfall transformed into runoff is lost to floods [10].Water is therefore abundant globally but scarce locally, [10].

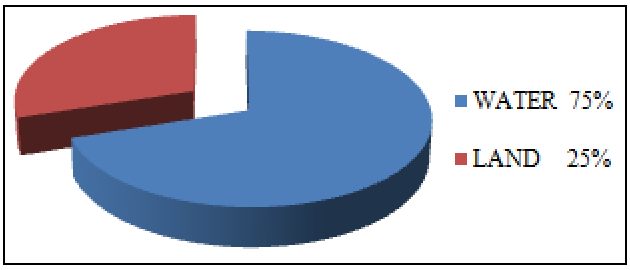

Figure 4: A chart showing the Percentage of the Universe Covered by Water and Land

Water is an important requirement in all spheres of human endeavors. It is a scientific fact that 70% of the human body consists of water. The 2003 world environmental Day was commemorated under the theme ''Water, vital resource for life'',[11] Indicating that the importance of water is widely acknowledged. It is important therefore that the distribution of water is undertaken in such a way that people are not denied access [12].

Historically, most towns and villages were established at the banks of rivers and lakes such that access to water was uninhibited hence water is life [13]. It is closely related to food, and is needed for personal, domestic and industrial uses and for raising crops and animals. Thus, availability of more water can improve food production and life standards. Many diseases abound in the developing countries because of the inadequate supplies of clean water, hence the need to supply and sustain the water supply to every household in Ghana [14].

An adequate supply of easily accessible clean portable water is a necessary condition for households to attain good quality life.

At the national level, it is observed that only 39.9% of households have access to pipe borne water supply. An additional 2% get supply from tankers that may come from any safe source including pipe borne water. The majority of Ghanaians have access to good and safe drinking water (defined as pipe borne water, tankers supply and borehole) [15].Data available from Ghana statistical service indicates that apart from Greater Accra and Ashanti, less than 10% of households living in the other regions have pipe borne water inside their houses. Wells and boreholes provide drinking water for about 32% of households in each region except Greater Accra [16]. Rivers, streams, ponds and lakes provide drinking water for a significant percentage of households living in the Western, Volta, Eastern, Brong- Ahafo and Northern region (Ghana Statistical service). Table 1, gives these statistics.

Table 1: Household Access to Drinking Water by Source by Regional Capital

Sources	Takoradi	Cape Coast	Accra	Ho	Koforidua	Kumasi	Sunyani	Tamale	Bolga-Tanga	Wa
Pipe-borne inside	32.8	51.1	43.6	35.1	51.2	48.8	46.3	41.5	30.7	16
Pipe-borne outside	57.8	46.9	47	46.8	30.9	33.7	39.6	46.9	39.1	37.4
Tanker supply	0.8	0.2	3.1	0.7	0.7	0.8	0.3	5.3	0.8	2.1
Well	6.3	0.8	4.4	11.9	12.8	11.5	7.2	2	10.5	21.2
Bore-hole	0.3	0.3	0.2	0.7	0.8	1.8	1.5	0.6	11.4	16.1
Spring/rain water	1.1	0.4	1	1.5	2	1	1.8	0.1	5.6	4.5
River/stream	0.3	0	0.1	1.1	0.9	1.5	2.6	0.3	0.7	1.4
Dugout	0.3	0.1	0.3	0.8	0.5	0.5	0.4	2.6	0.5	1.1
Other	0.4	0.2	0.3	1.4	0.2	0.3	0.3	0.8	0.7	0.2

2. Material and Methods

2.1 Study Area

The History of Weija

Weija water works started water production and distribution in 1928 with a total production of 400,000 gallons per day [18]. It has two branches, the plant treatment and the distribution /customer relation center.The treatment center is situated 100m above sea level. As a result of this high altitude Weija operates greatly under gravity in the distribution of water produced [19].

In 1953, a new treatment plant by name Candy Plant was installed with a production capacity of 5 million gallons per day. As the coverage area of Weija water supply increased, the Candy Plant capacity was inadequate to supply to its noble and cherished customers. So in 1963 another plant was installed called the Bamag plant which has a capacity of 5million gallons per day to support the Candy Plant.

By the installation of the Bamag plant, Weija was supplying water capacity of 10million gallons per day. The initial plant producing the 400,000 gallons of water per day was abandoned on the introduction of the Bamag and Candy Plants [20].

Bamag and Candy were rehabilitated in the mid 90's with an additional capacity of 5million gallons per day resulting in a total of 15 million gallons per day [20]. Due to good and prudent management of the water works, another plant was installed in 1983 called the Adan Clank Plant with a capacity of 15 million gallons per day. These gradual upgrading of the treatment plants was to enable the firm to supply portable and safe drinking water to the fast-growing population of its coverage area.

In 2002, 15 million gallons per day was added to the Adan Clank to boost its capacity from 15million gallons per day to 30 million gallons per day. In 2008 another 15 million gallons per day was added to raise the capacity to 45 million gallons per day.Currently, Weija water works produces an amount of 60 million gallons of water per day and supplies water to Accra West down to Winneba junction in the Central Region.

Weija Water Resource takes its source of water supply from the Densu River. It has to its credit a well-built Dam which stores more than enough water should the river dries off [21].

Weija water works as one of its objectives to give continuous safe water supply, gives an hourly monitoring to the water from the treatment plant.

2.2 Water Treatment

Water treatment is the most important part of the production process. The main objective of the treatment process is to remove the impurities in the raw water and bring the quality water to the required standards. The treatment process should be designed such that they should treat the water up to the desired standard for which it is to be used. The treatment process directly depends on the impurities present in the water. As such, the process varies from one treatment plant to the other. However, the general treatment process used for removing various types of impurities is given below.

Table 2: General Treatment Process for Removing Various Types of Impurities

S. No.	Impurity	Process used for removal
1	Floating matter as leaves, dead animals etc	Screening
2	Suspended particles such as silt, clay, sand etc	Plain sedimentation
3	Fine suspended matter	Sedimentation with coagulation
4	Micro-organisms and colloidal matter	Filtration
5	Dissolved gases, taste and odours	Aeration and chemical treatment
6	Softening	Permutation method
7	Pathogenic bacteria	Disinfection

It should be noted that the more polluted the raw water is, the higher the cost of treatment. Hence pollution controls requirements and measures should be considered when selecting the raw water source.

After complete treatment of water, it becomes necessary to distribute it to a number of houses, estates, industries and public places by means of a network of distribution system. The distribution system consists of pipes of various sizes, valves, meters, pumps, distribution reservoirs, hydrants, stand posts etc. the pipe lines carry the water to each and every street, road, and should convey the treated water up to the consumers with the same degree of purity.

2.2.1 Pre-Chlorination/Pre-liming

The colour, odour and taste in the water come due to presences of dissolved gases such as hydrogen, sulphide, organic matter, micro organism and contamination due to industrial waste. An effective way to deal with the odour and taste is the addition of chlorine. In the case where the alkalinity of the water is low, lime is added to prepare the water for the coagulation

2.2.2. Coagulation

In Ghana the most commonly used coagulant is Aluminum Sulphate ($AL_2(SO_4)_3.18H_20$). It is simply known as alum. Alum is dirty grey solid in the form of lumps containing about 17% Aluminium Sulphate. Alum reacts in water in the presence alkalinity (hence pre-liming is encouraged when natural alkalinity is not present). The following chemical reactions take place with the various types of alkalinity.

$Al_2(SO_4)_3.18H_20 + 3NaCO_3 \rightarrow 2Al(OH)_3 + 3Na_2SO_4 + 2C0_2 + 15H_20$

$Al_2(SO_4)_3.18H_20 + 8H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 18H_20$

$Al_2(SO_4)_3.18H_20 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 2CaSO_4 + 6CO_2 + 18H_20$

Figure 5: Lump size of Aluminium hydroxide ($Al(OH)_3$) (alum)

The insoluble and colloidal aluminium hydroxide ($Al(OH)_3$) form the floc which removes the fine suspended and colloidal impurities. Thus coagulation removes the colour of the water. For best result the pH value of water should be between 6.5 and 8.5. Other coagulant that could be used includes sodium aluminate ($Na_2Al_2O_4$), ferric coagulant, ($FeCl_3$, $Fe_2(SO_4)_3$), chlorinated copperas (a mixture of the two), ferrous sulphate and lime.

2.2.3 Flocculation

After thoroughly mixing of coagulants in the water the next operation is flocculation. Flocculators are slow stirring mechanisms which forms flocs. Flocculators mostly consist of paddles which are revolving at very slow speed. The paddles may revolve on vertical or horizontal shaft. The flocculators provide a number of gentle contacts between the flocculating particles which are necessary for the successful formation of floc.

2.2.4 Sedimentation

For the best results, flocculation is carried on for about 30-60 minutes. The water is then channeled to the sedimentation tank where the floc is allowed to settle at the base. The nature of the sedimentation tank also provides an avenue for the sunlight to reach the water hence disinfection takes place here.

Figure 6: A sieve fitted to the intake point

2.2.5 Filtration

This is the stage where the water is passed through a layer of fine sand and sometimes gravels. Sand usually meant for this purpose should have the under listed properties

- It must be obtain from hard clay, loam lime and organic matter etc.
- It should be free from clay, loam, lime and organic matter etc.
- It should be of uniform size and nature.
- It should be resistant and hard
- If placed in hydrochloric acid for 24 hrs, it should not lose more than 5% of its weight.

2.2.6 Chlorination

This is the addition of chlorine to water as a disinfectant. The following observations are seen while adding chlorine in water containing various impurities

a) When chlorine is added to water containing ammonia and organic nitrogen compounds, monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and tri-chloramine (NCl_3) are released.
b) When water is free from organic impurities, hypochlorous acid (HOCl), hypochlorite ion (OCl) are called "free available chlorine" in practice and are responsible for the disinfection of water.
c) If water contains sewage and waste waters, comples organic chloromine are released on the addition of chlorine.

Disinfection could also be carried out by

- By ultra violet rays
- By the use of iodine and bromine
- By the use of ozone
- By the use of excess lime
- By using potassium per manganate
- By treatment with silver or electro-katadyn process

2.2.7 pH Correction

This refers to the correction of the weak acid nature of the water after the addition of the alum. Also temporal hardness of the water is removed if the hardness is caused by $Ca(HCO_3)$ is used in the case where hardness is caused by $CaSO_4$.

2.3 Storage system

2.3.1 Purpose of Storage.

a) *Flow Requirements.*

Storage should meet peak flow requirements, equalize system pressures, and provide emergency water supply. The water supply system must provide flows of water sufficient in quantity to meet all points of demand in the distribution system. To do so, the source must produce the required quantity and quality, pressure levels within the distribution system must be high enough to provide suitable pressure, and water distribution mains must be large enough to carry these flows. It is usually inefficient and uneconomical to construct the treatment plant and pumping stations sufficiently large to meet the largest anticipated water demands. A water treatment plant is less efficient if flow rates through the plant are rapidly varied. Water storage facilities are constructed within a distribution network to meet the peak flow requirements exerted on the system and to provide emergency storage.

b) *Meeting peak flow requirements.*

Water supply systems must be designed to satisfy maximum anticipated water demands. The peak demands usually occur on hot, dry, sunny days when larger than normal amounts of water are used for watering lawns and washing vehicles and equipment. In addition, most industrial processes, especially those requiring supplies of cooling water, experience greater evaporation on hot days, thus requiring more water. The water treatment plant can operate at a relatively uniform rate throughout the day of maximum demand if enough storage is available to handle variations in water use. The necessary storage can be provided in elevated ground, or a combination of both types of storage.

2.4 Method of supplying water

The water can be supplied to the consumers by the following two system:

- **Continuous system.**

This is the best system and the water is supplied for all the twenty four hours. This system is possible when there is adequate quantity of water for supply. In this system sample water is always available for fire-fighting and due to continuous circulation water always remains fresh.

- **Intermittent system.**

If plenty of water is not available, the supply of water is divided into zones and each zone is supplied with water for the fixed hours in a day. As the water is supplied after intervals, it is called intermittent system.

2.5Layout of Distribution System

Generally, in practice there are four different systems of distribution which are used. Depending upon their layout and direction of supply, the common ones in Ghana are classified as follows

2.5.1 Dead end or tree-system:

In this system one may starts from service reservoir along the main road. Sub-mains are connected to the main in both the directions along other roads which meet the road. In the streets, lanes and other small roads which meet the roads carrying sub-mains, branches and minor distributors are laid and are connected to sub-mains. From these branches service connections are made to individual.

2.5.2 Grid iron system:

This system is also known as reticulated system and is most convenient for towns having rectangular layout of roads. Actually, this system is an improvement over dead-end system. All the dead ends are interconnected with each other and water circulates freely throughout the system.

2.6Application of Geographic Information System

Geographic information system (GIS) technology can be used for scientific investigations, resource management and development planning [22]. GIS is applicable in primarily government related town planning sectors, local authority and public utility management, environmental, resource management, engineering, business, marketing and distribution. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of natural disaster, GIS might be used to find wetlands that need protection from pollution. Town planners use GIS to keep track of property details of parcels of land, maintenance and of roads, drainage system, electrification and pipelines.

Present Problems Associated with Water Supply:
a) Outdated map information
b) Unread meters
c) Manual customer database
d) Illegal water consumption
e) Transmission losses.

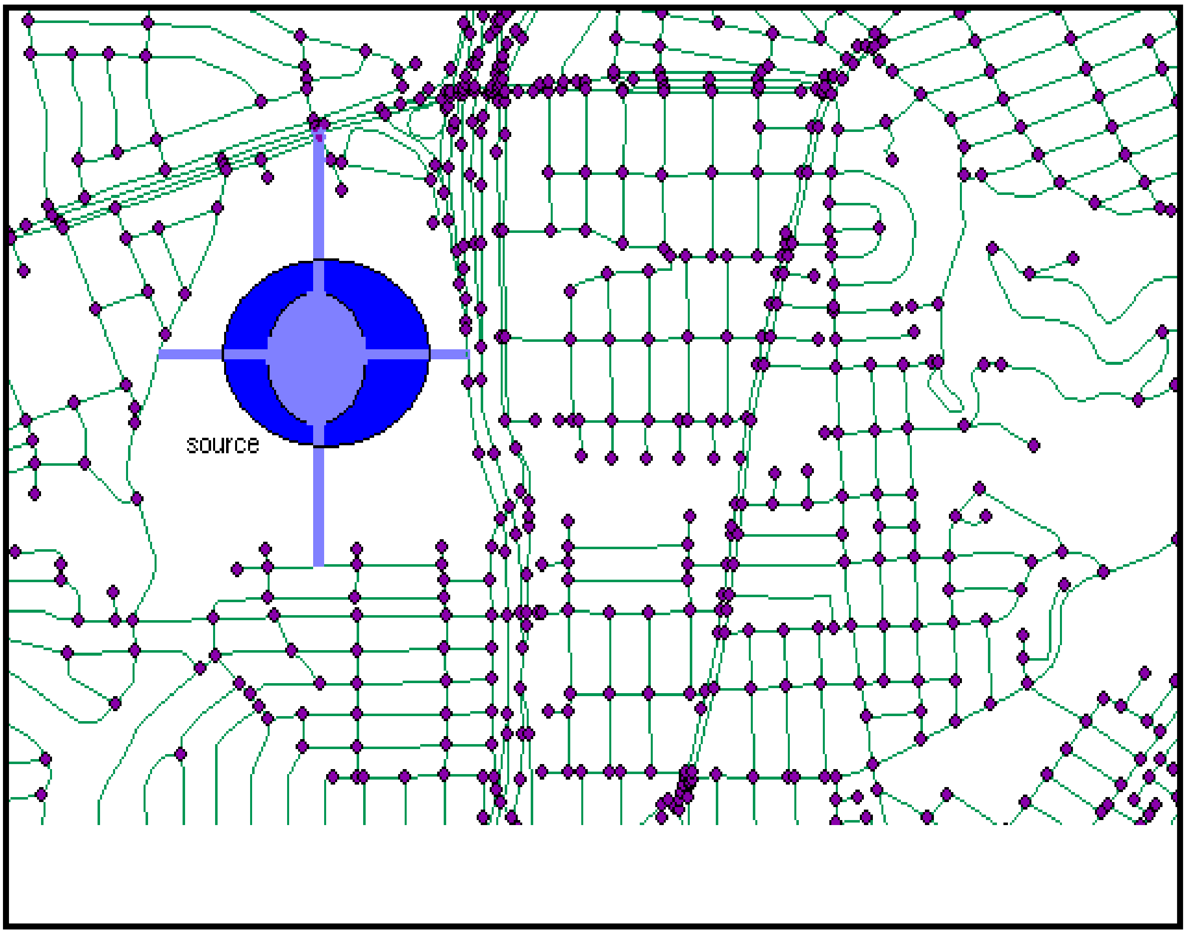

Figure 7: A proposed map of a GIS applications for Water Supply System.

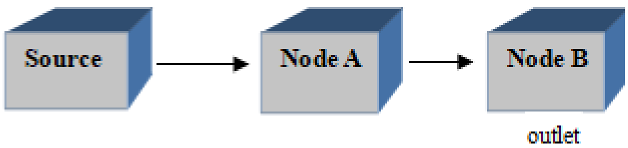

Figure 8: Diagram of Water Flow from a Source to Two Nodes

Figure 8, above is a section of a water supply from a source through a pipe to an outlet.At every node in the figure, information sending sensors are mounted in all the nodes to send information to the GIS system that is displayed on the screen as shown in figure 3.

With a simple code, these information sending sensors sends information such as;
1) The volume of water received
2) The pressure at which they are flowing
3) Other information such as (Ph, salinity, etc)

This is received by the GIS system. For instance, if Node B is expected to receive water at a total of 50pascal from Node A, but only receives 10pascal at a given time interval, information from these two nodes will be displayed on the screen for the necessary measures to be undertaken.

3. Mathematical Modelling

3.1 Population

The population of Ghana as captured by the 2000 Population and Housing Census was 18,912,079. In 1984 the population of Ghana was 12,205,574 yielding an annual inter-census average growth rate of 2.7 percent for 1984-2000, compared to the inter census population growth rates of 2.4 percent in 1960-1970 and 2.6 percent in 1970-1984. The population has increased from 24.7million recorded in 2010 constituting an annual intercensal growth of 2.1%. The intercensal period between 2000 and 2010 was 2.5% and is the lowest observed since independence according to GSS and between

2010 and 2021.Due to the emergence of COVID-19, the Census that had been planned for 2020 had to be conducted in 2021 and had a total population of 30,832,019 was recorded. In addition, it was observed that, the more rapidly increase in population, the much slower increase in rate of household formation. The total number of households has grown by 2.8million representing a 52% increase over the 5,467,136 households enumerated in2010. Household size declined by 0.8 from 4.4 in the 2010 census,a similar decline of 0.9 was observed between the 2010 and 2000 censuses. The 2010 PHC recorded 3.4structures for residentialuse, which is 2.5milloin less the 5.9 counted in 2021.

3.2 Implications for Housing Needs in Term of Number and Housing Typeand Water Demand

In designing the water supply scheme for a town or city, it is important to determine the total quantity of water required for various purposes by the city. As a matter offact, it is important for the engineer to determine the water demand of the town and then to find out the suitable water sources from where the demand can be met. There are so many factors involved in the demand of water, it is not possible to accurately determine the actual demand. The following are the various types of water demand of a town or city:

1) Domestic water demand
2) Commercial and Industrial demand
3) Fire demand
4) Demand for public uses
5) Compensate loss demand

Domestic Water Demand

Domestic water demand includes the quantity of water required in the houses for drinking, bathing, cooking, washing etc. The total consumption of this demand is generally about 55 to 60% of the total water supplied. The quantity of water required for domestic use mainly depends on the habits, social status, climatic conditions and customs of the people. It is assumed that, the average domestic consumption of water under normal condition is about 130 litres/day/person. A breakdown of this is given in the Table3.

Table 3: Breakdown of average water consumption per day per person

Domestic Water Demand	Consumption in litres /day/person
Drinking	5
Cooking	5
Bathing	55
Washing of clothes	20
Washing of utensils	10
Washing and cleaning of house and residence	10
Flushing of latrines etc.	30
Total	**135**

Source: GSS

3.3 Model Formulation

Let D_T be the total demand for water (that is D_T = domestic demand + other demands)

Let $P(t)$ be the population as a function of time t

Let S be the supply of portable water

Note: D_T is directly proportional to the population growth ($D_T = C \times P$) where C is a constant.

Domestic demand =Average demand per person per day × Population of a particular group.
Assume average demand per person per day for Ghana =130 litres, then the domestic demand is represented as Equation (1)

$$DD = 130 \times P \qquad (1)$$

Again, it is noted that S is directly proportional to D_T . This implies also that there can be three cases: the first scenario is a case where supply does not meet the demand hence under supply, the second case is where there is over supply, and lastly, when demand meets exactly up to the demands and in this case the constant of proportionality is one. Hence,this is represented as Equation (2)

$$S = rD \qquad (2)$$

3.3.1 Logistic Modelling

So long as the population available changes with time, the population available at any time t is given as Equation (3)

$$\frac{dP}{dt} = rP \qquad (3)$$

Where **P** is the population as a function of time **t**, and **r** is the growth rate. The solutions of this natural-growth equation have the form given as Equation (4)

$$P(t) = P_0 e^{rt} \qquad (4)$$

whereP_0 is the population at time$t = 0$or the initial population of a particular group of people. In short, unconstrained natural growth is exponential growth. Most populations are constrained by limitations of resources, birth rate, death rate etc. The following figure shows two possible causes of growth for a population, the green curve following an exponential (unconstrained) pattern. The blue curve is so constrained that the population is always less than some number K. When the population is *small* relative to K, the two patterns are virtually identical -- that is, the constraint doesn't make much difference. But, for the second population, as P becomes a significant fraction of K, the curves begin to move apart, and as P gets close to K, the growth *rate* drops to 0.

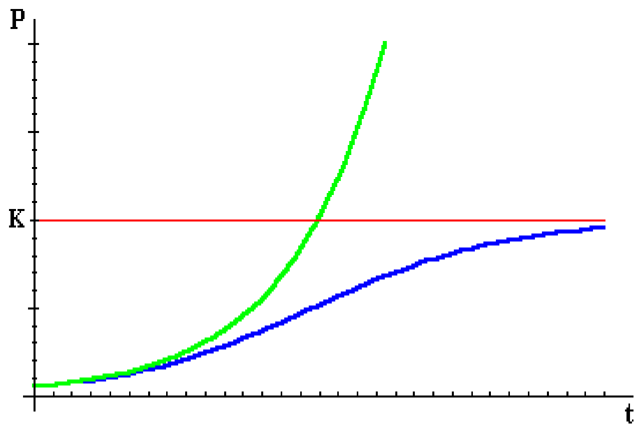

Figure 3: Population growth by Logistic

We may account for the growth rate declining to 0 by including in the model a factor of $1 - \frac{P}{K}$ which is close to 1 (i.e., has no effect) when P is much smaller than K, and which is close to 0 when P is close to K. The resulting model is then obtained as Equation (5),

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) \quad (5)$$

This differential equation given as Equation (5) has a solution of the form given as Equation (6)

$$P(t) = \frac{KP_0}{P_0 + (K - P_0)e^{-rt}} \quad (6)$$

where dP/dt is the population growth rate.

The Logistic Model Equation(5) can be written in the form as Equation (7)

$$\frac{dP/dt}{P} = rP\left(1 - \frac{P}{K}\right) \quad (7)$$

In the *proportional growth rate* (i.e. the ratio of $\frac{dP}{dt} = P$ is a *linear* function of P. Fit a line of the form $y = mx + b$ to the plotted points. The slope 'm' of the line must be $-r/K$ and the vertical intercept 'b' must be 'r'.

3.3.2 Estimation of the Population Size

Employing the works of P.F Verhulst, the solution of the logistic curve can be given in the form of Equation (8)

$$\log_e \frac{(Ps - P)}{(P)} - \log_e \frac{(Ps - P_0)}{(P_0)} = -kPs.t \quad (8)$$

where P_0 =the population of the town at point j
P_s = saturation population
$P(t)$ = population at time t
K = constant

Now solving for P, in Equation (8) one obtains Equation (9)

$$P(t) = \frac{Ps}{1 + M\,e^{-Nt}} \quad (9)$$

Mc Lean further suggested that if three pairs of the characteristic's values P0, P1 and P2 at times t_0,$t_1$and t_2 which are extending over the useful range of the population are so chosen that $t_0 = 0, t_1$ and $t_2 = 2t_1$ the saturation values Ps and constants m and n can be determined from the Equations (10) to (12)

$$Ps = \frac{2P_0P_1.P_2 - P_1^2(P_0 + P_2)}{P_0.P_2 - P_1^2} \quad (10)$$

$$M = \frac{P_S - P_0}{P_0} \quad (11)$$

$$N = \frac{2.3}{t1}\log_{10}\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)} \quad (12)$$

4. Analysis of Results and Discussions

From Table 5, we have 1960, giving$P_0 = 6726800$, at $t_0 = 0$, $P_1 = 8559313$at $t_1 = 10\ yrs$ and $P_2 = 1077927$ at $t_2 = 20\ yrs$, one obtains $P_S$by substituting P_0, P_1 andP_2 into Equation (13)

$$P_S = \frac{2P_0P_1.P_2 - P_1^2(P_0 + P_2)}{P_0.P_2 - P_1^2} = 57372507.5 \quad (13)$$

Applying same procedure M is obtained as Equation (14)

$$M = \frac{P_S - P_0}{P_0} = 7.528945041 \quad (14)$$

and N as Equation (15)

$$N = \frac{2.3}{t1}\log_{10}\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)} = -0.027746235 \quad (15)$$

Now substituting the values of Ps, M, and N into the equation (9) one obtains Equation (16)

$$P(t) = \frac{57372507.5}{1 + 7.528945041\,e^{-0.027746235\,t}} \quad (16)$$

For the year 2010, at $t = 50$, one obtains Equation (17)

$$P(t) = \frac{57372507.5}{1 + 7.528945041\ e^{-0.027746235 \times 50}} = 19918781 \quad (17)$$

The Domestic demand for water in 2010 is obtained as Equation (18)

$$\text{DD for 2010} = 135 \times 19918781 = 2689035435 \quad (18)$$

Using Equation 16, the population is predicted as shown in the Table 4.

In 2010, the predicted population at$t = 50$,was19,918,781 people. Hence the demand for water supply for domestic use was2,689,035,435and therefore this amount of portable and clean drinking water was required to be produced to satisfy the consumers.

For 2030, the predicted population would be 27,589,274 with a domestic demand of 3,724,551,990litres of water. Continuing in the same trend for the next ten years (2040), the demand is expected to increase to 4,260,432,337 with a corresponding population size of 31,558,758. For 2050, the predicted population is calculated at $t = 90$, hence, the estimated population size would be 35,420,148 and a demand of 4,781,719,980 see as shown in Table 4.

Table 4: Predicted Population of Ghana and Estimated Water Demand

Post Independent Years	Population of Ghanaians (million) Actual	Population of Ghanaians (million) Predicted	Portable Water Demanded (Litres) Predicted	Growth Rate%
1960	6911510	6726800	90811800	3.31
1970	8861895	8557042	1155200670	2.69
1980	11865246	10779273	1455201855	3.04
1990	15446982	13419955	1811693925	2.62
2000	19665502	1,64,78,753	2,22,46,31,655	2.55
2010	25574719	1,99,18,781	2,68,90,35,435	2.5
2020	32180401	2,36,61,421	3,19,42,91,835	2.09
2030	-	2,75,89,274	3,72,45,51,990.00	-
2040	-	3,15,58,757	4,26,04,32,337	-
2050	-	3,54,20,148	4,78,17,19,980	-

Source: United Nations World Population Prospects

5. Conclusion

This paper concludes that as the population of the catchment area of the Weija Water Dam grows at an astronomical rate, the demand for water increases. In2010, the population of Ghana was 25, 574, 719 million whilst the predicted population was19,918,781with a demand for water supply for domestic use as3452587065 and 2,689,035,435litres respectively.

Thus, for 2030 the predicted population is expected to be 27,589,274 with a domestic demand of 3,724,551,990litres. Continuing in the same trend for the next twenty years 2050,the estimated population size would be about 35,420,148 and a demand of 4,781,719,980litres of portable water would be needed, However, in the next 10years, the cost of treating portable water for domestic use would be very high due to the extent of pollution of the water bodies as a result of illegal mining activities along the rivers banks. It is obvious that, Weija and Bonsa water works would have to treat and supply more water in order to satisfy the people.

The paper suggest that more dams should be constructed, more storage systems and elevated tanks to sustain constant supply of portable water for the people of Ghana especially those at the catchment area of the WeijaWater Works in the Greater Accra and Bonsa in the Western Region.

Acknowledgement: The authors would like to appreciate the management of Bonsa, and Weija Water Works, and the Statistical Service Department for their contributions and generous support to the success of this paper.

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