

A Software Engineering Approach to Implementation of SDG 6 in Adum-Aiona Community of Nigeria

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Abstract. In this work, we adopt an engineering problem-solving approach to the open-air defecation health problem. We model social and behaviour change communication intervention among other components of a water-sanitation-hygiene (WASH) system in response to the menace of open defecation in rural and urban communities globally. We also used experimental outcomes to show empirically that patterns in data captured in the WASH process could be learnt for effective decision making using deep learning neural networks as an intelligent software engineering technique. Eradicating open defecation is one of the indicators used for measuring progress made towards the attainment of Sustainable Development Goal 6 (SDG 6). We use the Adum-Aiona community in Nigeria as case study in designing community-based total sanitation programs using software model-driven engineering approaches with the aim of promoting their implementation. This is because even when toilets and other sanitary infrastructure are available, behavior and social change efforts are needed to promote their large-scale use. Also, we demonstrate that besides being used to model software systems, computational models (software architecture) are useful in documenting and promoting understanding of concepts in virtually all fields of human endeavour. Our motivation is that enhancing understanding of open defecation through software modelling would help SDG 6 implementors and actors attain set sanitation goals in both rural and urban communities towards the SDGs target year 2030.

Keywords: Adum-Aiona · Behaviour change · Open defecation · Sustainable Development Goal 6 · Software models · Water-sanitation-hygiene

1 Introduction

Open defecation is an age-long concern which researchers and health practitioners have intensified efforts to curb. This work uses software architecture to proffer solution to the open defecation problem, a public health event of global concern. Software architecture

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does not only enhance documentation of system requirements but promote understanding of concepts among stakeholders for enhanced collaboration and participation in projects. A community-led total sanitation programme aimed at ending open defecation is a comprehensive water-sanitation-hygiene system whose interactive components need to be properly documented and understood by Sustainable Development Goals (SDGs) actors and implementors even at the rural settings for success attainment of SDG 6 by the year 2030.

Open defecation remains a public health event of international concerns as many urban and rural areas particularly in developing economies are battling to curb the menace [1]. Studies have shown that the provision of toilets and other sanitation ware by government, non-state actors and public-spirited individuals may not solve the problem as there is the challenge of social and behaviour change [2]. This implies that community-based water-sanitation-hygiene (WASH) system needs to be comprehensive and adaptive. WASH doubles as a public health foundation and galvanizer of several aspects of development. Though SDG 6 aims high, each step geared at better WASH services is crucial. It would help greater number of people to eradicate severe poverty just as it improves health and well-being of all.

In this study, we examine the open defecation problem in Adum-Aiona community of Nigeria and model a WASH system in response using software architecture. Our aim is to promote understanding of the problem among stakeholders so as to facilitate the implementation of a community-led response system. Adum-Aiona is a rural setting [3]. Particularly, we identify viable SDG actors and implementors in Adum-Aiona to include individuals, religious bodies, traditional institutions, health facility whose actions within the WASH framework could significantly impact on the open defecation free campaign and drastically reduce associated health risks. These stakeholders are their roles are captured in Fig. 1.

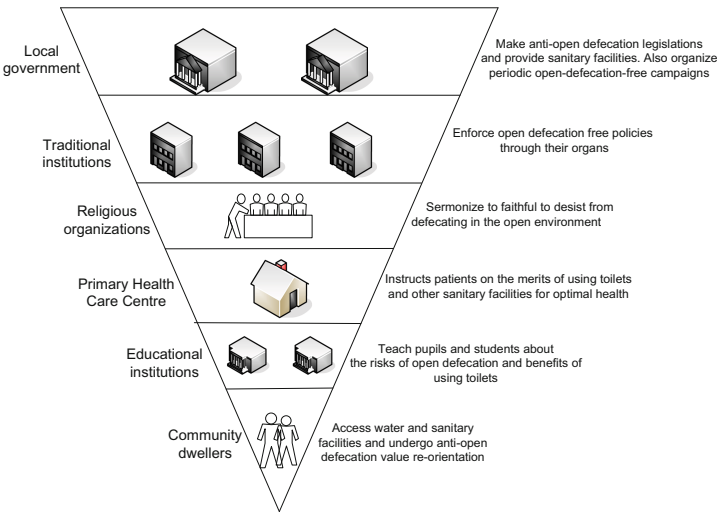

Fig. 1. Community-led WASH System actors and implementors

The model-driven Adum-Aiona WASH system would complement government's efforts towards eradicating open defecation by year 2025 as contained in the Nigeria's national open defecation-free plan [4]. Peculiar natural features of Adum-Aiona that need to harnessed for the availability and sustainable management of water and sanitation in line with SDG 6 are its lush vegetation and several bodies of water, otherwise called streams. These streams are natural spring waters which are clean, cool and pure. Hence, water purification as a functional requirement in some other climes, would be absent in Adum-Aiona's WASH system.

Studies carried out in other low-income communities in Indonesia, India, Malawi [5–7] corroborate the fact that social and behaviour change [2] are key to ensuring that no one is left behind in the global fight against open defecation and the realization of SDG 6 by target year 2030. Findings revealed that mere provision of sanitary infrastructure like toilets does not dissuade people's disposition towards open defecation. Rather, infrastructure provision needs to be complimented by comprehensive sensitization and mobilization strategies against the age-long practice. The anti-open defecation campaigns should be adaptive, taking into cognizance the peculiarities of the locals.

2 Background and Related Work

2.1 Software Architecture and Concept Understanding

Like mathematical models, the use of computational models for documenting and understanding concepts is gaining ground. The use of software architecture offers incisive and in-depth analysis of concept. Thereby enhancing stakeholders understanding and cooperation for sustainable project implementation.

We show in this work that software architecture as a model for providing incisive and in-depth analysis of concept is not the exclusive preserve of software projects but is applicable in enhancing implementation of projects in all fields of endeavor by providing clear-cut and intuitive designs.

2.2 Open Defecation and Sustainable Development Goal 6 (SDG 6)

The SDG 6 aims at ensuring availability and sustainable management of water and sanitation for all by the year 2030. One of the targets is to ensure all have access to sufficient and fair sanitation and hygiene and eradicate open defecation with priority attention given to women, girls and vulnerable people [8]. This is to be measured by proportion of the populace that use safely managed sanitation services such as handwashing facility along with soap and water. Clearly, in many rural and urban communities in developing economies, this index is failing as the widespread practice of open defecation negates these best practices. This often degenerates in to public health emergencies, fueling epidemics and high mortality rate. As observed by [9], achieving open-defecation-free-society requires more than the provision of sanitation and hygiene facilities. There is need for massive campaign and public advocacy against the practice which has assumed the dimension of a culture in many communities in developing

countries [10]. This is why behavioural and social change management becomes a critical component of any successful WASH system. In modelling the WASH system for the Adum-Aiona community using component-based n-tier architecture, prominent attention is given to the Behaviour/Social Change component with a view to sensitizing all SDG 6 stakeholders on the importance of behaviour change in the anti-open defecation drive.

2.3 WASH System and Open Defecation in Adum-Aiona Community

Adum-Aiona residents have equitable access to safe and affordable drinking water in line with SDG 6.1. This is because of the prevalence of several streams within the community that naturally produce cool, pure and clean spring water. However, this is being threatened by the widespread practice of open defecation in the community. An effective and efficient WASH system that is anti-open defecation needs infrastructure such as water, toilets, among others. The community-based approach to the menace as advocated in this study examines water resources in Adum-Aiona viz-a-viz the open defecation problem. Using ontological analysis, the streams and the various settlements in Adum-Aiona community that patronize them are illustrated in Fig. 2 below.

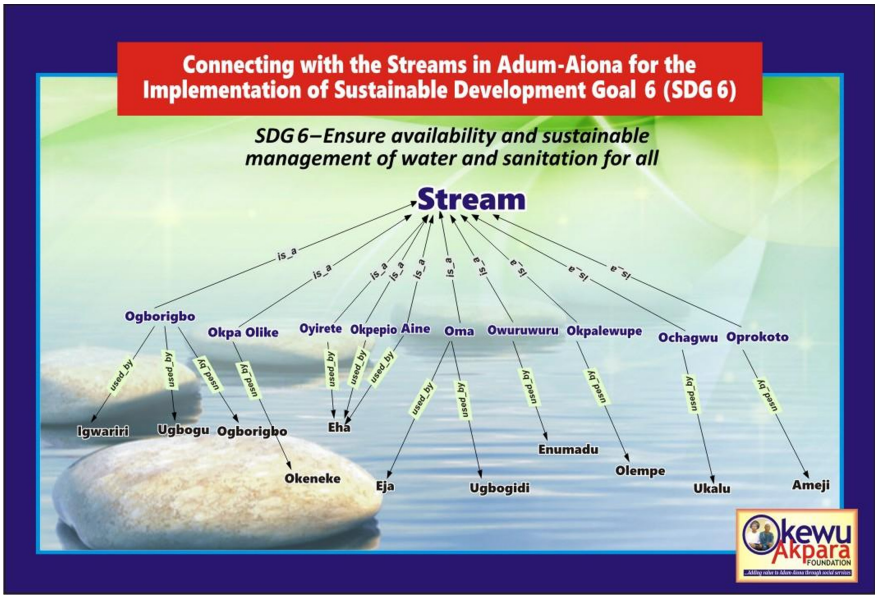

Fig. 2. Bodies of water in Adum-Aiona and patronizing settlements (Source: Okewu Akpara Foundation)

The verification, validation and documentation of these bodies of water in Adum-Aiona, a clan of Orokam in Benue State of Nigeria is to correct the wrongly held notion in the literature and among Orokam indigenes that Enumabia is the only body of water

in Orokam district of Benue State [11]. Our study revealed that patronage is largely based on nearness of households in each settlement to a particular stream. Water is fetched from these streams majorly for cooking, agricultural activities, and for personal and environmental hygiene practices such as bathing, washing of cooking/food utensils. The use of water for toileting is still very unpopular as open defecation has assumed the status of a culture. This is the problem this study set out to address. Even with the provision of toilet facilities and hand-washing stations, value re-orientation through massive enlightenment on the health risks of open defecation is required. Beside the fact that open-air defecation does not encourage hand-wasting after excretion, human waste can be washed into the streams, making the community prone to diseases.

2.4 Related Works

Previous works on the implementation of software systems for global WASH initiatives are as follows.

In [4], it was stated that the Nigerian Federal Ministry of Water Resources is working with communities, development agencies, civil society, government at subnational levels and private sector to curb the scourge of open defecation. The work revealed that Nigeria has about 46 million people practicing open defecation, one of the nations in the world with the highest number of people engaged in the practice. Besides its negative impact on health and education of the populace, it contributed to the inability of the country to meet the Millennium Development Goal (MDG) target. In tandem with the global campaign for ending open defecation by the United Nation, an initiative was launched tagged "Making Nigeria Open Defecation Free by 2025: A National Roadmap". The Roadmap advocates different approaches such as Community-Led Total Sanitation; capacity development; provision of sanitation facilities in public places; promotion of improved technology options through sanitation marketing; creating enabling environment and coordination mechanism; and promotional and media campaigns, Among others, a multi-sectoral partnership between government, development partners and the private sector would be established empower rural dwellers such as Adum-Aiona dwellers in the provision of adequate water supply and sanitation services. However, the work did not explore the possibility of using software models to document and promoting understanding among stakeholders as advocated in our present study.

The authors in [12] focused on low sanitation coverage figures in the developing world. They argued that only sanitation hardware is not sufficient but needs to be complemented by sanitation software. While toilets and washing facilities constitute hardware, they refer to their acceptance by communities and proper usage as software. The work emphasized that except there is proper hygiene practices in homes and community at large, the expected impact of water and sanitation services remains a mirage. Hence, efforts are being made by health practitioners to reduce both the number of people without access to toilet as well as reduce the large number who don't use available facilities hygienically. The software approach targets change in behaviour and creation of service demands for the hardware sanitary facilities. The critical stakeholder targeted for open-defecation-free society include households, individuals, communities,

organizations and institutions who are engaged in development programmes for social/behavioural change. In any case, the work did not specify how software engineering models (software architecture) could be used for documenting and enhancing understanding of SDG 6 actors and implementors about WASH system components as done in this paper.

In [13], it noted that Informationa and Communications Technology (ICT) could be used to bridge the information gap in the WASH sector and there solve several of the problems confronting it. The authors specifically observed that mobile phones are common in developing countries and could be harnessed for this purpose, thus promoting the mWASH concept. The study identified the challenges in the WASH sector to include lack of education on safe hygiene behaviours, inability of the poor to access basic water and sanitation services, as well as education about safe hygiene behaviors, high failur e rate of water and sanitation projects, unreliabe and poor quality of water and sanitation services, challenges of over-extraction, urbanization, pollution and climate change facing water systems sustainability globally. With better use of information by stakeholders, these challenges could be addressed. Actors such as the populace, non-state actors, governments need information for better management of water supply and enthrenching good sanitation/hygiene practices. The mWASH initiative through mobile phones with mobile software applications makes the collection, aggregation, and analysis of data WASH-related data from remote regions easy. Hence ICTs can address existing information gap in the WASH sector by the transformation of the process of data generation, communication, and sharing. Already, mobile phones are handy tools for data collection and dissemination in verticlas like health, agriculture, socio-economic development, disaster relief, and natural resource management. Though the paper stressed how software simulation (mobile application) is used to enhance WASH sector, it did not emphasized the role of software model-driven engineering in documenting and promoting understanding of concepts among stakeholders, the primary focus of our present study.

The study by [14] explored the use of Internet of Things (IoT) as one of the new development in ICT in the WASH sector of South Africa. The researchers opined that IoT could be used to address disease burden and improve quality of life since it aids the management of water, sanitation and hygiene. The technology integrates both digital and physical worlds, culminating in new services that could useful in various sectors, WASH inclusive. Already, the use of IoT in WASH context has been demonstrated by a system that uses accelerometers in water lever hand pumps to measure both the status and level of utilization a hand pump. This offers near-real time insight into the device operational status for prompt and better maintenance. The work however observed that there is limited deployment of the technology for rendering WASH services in South Africa. It was established that IoT could enhance the provision, monitoring and evaluation of WASH services just as it is useful in regulation and enforcement. Nonetheless, the report did not emphasize the role of model-driven engineering in the WASH sector as we do in this current study.

The paper of [15] emphasized the use of computer software for enhancing the sanitation component of WASH. The study proposed a sustainable sanitation management tool for decision making after reviewing ecological alternatives of small and isolated communities in Brazil. The authors opined that household-based worldwide range of technical sanitation guidelines could be connected using software with database to generate a single reference. This would promote resource-oriented decision making with respect to sanitation. A sanitation management tool was therefore developed whose outcome indicates that decision making process could be enhanced to choose sustainable sanitation solutions. The improved decision making also enhances sustainable maintenance and operational options of the systems. Other uses of the proposed tool include assisting local technicians, designers, engineering students, environmental licensing agencies, and elaboration of municipal sanitation plans. The software is applicable to other management tool. Nonetheless, the work is not based on demonstrating how model-driven engineering aids the documentation of concept, and promotes understanding among stakeholders for participatory implementation.

3 Methodology

Our study focused on the open defecation problem in rural settings. Though a public health emergency of international concern, the phenomenon is more prevalent in rural and urban communities in low-income countries [16]. We reviewed literature on open defecation, water-sanitation-hygiene (WASH) and SDG 6 implementation, used Adum-Aiona community as a case study, gathered requirements of a comprehensive and adaptive WASH system, and model WASH system using software models (Use Case Diagram and N-tier Layered Architecture). We aim at leveraging on the power of software architecture for not just documentation of processes and procedures within a system but promoting understanding among the stakeholders for maximum cooperation and collaboration towards optimal system implementation [17]. We also performed experiments to show that intelligent software engineering techniques like deep learning neural networks could be used to detect patterns in existing health-related image data so as to predict future occurrences of health emergencies with high degree of accuracy for proactive management of imminent water-and-hygiene-related disease burden. For our experiments, we used the MNIST database of images of handwritten digits.

The Adum-Aiona community is endowed with bodies of water referred to as natural streams which are also natural springs. Spring water is clean, pure and cool and therefore the safest form of water [18]. Though springs are used for a range of human needs such as drinking water, irrigation, domestic water supply, mills, electricity generation, and navigation, the main uses in the rural community of Adum-Aiona are drinking, bathing, washing, cooking and agricultural production, In other climes, modern uses of springs include water for livestock, therapy, supply for bottled mineral water, fish hatcheries, and for recreational activities like swimming, fishing and floating [19].

3.1 Requirements Analysis

To build an adaptive and comprehensive WASH system that adequately respond to the anti-open defecation needs of the Adum-Aiona people, we used interview and observation as requirements engineering tools [20]. The requirements gathering process culminated in a list of functional and non-functional (quality) requirements of the proposed WASH system.

The functional requirements of the SDG 6 actors and implementor vis-à-vis open defecation free community include Water Sources Services, Sanitary Container Services, Toilet Infrastructure Services, Behaviour/Social Change Services, Monitoring/Evaluation Services shown as use cases in the Use Case diagram in Fig. 3 and actions in the Class diagram in Fig. 4.

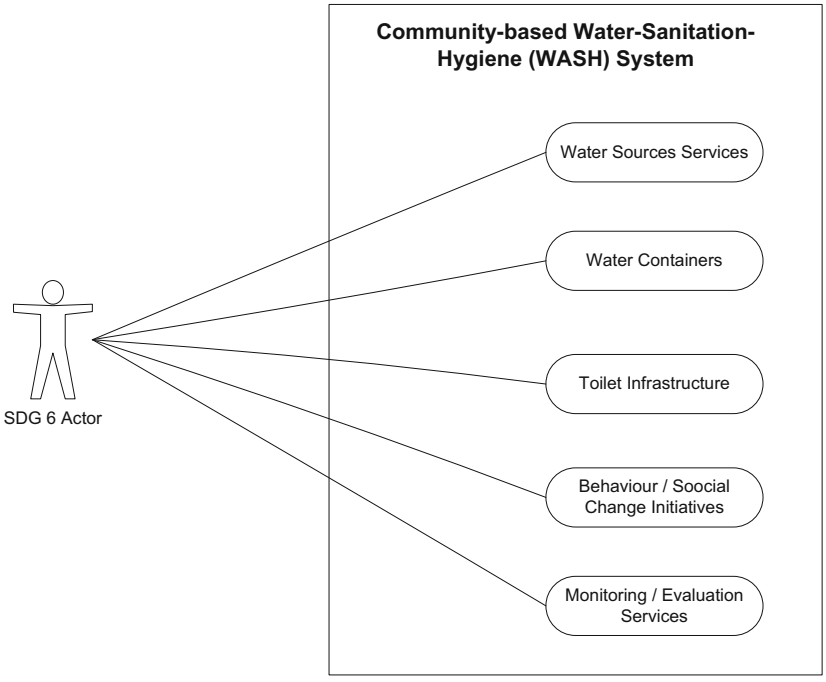

Fig. 3. Use Case Diagram showing functional requirements of proposed WASH system in Adum-Aiona

The SDG 6 actor is any of rural dwellers, primary healthcare centre, religious organization, educational institution, traditional institution and local government who have stake in the implementation of WASH in the Adum-Aiona community using available water and sanitary resources. They interrogate the WASH system with a view to getting vital and robust information for the performance of their statutory roles in the community-led sanitation and hygiene system directly targeted at combatting open defecation.

We model the actions of the SDG 6 actors and implementors in the rural community of Adum-Aiona using Class Diagram as illustrated in Fig. 4 below.

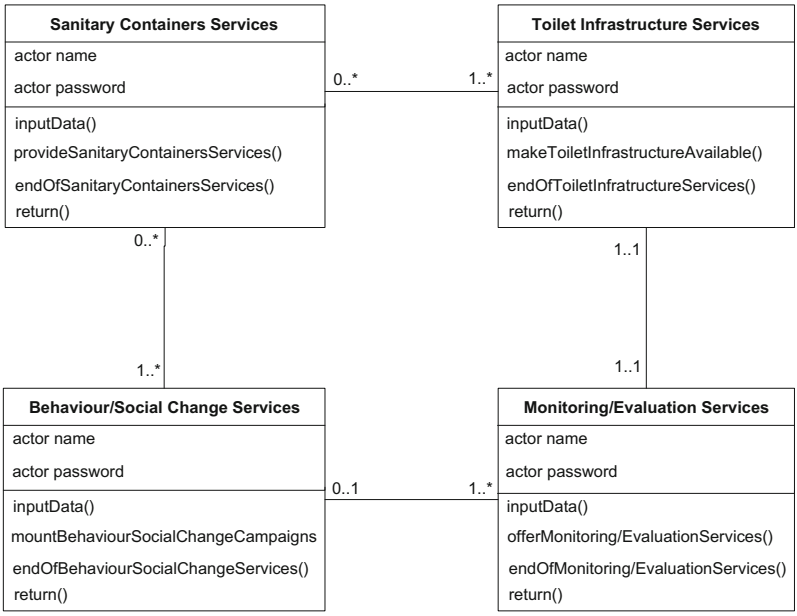

Fig. 4. Class Diagram for Adum-Aiona community-based WASH system

In the software analogy of the Adum-Aiona community-based WASH system shown in Fig. 3 above, there is need to keep track of SDG 6 actors and their actions. This is done by uniquely identifying each actor expressed as identity features (actor name and actor password). Practical services rendered by the open defecation free WASH system as denoted by use cases in Fig. 3 and actions/methods in Fig. 4 are outlined as follows:

Water Sources Services, Sanitary Container Services, Toilet Infrastructure Services, Behaviour/Social Change Services, Monitoring/Evaluation Services.

Water Sources Services () – every local in Adum-Aiona needs information on the various bodies of water available in the community for accessibility and usage for the purposes of sanitation and hygiene, among other uses.

Sanitary Container Services() – the system should offer services such as provision of water containers and accessories for enhancing preservation of water for sanitation and hygiene. Actors such as public-spirited individuals, the local government, schools and churches can assist in this area.

Toilet Infrastructure Services () – the proposed WASH system would provide toilet facilities such as well-maintained pit toilet (latrine), water system-based toilet, and hand-washing station.

Behaviour/Social Change Services () – Periodic anti-open defecation campaigns by the local government, religious organizations and primary healthcare centre in Adum-Aiona would go a long way in value re-orientation and advocacy for use of toilets.

Monitoring/Evaluation Services () – Traditional institutions should periodically review compliance with open defecation free policies and strengthen compliance enforcement.

[17] outlines the non-functional requirements (quality attributes) of systems such as WASH as including service availability, reliability, modifiability, adaptability, performance, scalability and portability.

3.2 System Design

Our computational metaphor of the community-led sanitation initiative uses an n-tier layered architecture to promote understanding of the components of an adaptive WASH system in a rural setting like Adum-Aiona. As shown in Fig. 5 below, the system is expected to hand-shake with components of external systems such as sources of water and people in neighbouring communities.

The three layers of the WASH system are Water Layer, Sanitation Layer and Hygiene Layer (Fig. 5). The water layer has two compartments – bodies of water in the Adum-Aiona community and water management services. The components of the Bodies of Water compartment are largely streams which are natural springs which are characterized in the literature as clean, pure and cool water [18]. They include ogborigbo, oprokoto, oma, okpalewupe, okpa-olike, okpepio, owururu, okpecho, ochagwu, Oyirete, Idiri, and Aine. The streams and their names are a cultural heritage that need to be preserved for a sustainable community in line with the ideals of Sustainable Development Goal 11 (SDG 11). The Water Management Services compartment accommodates two components - Purification and Accessibility. Although purification of water is a necessity especially for sanitary and hygiene purposes, the

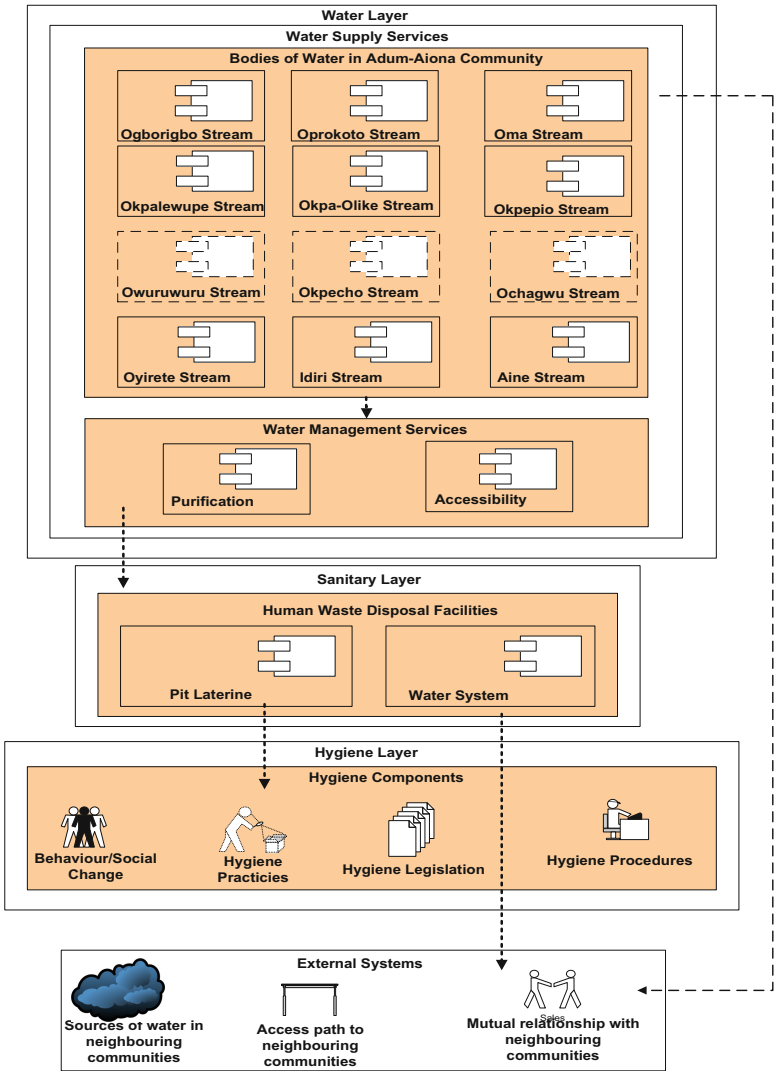

Fig. 5. WASH system n-tier Layered Architecture

spring water in Adum-Aiona may not need the purification process. However, for the purpose of applying the model in other climes whose sources of water may differ, water purification particularly in a rural setting involves among others, boiling, use of chemical and filtering. The Accessibility component offers sustainable management and access to water in line with SDG 6. It ensures that access to the bodies of water is guaranteed and the water beds adequately catered for. In Adum-Aiona, locals periodically clear bush paths leading to the streams while the Oprokoto stream has a bridge across it linking the neighbouring community of Okpoga as shown in Fig. 6 below despite the challenges of infrastructure financing and development in Nigeria [21, 22].



Fig. 6. The Oprokoto bridge in Adum-Aiona for accessibility and sustainable management of water

As posited by [10], provision of sanitary facilities alone would not suffice in the war against open defecation, given the level of illiteracy and ignorance in rural areas. The Hygiene Layer therefore contains the Behaviour/Social Change component that handles mass mobilization and awareness campaign on the health and economic risks of open-air defecation. This makes it incumbent on SDG 6 actors and implementors in Adum-Aiona to evolve value re-orientation strategies and mount sustainable campaigns for open defecation free advocacy among the locals. When no one is left behind, greater success would be recorded in SDG 6 implementation.

3.3 Experimentation

Besides using the power of software architecture to model a water-sanitation-hygiene system for a rural community, we performed software simulation using image and deep learning libraries. The essence of the software engineering modelling is for sharing knowledge among SDG 6 stakeholders and promoting understanding of what it takes for successful anti-open defecation campaign while the software simulation is to enable policy makers and health practitioners know the importance of applying predictive analytics to existing water-and-hygiene-related data for robust and reliable decision making. We applied deep neural networks (convolutional neural networks) to MNIST dataset using Python deep learning libraries (Keras and Tensorflow). The neural network algorithm used for the 2 separate experiments is Adam, a popular algorithm for training deep neural networks [23]. Our choice of Adam is hinged on the fact that it is an efficient stochastic gradient descent algorithm that offers good results in a vast range of problems; also, it tunes itself automatically [23]. The dataset was partitioned into training data and testing data, respectively containing 60,000 and 10,000 images. Each image is represented by 784 pixels. In each experiment, 10 iterations were observed.

4 Results and Interpretations

The results of the experiments are outlined in Table 1 as follows:

Table 1. Results of experiments

	Experiment 1	Experiment 2
Optimizer	Adam	Adam
Training data shape (dimension)	(60000, 28, 28, 1)	(60000, 28, 28, 1)
Number of images in training dataset	60,000	60,000
Number of images in testing dataset	10,000	10,000
Number of epochs (iterations)	10	10
Mean Accuracy	98.2%	98.3%

Though the Python code generated other metrics such as Loss in the output of the experiments, our major concern was the Accuracy metrics. This metrics shows the extent our model was able to map the inputs into output.

Since the accuracy output differs from one iteration to another, we calculated the average accuracy which is shown above as 'Mean Accuracy'. While experiment 1 has mean accuracy of 98.2%, that of experiment 2 is 98.3%. The empirical implication is that our neural network model has above 98% accurate prediction capacity. In other words, above 98% of all instances of health-related issues that require forecasting for proactive management would be predicted correctly. This is an encouraging result that can enhance efficient utilization of resources for the attainment of the SDG 6 goal by target year 2030.

The experiments also proved that Neural network is a stochastic algorithm. This means that when the same algorithm is applied to same dataset in different experiments, different results are obtained as a result of the application of different skill any time the code is run. This is not a bug but a feature of neural networks [24]. We observed that while both experiments used the same MNIST dataset with Adam stochastic algorithm as the only optimizer, the outcomes were different for corresponding iterations in both experiments.

5 Implications of a Community-Based WASH System and Predictive Analytics for Implementation of SDG 6

The SDGs aim at carrying everyone along for a future we desire. Poor health means low productivity. Studies have shown that open defecation increases global burden of diseases. However, efficient and effective sanitation and hygiene practices could be used to solve the problem of open defecation. As a result, water and sanitation are articulated in SDG 6 for the purpose of addressing this global health risk.

Even though we think water and sanitation as global solution, the strategies adopted have to be community-based for inclusivity. The bottom-up approach involves water-

sanitation-hygiene strategies that take into cognizance the peculiar water and sanitation needs of every community. There is also need to assess the social and behavioural disposition of locals to the phenomenon of open-air defecation in every community. For instance, while in developed climes many see open defecation as anti-social and anti-health, many in developing economies believe it is a normal lifestyle that does not need to be challenged.

Hence, this study used software architecture to document and promote understanding of strategic components of a community-led anti-open defecation WASH system. Also, the experiments revealed that applying predictive analytics to WASH-related data could generate robust information for proactive decision-making during health emergencies. The adaptive WASH system took into cognizance the Adum-Aiona community of Nigeria as a template for other communities. Among others, the proposed system integrated a behaviour/social change component in its n-tier layered architecture to underscore the complimentary role of value re-orientation in the fight against open defecation. Therefore, SDG 6 actors and implementors are sensitized on the need to focus on both physical infrastructure and social/behavioural rebirth for a comprehensive solution to the global health challenge and attainment of SDG 6 by the target year 2030.

6 Conclusion

Participatory implementation of SDG 6 is required and a software engineering modelling approach that documents, promotes understanding and elicit cooperation and collaboration among stakeholders is key. In this vision paper, we examined open defecation as an indicator of progress made towards the actualization of SDG 6. Our proposed system particularly draws attention to the significance of behaviour/social change as a vital component of any viable WASH system as provision of sanitary facilities alone is not sufficient.

Our study proved that software models are not only useful for developing software systems but are invaluable in documenting activities and enhancing stakeholders understanding of operations in any human field of endeavor. If implemented, the proposed WASH system would go a long way in addressing the global problem of open defecation as well as facilitating the actualization of SDG 6 by the target date of 2030.

Regrettably, even with the provision of sanitary facilities and availability of water, community-led sanitation and hygiene is suffering set setbacks as poverty, illiteracy and ignorance have made people to accept open defecation as a norm rather than exception [1, 10]. In future works, researchers should explore and close this gap by evolving adaptive and strategic value re-orientation strategies and interventions that help everyone internalize the fact that open defecation poses serious health risks and could reduce global productivity as diseases deplete human productive capacity.

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