Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI: 10.21474/IJAR01/21775
DOI URL: http://dx.doi.org/10.21474/IJAR01/21775

RESEARCH ARTICLE

ASSESSMENT OF HYDRAULIC PERFORMANCE AND INEQUALITIES IN ACCESS TO THE YOPOUGON-KOWEIT DRINKING WATER SUPPLY NETWORK (ABIDJAN, COTE D'IVOIRE)

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Manuscript Info

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Manuscript History
Received: 13 July 2025
Final Accepted: 15 August 2025
Published: September 2025

Key words:-
Water supply network, water drinking, hydraulic performance, Yopougon-Koweït

Abstract

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The drinking water supply in the Yopougon-Koweït neighborhood faces challenges in terms of accessibility and performance of the drinking water supply network. This study aims to evaluate the hydraulic performance of the drinking water supply network in the Yopougon-Koweït neighborhood in Abidjan. The methodological approach is based on data relating to water production and water demand from the population, collected by SODECI in 2010, 2015, and 2022. The results reveal a significant but incomplete improvement in access to drinking water. The access rate rose from 39% to 68% between 2015 and 2022. Analysis of the state of the network highlights its aging and poor hydraulic performance, despite progress. The network's efficiency improved from 32% to 62%. Linear losses have been reduced from 88 to 28 m³/day/km. However, the network has a very heterogeneous and fluctuating pressure profile, ranging from -1.25 to 32.1 mWC. This situation creates inequalities in access between sub-neighborhoods.

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Introduction:-

Water is essential for sustaining life and good health. It is now widely recognized as a fundamental human right (Yao, 2022).It is clear that Sustainable Development Goal 6 (SDG 6) played a decisive role in the United Nations (UN) commitment to ensure universal access to water and sanitation by 2030, in addition to promoting sustainable water resource management (UN Water, 2023).In sub-SaharanAfrica, approximately 30% of the urban population resides in informal neighborhoods (WHO/UNICEF, 2023).

As UN Water (2019) points out, residents of these neighborhoods often face difficulties accessing basic services, particularly drinking water.This situation isevident in Cote d'Ivoire, a developing country where people still have insufficientaccess to drinking water. This is in spite of the factthat acceptable coverage rates have been achieved.Abidjan, the largest city in Cote d'Ivoire and the fourthlargest city in Africa, is no exception in terms of

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Difficulty accessing water (Goe et al., 2024 and 2025). It is estimated that this region is home to more than 30% of the Ivorian population and has an annual growth rate of 2.9% (INS, 2021). Although it accounts for less than 1% of the country's territory, it provides 60% of the total production and consumption of drinking water in Cote d'Ivoire. In 2020, the volume of water produced in Cote d'Ivoire amounted to 302,814,000 m^3, of which 227,668,000 m^3 was billed, representing a loss of 7,514,600 m^3 (ONEP, 2020).

The Koweït neighbourhood, the setting for thisstudy, has a population of 46,932, comprising 7,822 households, with an averagehousehold size of 6 people (INS, 2021). The population subscribing to RePEPisestimated at 5,483 (SODECI, 2022). In the context of inadequate water infrastructure, households have been observed to adopt alternative strategies to compensate for the inconsistency of supply (Angueletou-Marteau, 2009).

Indeed, a surveyrevealed that 59% of households obtained their water supplyfromresellerswhohadconnectedillegally and weretherefore not billed by SODECI. However, thismethod of supply carries risks of water contamination linked to the quality of the pipes used, water collection, transport, and storage at home (Konan et al., 2011). The averagecost of households' compensatorystrategiesis five times higherthantheirquarterly water bill, representing at least 10% of their monthly in come (Angueletou-Marteau, 2009).

A study conductedin 2010 on network performance in the same neighborhood demonstrated that for a daily water production of 2,450 m^3, a mere 706 m^3 wasbilled, representing a loss of 61% of the water supplied. This loss was attributable to 59% of households that obtained their water exclusively and fraudulently from resellers. This has resulted in considerable financial losses for the water sector, estimated at 169,190,525 CFA francs per year (Toure et al., 2013). It is vital to acknowledge the significance of access to water for the population of Yopougon-Koweït in order to ensuretheirwell-being. Therefore, the primary objective of thisstudyis to evaluate the performance of the drinking water network in the Yopougon Koweït neighborhood. This will ensure sustainable acc ess to water for the population of that neighborhood.

Material and Methodes:-

Study area:-

The Yopougon-Koweït neighborhood is located in southern Cote d'Ivoire, between longitudes 4°3'0" and 4°3'36" West and latitudes 5°18'15"N and 5°19'20"N (Figure 1). The area under consideration is 1.7 km², and the population is estimated to be 46,932 residents (INS, 2021). Yopougon-Koweït is bordered to the north by the Toit Rouge neighborhood, to the south by the Ebrie lagoon, to the east by Sante neighborhood, and to the west by Camp Militaire neighborhood. It is subdivided into six (6) sub-neighborhoods: Johannesburg to the north, Ravin to the northeast, Konan Ferrand and Sante Extension to the southwest, and Sous-Koweït and Gouro to the southeast.

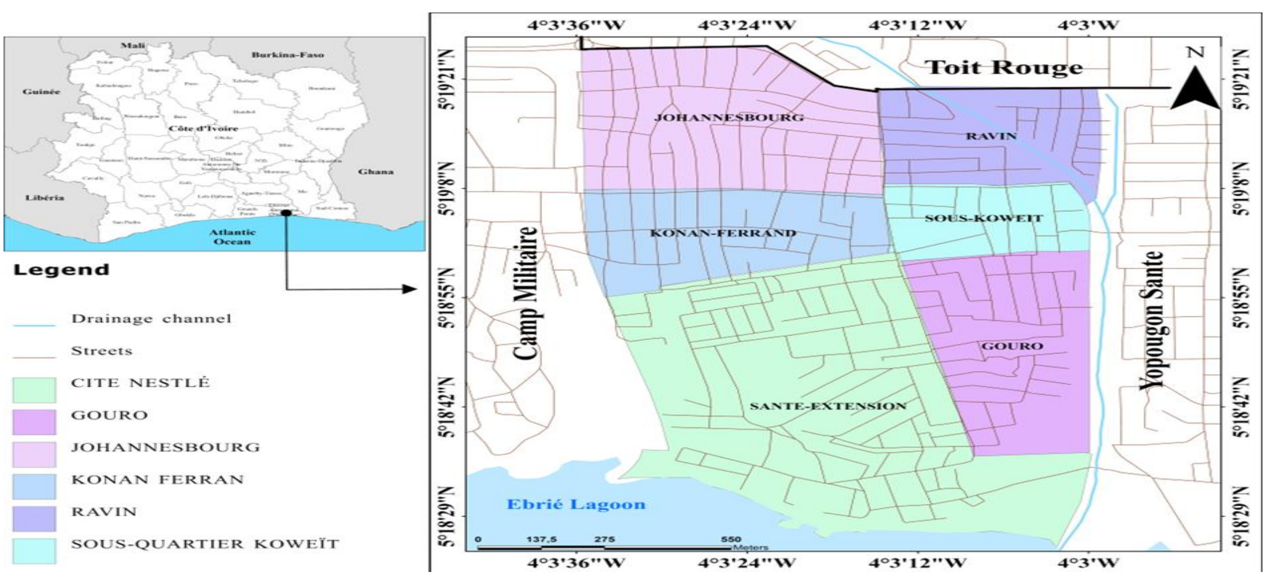

Figure 1:Study area

Data:
This study required socio demographic and drinking water supply data. The latter includes the number of subscribers, cancellations, and volumes distributed, consumed, and billed for the years 2010, 2015, and 2022. This data was provided by the Ivorian Water Distribution Company (SODECI) (SODECI, 2022). The choice of years (2010, 2015, and 2022) is justified by the fact that they correspond to the project years for which the data necessary for the study are available. Field surveys were conducted using an interview guide, while data processing and analysis were performed using Excel 2013.

Methodes:

Evaluation of subscriberdensity:
Subscriber density is a metric that quantifies the number of subscribers per unit of network length. The application under discussion enables the distribution of subscribers across the water distribution network to be assessed, and the network to be characterised in terms of urban planning. This density is expressed in subscribers per kilometer (subscribers/km). The calculation is derived from the following equation:

$$D = \frac{\text{number of subscribers}}{\text{network length}} \text{(Eq. 1)}$$

Estimation of domestic water consumption in the neighborhood:
Population consumption was calculated based on specific consumption obtained from water volumes billedin 2015 and 2022. Specificconsumption (equation 2) iscalculatedfrombilled volumes using the Krayenbuhl formula (1993):

$$SC = \frac{Vc}{365 \times \overline{T} \times A} \text{ (Eq. 2)}$$

Avec :
SC : Specificconsumption ;
Vc : Annual water volume consumed ;
$\overline{T}$: Averagehousehold size ;
A : Number of subscribers.

Estimation of water loss:-
The approach consisted of comparing daily consumption data determined from the volume of water consumed supplied by SODECI with the daily volume of water produced. This method made it possible to evaluate the performance of the Yopougon-Koweït water supply system.

Performance indicator assessment:

- **Technical network efficiency or billing ratio**

The technical efficiency of the drinking water network is an indicator that measures the efficiency and performance of the network. This ratio isdefined as the proportion of water consumed by subscribers relative to the total water input into the network, as depicted in equation 3 (Hugues, 2000). This isdenoted by the letter η and expressed as a percentage (%).

$$\eta = \frac{\text{consumedvolume}}{\text{distributedvolume}} \times 100 \text{(Eq. 3)}$$

- **Linearconsumption index (LCI):**

It represents the total volume of consumers per linearmeter of pipes. It isexpressed in cubicmeters per day per kilometer (m^3/day/km) and isused to classify the type of network. In thisstudy, itisgiven by the followingequation (4) (Demassue, 1994):

$$LCI = \frac{\text{consumedvolume}}{\text{networklength} \times 365} \text{(Eq. 4)}$$

- **Linearloss index:**

The linearloss index is a performance indicator for drinking water distribution networks. It isexpressed in cubicmeters per day per kilometer (m^3/day/km). Knowledge of this index makesit possible to bettertarget the sections to beexamined as a priority. It isgiven in thisstudy by equation 5 (Demassue, 1994):

$$LLI = \frac{\text{Volumereleasedfordistribution} - \text{consumedvolume}}{\text{networklength} \times 365} \text{ (Eq. 5)}$$

Evaluation of indicators for the operation of the drinking water supply network:

Water access rate:

The rate of access to drinking water represents the proportion of the population withregularaccess to a water source of sufficientquality to meettheir basic needs. It is the ratio betweenthe population with effective access to drinking water and the total population of the area. It isexpressedaccording to equation 6 (MINHAS, 2021):

$$\text{Ta} = \frac{\text{Numberofsubscribers} * \text{householdsize}}{\text{Totalpopulationcovered}} \times 100 \text{ (Eq. 6)}$$

Cancellation rate:

This indicator refers to the proportion of households that voluntarily and formally disconnect from the distribution network. This isgenerally due to economic factors (financialinsecurity, prohibitive cost of service) or technical factors (recurring service failures). This indicator reflects both supply failures and inequalities in access to an essential resource. It is the ratio between the number of subscriberswho have terminatedtheir service and the number of actual connections in the locality in question. In thisstudy, itisgiven by the following formula, equation 7 (MINHAS, 2021):

$$\text{Cr} = \frac{\text{Number of subscribers canceled}}{\text{Total number of actual connections}} \times 100 \text{(Eq. 7)}$$

○ **Desert rate:**

The capacity of the water supply system to provide safe drinking water to the population ismeasured by thisindicator. The ratio between the volume of safedrinking water supplied to the residentsof a givenlocality and their safe drinking water demandis a key indicator of water supply efficiency. The termisdefined in equation 8 (MINHAS, 2021):

$$\text{Dr} = \frac{\text{Supplied volume}}{\text{Demand}} \times 100 \text{ (Eq. 8)}$$

In the domain of urbanhydraulics, the volume of water supplied is determined as the difference between averagedaily production (m^3/day) and averageloss (m^3/day).

○ **Number of hours of service or number of hours of coverage of the demand:**

This indicator quantifies the mean service time, or the mean duration of supply over a 24-hour period. This calculation is derived frome quation 9 (MINHAS, 2021):

$$\text{Nh} = \frac{\text{Supply}}{\text{Demand}} * 24 \text{ (Eq. 9)}$$

Production deficit rate:

The production deficit rate measures the proportion of the production deficit in relation to the over all drinking water demand of the population in the area under consideration. It is the ratio between the production deficit and the total demand of the locality under consideration. It isgiven in this study by equation 10 (MINHAS, 2021):

$$\text{PDr} = \frac{\text{Total demand } (m^3/d) - \text{current production } (m^3/d)}{\text{Total demand } (m^3/\text{day})} \times 100 \text{(Eq. 10)}$$

Measurement of pressures on the drinking water supply network:

The portable flow meter (Sewerin) and pressure sensors (Cello 4s) wereutilized to assess flow rates and pressure at sectormeters and at specificnodeswithin the sub-district network of the study area (Figure 2).

Figure 2.Field equipment :The Flowmeter (Cewerin); b)Pressure sensors (Cello 4^s)

Results and Discussion:-

Density of subscribers in Yopougon-Koweït:

- **Evolution of the number of subscribers**

The primary source of drinking water for the population of Yopougon-Koweït is the public drinking water network (SODECI). Initiatives such as the URBIS project, the Emergency Urban Infrastructure Project, the Abidjan Restructured Neighborhoods Development Project, and the Drinking Water for All Project, which have been implemented in the neighborhood since 2006, have contributed to enhancing access to drinking water for the population. The number of subscribers increased from 18 in 2006 to 5,438 in 2022 (see Table I). From 2010 to 2022, the subscription rate in the Yopougon-Koweït neighborhood exhibited a substantial increase of 53%.

Table I.Evolution of the number of subscribers in Yopougon-Koweït (Abidjan District, Cote d'Ivoire)

Years	2006	2010	2015	2022
Subscribers	18	2863	2588	5483

- **Subscriberdensityanalysis**

Subscriber density is indicative of the number of households connected to RePEP per unit of area. The number of subscribers per kilometer increased from 154 in 2010 to 167 in 2022, but decreased to 139 in 2015 (Table II).

Table II.Evolutionof thesubscriber density in Yopougon-Koweït

Years / Indicators	2010	2015	2022
Subscriberdensity(subscriber/km)	154	139	167

As illustrated in Figure 3, the Johannesburg sub-neighborhood (1,840 subscribers) exhibits the highest concentration of subscribers. The Sante Extension sub-neighborhood, with a subscriber base of 975, is noteworthy as the second most connected area. The Konan Ferrand (767 subscribers), Gouro (714 subscribers), and Koweït (710 subscribers) sub-neighborhood demonstrate moderate coverage. The Ravin area (540 subscribers) appears to be the least connected.

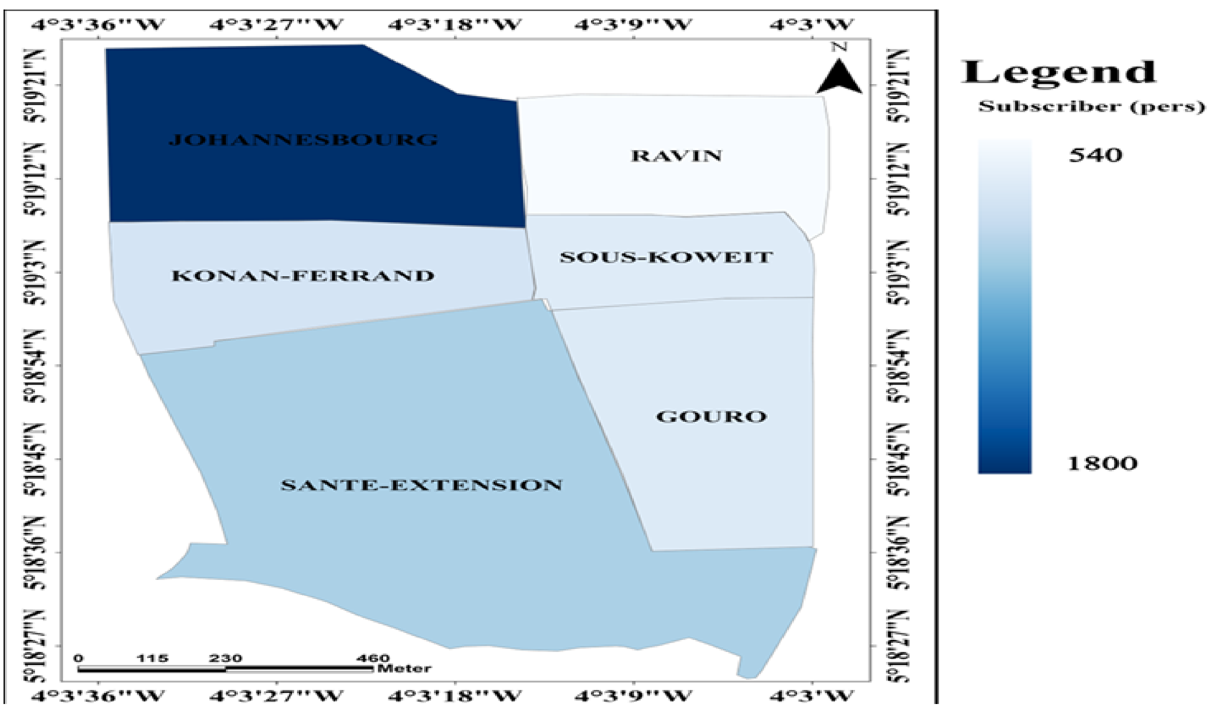

Figure 3. Density map of subscribers in Yopougon-Koweït

Household water consumption of the population:

Water consumption in the Yopougon-Koweït neighborhood, based on SODECI data, was 300,957 m³/year in 2010 and 542,259 m³/year in 2022. The number of subscribers billed rose from 2,863 in 2010 to 5,483 in 2022. The average household size remains unchanged and is estimated at six people per subscriber. This leads to a specific consumption of 48 L/day/resident in 2010, compared to 55 L/day/resident in 2015 and 45 L/day/resident in 2022 (Table III). In addition, the average domestic water consumption of a subscriber in the Yopougon-Koweït neighborhood was 247 L/day/subscriber in 2010, compared to 330 L/day/subscriber in 2015 and 271 L/day/subscriber in 2022.

Table III.Evolution of billed water volumes and specificconsumption

Years	2010	2015	2022
Volume of water consumed (m^3/year)	300 957	311 723	542 259
Specificconsumption (L/day/resident)	48	55	45

Figure 4 shows that the Johannesburg sub-neighborhood (202,760 m³) stands out clearly as the area with the highest water consumption. The Konan Ferrand (89,720 m³), Koweït (68,996 m³), Ravin (65,772 m³), and Gouro (67,958 m³) sub-neighborhoods have moderate consumption levels. The Sante Extension sub-neighborhood (70,099 m³) is slightly above the lower threshold, but remains within a lower range than the others.

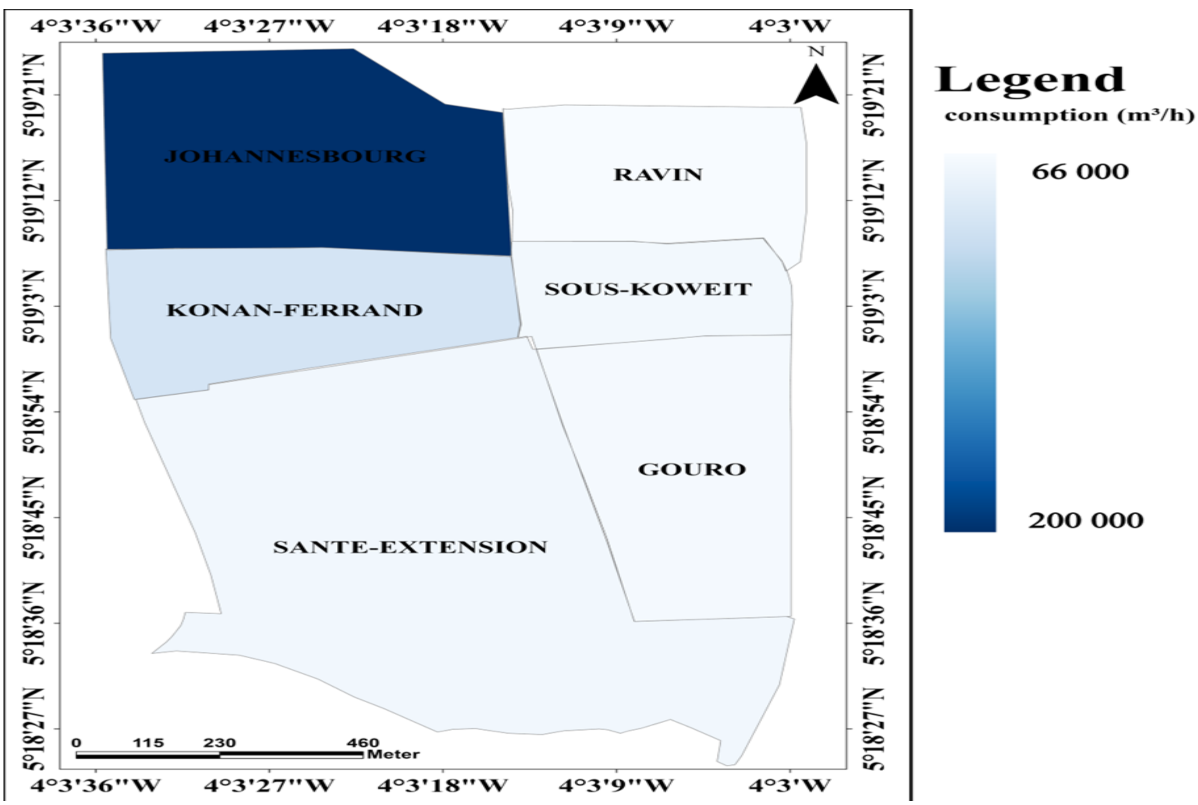

Figure 4.Consumptiondensitymap of Yopougon-Koweït

Evolution of the specific consumption:

Water consumption in the study area, based on SODECI data, was 300,957 m³/year in 2010 and 542,259 m³/year in 2022. The number of subscribers billed was 2,863 in 2010 and 5,483 in 2022. The average household size remains unchanged and is estimated at 6 people per subscriber. This leads to a specific consumption of 48 L/day/resident in 2010, compared to 55 L/day/resident in 2015 and 45 L/day/resident in 2022 (Table IV). In addition, the average domestic water consumption of a subscriber in Yopougon-Koweït was 247 L/day/subscriber in 2010, compared to 330 L/day/subscriber in 2015 and 271 L/day/subscriber in 2022.

Table IV.Evolution of billed water volumes and specificconsumption

Years	2010	2015	2022
Volume of water consumed (m^3/year)	300 957	311 723	542 259
Specificconsumption (L/day/hbt)	48	55	45

Analysis of water losses:-

The estimate of water losses based on SODECI consumption data indicatesthat water losses increased from 706 m^3/dayin 2010 to 854 m^3/dayin 2015 and to 1,486 m^3/dayin 2022, representing a loss of 71%, 65%, and 38% of averagedaily production, respectively (Table V). Between 2010 and 2022, the averagedaily production decreased by 10% per year/dayin 2022, representinglosses of 71%, 65%, and 38% of averagedaily production, respectively (Table V). Between 2010 and 2022, therewas a significantreduction in the loss rate in the Yopougon-Koweït neighborhood of 33%.

Table V.Assessment of water lossesfrom 2010 to 2022

Years	2010	2015	2022
Volume of water consumed (m^3/year)	888	854	1540
Water volume produced (m^3/day)	2450	2440	2406
Water loss (m^3/day)	706	854	1486
Loss rate (%)	71%	65%	38%

Network performance parameteranalysis:-

As illustrated in Table VI, there has been an enhancement in the primary technical efficiency of the network from 2010 to 2022. The percentage increased from 32% to 62%. However, this efficiency falls short of the established standard of 80%. The linear consumption index exhibited stability, maintaining an average of 45 m³/day/km. The linear loss index exhibited a substantial improvement, decreasing from 88 m³/day/km in 2010 to 28 m³/day/km in 2022. However, this value is indicative of the substandard condition of the RePEP.

Table II.Performance indicators for the RePEP in Yopougon-Koweït

Years / Indicators	2010	2015	2022
Technicalefficiency (%)	32	35	62
Linearconsumption index (m^3/day/km)	44	46	45
Linearloss index (m^3/day/km)	88	85	28

Drinking water supply network operating indicators:-

Table VII presents the operating indicators for the RePEP in the Yopougon-Koweït neighborhood. The rate of access to drinking water for the populations of Yopougon-Koweït has improvedsignificantly. It rose from 47% in 2010 to 68% in 2022, with a significantdecline of 39% in 2015. The service rate rose from 23% in 2015 to 31% in 2022. These rates reflect the investments made in the urban water sector.

The cancellation rate in 2010 and 2022 isvirtuallyzero. In contrast, this rate rose by 10% in 2015. The number of hours of service isaround 13 hours and remained relatively stable between 2010 and 2015. This numberdeclined to 10 hoursin 2022. In addition, the production deficit rate increased over the three (03) years. It rose from 32% in 2010 to 50% in 2022. This rate reveals a gap between the increase in production and the expansion of water service.

Table III.RePEP operating indicators in Yopougon-Koweït

Years / Indicators	2010	2015	2022
Access rate (%)	47	39	68
Cancelled rates (%)	0,3	10	0
Desert rate (%)	23	22	31
Number of hours of desert(H)	13	14	10
Production deficit rate (%)	32	38	50

Analysis of pressures on the Yopougon Koweït network:-

The Yopougon-Koweït network experiences significant pressure fluctuations (Figure 5). These vary from -1.25 mWC to 32.1 mWC and follow a daily cycle marked by two peaks (2 a.m. to 4 a.m. and 12 p.m. to 2 p.m.) and two low periods (7 a.m. to 9 a.m. and 4 p.m. to 7 p.m.). The distribution network shows significant spatial heterogeneity in pressure. It can be categorized into three distinct classes: (i) high-pressure areas, (ii) intermediate-pressure areas, and (iii) low-pressure areas.

The Johannesburg sub-neighborhood is the area under the most pressure and has the highest pressures in the network. These pressures range from 12 to 32.1 mWC at night (9 p.m. to 5 a.m.) and from 8 to 15 mWC during the day (6 a.m. to 8 p.m.). The Ravin and Konan Ferrand sub-neighborhoods are areas of intermediate pressure. Pressures in Ravin vary from 10 to 25 mWC at night and from 5 to 9 mWC during the day. In the Konan Ferrand sub-neighborhoods, pressures vary from 5 to 21 mWC at night and drop to a range of 2 to 7 mWC during the day. The Sous-Koweït, Gouro, and Sante Extension (Sikasso) sub-neighborhoods are low-pressure areas. In the Sous-Koweït area, the pressure, which is already low at night (1–7 mWC), drops to a very low level during the day (0–1 mWC). The situation is even more worrying in the Gouro and Sikasso sub-neighborhoods, which have virtually zero pressure both at night and during the day.

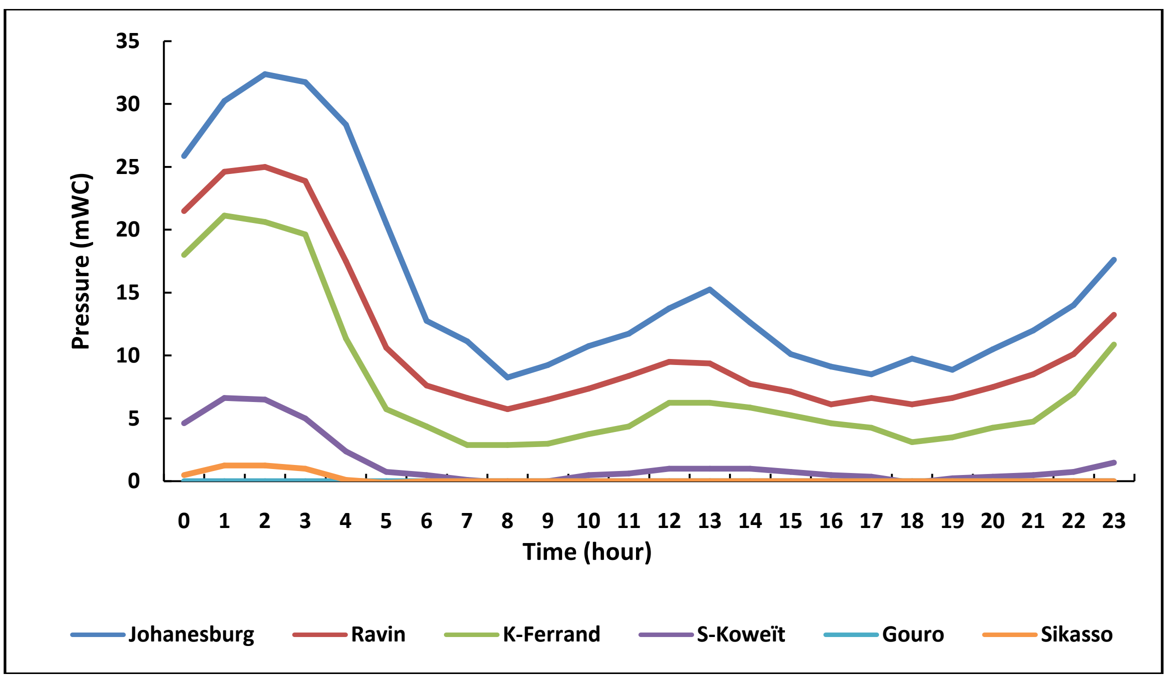

Figure 5.Pressure variations on the Yopougon-Koweït

Discussion:-

The study shows exponential growth in the number of subscribers in Yopougon-Koweït. This number rose from 18 in 2006 to 5,483 in 2022. This increase reflects the impact of government actions to improve access to drinking water for the population with a view to achieving SDG 6. Indeed, the rate of access to urban water supply rose from 80.7% in 2015 to 84% in 2020 (PND 2021). Conversely, specific consumption fell from 48 L/day/resident in 2010 to 45 L/day/resident in 2022. This decline has gone from 64.2 L/day/resident (Thompson et al., 2002) to 50–55 L/day/resident in 2023, due to demographic pressure and recurring shortages. Furthermore, this value is lower than the average consumption ratio set at 100 L/day/resident in the autonomous district of Abidjan (ONEP, 2020). However, this ratio masks disparities between different population groups' standards of living. Household daily drinking water consumption varies according to household income. It is 132 liters per person for high-income households and 88 liters per person for low-income households (Ta bi Boti et al., 2019).

In addition, the network's primary technical efficiency improved between 2010 and 2022, rising from 32% to 62%. The linear loss index also improved significantly, from 88 m³/day/km in 2010 to 28 m³/day/km in 2022. Subscriber density increased significantly, from 154 subscribers/km in 2010 to 167 subscribers/km in 2022. This improvement could be linked to the actions undertaken by SODECI in 2015 in the district of Abidjan. These actions consisted of pressure management, sectorization, active leak detection, replacement of old meters, modernization of metering, and the fight against fraud (N'cho, 2021). However, the study highlights the poor performance parameters of the Yopougon-Koweït network, with efficiency below the standard set at 80% for good efficiency according to Blarel and Merzouk (2005). The same is true for the linear loss index, for which the recommended standard is less than 15 m³/day/km (ANBT, 2020). This poor network performance could be explained by its age (17 years on average) (Kleiner et al., 2001). Furthermore, according to Alegre et al. (2022), the aging of pipes significantly reduces the hydraulic performance of the RePEP by altering the roughness of the walls.

Access to drinking water in Yopougon-Koweït has improvedsignificantly. It rose from 47% in 2010 to 68% in 2022, despite a significant drop of 39% observedin 2015. This significantdecline in access to drinking water wascaused by the consequences of the 2011 politicalcrisis. This situation severelycompromised water infrastructure and water sectorgovernance in Cote d'Ivoire (Kouadio et al., 2017;AfDB, 2016). In addition, the service rate rose from 23% in 2015 to 31% in 2022. Theseaccess and service rates are in line with the targets set by the National Water Investment Program (PNIH) for the period 2010-2022. This program aims to improvesustainableaccess to drinking water in urban and peri-urban areas in Cote d'Ivoire (MINHAS, 2022).

The cancellation rate remained virtually zero in 2010 and 2022. However, this rate increased by 10% in 2015. This could be explained by a crisis of confidence and/or irregular service linked to the discontinuity of SODECI's water service, leading to cancellations (Grafton et al., 2019). The number of hours of water service has fallen from 13 hours in 2010 to 10 hours in 2022. The production deficit rate has increased from 32% in 2010 to 50% in 2022. These results attest to a structural gap between the population's water demand and the volumes of water distributed by the network. Indeed, recent studies confirm that the reduction in service hours and the increase in the production deficit rate are the result of a mismatch between growing demand and actual distribution capacity (AfDB, 2020). The pressure profile of the Yopougon-Koweït network is characterized by extreme amplitude (-1.25 to 32.1 mWC) and a daily cycle contrasting peaks (nighttime/midday) and troughs (morning/evening).

These variations reflect typical behavior in water distribution networks under the influence of socio-economic demand (Alvisi and Franchini, 2018). Indeed, pressure peaks (night and midday) correspond to periods of low demand. Conversely, pressure troughs (morning and evening) are caused by peaks in domestic consumption (Buchberger et al., 2003). These observations are consistent with those of Haque and Rahman (2016), who highlight extreme pressure fluctuations, with critical drops at peak times, particularly in the morning and evening. This study also highlights that urban density exacerbates the problem and creates marked spatial disparities between the center and the peripheries.

Furthermore, the high spatial heterogeneity of stratified pressures in areas of high pressure (Johannesburg), intermediate pressure (Ravin, Konan Ferrand), and low pressure (Sous-Koweït, Gouro, Sante extension (Sikasso)) indicatesprofoundinequalities in access to drinking water services.Indeed, stratification of networks into classes according to pressure (high, medium, low) iscommon in poorlybalanced networks, as observed in Nairobi (Kenya) and Dhaka (Bangladesh) (Mutiku et al., 2014;Haque and Rahman, 2016). However, the virtuallyzero pressures observed in the networks in the Gouro and Sante Extension (Sikasso) areas reflect a hydraulicimbalance. According to Jadhav et al. (2016), persistent near-zero pressures in the Mumbai and Karachi networks reveal not only a hydraulicimbalance but also an acute healthrisk. Indeed, the negative pressure measured in Sante Extension (Sikasso) (-1.25 mWC) is a criticalindicator of healthrisk.

Conclusion:-

Performance analysis shows poor hydraulic performance of the network, particularly in terms of efficiency and water losses. Despite increased access to drinking water and subscriber density, network performance remains inadequate. Indeed, the decline in specific consumption, combined with a reduction in service hours and a growing production deficit, reveals a persistent mismatch between demand and distribution capacity. The Yopougon-Koweït network is characterized by a pressure profile fluctuating between -1.25 and 32.1 mWC, with peaks (nighttime/midday) and low periods (morning/evening). In addition, its high spatial heterogeneity of stratified pressures in areas of high pressure (Johannesburg), intermediate pressures (Ravin, Konan Ferrand), and low pressures (Sous-Koweït, Gouro, Sante Extension (Sikasso)) indicates profound inequalities in access to drinking water services.

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