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Performance Analyses of Water Distribution System Toward Water-Energy Nexus for Rural Area Transformation in West Africa: Case of Sekoukou Village in Niger

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Abstract: Water is the basic vital need of all living such as human being and environment species. Water demand is increasing day by day whether it is domestic, industrial and agricultural etc., but the source of water is limited. Recently, solar water pumping system is being used as a viable alternative to supply safe drinking water to the rural communities. So, the pumped water is afforded to the end-users through water distribution system. Therefore, the wrong sizing and installation of the water distribution network due to the lack of taking into account some parameters in the sizing of the system in order to supply water to the household at the right pressure and flow. This study aims to analyze the performance of the sekoukou village water distribution system toward water-energy nexus in rural area of Africa. Survey is conducted not only to assess the various water source available and accessibility for a safe drinking water within the sekoukou village but also the impact of the pressure losses to the remote hamlet to the storage source. Subsequently, the overall water distribution of the sekoukou village is analyzed using the Epanet software. To do so, first the characteristics of the water distribution network component are collected then the topographical survey of the area is conducted, and the quantification of the water consumed at the different hamlet tap. As a result, the study revealed that the water flow and the pressure are significantly affected by the topographical characteristic of the area the size of the pipe (length and diameter) as well as the height of the water storage tank. Thus, out of the 10 nodes 66.6% have pressure between 15 m to 22m while the node 2 has a pressure of 13.4 m. In contrast, the pressure at the node 10 is 7.15 (1 bar to 0.7 bar) m which is under the recommended minimum of 10 m (1bar), cause the slow water flow at the hamlet 4.

Keywords: Performance Analyses, Water-Energy Nexus, Water Distribution Network, Rural Area, West Africa, Niger

1. Introduction

Water supply in many developing countries is subject to diverse problems especially in Sub Saharan Africa. Arid and Semi-arid areas are particularly facing severe water scarcity due to rapid growing demand of water resources. Some of the challenges contributing towards inefficient and poor water supply have to do with population growth, inappropriate system design, and poor management of water supply facilities, low profile of operation and maintenance as well as insufficient and inefficient use of funds [1]. However, according to the World Health Organization (WHO) in 2017, 785 million people lack even a basic drinking-water service worldwide, including 144 million people who are dependent on surface water [2]. For instance, in Niger, according to the World Bank (WB) about 83.58% of the population are living in rural area in 2018 whereas only 10.84% have access to electricity and 58% have access to safe drinking water while the remaining 42% are supplying from the free water sources such as rivers, perennial streams, water ponds and unprotected wells which are susceptible to water borne diseases [3]. In addition, according to WHO, about 20% of child death in Niger is due to water-borne diseases every year [2].

Therefore, rural area demand of water for domestic use and crop irrigation supply are increasing. Meanwhile, in many arid countries, the average annual rainfall is shorting which lead to a scarcity of surface water. Nevertheless, groundwater seems to be the only alternative to this dilemma, but the groundwater table is also decreasing, that makes traditional hand pumping and bucketing difficult [4]. Water demand is increasing day by day whether it is domestic, industrial and agricultural etc., but the source of water is limited too. So, authorities around the world are faced with the problem of providing sufficient water from the limited water source.

Although, Niger has a huge potential of solar radiation whereas the major part of the population especially in rural area [3], are facing the problem of access to a safe drinking water. In order to tackle this issue, one of the most promising alternatives is solar water pumping system due to the high potential of solar radiation in Niger. Compared to the other traditional energy sources, solar photovoltaic pumping system is the most cost competitive for small-scale water pumping requirement for domestic and irrigation water demand. With the continuous increasing in fossil fuel cost and reduction in peak power (kilowatt) cost of solar cells because of mass production of PV systems, the photovoltaic power is becoming further economical in future [5]. To achieve the water-energy-nexus in a sustainable way a proper design of both solar pumping system and water distribution system is required. The Water distribution network (WDN) plays an important role in providing reliable water supply to the populations and end-users toward desirable life quality. Indeed, a well design WDN must supply water with sufficient quantity of water at the desired pressure and flow rate [6]. The pressure and the flow rate are the mains hydraulic parameters in WDN with depend of the other relevant factors design such as the pipe diameter, the velocity as well as the hydraulic gradient [7]. And upgrading it, is necessary for the reliability of the water supply [8]. However, its planning, should also be taken into account by using many factors such as location, current demand, future growth, pipe sizes, head loss, firefighting, leakages, etc., using pipe network analysis and other tool.

Traditional and obsolete methods of designing, operating and maintaining water distribution networks are to be replaced with accurate, speedy and computer-based software methods [9]. Recently, researchers have shown a growing interest in investigating the water distribution system (WDS). To compute the water flow in the WDS, many models such as graphical, physical analogies and mathematical models are being used. And to optimize the WDN's analysis, many methods have been done and used using both iterative and simulation software in recent years.

Hardy C. [10] had had published one of the first iterative methods in 1936 known as Hardy Cross methods Technique to resolve the problem of distribution of flow in networks of pipes. This method is the first and probably the most widely used method of water distribution network analysis [10]. The major drawback of this approach is the limitation in the changing pattern of the water demand and it converges very slowly or not at all [6]. Hence software-based simulation is being used to analyze both solar PV pumping system and the WDN.

Designing the water distribution of a given geometry and topology network, need to know some input parameters of components (e.g., flow rate and pressure) that made up the system [11]. Also, Martins and Peters [12] introduced the Newton-Raphson iteration method to solve water distribution system problems. This method had much improved convergence characteristics and forms the basis for more general applications [13]. Williams et al. [14] have also discussed in details the enhancement of convergence of pipe network analysis. Furthermore, engineers use many computers software for simulating water distribution network systems such as WASDIMP, WASDIMPRO, LOOP, EPANET etc, nowadays. Mehta et al. [15] have investigated the water scarcity problem in the Limbayat zone (Surat city, Ethiopia) to investigate the performance and quality of water which are supply to the consumers. The results showed that some leakages in the network are the main reason of the scarcity due to pressure fluctuation. Kolpe and Vaidya [16] have conducted an experimental analysis of water distribution network and its hydraulic simulation using Epanet software in Chirala municipality (India). The reliability on the network for the future has been investigated by doing a comparison between the loop Hardy Cross method and Epanet software. The results revealed that the experimental analysis by Hardy Cross method is similar for five cases of different source head, the discharge through pipes decreases by 19% as the source head decreases by 22%. And the pressure at each node decreases by 67% as the source head decreases by 22%.

For instance, in the sekoukou village, there is a lack of supplying the right flow rate of the water to some hamlet, a schedule of the accessibility of the water from the tap is not possible to the whole village at the same time. Thus, the furthest hamlet of the village could only get water from their tap in the night while the remaining are off. Therefore, the aim of this study is to evaluate the performance of the overall water distribution system from the storage tank to the various tap of the village using a software-based simulation to overcome the challenges of water accessibility in the village as a whole. This paper is structured as follows: Section 2 presents the methodology of the study; Section 3 describes the results and discussion and Section provides the conclusion of the study.

2. Methodology

2.1. Description of the Study Area

This study has been conducted at the village of sekoukou which is located in the department of kollo, in the eastern part of Tillaberi region (Niger). Situated at about 40km of the capital of Niger (namely Niamey), the village of sekoukou is geographically in southern-east of Niamey on the latitude and longitude of 13°16’25.49” N, 2°22’0.66” E. It has a total inhabitants and household of respectively 467 people and 64 households (INS, 2012). Agriculture is the main activity of the populations. A detail description of the village of sekoukou is given in Mounkaila et al. [17].

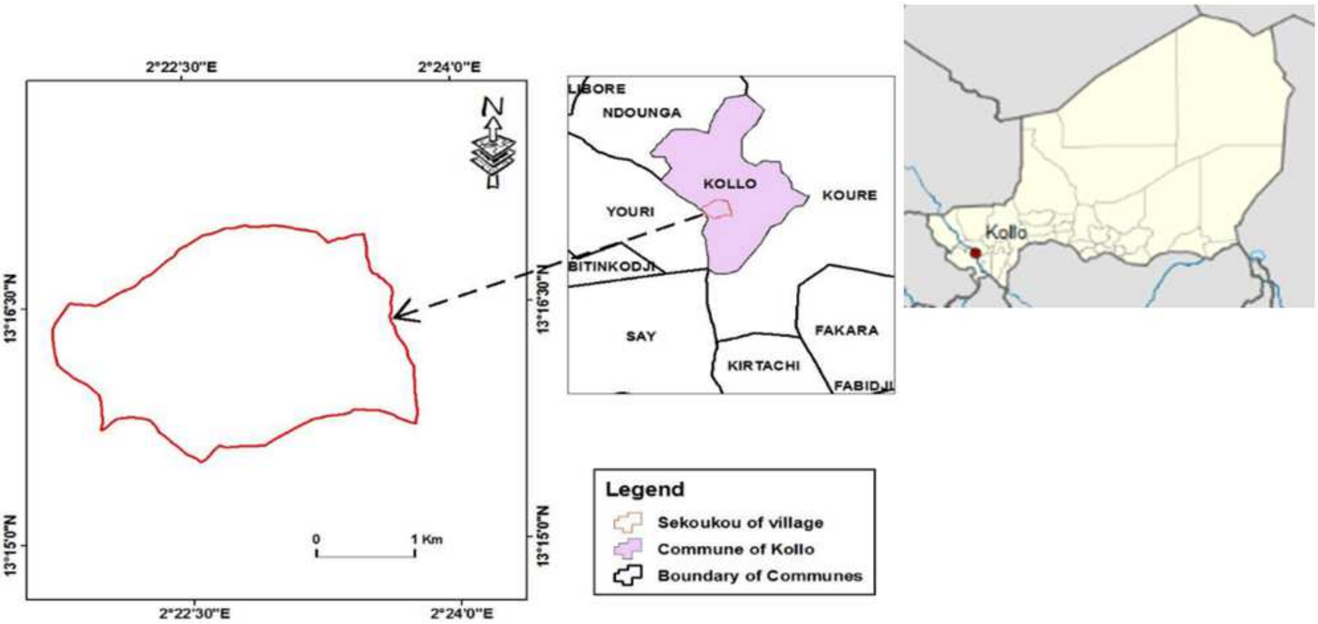

Figure 1. Map showing the location of the sekoukou’s village (adapted from [18].

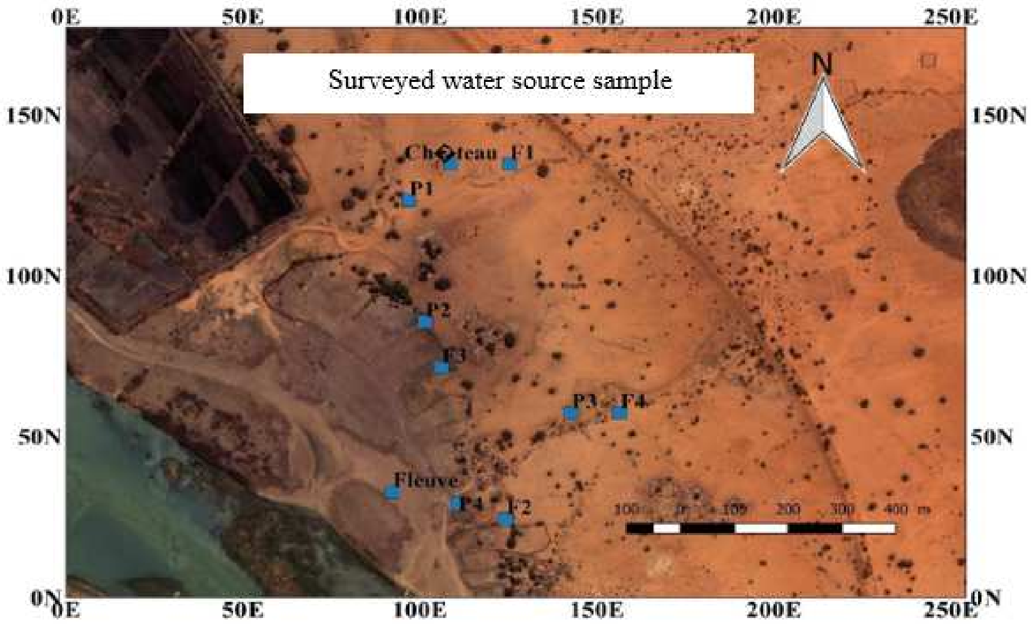

Figure 2. The position/location of the water sampling points for the village of sekoukou [18].

2.2. Sekoukou Village’s Water Distribution System

In the village of sekoukou, before the solar PV pumping installation, the inhabitants have been supplied their drinking water from open well, hand-pumping well and the river of Niger. As a result, they have been reached by water borne-disease such as diarrhea, cholera, etc. Indeed, Hassane and Rabani [19] have conducted a quality analysis of the drinking water in the village from the various sources to analyze the parameters such as alkalinity (carbonate and hydrogen carbonate ions), hardness (calcium and magnesium ions), chloride ions, germs and escherichia Coli, temperature, pH, conductivity, dissolved oxygen, turbidity and salinity using sterilized polypropylene for the storage of the samples for chemical and bacteriological analyses in the laboratory [18]. They have confirmed the pollution of all the drinking water resources (which are a water storage tank, the river, four wells (P1, P2, P3, and P4) and four boreholes (F1, F2, F3, and F4)) used by the populations in the village were sampled (Figure 1.). The sampling points for the drinking water are identified by the blue dots on Figure 2.

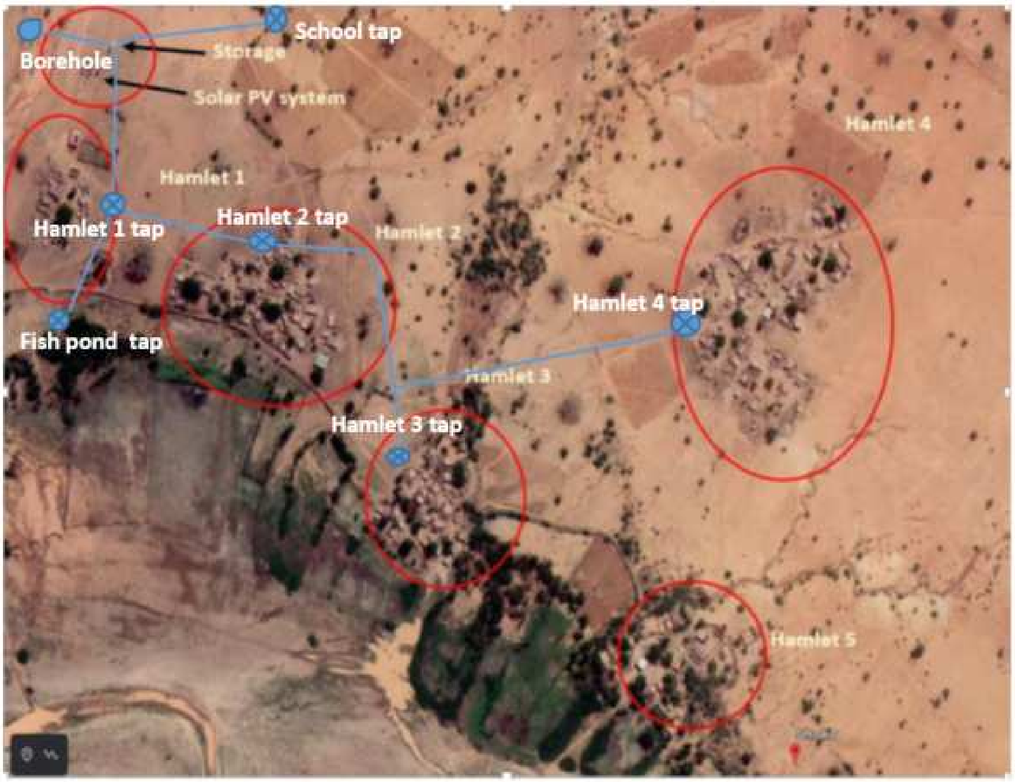

Figure 3. *Satellite picture of the different hamlets of the sekoukou's village.*

To overcome the challenges of water borne-disease, a solar PV pumping system is installed in the village of sekoukou within the framework of the West African Center for Sustainable Rural Transformation (WAC-SRT) of WASCAL Graduate Studies Program. The study area has been chosen as demonstration site for the Integrated Master Program for Sustainable Rural Transformation (IMP-SRT) of WASCAL. The solar PV pumping system has been setup to ensure safe drinking water for the populations in the village. It uses ground water supply for domestic use and irrigation. Thus, this study seeks to analyze the sustainability of the water-energy nexus using solar PV for pumping water to match the water supply-demand for domestic use and irrigation. Therefore, this study seeks to evaluate the performance of the water distribution network of the village of sekoukou toward water-energy nexus for sustainable rural area transformation. Based on the variability of water demand for domestic use and irrigation, this study will also undertake some scenarios on sustainability of the systems based on the population growth and seasonal variation of the demand.

Three methods of water distribution, namely the gravity distribution, the distribution by pumping without storage and the distribution by means of pumps with storage, exist according to Shaher et al. [20]. Throughout, the water distribution system occur energy losses caused by friction and local losses respectively due to the water flowing at different velocity in the piping and to the fitting of the component that made up the system [20]. The WDN of the sekoukou's village is consisting of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs, which transport water resources to the consumers in different hamlet. The gravity water distribution system is used in the village and the network is dead end system where the water supply to the users will not always be reliable to the upcoming years. Hence, this study in investigating the reliability of the WDN for the future within the time life of the solar PV pumping system. The analysis will be carried out based on various public demands, quantity of the inflow and outflows of the over-head reservoirs, availability of other water sources regarding seasonal variation. This analysis will provide information about various demand, losses, and the sustainability of the system components. The design is made keeping in view of the population growth rate, the off-season, micro-irrigation system water demand in the village. The design will bring out improvement in the existing network.

The sekoukou's village is made up with five (5) hamlets (Figure 3) each equipped with public taps except the fifth which supply water from the third hamlet and from the Niger river in the rainy season.

2.2.1. Data Collection and Analysis Methods

In this study, a socio-economic data is collected through survey using Kobo toolbox. The different water source supply is evaluated in order to find out the rate of water satisfaction from various hamlets of the village. The water consumption data of the different hamlets is collected from the flow meter to know whether the water need is covered.

Moreover, to analyse the performance of the water distribution system of the village the characteristics of the component that made up the system is sorted and the topographical survey of the area.

2.2.2. Water Distribution System Analysis Methods

A field visit was carried out to appreciate the water supply flow and pressure from the different hamlet of the sekoukou's village. Then, the water source such as the storage tank, the flow meter and the pipe of the system is surveyed. The theodolite and GPS are respectively used. The elevation of the area and the geographical coordinate are measured. The figure 4 gives an overview of the water distribution of the sekoukou's village and some of the tools used for data collection.

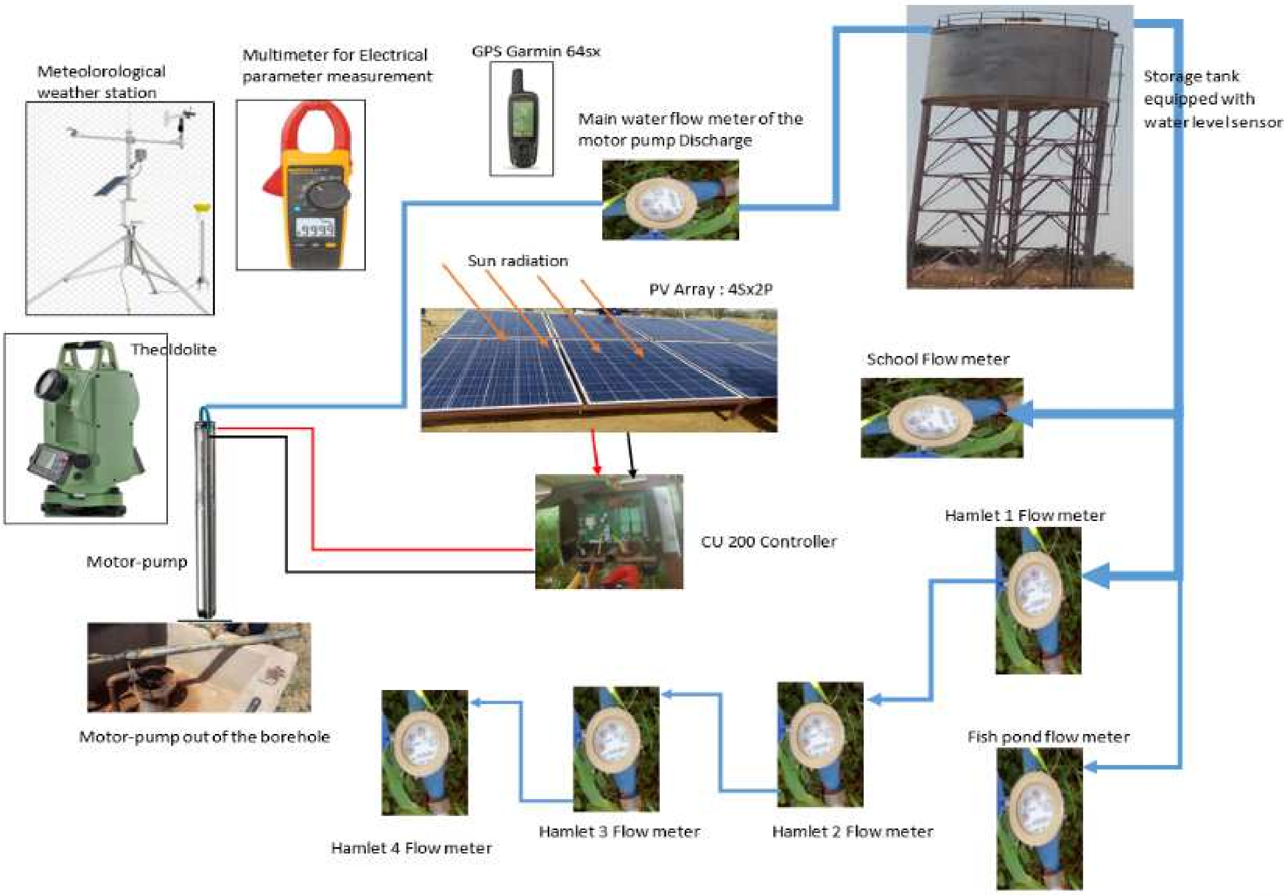

Figure 4. *Overview of the sekoukou's village water distribution system.*

The water distribution system is analysed using Epanet software. Epanet is a computer-based software program developed by the US environmental protection agency's national risk management research laboratory that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. The network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. Epanet tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species along the distribution network. In addition, simulation of the chemical species, water age and source tracing can also be performed [15]. The input data file needed to analyse the WDN are mainly at a junction (elevation, the water demand, initial water quality) and also data of the pipe (start and end nodes, the diameter of the pipe, the length, roughness coefficient and the status of the pipe whether open, closed or contains a check valve). The methodology used for the WDN using Epanet is summarize in the following steps:

Step 1: Draw a network representation of the system's distribution or import of a basic description of the network placed in a text file.

Step 2: Then the WDN components properties that make up the system. It includes editing the properties and entering required data in various objects like reservoir, pipes, nodes and junctions.

Step 3: Describe how the system is operated.

Step 4: Select a set of analysis option.

Step 5: Run a hydraulic/water quality analysis.

Step 6: The output result of the simulation can be view in tables or graphs.

Subsequently, the output of the WDN are the hydraulic head, the pressure, water quality, the water flow rate, the velocity, the headloss, etc.

3. Results and Discussion

3.1. Socio-Economic Survey Outcome

The survey undertaken was carried out in the month of August, Hence, 47 household chiefs out of the 87 have been interviewed. The chart below shows the rate of water access regarding the various water sources in sekoukou's village and the time spent for fetching water as well as the household ownership of water tap.

It can be seen from the figure 5, the chart (A) gives the rate of satisfaction for water from the solar pumping system regarding households in each hamlet. The chart (A) shows a higher decrease of the rate of water supply from the public tap as the solar pumping system is being far away from the hamlets. It is worth to notice that the rate of water access in the first hamlet in about 100% while in the fifth hamlet it is about 15%. The reasons are respectively the higher water pressure in the first hamlet meanwhile the fifth hamlet does not have tap and are supplied seldomly from the hamlet three. Therefore, according to the inhabitant surveyed in the hamlet fifth they supply mostly in the rainy season from the river which is nearby. The chart bar (B) indicates the rate of water supply from the various water sources that made up the sekoukou village. Before installation of the solar pumping system, households supply their water mainly from the Niger River, open well and hand pumping borehole. Since the implementation of the solar pumping system, the community water is provided from the public taps installed in the village. Afterwards, the water supply from the solar PV system has rapidly increased up to 72.8% to avoid the water borne diseases caused by previous from sources.

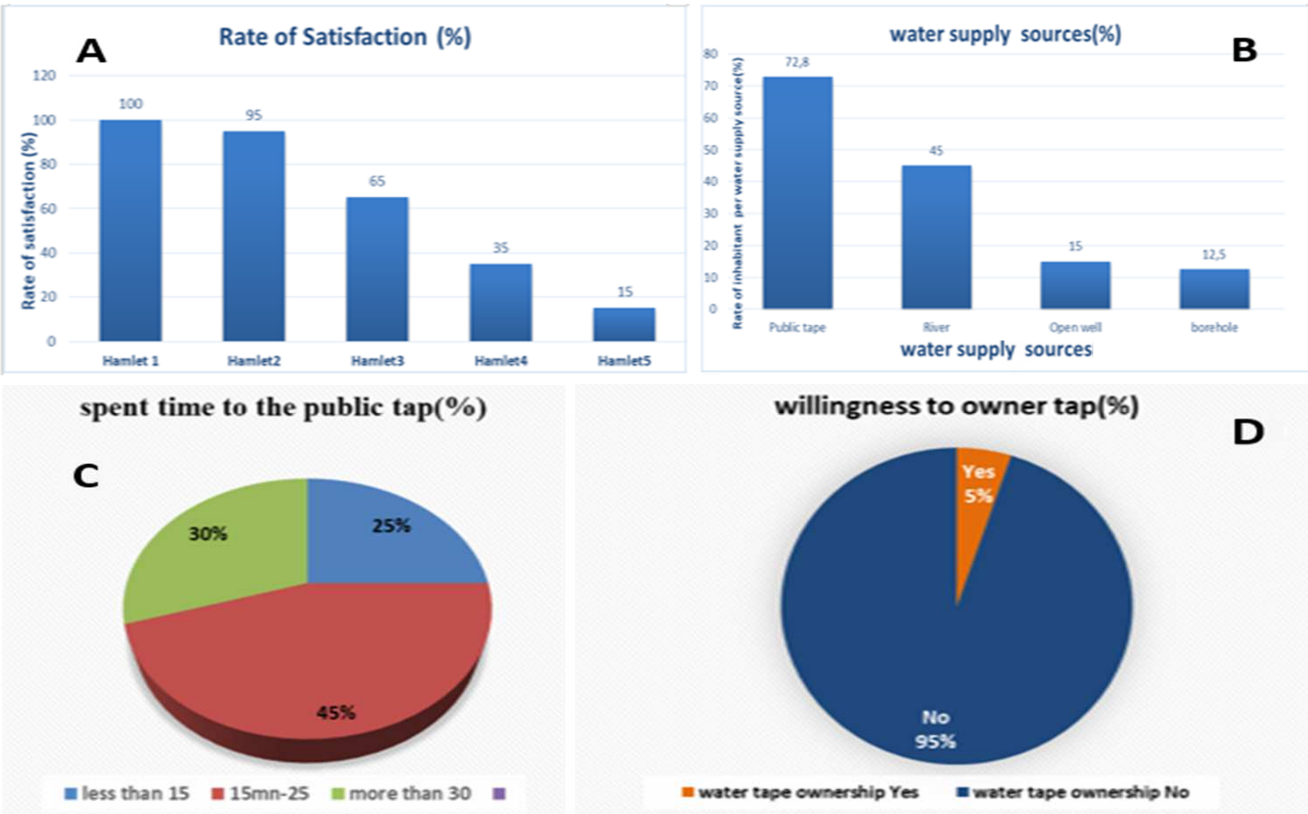

Figure 5. *The outcome of the survey:(A) rate of satisfaction of public tap; (B) rate of various water source used (C); spent time to supply from public tap (D) willingness to owner tap.*

The pie chart (C) and (D) give the time spent to supply water from the public taps and the willingness to own household tap connection, respectively. The time spent to fetch water depends on the distance of the public taps to the household, the pressure of water flow from the tap as well as the water demand from each tap. The pie chart (C) shows nearly half of the inhabitants fetch water in less than 15 minutes, those are mostly from the hamlet 1 and 2. However, the supply between 15 to 25 minutes and more than 30 mn are respectively 30% and 25% coming mainly from the hamlets 3, 4 and 5. This is due to the very low water flow from hamlet 4, the distance of the public water tape from the hamlet 5 and the increase water demand from the hamlet 3.

3.2. State of Water Consumption

The village of sekoukou has access to other water sources, such as the river which is the main water source of the country (only few meters depending on the hamlets). So, animal's water consumption is from the river, pond, open well and borehole to ensure sustainability of access of water for domestic needs and garden vegetables grow. The figure 6 gives the water consumed per Hamlet since the installation of the system up to 21 august 2020.

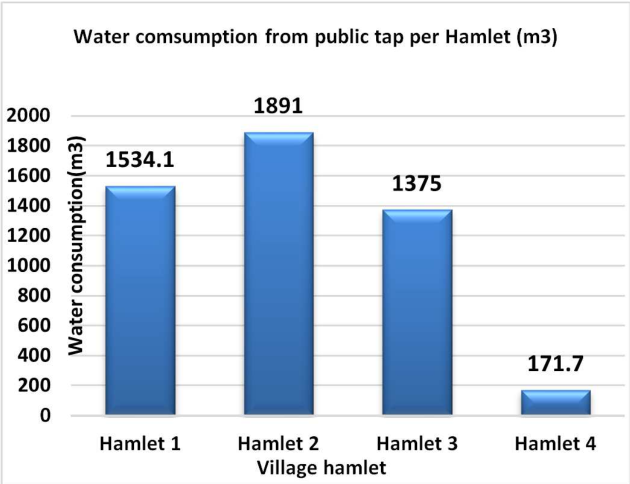

Figure 6. Per Hamlet water consumption from the public taps in the village of sekoukou.

Rural water demand varies based on the seasonal variation. For example, in the sekoukou village during the rainy and cold season (when the river bed is rising) most of the inhabitant used water from the river for washing and other usage, except for drinking and cooking. While in the hot season, the demand is very higher and in that period the pump discharge is also very higher due to increasing of solar radiation. The pumped water is stored in the water tank at about 10 meters from surface, then it is distributed to the different hamlets using gravitation through the water distribution network. The sekoukou village water demand is mainly for domestic use, non-domestic use and for irrigation purpose. In this case, the pumped water is intended mainly for domestic water use.

Therefore, the objective of the sekoukou's village water distribution system is to supply sufficient quantity of water for each end-user (Hamlets) at the required pressure and flow. Generally, this function of the water distribution system is failed not only to the improperly design of the system but also the increasing water demand due to the population growth that has not been taking into account within the time life of the system. For instance, the survey carried out revealed that the pressure at hamlet 4 is very low in the village compared to the minimal standard of 10m (1bar) and end-users spend about at least 15 minutes to fill in 20 liters of jerrycan.

3.3. The Topographical Survey of the Village of Sekoukou

In water distribution network implementation project, the topographical survey is one of the first task that should be carried out in order to know with precision the elevation of the area. The figure 7 shows the elevation contour map of the study area. As shown in the figure 7, the evaluation of area varies generally from 184.5 m to 174 m above the sea level. Based on the elevation contour map, there are five different elevation zones. The lowest elevation zone is located in the third hamlet in between 174.5 to 176.5 m elevation. Where, the elevation decreased at about 5.67% (10.5 m) compare to the average altitude of the area. While the highest altitude of the area is situated in the fourth hamlet about 184.5 m, this significant variation of the surface elevation in the sekoukou village could lead to an inequality in services provision and rise the pressure loss throughout the distribution network.

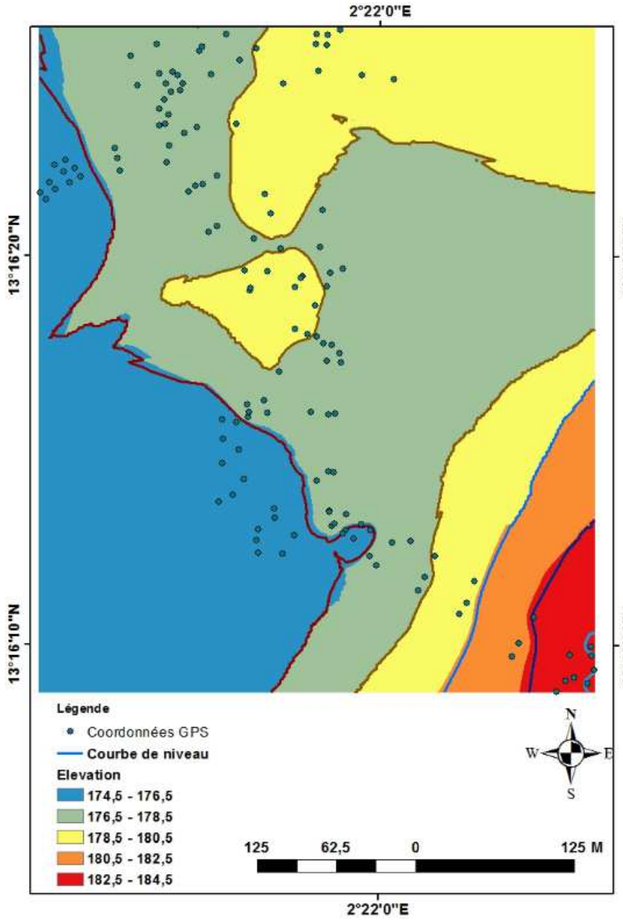

Figure 7. Elevation contour map of the village of sekoukou.

3.4. The Topographical Survey of the Water Distribution Network

The water distribution analysis required thorough survey of the network. The survey of the distribution network has allowed not only to identify the various characteristics of the different component such as the type of pipe, length, diameters, numbers of junctions, the elevation of each node, etc. but also the water demand from each tap and the perceptions of the end-users regarding the water flow rate and pressure. The figure 8 shows the topographical profile of the water distribution network, the hydraulic gradient losses (HGL) throughout the piping system, and the pressure zone of the system in reference to the elevation of the water outlet from the storage tank.

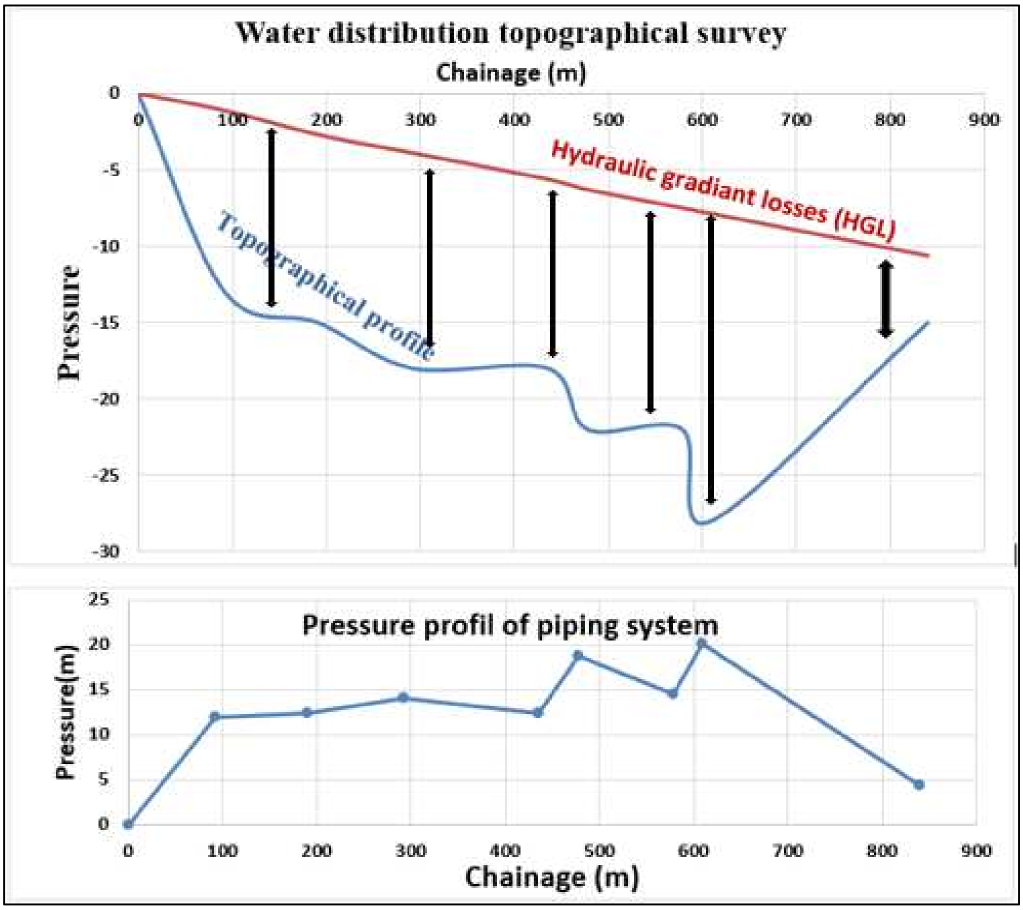

Figure 8. *The hydraulic gradient losses and the topographical survey of the sekoukou's village water distribution network.*

In the current study, water is delivered using gravity distributions system, so the storage tank is considered as the datum (reference elevation level) of the system rather than the motor-pump level in the borehole. The red graph of the figure 4.14 shows that the Hydraulic gradient loss HGL or (Energy grade line) is dropping in the direction of the flow as the network is moving away from the storage tank. Thus, the hydraulic gradient loss is less than 5m around the first hamlet which is about 34.75% pipeline length out of the 840 m of pipe installed and between 5.6 m to 7.87 m for the second and third hamlet. This represents 37.7% of the total system. Moreover, the hydraulic gradient loss is more than 10m in the fourth hamlet. As a result, the energy grade line or HGL loss due to frictional and local losses during the water flow in the system influences the delivery pressure service, which is the hydraulic gradient loss minus the elevation of the ground level in reference to the datum. According to the figure 8, 75% of the points surveyed have pressure (in between 11 to 15 m) (1.1 to 1.5 bar) that are in agreement to the standard pressure in between (10 to 30m) or (1 to 3 bar) while the highest-pressure zone is at about 20m.

On the other hand, the lowest pressure zone is less than 5m located at the hamlet fourth. Therefore, the topographical characteristics, the friction and the local water losses through the pipe affect the pressure service at the taps.

3.5. The Water Distribution Network Layout Using Epanet Model

The sekoukou's village water distribution network simulation has been performed by Epanet model using steady state analysis. Input data for junction and link have been used to conduct the simulation such as the elevation of the junction, the water demand of the junction the pipe diameter and length to get as output the pressure at the junction, the velocity along the pipeline and the head-loss. The table 1 summarizes the characteristic of the pipe used in the network.

Table 1. *Sekoukou network pipe characteristic.*

Pipe start-end node	Pipe type	Diamter (m)	Length (m)
Storage tank-school node	PVC	32	91.44
Tank-tape Hamlet 1	PVC	63	98.75
Tape H1- Fish pond tape	PVC	32	102
Tape H1-tape H2	PVC	63	144
Tape H2-H3	PVC	32	149.35
Tape H3- H4	PVC	32	251.46

In order to cover the water demand for all nodes, the base water demand assigned to each node is considered to be 0.3l/s using the current while the pressure should be between the recommended limit of 10 m to 30 m in rural area. The figure 9 represents the network layout of the sekoukou village.

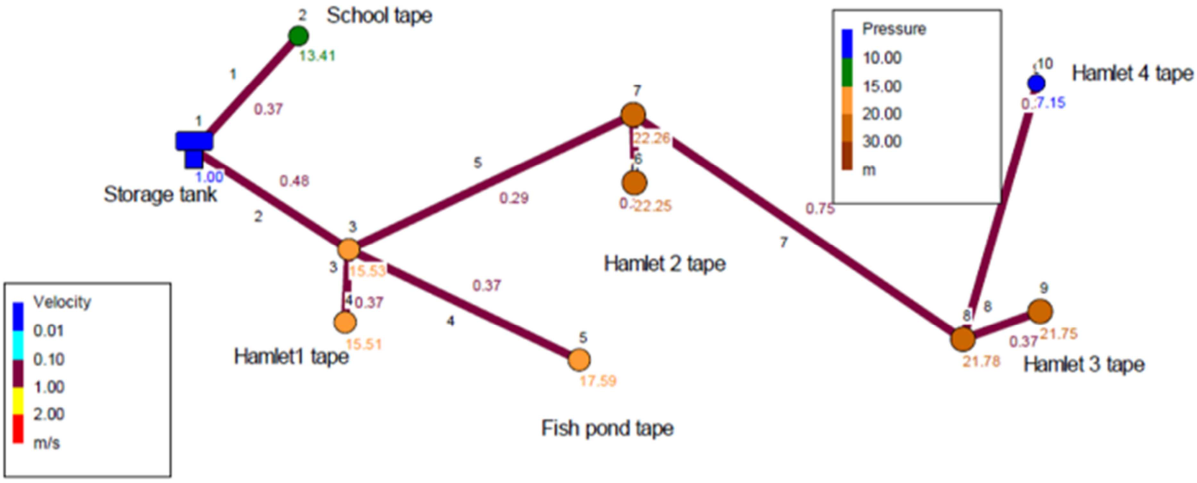

Figure 9. *The water distribution network layout of sekoukou.*

At about 71% of the total polyvinyl of chloride (PVC) pipe installed has a diameter of 32mm while the 29% only has 63 mm diameter (see table 1). The legend of the figure 8 show clearly that out of the 9 nodes that made the system, 8 nodes have a pressure which respects the recommended limit. Furthermore, among those nodes, four (4) have pressure less than 20m while the remaining four have average pressure of 22 m.

Indeed, the pressure at the hamlet 4 is under the required recommended value which is at 7.15m. The latter pressure below the minimum will not afford sufficient amount of water to the consumer at the corresponding public tap. Totsuka et al. [21] have showed that those consumers furthest away from supply points will always collect less water than those nearer to the source due to pressure losses increasing in the network. Thus, nodes with lower pressure are located at higher elevation such as the node 10 of the hamlet 4 and node with higher pressure are located at lower elevation as given in the table 2 below. In a similar study, Hailu Gisha [22] has also find out the same pressure variation of the Bodditi Town water distribution analysis using Epanet. Thus, the nodes with lower pressures are located at higher elevations and also far away from the storage tank while the higher-pressure nodes are located at lower elevation or and closer to the storage. The results of hamlet 4 are similar to Wiwik et al. [23] who have found that an additional discharge is required to increase the pressure and velocity to fulfil the standards of water availability in the WDS.

Table 2. *The model output at different junctions.*

Node ID	Elevation (m)	Demand LPS	Head (m)	Pressure (m)
Tank junction1	0	-1.8	1	1
junction2	-13	0.3	0.41	13.41
junction3	-15	0.0	0.53	15.53
junction4	-15	0.3	0.51	15.51
junction5	-18	0.3	-0.41	17.59
junction6	-22	0.3	0.25	22.25
junction7	-22	0.0	0.26	22.26
junction8	-25	0.0	-3.22	21.78
junction9	-25	0.3	-3.25	21.78
junction10	-12	0.3	-4.85	7.15

The water velocity along the piping system of the sekoukou villages's water distribution network (figure 8) is in agreement with the limit recommended except in the pipe 7 (0.75 m/s) where the water velocity is excessive and the pipe 5 (0.29 m/s) which has less than the minimum velocity of 0.3m/s (see in the table 3 below). As in the study of E Kurniati [24] on the analysis of clean water distribution system using Epanet at the Uma Sima Village of Sumbawa Regency, it has been noticed that the lowest water velocity is due to the flat topography of the area while it became higher when closer to the storage tank and for a smaller pipe diameter. Although, the required water and pressure flow will be in accordance to the regulation until the lifetime of the system regarding the increase population water demand.

Consequently, excessive water velocity creates water hammer and higher head-loss in the network which brings pressure reduction at the tap. Hence, in order to prevent sediment accumulation in the water distribution system, an average velocity is required along the pipeline for raison of self-cleaning of the network.

Table 3. *Simulation result of the water flow along the distribution network.*

Link	Length (m)	Diameter (mm)	Flow (LPS)
Pipe 1	92	32	0.3
Pipe 2	101	63	1.5
Pipe 3	3	32	0.3
Pipe 4	144	32	0.3
Pipe 5	143	63	0.9
Pipe 6	3	32	0.3
Pipe 7	149.35	32	0.6
Pipe 8	5	32	0.3
Pipe 9	251.46	32	0.3

Table 4 indicates the simulations results of the water distribution system. The unit head-loss recorded is at about 66% equal to 6.46 m/km while, in the pipe 7, the unit head_loss is significantly higher at about 23.33 m/km. As the head_loss is due to friction and local loss (fitting), so more the velocity is higher, higher will be those losses. The water velocity in the pipe 7 that increases the unit head_loss can be reduced by changing the pipe diameter to 63mm rather than

32mm. Hence, the recorded unit head_loss is reduced to 0.86 m/km. Therefore, the pressure at the node 10 (hamlet 4) is improved to 15 m instead of 7.15 m and overcome the lower pressure at that point. Finally, the low water delivery service is due not only to the topographical profile of the study area that has not been taken into account but also to the lack of adequate design of the network regarding the peak water demand and diameters of the pipe installed. The comparison of these results indicates that the simulated model seems to be reasonably close to the actual network according to the technical data survey on the system.

Table 4. *Simulation result of the water distribution system.*

Link	Length (m)	Velocity (m/s)	Unit head-loss	Friction factor
Pipe 1	92	0.37	6.46	0.029
Pipe 2	101	0.48	4.7	0.025
Pipe 3	3	0.37	6.46	0.029
Pipe 4	144	0.37	6.46	0.029
Pipe 5	143	0.29	1.82	0.027
Pipe 6	3	0.37	6.46	0.029
Pipe 7	149.35	0.75	23.33	0.026
Pipe 8	5	0.37	6.46	0.029
Pipe 9	251.46	0.37	6.46	0.029

4. Conclusion

This paper has focus on the performance analysis of the sekoukou's village water distribution network for the sustainability of both the water-energy nexus respectively (solar pumping) system and water distribution network. The results show that the low water pressure at the fourth hamlet tap is due to the under design of the network regardless the topographical characteristic of the area, the pressure losses along the pipe and water demand increasing in the village. The performance of the overall system is not only from the solar pumping system but also the water distribution network. The results of the topographical area and the pipeline together with the frictional and local losses due to respectively the water velocity in the pipe and the fitting, revealed that the water flow and the pressure are significantly affected. Thus, out of the 10 nodes 66.6% have pressure between 15m to 22m while the node 2 has a pressure of 13.4 m.

In contrast, the pressure at the node 10 is 7.15 (1 bar to 0.7 bar) m which is under the recommended minimum of 10m (1bar), justifies the slow water flow at the hamlet 4.

Moreover, in order to cope with the lower pressure of the water flowing from the hamlet 4 tap and meet the future water demand of the sekoukou's village, the following recommendation could be carry out:

i) Increase the size of the storage tank to 30 at least 30 m^3 in order to cover the future water demand of the community;
ii) Increase the diameters of the pipe of the water distribution mainly between the Hamlets two (2) to three (3) and three (3) to four (4) from 32 mm to 63 mm in order to increase the water pressure in the Hamlet (4);
iii) Plan to build a public tap for the hamlet five (5) for reducing the supplying from the river for drinking purpose because they are further away from tap.

In addition, the present study could be pursued by implementing a real time measurement sensor at the different junction and throughout the link (piping) of the water distribution network to compare the measurement data and the simulation. In order to evaluate the pressure reduction, the losses (friction and head) and the water flow at the different hamlet as well as the topographical characteristic of the area.

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References

[1] Lehmann, P. (2010). Challenges to Water Pricing in Developing Countries: The Case of Lima, Peru. Report 2010, p1-20, Helmholtz Centre for Environmental Research – UFZ, Department of Economics. Available online at https://www.lima-water.de/documents/plehmann_berlin2010.pdf, accessed 17/11/2022.

[2] WHO. (2017). Access safe drinking water challenges opportunities improving global health.

[3] World Bank. (2018). Rural population percent of total population.

[4] Argaw et al. (2003). Renewable energy for water pumping applications in rural villages. In New Mexico State, United States (Issue July).

[5] Chandel et al. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renewable and Sustainable Energy Reviews, 49, 1084–1099.

[6] Venkata et al. (2015). Network analysis of water distribution system in rural areas using EPANET. Procedia Engineering, 119 (1), 496–505.

[7] Masri, M. (1997). Design of Optimal Water distribution Networks. M.SC. Thesis, An-Najah National University.

[8] Yadav et al. (2015). To Assess the Prevailing Water Distribution Network using EPANET. International Research Journal of Engineering and Technology, 2 (8), 777-781.

[9] Pandya, N. C., & Popawala, R. 2017. A Review on paradigm shift of Water Distribution Infrastructure. IJEDR, 5 (2), 1962–1966.

[10] Hardy cross. 1936. Analysis of flow in networks of conduits or Conductors. Engineering Experiment Station, University of Illinois, 286.

[11] Dejan et al. 2019. Short Overview of Early Developments of the Hardy Cross Type Methods for Computation of Flow Distribution in Pipe Networks. Applied Sciences 9 (10).

[12] Martin, D. W. and Peters G. 1963. The application of Newton's method to network analysis by Digital Computers. J. Inst. of Water Engrs., 17, 115-129.

[13] Brkić, Dejan, and Pavel Praks. 2018. "Improved Hardy Cross Method for Pipe Networks." (December): 1–13.

[14] Williams et al. 1973. Enhancement of Convergence of Pipe Network Solutions. PENCIL Pub. Phys. Sci. Eng, 33 (1057–1067).

[15] Mehta et al. 2016. Study of Water Distribution Network Using EPANET. International Journal of Advanced Research in Engineering, Science, Management, 1–11.

[16] Kolpe, S., & Vaidya, D. 2018. Experimental Analysis of Water Distribution. 9153–9160. https://doi.org/10.15680/IJIRSET.2018.0708038

[17] Mounkaila Saley Moussa, Djibo Bachirou, Ibrahim Halidou. Assessing the Performance of Solar Photovoltaic Pumping System for Rural Area Transformation in West Africa: Case of Sekoukou Village, Niger. International Journal of Energy and Power Engineering. Vol. 11, No. 6, 2022, pp. 114-124. doi: 10.11648/j.ijepe.20221106.11.

[18] Lekombo Claude Sara. Potential role of renewable energy in energy mix to overcome energy shortfall in Niger case of sekoukou village, Master Thesis, PAUWES, 2019, online at URI: http://repository.pauwes-cop.net/handle/1/326

[19] Hassane A., Rabani A. 2018. Qualité Physico-Chimique et Bactériologique Des Eaux de Consommation Du Village de Sekoukou.

[20] Shaher et al. 2003. Hydraulic Performance of Palestinian Water Distribution Systems (Jenin Water Supply Network as a Case Study) (Doctoral dissertation).

[21] Totsuka, N., Trifunovic, N., & Vairavamoorthy, K. 2004. Intermittent urban water supply under water starving situations.

[22] H. Gisha, A. W/Mariam, and B. Abate, "Water Distribution Network Analysis of Bodditi Town by EPANET," J. Inf. Eng. Appl., vol. 6, no. 10, pp. 10–17, 2016.

[23] Wiwik Yunarni Widiarti *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* 437 012043 DOI 10.1088/1755-1315/437/1/012043.

[24] E Kurniati, Kamariah and T Susilawati. Analysis of clean water distribution systems using EPANET 2.0 (Case study of Uma Sima Village, Sumbawa Regency). 2021 IOP Conf. Ser.: Earth Environ. Sci. 708 012105 DOI 10.1088/1755-1315/708/1/012105.