Towards Building a Smart Water Management System (SWAMS) in Nigeria

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***Abstract*—The water management landscape in Nigeria struggles with formidable obstacles characterized by a lack of adequate infrastructure, an uneven distribution of resources, and insufficient access to clean water, particularly in rural areas. These challenges are further compounded by the impacts of climate change, contributing to a heightened sense of water scarcity and the inefficient utilization of available water resources. In response to these challenges, collaborative endeavors involving both public and private sectors have emerged as critical components of the solution. The concerted efforts aim to establish equitable access to clean water, bolster public health initiatives, and catalyze socio-economic development across Nigeria. This comprehensive examination of the nation's water dynamics underscores the need for innovative solutions. As part of this endeavor, we propose the implementation of a distributed service-oriented software architecture. This technological approach is designed to optimize water distribution networks and facilitate the implementation of effective water management policies, marking a pivotal step towards ensuring a more sustainable and resilient water future for Nigeria.**

***Index Terms*—flex-offer, water management, service oriented architecture, optimization**

I. Introduction

It is no doubt that the sustainability of the management and provision of water resources has become very essential with the growing threat to human existence as a result of climatic change. In Nigeria, taking the south-west as an example, about 4,000mm of rainfall is experienced annually which is enough to processed for small domestic needs. However, factors such as inappropriate water distribution, poor management/service, inadequate infrastructure, and excessive billing system have been the major setback to safe, affordable, and sustainable provision of water to citizens [1], [2]. A recent study [3] has also shown inequitable access and distribution to public water supply is highly associated to the high deprivation in many regions of Nigeria. The poor management of water resources encompasses issues relating to water security, water quality and poor policy implementation strategies. In addition, the adoption of the centralised approach to management of water resources and its distribution in Nigeria has also been seen as a major contributing factor to the water management problem. It has limited the involvement of private enterprises in the management and distribution of water resources across the nation including the south-west of the country [4].

It has been established that the provision of sustainable water management and distribution in Nigeria can only be realised with the involvement of stakeholders, which has often involved only the private sector participation [5]. Despite the initiatives put forward by the federal government of Nigeria and various state administrators to provide a sustainable water management and distribution across the country, there is little or no involvement of stakeholder's participation as part of these initiatives. Furthermore, the initiatives revolve around encouragement of private participation, provision of water and policies with the introduction of the so called water law[1]. Similarly, the need to control the demand of water usage for domestic and commercial is advocated to require variation in household tariff, improved and reliable industrial supply, and efficient management of water with appropriate technology and price mechanism [6]. Therefore, introducing a more realistic technological and software-driven solution that is complementary to the existing proposals is a way of achieving a better sustainable water management and distribution.

In this work, we describe the SWAMS approach also known as Smart Water Management System. It is a distributed service-oriented approach incorporating the notion of the water market and flex-offers to enable on-demand water pricing, optimal scheduling of water distribution and effective water management policies. The flex-offer works in association with the virtual distribution structure to schedule the on-demand water distribution. The approach with the associated architecture can provide an optimised technique for water distribution and efficiently support an in-advance provision of the need in water, which will better support both domestic and industrial needs of the population, companies, etc.

The rest of the paper is structured as follows. Section

[1]http://extwprlegs1.fao.org/docs/pdf/nig158231.pdf

TABLE I
PERCENTAGE OF WATER SOURCES DISTRIBUTION

Water Source	1995 /96	1997 /98	1999 /2000	2006	2007	2008	2010
Pipe Water	61.60	56.57	54.10	11.37	10.40	8.80	9.50
Borehole	1.00	1.07	0.40	13.61	26.80	28.40	21.50
Wells	8.50	13.41	15.80	35.77	33.30	31.50	35.00
Streams /Ponds	28.90	28.97	29.70	21.45	24.40	27.10	13.90
Tanker /Truck	-	-	-	5.88	4.10	3.20	2.00
Rain	-	-	-	8.65	0.60	0.50	27.10
Others	-	-	-	3.26	0.3		1.00

II and Section III present the current status and challenges on water management as a whole in Nigeria. Section IV in detail presents the proposed SWAMS approach and Section V concludes this work.

II. ACCESSIBILITY OF WATER SUPPLY IN NIGERIA

Based on the report published by the National Bureau of Statistics as presented in Table I,the major sources of domestic water supply in Nigeria before year 2000 is found to be mainly from Pipe-borne water. This type of water supply comes from government or municipal water supply schemes. Expressed as percentage of water produced from other sources, the reliance on Pipe-borne water has continue to decrease over the years. There seems to have been an increase in water supply from wells, which are privately owned hand dug shallow water source. Boreholes (privately and publicly owned water sources can be powered by either solar or electric machine, or manually hand pump) has also seen an increase as alternative means of water supply since 2006. A recent survey data published by statista[2] in 2021, clearly shown that both borehole and protected wells remains the major sources of water for household with 41.6% and 44.7% respectively. The reliance on streams, which are water from rivers, lakes,pond and other sources mostly provides water for irrigation and agricultural purposes. It has also seen a continuous decline over the period of years. Poor households that cannot afford the well or borehole also consider water supply from vendors using water tanker,trucks and carts as alternative. This has seen a continuous decrease based on the evidence provided in the survey and the table considered in this report. The decrease is also attributed to issues relating to climate change and other related human activities. Rain water supply represents 27.1 percent in 2010 and has shown its lowest reliance for domestic use based on the survey conducted by Statista in year 2020. The same reason can be attributed to the effect of greenhouse gases resulting to climatic change.

[2]https://www.statista.com/statistics/1269086/main-source-of-water-in-nigeria-by-area/

III. CHALLENGES ON DEMAND AND SUPPLY MANAGEMENT FOR SUSTAINABLE NATIONAL DEVELOPMENT IN NIGERIA

The development, exploitation and overall management of water resources in Nigeria is currently coordinated and controlled by the Federal Ministry of Water Resources. The agency has been established by law and backed by set of statutory policies that were also enacted into these laws. The weak policy-oriented approach as well as poor implementation of these policies has contributed to poor water governance and ineffective management of water resources in Nigeria. Many of these weak approaches, including their legal frameworks are also considered as major contributor to water scarcity and inefficient water usage for domestic and agricultural purposes [7].

The current management approach for water resources is more focused on ensuring availability of water supply through expansion of infrastructures, instead of ensuring right approach is in place for optimal consumption and availability on demand [8]. Also, the wide gaps between the demand and supply of water resources is considered a management and governance issue that lacks the use of effective cost recovery in the pricing of water resources [4]. In addition, the demand for high quantity of portable water in Nigeria has been projected to increase on annual basis due to estimated average population growth of 2.5% within the last 10 years[3].

In line with United Nations 2030 Agenda for sustainable development and furtherance to building a sustainable cities and communities within developing nations such as Nigeria, the need for effective management of demand and supply of water resources is very important. Among the several challenges relating to sustainable water management resources in terms of demand and supply can be inferred from the study that was presented by [4]. These challenges are inadequate human resources, poor financial management and centralised control of water management, lack of coordination among relevant agencies, unavailability of relevant data to implementation of sustainable water management, limited use of modern technologies, and lack of long-term system approach with theoretical concepts for the design,and maintenance of water resource planing in the country.

To effectively manage the demand and supply of water, application of technology to manage efficient water usage and appropriate pricing mechanism will need to be put in place [6]. it is also mentioned that traditional methods of water resource monitoring have substantial limitations, as they do not address water quality, equity of access, or extra-household services, thus emphasizing the need for innovative monitoring and management techniques of this natural resource [9]. Furthermore, incorporating new water management technologies into water supply systems has been proven to improve water supply from financial, political, and socioeconomic perspectives. The development of these technologies provides flexibility to the

[3]https://data.worldbank.org/indicator/SP.POP.GROW?locations=NG

water supply system and effective means of risk management [10].

IV. The SWAMS Approach

The SWAMS approach takes inspiration from the integrated architecture [13], previously applied to the demand response provisioning for Smart Grid. The proposed service-oriented approach has been meticulously modified to accommodate the peculiarity and context of the current water resource management in Nigeria. The approach is based on majorly on the flex-offer concept [12] and the water management/distribution Structure. The intention is to integrate both concepts into a single unified architecture that will discussed in the subsequent section.

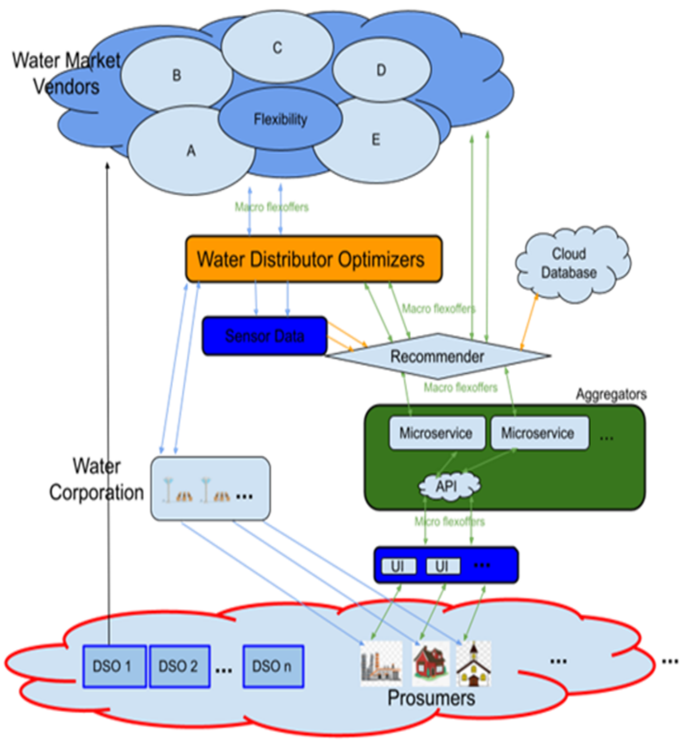

Fig. 1. Water Management/Distribution Structure (*Adapted from [11]*)

A. Flex-offer Concept and Water Management Structure

Flex-offer is a concept that allows exposing demand and supply loads with associated flexibilities in time and amount for water trading, load balancing, and other use-cases. Flex-offers are generic entities, and can accommodate various types of consumers; Industrial Consumers (e.g, factories, office complex, etc) and Domestic Consumers (household usage) and producers (water corporations). In this case, we anticipated that water management resources will be centrally managed by dedicated government agencies, irrespective of privately or publicly-owned water sources. This proposal also takes into consideration that owners of private sources of water such as pumped wells and boreholes will benefit from government incentives based on the unit of water produced over a period of time.

In the Nigeria water management context, flex-offer approach require entities such as water market vendors, water consumers, aggregators,distributor optimiser, and recommender. The sensor attached to each water consumption node collects data on volume of water usage, and transform this to actual domestic or industrial water request using the flex-offers. Specific information relating to the history and device profile of the consumption node is contained within the flex-offers. The consumption node represents the water mains that are located close to water users, which also supply water to individual households.

To better describe the flex-offer concept from the user's perspective, a specific amount of water required for consumption, the duration(specifying the earliest start time and latest end time), and the price (in Nigerian Naira) per unit of litre will need to be specified. A good example can be in form of "Consumer need 100 litres over 2 hours between 5AM and 10AM, for a price of 10Naira/litre". The exact quantity of water demand is expressed in variable-length intervals, during which minimum and maximum water amounts are additionally specified . These variations are used to better accommodate a real situation, where the water consumption exhibits variations in adjacent time intervals.

Similarly, flex-offers also applies to the supply management in this context, e.g., "water vendor can deliver between 100 and 200 litres, between 1 PM and 5 PM, for a price of 10Naira/litre". Note that the amount of water represented in flex-offers can be small, e.g., for household use, or large, e.g., for industry.

For managing flex-offers, we propose the use of the Virtual water management/distribution structure (see Fig. 2) that provides a set of Service Oriented Architecture (SOA) interfaces, interconnects several (existing and new) Water Market Actors as elaborated below.

- *Prosumers* are entities, aka. Distributed Water Resources (DWRs) that can both consume and produce water. Examples of *Prosumers* are residential houses, commercial buildings, manufacturing, and process industries. These generate flex-offers and consume schedules..
- *Aggregators* are specialized entities capable of aggregating several (micro) flex-offers from Prosumers into larger (macro) flex-offers. It is also capable of disaggregating (macro) flex-offer schedules, e.g., received from the Water Market. An aggregator might be an integrated part of Water Distributor Optimisers (WDOs).
- *Recommender* is powered by an Analytic Engine with a separate interface that uses sensors to gather data relating to water demanded by consumers and water supplied over a period of time and applies a learning algorithm to place demand automatically when the consumer has failed to place his/her own demand and backup the data into a cloud database for future inferencing.
- *Water Distributor Optimisers* are water market entities that secure the balance in a logical sub-domain within the

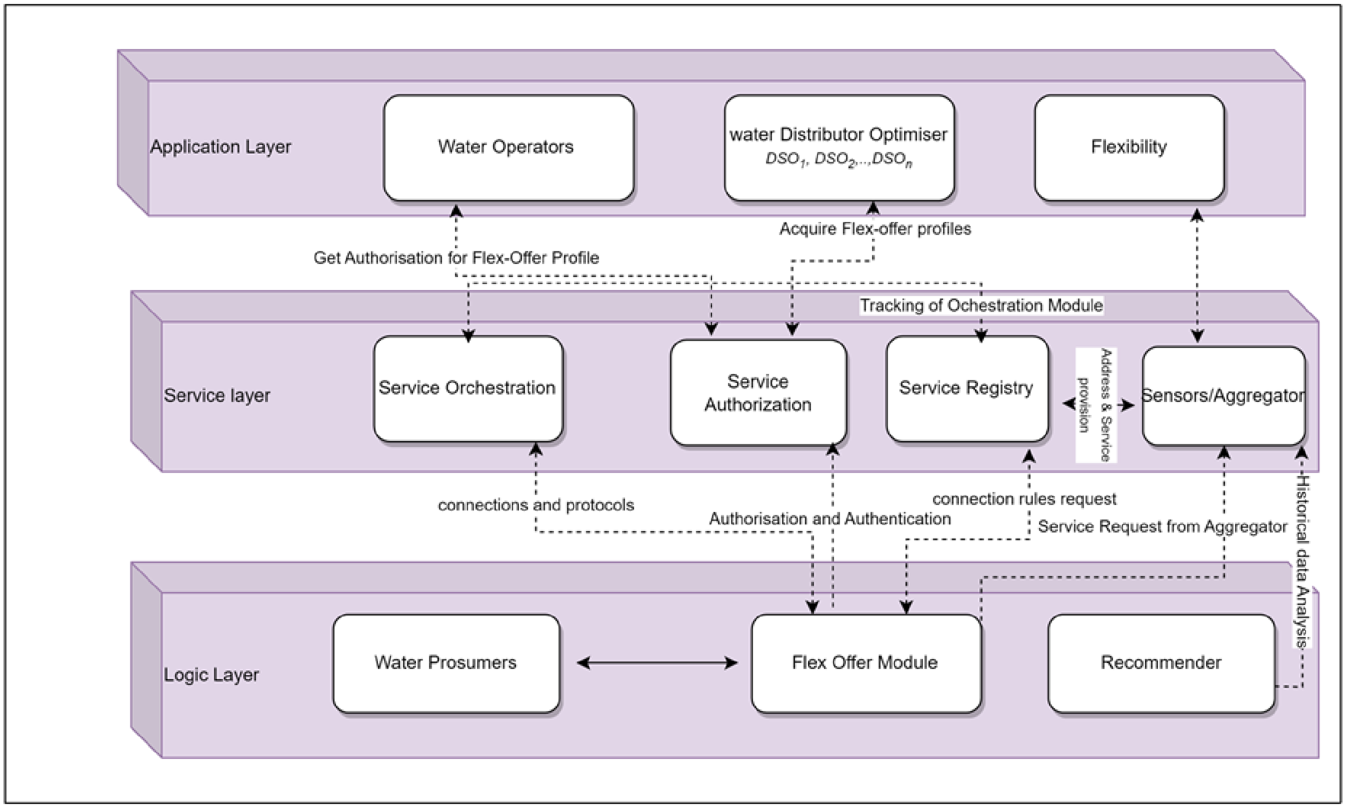

Fig. 2. Layered SWAMS Architecture.

grid, i.e, ensure that consumption is equal to production. It utilizes the aggregated flex-offers from Aggregators for an internal water balancing and placing flex-offers on a so-called Flexibility Market for trading with other WDOs or Distribution System Operators (DSOs).

- *Distribution System Operators (DSO)* are entities responsible for uninterrupted supply of water in the distribution grid.
- *Flexibilities* represented by flex-offers and offered on the market enable DSOs new ways to smoothen loads on the distribution grid by buying and then controlling the timing of loads.
- *Flexibility Market* offers WDOs and DSOs the common place for trading flex-offers. It minimizes total costs by scheduling water loads while respecting the constraints contained in the flex-offers (minimum/maximum quantity, earliest/latest start of water consumption, etc.). The Flexibility Market may also interface other traditional markets of water.

B. Architecture and Component Interactions

In attempt to realise the distributed service oriented approach for SWAMS , a 3-layered software architecture presented in figure 2 has been proposed. The architecture follows a bottom-up approach consisting of Application layer, Service layer and the Logic layer. The logic layer represent the heart of the framework driving the interactions between the other components and the upper layers. It is designed to run on a number of core services to achieve the service-oriented functionalities.

Within the logic layer is the Flex-offer module that contains the relevant agents or collection of software components that is needed to implement the flex-offer concepts. The flex-offer agent within the flex-offer module relies heavily on the set of micro-services provided in the service layer of the architecture. The Flex-offer agent is responsible for information acquisition of water consumption rate/profiles related to specific node, generate the appropriate flex-offer, and coordinate the implementation of the generated flex-offer. The Flex-offer module is also designed to support the remote connection through a network with the water meter system at the individual nodes, and with other external relevant services and applications. The Flex-offer agent can initiate a requests for connection from the service registry to get the address of various services in the service layer in order to enable access. For example, the address of the sensor/Aggregator module is obtained by registering the Flex-offer agent within the service registry. This will equally allow the Service Orchestration module to be available to facilitate the matching of aggregators with the connection protocols within this module.

Service Orchestration Module is solely responsible for the storage of all relevant profiles and metadata relating to all services produced, the features of each service and where each service originates from. Similar to the aggregator, the Flex-offer agent can retrieve the address of this module from the service registry. To simplify the service discovery of this module, a node or operator from the water market will need to initiate communication with the service registry and get registered while updating the service registry with its own specific address and the type of service it can offer. Furthermore, the Orchestration module contains specific information relating to the connection rules and configurations, which permits the easy identification of the address most suitable Aggregator for the system coordinating the module itself.

Most Security services will be guaranteed through the Service authorization module. The module also provides the authorisation and authentication service to the Flex-offer module. The Water Operator initially establish a contract with the Prosumers and is responsible for managing the Authorisation module. All data exchange between this module is encrypted using the appropriate key management system. This allow the Flex-offer and the Aggregator module to be able to securely get the required security certificates through the Service Authorisation Module.

Finally, the Application Layer is the topmost layer of the architecture that is next to the water market. It consist of the interface and modules for the Water operators, Water Distributor Optimiser, and the flexibility module. The operation of each module is intentionally decoupled from other modules in the layer to help facilitate the deployment of the distributed services and adopted strategies for optimised water resource management. The water operator are the water Distribution System operators and can often rely on the water Distributor optimiser to guarantee to the appropriate flex-offers. Both the water operator and water Distributor Optimiser will first require authorisation from the Service Authorisation module from the service layer before each can have access to the flex-offer profiles. The flexibility takes advantage of the rich set of data provided by sensor and aggregator module to suggest the most suitable plan for water consumption.

V. Conclusions

In this work an approach involving the use of service oriented to smart water management systems has been proposed. The proposal established a clear design pathway for developing a technology that can actualise the successful implementation of the water management policy in Nigeria.

Managing dynamic and diverse water resources and services, especially within decentralized ownership structures, presents distinctive challenges in representation, allocation, and administration within the water distribution system. This study by using the flex-offer concept (taken from the energy world) proposes a tailored architecture for optimizing water distribution networks. Specifically, it enables any water-related infrastructure or device with flexibility in its water usage timing to align with the overall requirements of the water supply network and benefit from efficient water distribution.

This concept finds practical application within water distribution projects, akin to the TotalFlex project in the energy sector. Integrated into a versatile multiprotocol platform, the flex-offer concept becomes an integral component of the SWAMS approach, supporting crucial services for the establishment of a Service-Oriented Water Distribution System. The paper outlines how this framework can be effectively utilized to meet the unique demands of the flex-offer concept, ensuring optimal water allocation.

Furthermore, a flexible and highly adaptable architecture is proposed for the implementation of the Water Market in Nigeria. This involves pivotal actors such as Water Operators, Aggregators and Flex-Offer Agents. The Water Aggregator plays a central role in receiving flex-offers related to specific water usage scenarios, aggregating them, and strategically placing the requests within the water distribution network. Meanwhile, the Flex-Offer Agent generates flex-offers based on data from water-related devices and prediction models, sending them to the Water Aggregator and executing schedules aligned with the overarching water distribution strategy.

Acknowledgment

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