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Sustainable Strategies for Solving Perennial Water Crisis in Enugu Using Infiltration/Sump Technology

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Abstract

Purpose: Perennial water crises is a monster that threatens the very essence of human existence globally. Efforts have been made to stamp out water crises by the provision of pipe borne water, artisanal well, etc but to no avail. Notwithstanding these efforts, a visit to the streets of Enugu showed the excruciating hardship faced by the people as a result of scarcity of portable water. This study aimed at determining the current condition of portable water supply, challenges to sustainable water supply as well as suitability and sustainability of harvesting portable water through infiltration/sump technology adaptation in solving Enugu metropolis water crises.

Methodology: The survey and experimental research methods were used. A total number of 48 water samples were aseptically collected from 3 points on a weekly basis. The points are A: from the flowing Asata River, B: from the infiltration sump and, C: from the locally fabricated water treatment plant. These samples were subjected to physical, chemical and biological analysis to determine the level of impurities, chemical and biological pollutants contained therein. Atomic Absorption Spectrophotometer (AAS) was used to determine the concentration of heavy metals in the water samples. Direct culture plate count was used to determine bacterial load while sample concentration method was used for the microscopic examination.

Findings: The results were presented in tables and analyzed with simple percentages. It was discovered that water supply to Enugu residents has been abysmally low compared to the Enugu State Water Corporation (ENSWC) installed capacity. Out of the six (6) years under study, the highest annual water production of 6,082,962 m^3 representing 12.62% of the installed capacity, supplied to the inhabitants of Enugu metropolis was achieved in the year 2018. The study discovered that the raw Asata River is contaminated with (a) heavy metals, (b) E. coli and Coliforms (c) debris, non-metallic contaminants etc. However, with the application of sump/infiltration technology and minimal treatment the river is a veritable and sustainable alternative to the epileptic pipe borne water supply from ENSWC to the inhabitants.

Recommendation: Adaptation and application of sump/infiltration smart indigenous water harvesting technology in solving the perennial water crisis in Enugu metropolis is recommended.

Keywords: *Sustainable Strategies, Perennial Water Crises, Infiltration/Sump Technology.*

1.0 Background to the Research

Water is an essential requirement of human and industrial developments and it is one of the most delicate part of the environment (Das & Acharga, 2003). In the last few decades, there has been a tremendous increase in the demand for freshwater due to rapid growth of population and the accelerated pace of industrialization (Ramakrishnaiah et al., 2009). For almost as long as humans have existed, they have engaged in water harvesting. The act of harvesting rainwater, floodwater and groundwater has been in practice for thousands of years, from the most rudimentary techniques to large and complex methods such as the roman aqueducts. For many cultures, water harvesting was an effective way to meet their water needs in a time when no other alternatives were available to them. This was mainly due to the fact that alternative sources of drinking water and water for agricultural purposes were not readily available.

Historically, many settlements have been situated in arid and semi-arid climates, such as the Middle East, Northern Africa, and Western Asia. These cultures were largely dependent on subsistence farming and there were few other opportunities to generate income. Water harvesting became widespread in many of these regions and although various methods were devised almost universally, each emerging culture established their unique way of collecting and diverting runoff for productive purposes (Prinz, 1996). In Enugu urban, water supply from the greater Enugu Water Supply Scheme is delivered to residents in a most intermittent manner (Enewaji, Eduputa & Okoye, 2016). This intermittent service is not as a result of the fact that the construction of the water scheme was originally deficient but rather due to lack of proper maintenance of the equipment at the head works, sitting of water sources and channels, as well as, heavy water losses from the water transmission and distribution lines.

The stated inefficiencies have resulted in the following problems among residents. First, is the absolute and relative water shortages in the residential sector between the amounts demanded and supplied most especially as a result of poor funding and damaged infrastructure. Second, the parlous water supply situation found in many parts of the town has forced residents to rely more on polluted water supply source (Udeze, 1998). Third, is the often reported case of motor accidents and occasional deaths involving children and women who daily fetch water by walking and crossing the high vehicular traffic streets on their way to and from water sources. Fourth, children and women who form a high percentage of the group that fetch water spend enormous amount of time and energy searching for it in the urban area (Ani, 1980).

The above are results of high water scarcity in the residential sector of Enugu. Despite some intervention programmes by previous administrations, water scarcity still raises its ugly head (Enewaji et al., 2016). The summary of the reasons for the water scarcity could be stated as the growing disparity between decreasing effective supply and increasing demand for water. A necessary first step towards realizing the degree of this disparity is the knowledge of total amount of water demanded and supplied in the sector and an assessment of the factors involved, management practices as well as application of indigenous technology.

1.1 Statement of the Problem

Some school of thought in Nigeria has described portable water as "Liquid gold" due to its scarcity in most parts of the country especially Enugu (Abubakar, 2022**)**. On the contrary, the United Nations General Assembly on 28th July 2010 through Resolution 64/292 explicitly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realization of all human right. The UN explained that the human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses. Unfortunately, irrespective of the huge fresh water bodies available in the state, scarcity of portable water has killed the tenets and aspirations of this universal declaration of human right to water in Enugu. As a result, the perennial water crisis in Enugu has thrown up lots of questions: especially, as most of the agencies saddled with provision of this essential commodity to the populace has failed resulting in absolute and relative water shortages between amounts demanded and supplied. Enugu urban is beset with perennial water crises as a result of poor funding, damaged infrastructure, lack of maintenance culture, distance of water sources to the points of need, losses from transmission and distribution lines, white elephant projects as well as lack of indigenous technology.

1.2 Objectives of the Study

1. To determine the current condition of portable water supply in Enugu Metropolis.
2. To identify challenges of sustainable supply of portable water in Enugu Metropolis.
3. To determine the sustainability and suitability of harvesting portable water through infiltration/sump technology adaptation in solving Enugu metropolis water crises.

1.3 Research Questions

1. What is the current condition of portable water supply in Enugu Metropolis?
2. What are the challenges to sustainable portable water supply in Enugu Metropolis?
3. To what extent is infiltration/sump technology adaptation sustainable and suitable for harvesting portable water in Enugu Metropolis?

2.0 Literature Review

Human would have inhabited other planets if not for the absence of portable water. Scientist and space explorers have made concerted efforts at finding water in other planets to no avail. Earth has remained the only planet so blessed with huge fresh water bodies for man's utilization. However, of the about 70% of the earth surface that is covered with water, only 3% of the earth's water is fresh. Meanwhile 2.5% of the earth's fresh water is unavailable: locked up in glaciers, polar ice caps, atmosphere, and soil; highly polluted; or lies too far under the earth's surface to be extracted at an affordable cost. Only 0.5% of the earth's fresh water is available for human's use (Glavan, 2018). This quantity of fresh water is abysmally low for human's use when compared to its demand and supply chain.

Sustainable supply of adequate, clean and portable water has remained one of man's unending mirages the world over. The water supply and sanitation facility for each person must be continuous and sufficient for personal and domestic uses. These uses ordinarily include drinking, personal sanitation, washing of clothes, food preparation and personal and household hygiene. According to the World Health Organization (WHO), between 50 and 100 litres of water per person per day are needed to ensure that most basic needs are met and few health concerns arise. In the USA, Europe and Asia, the human need for portable water has not been completely met Chukwurah (2018). Though most of the advanced, transitional, and developing counties could be said to have achieved some level of sustainability, the Nigerian scenario has kept downwards slope. Olawale (2016) stated that acute water shortage is related to the challenge of meeting up with the water demands of a metropolis which is experiencing geometrical population and industrial growth.

According to World Bank from 2000-2015, access to water supply in Nigeria increased from 55% in 2000 to 69% in 2015, largely in line with regional trends. On the other hand, access to improved sanitation; which saw no large-scale improvement efforts by government or development partners, decreased from 34 to 29%. Since 1990, 3.3 million people in Nigeria have gained access to an improved water source per year. Current estimates by World Bank

(2017) showed that 42% of the population still lack access to safe water and 68% lack access to improved sanitation. On the contrary Ezenwaji et al., (2016) indicated that percentage of water demand achieved by supply of residential demand and supply projection for Enugu Urban Area from 2010-2015 has been on a consistent decline showing 52%, 51%, 49%, 47%, 46% and 44% respectively.

The National Population Commission (NPC) 2016, population of Enugu metropolis (Enugu East, Enugu North and Enugu South) Local Government Areas stood at seven hundred and fifty thousand (750,000) inhabitants with a projection of over one million (1,000,000) people by the year 2020 (NPC, 2016). This meant adding more pressure to the already over stretched water infrastructure in Enugu urban. Nigeria's Federal Constitution accords authority over water supply services to the States. The national government focuses on policy development, coordination, and monitoring with the states mandated to provide water supply and sanitation services. Key institutions include: The Federal Ministry of Water Resources (FMWR), River Basin Development Authority (RBDA), State Water Agencies (SWA).

The Federal Ministry of Water Resources (FMWR) formulates and delivers policy, data collection, monitoring and co-ordination of water resources development at national level. River Basin Development Authorities (12 in number) develop, operate and manage the reservoirs for the supply of bulk water for domestic among other uses in their areas of jurisdiction. Meanwhile, the State Water Agencies (36 in number plus a Federal Capital Territory) – responsible for urban semi-urban and rural water supplies coverage of SWA's within their respective areas of responsibility varies from less than 20% of the population in some state such as to over 80% in others. In some states separate agencies called State Rural Water Supply and Sanitation Agencies (RWASSAs) exist for rural water supply. Several states also have established agencies for small towns namely known as state Small Town Water Supply and Sanitation Agencies (STWSSAs).

The National Water Policy (NWP), first drafted in 2004, was subject to delays and revisions before receiving sufficient priority to be approved in September 2016. The policy requires government to collectively appropriate funds for water supply and sanitation programs of an amount equivalent to not less than 15% of total annual appropriations. The document also defines institutional structures including: Water sanitation division within the department of water supply in the Ministry of water resources, State steering committees on water and sanitation and the Local government steering committees on water and sanitation. Unfortunately, despite this institutional structures, water scarcity continued to rear its ugly head in Enugu State.

2.1 Concept of Water Harvesting

Water Harvesting (WH) has been defined as the collection of runoff for its productive use (Critchley & Siegert, 1991). This initial definition is too general but has been more accurately defined as the process of collecting and concentrating water from runoff into a run-on area where the collected water is either directly applied to cropping area or stored in the soil profile for immediate use by the crop (Prinz & Singh, 2000). However, it is pertinent to note that WH is not only executable from runoffs in the real scientific world like ours, where advancement in water technology has assumed phenomenal dimensions. Water can be harvested from various sources in addition to runoffs viz; direct from the atmosphere, from rivers and streams, from surface and underground aquifer and etc. In most cases, the nature of the water source and the degree of purity required, determines the type of technology and or method of WH to be employed. The more complex and advanced the technology to be employed, the more the financial demand. Invariably, where the nature of water source is not complex but easily accessible and the level of impurity is not very high, very simple and indigenous technology would suffice.

As such WH has been employed for thousands of years in irrigation and to restore productivity to the land, provide drinking water (to both humans and animals), minimize risk in drought prone areas, increase groundwater recharge, and reduces storm water discharge (Rainwater Harvesting, 2006). Today, WH is used for crop irrigation, groundwater recharge and water storage for future use in drought prone areas. Water plays the most critical roles in our everyday lives, water is needed for basic human needs, such as drinking, cooking, sanitation and hygiene, productive activities like religious ceremonies, environmental enhancement and aesthetic values (Mokgope & Butterworth, 2001). The utility of water in the industrial process, pharmaceutical, food and beverages production is also paramount in our daily lives. Many peoples in the world have continued to rely on water harvesting practices. Others have returned to it in order to relieve pressure on overburdened underground water tables or municipal water systems (Palmback, 2004).

2.2 Requirements / Critical Factors for Selecting Appropriate Water Harvesting Method

It is evident that there is enough freshwater bodies available every year to fulfil the needs of the present population of this planet. However, in certain regions and countries, the annual renewable supply of water is less than 500m^3 (Qadir et al., 2007). Therefore, the need for WH arises from many factors such as low rainfall and uneven distribution, high losses due to evaporation and runoff, and an increased demand for water due to population growth (Abu-Awwad & Shatanawi, 1997). With a large portion of the human race living in arid and semi-arid regions of the globe as well as densely populated urban areas, it is necessary to look at WH to increase access to water in these areas.

As WH becomes an important strategy to deal with water scarcity or water stress, it is important to consider the factors that go into selecting the appropriate WH methods to maximize hydrological returns. To achieve optimal hydrological returns, all the variables, necessary for cost effective method should be x-rayed. It is tempting to assume that a system which works in one area will also work in another, superficially similar, zone. However there may be technical dissimilarities such as availability of stone or intensity of rainfall, and district socio-economic differences (Critchley et al., 1997). There are a number of critical factors that need to be taken into consideration when selecting the appropriate WH method (Prinz et al., 2000).

2.2.1 Rain Fall

WH depends on limited and uncertain rainfall, and this understanding the dynamics of precipitation within the environment can influence the method of WH that would fit best in each context (Qadir et. al., 2007). Prinz et al., (2000) gave the various factors which should be taken into account to include: The number of days in which rain exceeds the threshold rainfall of the catchment, on a weekly or monthly basis. Also the probability of occurrence (in years) for the mean monthly rainfall with probability and reoccurrence for the minimum and maximum monthly rainfall. Frequency distribution of storms of different specific intensities

2.2.2 Land Use or Vegetation Cover

Working to reduce erosion and redirect runoff into appropriate catchments can lead to high labour inputs resulting from the necessity to keep the catchment area free from vegetation, to ensure that it is as effluent as possible. The vegetation of the selected area will heavily influence runoff, infiltration and retention levels and must be taken into account prior to implementation, to reduce high labour costs in the future (Qadir et al., 2007). Maintenance of the catchment system must also be understood when selecting the size of catchment. The system maybe damaged during heavy rainstorms or require regular maintenance which could prove problematic in the future (Qadir et al., 2007).

2.2.3 Topography and Terrain Profile

Topography is an important aspect of WH as the slope of the terrain and gradient will greatly impact the size and type of catchment area of the WH (Prinz et al., 2000).

2.2.4 Soil Type and Soil Depth

Soil type and depth helps judge the percolation and infiltration rates, potential for runoff, and storage potential of water within the soil (Prinz et al., 2000).

2.2.5 Hydrology and Water Resources

Hydrology monitors the available water sources that are involved in storage, production and runoff of the WH system, which will aid in the informed selection of the appropriate WH technique for the proposed site (Prinz et al., 2000).

2.2.6 Socio-Economic and Infrastructure Condition

There are several social, cultural and economic factors that are important to consider when selecting the appropriate WH technique.

a) People's Priorities: Need to be taken into account when opting to introduce WH methods to a specific area. WH aims to increase the availability of water resources for productive use, and it is therefore important that the WH infrastructure meet the needs of the individuals who are using it (Critchley et al., 1997).

b) Land Use Management: How land, both communal and private, is managed and used can determine the effectiveness of the WH strategy being proposed or implemented. Effective land management is important as conflicts and disputes over water rights, land ownership and use can arise (Oweis & Hachum, 2005).

2.2.7 Environmental and Ecological Impacts

Ecosystems are often fragile and can be adversely affected if the water table is tampered with. Thus, it is important to pay attention to these factors, understanding where the water flows and how it affects the surrounding ecology, before implementing any kind of water harvesting system. Some negative impacts that water harvesting can potentially have on the existing environment are the reduction of valuable cropland that would be occupied by the catchment area. The catchment often requires a large area and thus occupies valuable crop land (Qadir et al., 2007). However, today the technology exists to allow WH to occur on a large scale, allowing for various commercial uses as plant nurseries, garden centres, vehicle washing plants, agricultural uses and for use in washrooms and urinal flushing in public buildings (Rain harvesting System, 2006).

2.2.8 Proximity of Source to Point of Need.

Closeness to the point of need is a critical factor in the choice of water source. The farther the source from the point of need, the more the materials, labour and other overhead costs. All these would translate to increased financial burden. In other words, if the source is close, the cost of materials, installations and other incidentals would be drastically reduced.

2.2.9 Nature of the Water Source/ Level of Pollution

Pollution is key to determining the suitability of a water source for public water scheme. The higher the quantity and concentration of pollutants in a water source, the more the treatment demand. Removal of some pollutants especially some chemicals, entails the deployment of complex and sophisticated technology. Some of these complex and advanced water treatment technology are very expensive to acquire, install and maintain. The absence of such technology would impact negatively on the acceptable purity level of a highly polluted water source.

2.2.10 Financial Demand

Funding is the bedrock for infrastructural provision. Urban water scheme is a capital intensive project to execute. It demands both skilled and unskilled manpower, technical knowhow, space, proper management and maintenance of the infrastructure. On the list of the funding are the equipment, treatment plant, machines, installation, procurement and cost of fund. This is where the cost benefit analysis of the project (feasibility studies) becomes imperative (Garg, 2011)

2.2.11 Regularity/Adequacy of Raw Water Supply

The regularity of raw water supply is one of the key components of successful WH. Any source of water that cannot provide the needed quantity and quality of water all year round, does not meet the desired requirement. If the source fails to supply raw water all year round, such scheme has failed the litmus test of sustainability ab-initio. In temperate climes like ours, low humidity, (climate variability and change) occasioned by extreme seasonal high temperatures have been identified to be responsible for the increase in the frequency and intensity of surface runoff, soil water erosion, drought, pollution, decrease in surface water/runoff and groundwater, with negative impacts on agricultural lands, grasslands and terrestrial and aquatic ecosystems (Water Action Decade 2020). During dry season, the above factors render the source of water supply from rainfall and direct source from atmosphere unsuitable and unreliable due to irregularity of supply.

2.3 Forms of Water Harvesting

There are three(s) main categories of WH that have been devised and perfected over the years. Each category has its own subset of methods and techniques that are employed to get the maximum amount of profit from each water source, be it floodwater, rainfall or groundwater. The three (3) main forms of WH include Rainwater Harvesting (RWH), Floodwater Harvesting (FWH) and Groundwater Harvesting (GWH).

2.3.1 Rainwater Harvesting (RWH)

Rainwater Harvesting uses a wide range of techniques for concentrating, collection and storing rainwater and surface runoff for different uses by linking a runoff – producing area for a separate runoff – receiving area (Mbilinyi et al., 2005). In this sense, RWH collects rainwater runoff and stores it for future use, be it for agriculture, domestic or drinking purposes. As such, RWH encompasses all WH techniques that collect and harvest runoff from roofs or ground surfaces (Critchley et al., 1991). The three main forms of water collection that make up RWH are water collection, rooftop harvesting and micro-catchments.

a) Water Collection: Also known as water conservation, this method of RWH is essentially the prevention of net runoff from a given area by retaining rainwater and prolonging the time for infiltration (Mbilinyi et al., 2005). This practice employs a number of different techniques to "Catch the water where it falls". The methods for this form of RWH are diverse and are often a product of local ingenuity and varying cultural practices. Examples of water collection include deep tillage, dry seeding, mixed cropping, ridges borders, terraces, trash lines, ponds, for harvesting and finally rooftop harvesting (Prinz, 1996). For the most part, these practices are mainly used for irrigation.

b) Roof top Harvesting: Is generally practiced as a way to obtain relatively clean drinking water as well as water for domestic purposes. This method involves a relatively small catchment area the size of the individual's roof of their house with gutters and pipes to guide the water into a tank on the ground. Often a tap is attached to the tank for individuals to access this water (Miblinyi et al., 2005). There is concern over whether or not the water is clean enough for drinking, as pollutants in the atmosphere have been known to be present in rainfall. Today, water harvesters must be wary of pesticides contamination, high mineral levels, bacteria and other impurities in their runoff water (Palmback, 2004). Most rooftop harvesting systems have screens and purification systems built into the infrastructure to remove leaves and twigs from the water as well as to purify the water prior to use (Palmback, 2004).

c) Mirco-Catchment: Involves a distinct division of a runoff – generating catchment area, and a cultivated basin where runoff is concentrated and stored in the root zone and productively used by plants (Miblinyi et al., 2005). There are multiple advantages to this WH system than the others in that the design is simple and cheap, there is a higher runoff efficiency than large scale WH systems, they often prevent or reduce erosion and finally, can be implemented on almost any slope and many level planes (Prinz, 1996). Micro – Catchments vary in size, method and technique from region to region. A micro – catchment system in Ethiopia, for example, may be completely different in style and operation than a micro – catchment system found in Western Asia. Although there are variations, there is a basis of methods used within the micro – catchment category, they include: pitting, contour ridges, negarin, semi – cirailar hoops, meskat –type, vallerani-type, contour bench terraces, and eye brow terraces or hill slope micro – catchment (Prinz, 1996).

2.3.2 Flood Water Harvesting (FWH)

This is often referred to as water spreading or water irrigation, FWH is involved in the collection and storage of creek flow for irrigation use (Prinz et al., 2000). The main characteristics of FWH are turbulent channel of water flow harvested either by diversion or spreading within a channel bed/valley floor where the runoff is stored in soil profile (Critchley et al., 1991). Two categories of FWH include Macro-Catchments and Large Catchments.

2.3.2.1 Macro – Catchment: Macro – catchment, sometimes called medium – sized catchments are characterized by large flood zones that are situated outside of the cropping area. Often farmers must use structures such as dams or bunds to divert, transfer, collect and store the runoff. Such systems are often difficult to differentiate from conventional irrigation systems and are considered FWH as long as the harvested water is available year round (Mbilinye et al., 2005). Examples of macro – catchments include: stone dams, large semi-circular hoops, trapezoidal bunds, hillside conduit systems and cultivated reservoirs all of which have a scale of between 1,000m squared to 200ha (Prinz, 1996).

2.3.2.2 Large Catchments Water Harvesting: This comprises systems with catchments many square kilometers in size from which runoff water flows through a large stream bed, also necessitating more complex structures of dams and distribution networks. There are two major forms of large catchments water harvesting outlined in the literature: floodwater harvesting within a streambed and floodwater diversion (Prinz, 1996).

2.3.3 Groundwater Harvesting (GWH)

GWH encompasses all methods, traditional and contemporary of harvesting water from the ground for productive use. It has also been used as a storage method for the other forms of water harvesting outlined above, with many of these techniques requiring a certain type of terrain so that the water diverted from its original source can seep into the ground for crop use. Traditional methods of groundwater harvesting include the use of dams, wells cisterns and aquifers.

2.3.3.1 Dams: Groundwater harvesting dams pertain to the blockage of groundwater sources for the use in agricultural practices. The subsurface dam and the sand storage dam are used to "obstruct the flow of ephemeral streams in a river bed. The water is stored in the sediment below ground surface and can be used for aquifer recharge (Prinz et al., 2000). Ritchie, Eisma and Parker (2021) stated that during the rainy season, water is stored in the sand that accumulates behind the dam. Sand dams provide communities in dry lands with water during the dry season via scoop holes, pools, and shallow wells. There are several advantages to this as evaporation losses are reduced, there is no reduction in storage volume due to siltation, the stored water is less susceptible to pollution and health hazards due to mosquito breeding are avoided (Prinz et al., 2000).

2.3.3.2 Wells: This is probably the most common GWH techniques, they tap into water table from a hole excavated on the surface. Wells have been employed as a source of water for thousands of yours, with one of the oldest wells found dating back to 8100-7500 BC. Like other forms of water harvesting, wells have been adapted to meet the needs of individuals living in specific regions. Technology has also increased the returns from wells, making water easier to obtain. Manzoor and Vladimir (2021) posit that from Earth's seabed to its upper atmosphere, we have a variety of water resources that can be tapped. But making the most of these requires a diverse range of technological interventions and innovations.

2.3.3.3 Cisterns: These are man-made caves or underground construction to store water. Often the walls of these cisterns are plastered to prevent water loss, deep percolation and/or evaporation (Prinz et al., 2000). The underground cistern (China type) found in Ethiopia, is employed to supply water for domestic and irrigation purposes to drought prone areas. There are two variants to this cistern, one being shaped like a bottle, the other in a circular formation. Both are constructed in a similar fashion with the ground excavated to form the shape of the cistern. The surface is covered with polyethylene or concrete plastering to avoid seepage loss. Both cisterns are expensive and difficult to build, often too complex for individual farmers to construct themselves (Alem, 2003).

2.3.3.4 Aquifers: These form underground layers of water seeped into permeable rock or other materials such as sand, gravel, silt or clay. They generally occupy large areas under the earth's surface and will often supply other water sources such as streams, rivers and springs. Often aquifers are on the receiving end of water harvesting, in that they are often used as a way to store harvested rainwater. Recently, awareness of depleting aquifers has spurred an increase in WH techniques that aim at directly recharging these rapidly depleting resources. Many forms of rainwater harvesting collect water and store it underground for future use. Not only does this recharge deplete ground water sources, it also raises the declining water table and can help augment water supply (Edugreen, 2006).

2.3.4 Infiltration/ Sump Method of Water Harvesting.

According to Garg (2011) the basic function of the infiltration/sump (intake) structure is to help in safely withdrawing water from the source over a predetermined range of pool levels and then to discharge this water into the withdrawal conduit (normally called intake conduit), through which it flows up to the water treatment plant. There are two basic types of infiltration/ sump structures. They are the single well and twin well types. Both types can either be constructed at the river banks or on the river floor.

3.0 Gap in Knowledge

Previous studies focused on water demand and supply situations, assessment and determination of surface and underground water quality, location and sources as well as spatiotemporal trends of water borne diseases in Enugu urban. However, studies focusing on harvesting portable water through infiltration/sump technology from the abundant fresh water bodies, especially from Asata River, to quell the perennial water scarcity in the state, has received little or no attention.

4.0 Research Methodology

The survey and experimental research methods were used. A total number of 48 samples were aseptically collected from 3 points on a weekly basis. The points are A: from the flowing Asata River, B: from the infiltration sump and, C: from the locally fabricated water treatment plant. These samples were subjected to physical, chemical and biological analysis to determine the level of impurities, chemical and biological pollutants contained therein. Atomic Absorption Spectrophotometer (AAS) was used to determine the quantitative level of heavy and none heavy metals present in the samples. Direct culture plate count was used to determine bacterial load of the water samples while sample concentration was used for the microscopic analysis.

4.1. Current Condition of Water Supply in Enugu

Table 1: Expected Target Production and Actual Water Supply in Enugu Urban From 2016 to 2021

Year	Targeted annual production (m^3)	Actual annual production (m^3)	Average monthly production (m^3)	Annual production (%)	Remarks
2016	56,584,800	2,981,871	248,489.25	5.26	
2017	56,584,800	3,406,244	283,853.67	6.02	9th mile old road and 9th mile crash program were inactive.
2018	48,204,000	6,082,962	506,913.50	12.62	9th mile old road and 9th mile crash program were inactive.
2019	24,102,000	2,452,106	204,342.17	10.17	9th mile old road and 9th mile crash program were inactive. Data available only for January –June.
2020	56,584,800	4,345,719	362,143.25	7.68	
2021	56,584,800	3,436,017	286,334.75	6.07	
Average annual production		3,784,153.2	315,346.10	7.97	

Source: Enugu State Water Corporation (ENSWC) progressive water monthly production

From available data, the Enugu urban has continued to suffer unprecedented water scarcity. This is mainly due to a number of factors as were enunciated in the literature review. It can be seen that within the 6 years covered by the study, the highest annual supply of water by ENSWC was achieved in the year 2018.

A total volume of 6,082,962m^3 of water representing 12.62% of the expected annual production was supplied to the inhabitants of Enugu urban. Invariably, this translated to monthly average supply of 506,913.50m^3 of water translating to 16,897.11m^3 of daily water supply to the people. When the water supply for the year 2020 is analyzed, the average daily supply was 11,906.08m^3 of water for the entire population of Enugu urban. With the projected population of Enugu urban at above 1million by 2020, it means that daily per capita of water stood at 0.0119m^3 or 11.9 liters of water. This quantity is abysmally low when compared to United Nation's standard of between 50 to 100liters per capita/day. When the threshold of the UN standard daily water need is compared with the Enugu urban scenario, only about 23.8% of the daily water need per capita was met in the year 2020. Analyzing the entire period of 6 years, an average yearly supply of 3,784,153.2m^3 representing 7.97% of the expected water supply was achieved. This gives an average monthly water supply of 315,346.10m^3 of water or 10,511.54m^3 of daily water was supplied to Enugu urban. With the projected population growth of 2.5% of the previous year, it meant that the estimated population of Enugu urban in 2021 is one million twenty five thousand (1,025,000). With this population, the average per capita /day water supply was 0.01025m^3 or 10.25liters of water.

A comparative analysis with the UN threshold standard shows that only 20.5% of daily water need in Enugu urban was met. This shows that over the period under study, ENSWC was only able to supply 20.5% of her targeted water production. A whopping 79.5% of her annual targeted water production to serve Enugu urban on annual basis were not met. These outcomes are signs of poor management and maintenance, obsolete equipment, bureaucratic bottle necks, white elephant projects and application of complex foreign technology resulting in the inability of the water schemes to function at installed capacity. This scenario has given rise for the search of sustainable, cost effective, smart and indigenous suitable alternative water supply technology to bridge this huge gap. A feasible alternative that met this aspiration became sump/infiltration method of water harvesting from available rivers. Asata River is one of the main rivers that drain the Enugu urban. It flows from Udi hills through the main city of Enugu metropolis. Asata is a perennial river with many other streams feeding it and tributaries that aid its discharge. The river is approximately 19.8 km long with an average discharge of 0.4m^3/sec. (Olawale 2016).

4.2 Materials and methods

The materials used for this research included but not limited to the following:

4.2.1 Sump/ infiltration (infiltration well): this consists of a dug well along the river bank lined with 1.00m x 1.00m ring culverts, constructed to allow water into the sump only through infiltration from the underground base of the well. Inside the well is stuffed with graded sand for pre-filtration.

Plate 1. Sump/ Infiltration Structure

For the purpose of this study, the infiltration/intake sump was constructed at the bank of Asata River. The river bank composed mainly of sandy soil, highly pervious material. The intake work was constructed to harvest water into the well by infiltration beneath the river bed. Water from the intake/ sump was transported via duct to the holding tank (raw water reservoir). From the holding tank, the water was transported to the treatment plant for treatment.

4.2.2 Local water treatment plant: This consists of 2 stainless steel columns, one of the columns stuffed with graded sand and the other stuffed with activated charcoal. A total of 5 micro filters (5micron, 1micron, 0.5micron, carbon and ion exchange resin) cartridges and 1 ultra violet beam.

Plate 2. Local Water Treatment Plant

4.2.3 Methods of Treatment: Water in the holding tank is pumped to pass through the treatment plant seamlessly. The water first hits the graded sand column. In the sand column, all the physical/ macro impurities, larger than 100microns in size, are trapped and removed by adhesion of the particles to the graded sand. After the sand filtration, the water moves to the activated carbon column. Here the odour and the colour are removed. The water then moves to the micro filters of varying porosity (5, 1, 0.5) microns in that order. The 5 micron removes all particles larger than 5microns while allowing particles less than 5micron to flow through it. The 1micron removes particles larger than 1micron from the water while particles less than 1micron in size flow through. 0.5micron polishes the water by removing all particles sizes above 0.5micron in size. The polished water then flows through the ion exchange resin cartridge where all the remaining metallic impurities are removed. After the deionization of the water, the water moves seamlessly to the ultraviolet (UV) chamber. Here the water is exposed to beam of UV light which sterilizes the water. At this point, the water is wholesome and portable for domestic use.

5.0 Laboratory Results

Results of water analysis of untreated, sump/infiltrate water and treated water samples collected from Asata River are presented in table 2, table 3 and table 4 respectively.

Table 2: Results of untreated water samples

S/N	Result Of Untreated Water Sample					Maximum Permissive Limits	Remarks
	Parameters Tested	Day 1	Day 2	Day 3	Day 4	WHO	
1	General appearance	Not clear	Not clear	Not clear	Not Clear	Clear	Failed
2	pH at 27^{0}C	5.0	5.8	5.8	5.9	6.5-8.5	Failed
3	Tempera-ture (^{0}C)	30	29.7	29.8	30.1	Ambient	Failed
4	Colour (TCU)	4.3	5.7	5.0	4.7	3.0	Failed
5	Taste	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Failed
6	Odour	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Failed
7	Turbidity (NTU)	8.6	8.5	8.3	8.1	5.0	Failed
8	Total hardness (mg/L)	180	200	170	160	100	Failed
9	Chloride (mg/C)	140	150	120	130	100	Failed
10	Nitrate (mg/L)	1.5	1.8	1.6	1.7	10	Passed
11	Total solute	400	350	332	420	1000	Passed
12	Phosphate	3.6	4.7	4.3	3.8		Passed

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13	Sulphate (mg/L)	8.3	8.6	8.8	9.4	100	Passed
14	Potassium (K)	12	10	13	13	1.2	Failed
15	Calcium (Ca)	6	12	18	14	50	Passed
16	Sodium (Na)	2.4	1.3	1.5	2.2	100	Passed
17	Iron (Fe)	0.429	0.528	0.279	0.386	0.3	Failed
18	Copper (Cu)	0.045	0.067	0.078	0.071	1.0	Passed
19	Manganese (Mn)	0.013	0.025	0.018	0.022	0.1	Passed
20	Nikel (Ni)	0.243	0.135	0.298	0.156	0.001	Failed
21	Total alkaline	12	7	10	13	100	Passed
22	Zinc (Zn)	0.148	0.197	0.167	0.173	5.0	Passed
23	Lead (Pb)	0.429	0.132	0.312	0.129	0.10	Failed
24	Chromium (Cr)	0.067	0.089	0.035	0.081	0.01	Failed
25	Cadmium (Cd)	0.019	0.044	0.036	0.041	0.005	Failed
26	Magnesium (Mg)	0.5	1.4	1.6	1.1	50	Passed

Table 3: Result of sump/infiltrate water sample

S/N	**Result of Sump/Infiltrate Water Sample**					**Maximum Permissive Limits**	**Remarks**
	Parameters Tested	Day 1	Day 2	Day 3	Day 4	WHO	
1	General appearance	Slightly clear	Slightly clear	Slightly clear	Slightly clear	Clear	Passed
2	pH at 27^{0}C	6.1	6.0	5.9	6.2	6.5-8.5	Passed
3	Tempera-ture (^{0}C)	30.3	29.6	30.0	30.1	Ambient	Passed
4	Colour (TCU)	5.0	4.2	4.0	4.1	3.0	Passed
5	Taste	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Failed
6	Odour	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Failed

7	Turbidity (NTU)	6.5	6.2	6.0	5.6	5.0	Failed
8	Total hardness (mg/L)	150	130	120	110	100	Failed
9	Chloride (mg/C)	90	110	100	100	100	Passed
10	Nitrate (mg/L)	1.9	2.0	2.5	2.3	10	Passed
11	Total solute	400	500	600	430	1000	Passed
12	Phosphate	4.7	4.0	4.4	4.9		Passed
13	Sulphate (mg/L)	9.0	8.7	8.6	8.8	100	Passed
14	Potassium (K)	5	8	10	7.0	1.2	Failed
15	Calcium (Ca)	6	4	3	3.0	50	Passed
16	Sodium (Na)	1.8	1.4	1.7	1.6	100	Passed
17	Iron (Fe)	0.299	0.257	0.344	0.330	0.3	Failed
18	Copper (Cu)	0.032	0.014	0.096	0.077	1.0	Passed
19	Manganese (Mn)	0.028	0.012	0.025	0.021	0.1	Passed
20	Nikel (Ni)	0.198	0.107	0.265	0.165	0.001	Failed
21	Total alkaline	11	8	9	9	100	Passed
22	Zinc (Zn)	0.124	0.034	0.122	0.176	5.0	Passed
23	Lead (Pb)	0.087	0.157	0.102	0.130	0.10	Failed
24	Chromium (Cr)	0.019	0.034	0.026	0.027	0.01	Failed
25	Cadmium (Cd)	0.017	0.026	0.012	0.013	0.005	Failed
26	Magnesium (Mg)	1.2	1.3	2.4	1.6	50	Passed

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Table 4: Result of Treated Water Sample

S/N	Result of Treated Water Sample					Maximum Permissive Limits	Remarks
	Parameters Tested	Day 1	Day 2	Day 3	Day 4	WHO	
1	General appearance	Clear	Clear	Clear	Clear	Clear	Passed
2	pH at 27^{0}C	6.5	7.0	8.5	8.1	6.5-8.5	Passed
3	Tempera-ture (^{0}C)	Ambient	Ambient	Ambient	Ambient	Ambient	Passed
4	Colour (TCU)	2.9	2.5	2.4	2.2	3.0	Passed
5	Taste	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Passed
6	Odour	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Passed
7	Turbidity (NTU)	4.0	3.0	2.0	2.1	5.0	Passed
8	Total hardness (mg/L)	20	10	5	7	100	Passed
9	Chloride (mg/C)	20	11	12	13	100	Passed
10	Nitrate (mg/L)	1.0	0.5	0.3	0.3	10	Passed
11	Total solute	12	11	10	13	1000	Passed
12	Phosphate	1.2	1.0	0.9	1.1		Passed
13	Sulphate (mg/L)	0.6	0.4	0.2	0.5	100	Passed
14	Potassium (K)	0.1	0.2	0.3	0.3	1.2	Passed
15	Calcium (Ca)	0.22	0.22	0.34	0.41	50	Passed
16	Sodium (Na)	0.4	0.8	0.7	0.6	100	Passed
17	Iron (Fe)	0.2	0.3	0.1	0.2	0.3	Passed
18	Copper (Cu)	Nil	Nil	Nil	Nil	1.0	Passed
19	Manganese (Mn)	Nil	Nil	Nil	Nil	0.1	Passed

20	Nikel (Ni)	Nil	Nil	Nil	Nil	0.001	Passed
21	Total alkaline	8	6.8	7.8	7.1	100	Passed
22	Zinc (Zn)	Nil	Nil	Nil	Nil	5.0	Passed
23	Lead (Pb)	Nil	Nil	Nil	Nil	0.10	Passed
24	Chromium (Cr)	Nil	Nil	Nil	Nil	0.01	Passed
25	Cadmium (Cd)	Nil	Nil	Nil	Nil	0.005	Passed
26	Magnesium (Mg)	0.2	0.1	0.01	0.01	50	Passed

5.1 Discussion of laboratory Results: (physico-chemical parameters)

a. Physical properties: The general appearance of the raw water (untreated) samples showed not clear, the samples from sump showed slightly clear while the treated samples were clear. The pH values for all the untreated samples were acidic, the sump samples neutral while the treated samples were more of alkaline. Temperatures of the samples from both the raw and sump were not ambient whereas the temperatures of the treated samples were ambient conforming to permissible limits. Taste and odour of raw and sump samples were objectionable but after treatment, both odour and taste became unobjectionable. Turbidity test failed at raw water level, improved at the sump level and passed after treatment. This shows that infiltration method has positive effect on the physical properties of the water.

b. Chemical parameters: On raw/untreated water samples, total hardness and chloride failed the maximum permissible level but their concentration level improved in the sump samples while their concentration were within maximum permissible limit after treatment. The concentration levels of nitrate, phosphate and sulphate were within maximum permissible limits in the raw/ untreated, sump and treated water samples.

c. Heavy metals and alkaline earth metals: The presence of heavy metals above permissible level were detected in the raw Asata river water samples. The heavy metals and alkaline earth metals investigated are cadmium (Cd), lead (Pb), magnesium (Mg), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), potassium (K), calcium (Ca), sodium (Na), iron (Fe), and manganese (Mn). The heavy metals that exceeded the maximum permissible limits in the raw flowing river and the sump samples are lead, nickel, cadmium and chromium. However their presence were eliminated after treatment. Sodium concentration maintained values within the permissible limits all through the samples. Potassium level in the untreated raw water samples were high and slightly reduced but still above permissible level in the sample obtained from the sump. The potassium level came down within permissible level after treatment. On the other hand, calcium, sodium, copper and manganese had values within permissible limit throughout the experiment. Iron has elevated values above normal in both untreated and sump water samples but came down to permissible limit after treatment.

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5.2 Microbial Analysis

Table 5: Microscopic Examination of Untreated Water

Parasite	Day 1	Day 2	Day 3	Day 4	Remarks
Ova of hook worm	(+)	(+)	Nil	(+)	Evidence of parasitic contamination.

Microscopic examination of raw/ untreated water showed ova of Hook Worm (+)

Table 6: Microscopic Examination of Sump//Infiltration Water

Parasite	Day 1	Day 2	Day 3	Day4	Remarks
Ova of worms	Nil	Nil	Nil	Nil	No evidence of parasitic contamination.

No ova was detected from the sump water samples.

Table 7: Microscopic Examination of Treated Water Samples

Parasites	Day1	Day2	Day3	Day4	Remarks
Ova of worms	Nil	Nil	Nil	Nil	No evidence of parasitic contamination

No ova was detected from the treated water samples.

Table 8: Bacteriological Analysis

Samples	Parameter	Day1 cfu/ml	Day2 cfu/ml	Day3 cfu/ml	Day4 cfu/ml	Method
Raw/untreated Asata River	E.coli Coliform	$1.5x10^2$ $2.3x10^4$	$1.7x10^2$ $2.3x10^4$	$1.7x10^2$ $3.0x10^4$	$1.7x10^2$ $3.0.x10^4$	Direct plate
Total bacterial count		$7.3x10^4$	$7.5x10^4$	$7.3x10^4$	$7.4x10^4$	Direct plate
Sump/infiltrate water	E.coli Coliform	$1.0x10^2$ $2.0x10^4$	$1.3x10^2$ 2.110^4x	$1.4x10^2$ $2.1x10^4$	$1.1x10^2$ $2.0x10^4$	Direct plate
Total bacterial count		$6.1x10^4$	$6.4x10^4$	$6.2x10^4$	$6.0x10^4$	Direct plate
Treated water samples	E. coli Coliform	No growth	No growth	No growth	No growth	Direct plate
Total bacterial count	Nil	Nil	Nil	Nil	Nil	Direct plate

5.3 Microscopic Analysis

Microscopic examination showed ova of Hook Worm (+) from the raw/untreated water sample, evidencing parasitic contamination of the Asata river water. No ova was detected from the sump and treated water samples. This shows that the sump infiltration and the UV method have positive effect in eliminating parasites from the water.

5.3.1 Discussion of Bacterial Result: Untreated water samples cultures yielded heavy growth of E. coli and Coliforms. This is an indication that the raw/untreated Asata river water is contaminated with bacteria and unsuitable for domestic use without treatment. Water samples from the sump showed significant reduction in bacterial load as evidenced from the total bacterial counts for the period under study. Total bacterial counts of raw water samples remained higher than sump water samples throughout the study period. However the treated water samples yielded no bacterial growth throughout the study. This is an indication that the sterilization method using ultra violet (UV) beam was effective in eliminating the microbial contaminants in the water.

6.0 Conclusion

It was discovered that water supply to Enugu residents has been abysmally low compared to the ENSWC installed capacity. Out of the six (6) years under study, the highest annual water production of 6,082,962m3, representing 12.62% of the installed capacity, which was supplied to the inhabitants of Enugu metropolis was achieved in the year 2018. The heavy metals that exceeded the maximum permissible limits in the raw flowing river and the sump samples are lead, nickel, cadmium and chromium.

Total hardness and chloride failed the maximum permissible level but their concentration level improved in the sump samples while their concentration were within maximum permissible limit after treatment. The raw/untreated Asata river water is contaminated with bacteria and unsuitable for domestic use without treatment. After treating the water with the indigenous infiltration/sump technology, all the chemical parameters, microbial and bacterial load came to permissible level.

7.0 Recommendations

In view of the cost effectiveness and efficacy of this indigenous smart technology, the study recommends that government at all levels, corporate bodies and individuals should embrace the sump/infiltration technology for sustainable water supply. Also white elephant water project(s) should be jettisoned and sump/infiltration smart technology adopted to mitigate the perennial water crisis. Conservation of all rivers and streams in the state should be properly pursued to reduce contamination, pollution and wastage of the fresh water resources. The study also recommends that all the perennial rivers and streams, with high water yield, in the State should be studied and their suitability or otherwise for WH evaluated. This will go a long way in solving the perennial water crises bedeviling Enugu State and the country at large.

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REFERENCES

Abu-Awwad, A.M. & Shatanawi, M.R. (1997). Water Harvesting and infiltration in arid areas affected by surface crust: examples from Jordan, *Journal of Arid Environment* vol.33

Abubakar B. (2022): The Liquid Gold Under Our Feet, World Water Day 2022 https://nigeriahealthwatch.com/world-water-day-2022-the-liquid-gold-under-our-feet/

Alem, G. (2003). Water Harvesting: A Water Security Strategy for Mitigating the Impact f Drought in Ethiopia. Water Security in the 21st Century 1-5.

Ani O.C. (1980). Urban Water Supply and Demand: The case of Enugu. Unpublished B.Sc Thesis, University of Nigeria, Nsukka.

Chukwurah G.O. (2018) Challenges and Opportunities of Water Supply in Enugu Metropolis, Nigeria. *International Journal of Environmental Sciences*. Vol. 7. No. 3. 2018. Pp. 111-116 ©Copyright by CRDEEP Journals.

Critchley, W. & Siegert, K. (1991). A manual for the design and construction of water harvesting schemes for plant production. FAO corporate document repository.

Das, J. & Acharya, B.C. (2003). Hydrology and assessment of lotic water quality in Cuttack City, India. Water, Air, Soil Pollut., 150: 163-175. Do1:10. 1023/A: 1026193514875

Enewaji E.E., Eduputa B.M, & Okoye C.O. (2016) Investigations into the Residential Water Demand and Supply in Enugu Metropolitan Area, Nigeria, *American Journal of Water Resources,* Vol. 4, No. 1, 22-29, Sciences and Education Publishing.

Garg S.K.(2011) *Water Supply Engineering,* Khanna Publishers, New Delhi, India

Glavan M. (2018) Water Challenges of an Urbanizing World, DOI: 10.5772/intechopen.68339, e Book (PDF) ISBN: 978-953-51-4049-8.

Manzoor Q. & Vladimir S. (2021) Five unusual technologies for harvesting water in dry areas, https://theconversation.com/five-unusual-technologies-for-harvesting-water-in-dry-areas-154031

Mbilinyi, B.P., Tumbo, H.F., Mahoo, E.M., Senkondo, E.M. & Hatibu, N. (2005). Indigenous knowledge as Decision Support Tool in Rainwater Harvesting. Physics and Chemistry of the earth 30,792-798.

Mokpoge, K. & Butterworth, J.A. (2001). WHIRL Project Working Paper 4: Rural Water Supply and Productive Uses: A Rapid Survey in Sand River Catchment, Water, Households and Rural Livelihoods (WHIRL) November. 1-21.

National Population Commission (NPC) 2016, Enugu (State, Nigeria)-Population Statistics, Charts, Map and location www.citypopulation.de.php

Nwanisobi G. (2018) Comparative Studies of Groundwater in Akpugo Area of Enugu State, Nigeria, *Organic and Medicinal Chemistry International Journal Vol. 7 No. 5*

Olawale. O.O. (2016). Water quality assessment of the Asata River catchment area in Enugu Metropolis, Southeast Nigeria *Journal of African Earth Sciences Volume 121, September 2016, Pages 247-254*

Oweis, T. & Hachum, A. (2006). Water Hervesting and supplemental irrigation for improved water sproductivity of Dry Farming systems in West Asia and North Africa agriculture water management. 80; 57-73.

Palm back, J. (2004). Traditional Water Harvesting. Spring 2004. University of Wisconsin – Eau Claire, USA. http://academic.evergreen.edu/g/grossmaz/PALMBAJP/.

Prinz, D. (1996). Water harvesting: Past and future. In Peveira, L.S. (ed.) Sustainability of irrigated agriculture. Proceeding, NATO Advanced Research Workship, Vimerio, 21-26.30. balkema, Rotterdam, 135-144.

Prinz, D. & Singh, A.K. (2000). Technological Potential for improvement of water harvesting study for the World Commission on Dams, Cape Town, South Africa. Report: Dams and Development.

Qadir, M., Sharma, B.R., Bruggeman, A. & Karajeh, C.F. (2007). Non-coventional water resources and Opportunities for water Augmentation to Achieve Food Security in water scarce countries Agricultural water management. 87:2-22.

Ramakrishnaih, C.R., Sadashivalal, C. & Rangann, G. (2009). Assessment of Water quality index for the groundwater in Temkur Tluk, Karnataka state Indiana J. Chem, 6:523-530

Rainwater Harvesting (2006). Directoral of Town Panchayats September 5th. http://www.tn.in/dtp/rainwater.htm.

Ritchie H.G , Eisma J, & Parker,A (2021) Sand Dams as a Potential Solution to Rural Water Security in Drylands: Existing Research and Future Opportunities, .org/people/u/809919 https://www.frontiersin

Singh G (2009) *Water Supply and Sanitary Engineering*, Lomus Offset Press, Delhi India

Udeze, A.O. (1998). River Water Pollution in Enugu Urban Area. Unpublished M.Sc Thesis, University of Nigeria Nsukka.

Ugwuoti A.I., Onah E. & Ojinaka O. (2019) Improving Enugu Urban Water Sourcing and Distribution Using Geospatial Technologies, FIG Working Week Publication.

Water Action Decade (2020) Accelerating Implementation of the 2030 Agenda through Water, Sanitation and Climate Action, Department of Economic and Social Affairs with the support of UN-Water

World Bank Group (2017) Project Performance Assessment Report, Nigeria National Sector Reform Project, IDA-39240 and IDA-47840, Report No. 115782, June 22 2017