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Water Treatment Operations: Case Study of Mada Water Works

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Abstract – Design and working principles of water treatment plants in other parts of the world, as well as in Nigeria are different and requires extensive study. This work looks at current trends undergone in water treatment plants in contrast with the one obtainable at Mada Water Works (MWW) in North Central, Nigeria. Because, majority of these plants including the MWW apply obsolete techniques and equipment, as they were built in the early 1980s and 1990s. Previous research only looks at metallic contamination levels of the Mada River which serve MWW with unclean raw water. Hence, this work entails an in-depth study of the plant's modus operandi, challenges faced and ways of solving them. Studies shows that the entire treatment plant needs a complete turnaround to prevent it from eminent system collapse. The attention of researchers is therefore drawn to the treatment plant's various unit operation in order to address challenges facing their functionality.

Keywords: Mada River, Water treatment, Surface water, Scraper bridges, Nasarawa

I. INTRODUCTION

Mada Water Works (MWW) or Treatment Plant is situated in Gudi, Akwanga Local Government Area of Nasarawa state in Nigeria. The state is located between latitude 7°58'36''N and longitude 7°58'19''E [1]. The water works at latitudes 08° 49'' – 08° 52" and longitude 07° 51" – 07° 56", treats surface water from Mada River, which gain its source from Jos Plateau where its major tributaries are Kogin Daji, Azuta, Rivers Katari, Kyeruku, Ekoalio, among others [2]–[5]. It was built in the year 1995 by S.C.C Nigeria Limited in collaboration with companies in Germany, Italy and France, and became operational in the year 1996 [6]. The water works (the largest supply scheme in the state) was constructed to serve a population of 250,000 people based on its design capacity to generate 53000 m^3/day of water (≅ 10 million gal/day) and supply Keffi, Akwanga, Army Barracks, Gudi, Gunduma, Sabon Gida and Garaku, spanning two zones of Nasarawa-West and Nasarawa-North on 4 major roads of Lafia-Akwanga, Akwanga-Wamba, Akwanga-Jos and Akwanga-Keffi with treated water [4], [7]. Presently, the water works could hardly produce more than half of this capacity. As of 2016, Blytheweigh (2021) reported a population equivalent to 85,911 people in Keffi, 27,137 in Wamba, 30,949 in Nasarawa and 15,985 in Akwanga, which is cumulatively 159,977 people or consumers. The plant had in it, engineering structures and buildings; some of which are chemical building, filtration unit, pumping station, balancing tank or clear water tank, fuel depot, mechanical workshop, power station, flash mixing chamber and clarifiers or sedimentation basins. For effective operation of the treatment facilities, services of skilled and unskilled personnel are employed. The plant management oversees the overall operation and running of the plants including water quality control, plant operation spanning all the treatment units and takes delivery of water treatment chemicals supplied by government on routine basis. The task on the top management of producing treated river water is aided by pump operators, cleaners, chemical operators, laboratory assistants, security watchmen, filter mates, mechanical and electronic engineers.

Conventionally, to treat water, it is basically subjected to processes including pre-chlorination, coagulation, flocculation, sedimentation, filtration and disinfection [8]. However, Opseyes (2020) reported eight steps, including, bar screening, screening, primary clarification, aeration, secondary clarification, chlorination, testing and discharge, which is typical of some plants. The treatment steps at MWW is in order of screening, aeration, chemical addition, flash mixing, clarification, filtering, and water storage which is then distributed via the treated water pumping station. These steps in many other treatment plants, are merged into five successive steps, namely, preliminary or pre-treatment (physical and mechanical) stage; primary treatment (physicochemical and chemical); secondary treatment or purification (chemical and biological); tertiary or final treatment (physical and chemical); and sludge treatment (supervised tipping, recycling or incineration), or clumped into primary, secondary and tertiary treatment steps [9, 10]. Regardless of the long/short steps or speed involved, the fundamental goal any water treatment plant is poised to achieve is to produce high-purity fresh water, of which scarcity is witnessed currently in about one-third of the world [11, 12]. Even though above 71% of the earth's surface is roofed by either river, stream, lake, ocean and spring water, only 1% is clean and safe for consumption and hence a survival threat to the world's population, which is approaching a number, twice its current size [11, 12]. Surface water, the likes of the Mada River, requires a thorough treatment procedure that would ensure its purity because of its characteristics turbidity, microbial population, and the presence of impurities (organic and inorganic), responsible for its altered colour, pH, taste and odour [11, 13, 14]. Therefore, this paper explains the method adopted in treating water for consumers relying on MWW for their daily water supply. In addition, problems encountered during water purification at the plant and possible solutions are lined up or suggested for onward adoption so as to improve the processes involved. Part of the objective is also, to bring these challenges faced to limelight to be addressed immediately to save the community from potential economic and health implications.

II. RELEVANT WORK

Limited studies conducted previously are specific to MWW water source. In Uwa (2015) and Uwa (2016), the author investigates the quality of drinking water by carrying out a qualitative analysis of heavy metal content present, developing a microbial assay, and a physicochemical analysis for the sample treated water at MWW in Gudi-Akwanga. The research outcomes shows that both microbiological parameters analyzed and heavy metals content present indicate a treated water of poor quality, while only few physicochemical parameters agree with the World Health Organization (WHO) recommended standards. All other recorded studies concentrated only on the Mada River that sourced MWW with raw water. For instance, Wokhe (2015) and Aremu et al. (2011) studied the heavy metal contents of the river while Ogah et al. (2013) carried out a flood risk assessment of the same river.

III. SCREENING AND AERATION

Raw or untreated surface water from River Mada is drawn into the plant via an in-take channel using submersible pumps [17]. The water may contain sticks, sand, silt, clay, grasses, leather, fishes, micro-organisms, industrial effluents and metals. At the raw water in-take, a wire-mesh that traps large solid particles (e.g. plastic waste, sticks, stone, grasses, leather and fish) before they get into the aeration chamber is most often available [18, 19]. This procedure is the beginning of the treatment process that prevents large item's entrance through the sewer system and is called bar screening. Doing so, shields the pumps and valves from damages and reduce the possibility of such items obstructing water flow to the next treatment stages [9]. The heavy material-free raw water, however, still contains sand, clay, silt, dissolved metals, industrial effluents and microorganisms which must be ridded-off in subsequent treatment measures in the plant. Unlike Mada Water Treatment Plant, after the first bar screening stage, the influent is passed through a grit chamber in other plants to trap heavier grit that escape the bar screening stage [9]. This would reduce the accumulation of sand at the bottom of the aerator and reduce the volume of sludge discarded at the clarifier. At the works plant, metals being Na, K, Ni, Cu, Mg, Fe, Ca, Zn, Pb, Cd, As, Se, Cr and Mn, among which Mn, Pb, Ni and Fe are heavy metals, is found to be beyond US Environmental Protection Agency (USEPA)/WHO limits according to previous research carried out by Aremu et al. (2011) and Wokhe (2015). Aluminium is amphoteric and also a proven metal found in most natural waters and waterworks [20]. Temperature governs the kinds of organisms that can live in rivers and lakes. The solubility of oxygen decreases with increasing temperature (viz., 10.15 mg/L at 15℃ to 7.1 mg/L at 35℃) [21]. Warm water is less capable of holding dissolved oxygen [22]. Often, summer heat can cause fish kills in ponds because high temperatures reduce available oxygen in the water. Therefore, in warm water streams, the temperatures should not exceed 89°F while cold water streams shouldn't be above 68°F [23]. But, as a result of poor record keeping or incomplete laboratory analysis, data on dissolved oxygen content is not available or is disregarded, and so the presence of microorganisms in the influent water shown in Figure 1 is always assumed.

Fig. 1: Mada River (left) and Intake Structure (right)

Aeration is the first major process at the treatment plant through which contaminated or raw water gets into the aeration chamber having a blade design, as seen in Figure 2a. Aeration brings water and air in close contact in order to eliminate dissolved gases like CO_2, H_2S, and volatile organic chemicals (VOCs) and oxidize dissolved metals such as Fe. The fact that water is odourless, one of the reasons for having an aerator is to clear the odour the water might come with, at least partially – also aiding bacterial growth and the breakdown of organic materials. As seen in Figure 2b, raw water from the in-take is being pumped (underground) through pipes to two cascade-like metal aeration chambers. The water forcefully goes up and splashes all the way down the cascade aerator, before flowing through a pipe beneath the aerator which takes it to the flash-mixer. MWW depends on natural air during aeration and hence reduces the cost of oxygen generation to be pumped to the water during aeration in other plants, due to their peculiar design. Again, the potential of the aerator at MWW getting contaminated with the same heavy materials trapped earlier at the screening chamber is high, if grasses are allowed to grow beside it, as shown in Figure 2c.

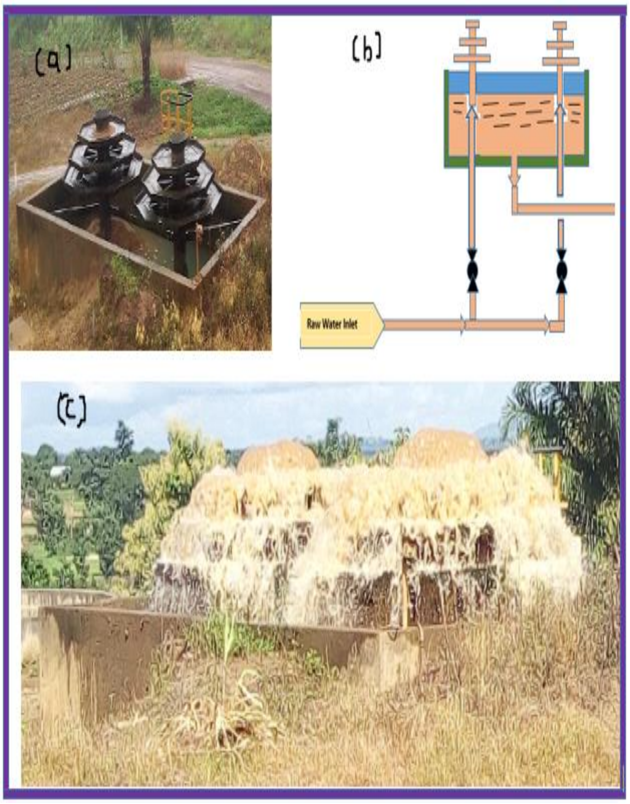

Figure 2(a) Aerator at Mada Water Works, (b) Schematic Diagram, and (c) Aeration in Progress

This puts the flow lines to other treatment units at risk of blockage of which manual hand picking is the only option to remove such materials. As a routine maintenance practice, removing the accumulated sand in the cascade aerator (Figure 2a) will increase the clarity of the exiting raw water, as significant portion of it flows from this unit to the chemical addition units.

IV. CHEMICAL ADDITION

Immediately the raw water leaves the aerator, it flows via pipes, directly to the reaction area of the flash mixer (Figure 3f) where all water treatment chemicals are released into it. These chemicals are found in the chemical building. Which is a 2-stairs building housing the chemical store (Figure 5), lime slurrer, the control panel room where the overall flow diagram and layout of the plant can be obtained, the administrative office, the chemical laboratory and the chemical tanks. Water treatment chemicals, such as lime, calcium hypochlorite ($Ca(OCl)_2$) and aluminium sulphate ($Al_2(SO_4)_3$ or alum) purchased and supplied by the government are kept in this place. $Ca(OCl)_2$ is usually brought in a covered rubber container to prevent it from agglomerating, while $Al_2(SO_4)_3$ and lime are in bags of 50kg each. The plant operator appropriately weighs the chemicals supplied using a weighing balance to rightly account for the amount added to the raw water. The store equally has a trolley for conveying the chemicals to a central position for lifting using a hoist, which is located upstairs inside the chemical building. Figures 3 depicts the chemical building, store, flash mixer, and the balancing tank.

(a) Chemical Building depicting the Chemical Tanks

(b) Wash Water Tank


(c) Solid Aluminum Sulphate (d) Extractor Fan

(e) Agitator Machine in Operation


(f) The Flash Mixer

Figure 3: Chemical Building, Wash Water Tank and Mixing Tanks

Figure 4: Depicting (a) Conveyor Trolley, (b) Weighing balance (c) Hoist controller (d) Hoist (e) Lime in sack

Figure 5: Chemical Building showing the Chemical Store

The conveyor in Figure 4a is capable of carrying 5-6 bags at a time and is used to convey such loads for uplift to chemical tanks upstairs. The hoist capacity is 300 kg and can carry 5 bags of alum which are 50 kg each, at a go. As shown in Figure 4c, the hoist is operated electronically, as it is a remote-like controller, having a motor (top of Figure

4d) and a path it follows when operated. This path leads either to the lime tank, calcium hypochlorite tank or alum tank shown in Figure 3a by moving the hoist either up, down or sideways. The three chemicals mentioned and used in 3 separate set of 3 tanks as shown in Figure 3a are the main chemicals used in MWW for the purpose of treating dirty water. They play a significant role in adjusting the pH, coagulation and disinfecting the contaminated water.

Chemical Coagulation: The process of destabilizing colloids by neutralizing the forces that keeps them apart, thereby amalgamating smaller particles into larger aggregates (micro flocs) is known as coagulation [24–26]. Coagulants is basically used to withdraw these forces that makes the particles to suspend in water and adsorbed simultaneously, the dissolved organic matter unto the particulate aggregates to be removed as impurities (or sludge) [24, 26]. More frankly, particles in raw water never come together because they have (negative) like charges which repel each other. Coagulation can be said to be a process of destabilizing the particles by charge neutralization because coagulants possess a positive charge. Once neutralized, particles no longer repel each other and can be brought together. Most widely used coagulants in treatment plants are aluminum sulphate (alum), aluminum chlorohydrate (ACH), polyaluminum chloride (PACl), lime, ferrous sulphate ($Fe_2(SO_4)_3$), ferric chloride ($FeCl_3$), cationic polymers and plant-based coagulants [24, 25, 27, 28]. But generally, alum and ferric chloride are the most widely applied chemical coagulants [29]. For instance, in Sarasota County, Florida, iron-based coagulants ($FeCl_3$ and $Fe_2(SO_4)_3$) and aluminum-based coagulants ($Al_2(SO_4)_3$, PACl and ACH) are used to treat surface waters [27, 29].

Alum and lime which is acidic are the two sole coagulants used at MWW at the moment. Since the phase of the alum used in the treatment plant is solid, based on Figure 3c, there is need to use clean water to dissolve it before channeling the mixture into the flash mixer. This clean water, otherwise called service water comes from the Wash Water Tank (Figure 3b) located outside the chemical building. Three tanks exist in the chemical building for dosing of alum. They are tagged, Tank, A, B, and C each having a volume equivalent to $11.2m^3$. Each tank has an agitator machine for mixing, electric motor (a machine that converts other forms of energy into mechanical energy and so imparts motion) and a basket. The basket holds the alum to be poured gently into the alum tank, in order to reduce splashing of the alum-water mixture. The electric motor on the other hand, is operated from the control panel shown in Figure 8 and is responsible for blending the solution of alum and water through the rotating mixer blades in all tanks. According to Figure 6, the tank has one inlet pipe via which the service water is fed. Attached is a flowmeter which reads the volume flow of clean water introduced. Alum is introduced manually into the tank. During the dry season the plant consumes 10-15 bags of alum while it consumes more than that (20-30 bags) during the raining season because, water becomes turbid during that season. The tank is 2m high, above which excess alum solution overflow out of the tank and have 3 outlet pipes which are (i) drainage pipe which allows dirty water beneath the tank to be washed out, (ii) an overflow pipe (Figure 7a), and (iii) mixture outlet pipe leading to the gravity dosing tank. Of the 3 outlet pipes, only the alum solution outlet, in Figure 21a and drainage pipes, in Figure 7b had a valve. Mixed alum solution in the alum tank flows through the outlet pipe into the gravity dosing tank. This tank pressurizes the flow by gravity, down to the flash mixer.

Perhaps alum’s low cost makes it the most widely used coagulant in most treatment plants. Compared to other coagulants out there, it produces lots of sludge, has high demand for hydroxide, works within certain pH range and is needed in large quantity. In essence, the dirtier or muddy the water (e.g. Mississippi water), the more alum it requires. However, this believe is not completely true and rarely guaranties purity of the water in some instances. As a replacement, scientist had proposed ATS 835, because it is effective at a very small dose and is soluble, thereby reducing solids formation [29]. For instance, 2-3 parts of ATS 835 yields almost same results with 25 parts of alum in water of same contamination level according to the same author. Because the water from the Mada River comes at different pH, ferric chloride, can be used at MWW as it is easy to use and works over a wide pH range [29]. But this alternative is highly corrosive and its price is not quite stable. It can eat through flow meters and hence requires special piping, storage equipment, and pumping equipment. Generally, chemical coagulants are hazardous – they produce high sludge volume which are most atimes very basic (pH $\geq$ 10). They require high operational cost and so a high sludge disposal cost is incurred, as experience by water treatment personnel at MWW [24, 28].

Natural Coagulants: In the quest of finding more options for efficient raw water coagulation, natural or plant-based coagulants that includes Nirmali seeds, *Euphoria malaiense*, *Jatropha curcas*, *Moringa oleifera*, *Hibiscus sabdariffa*, *Carica papaya* seeds, *Strychnos potatorum*, *Nephelium mutabile* seeds, *Cymbopogon citratus* leaves, *Centella asiatica* leaves, Pandanus leaves, Tannin, Cactus and fruit peels has been tested for efficiency in treating unclean water [24, 26, 30]. In other to curb cost associated with the use of chemical coagulants, natural coagulants are better substitute because they are locally available, can treat highly turbid water at optimum coagulant dosage, has zero health implications, are characterized by excellent removal efficiency and hence are considered sustainable [24, 25]. *Moringa oleifera* in that case rivals alum utilization looking at the above advantages and has been recommended for South Asian and African countries [24, 31, 32].

Chemical Disinfection: $Ca(ClO)_2$ is a chlorine-based compound used in treating water. They are granular or finer particles in nature. Seventy thousand gram of

$Ca(ClO)_2$ is introduced into a chlorine tank at MWW. When this chemical is secreted into the flash mixer, it kills all harmful organisms such as bacteria, protozoa and viruses in the raw water coming from the aerator. Bacteria that is mostly identified are shigella, salmonella, leptospira species, *Giardia lamblia* and *Escherichia coli*; viruses are Hepa A, Entero viruses and Rota virus; protozoa are *Giardia lamblia*, *Balantidium coli*, *Entamoeba histolytica* and Cryptosporidium and; helminths are T. solium, *Ascaris lumbricoides* and *Trichuris trichuria* [33]. The chlorine tanks (Figure 14) have their service water inlet, gravity dosing tank, overflow and drainage pipes just like the alum tank. The height of each tank is 1.2m with each having a capacity of 3.3m^3. The gravity dosing tank of the chlorine-based compound if dry, forms a cake which is capable of blocking or obstructing the flow of $Ca(ClO)_2$ solution out of it to the flash mixer. When these cakes accumulate, it is manually scraped and cleaned by cleaners in the plant.

Two types of disinfection approaches are applied at water treatment plants, namely, chemical and physical disinfection [33]. In chemical disinfection, chlorine gas (Cl_2), chlorine dioxide (ClO_2), hypochlorite (OCl^-), ozone (O_3), iodine (I) and potassium permanganate (KMnO4) are used while the physical means involve the use of ultraviolet (UV) light, sound (ultrasound) and heat (boiling). However, chlorination or the addition of Cl_2 gas (discovered in 1970's), is described as the most popular, cheap, relatively harmless, relatively easy to handle, dose and measure, because it provides a good residual and is an effective disinfection process to pre-treat contaminated water so as to reduce biofouling and kill germs [12, 33–35]. The gas is however, less effective in terms of its capability to kill Cryptosporidium oocysts and Giardia cysts, but best suited for larger waterworks, being highly toxic and corrosive; as well as having possibilities to leak through pipes and may result in the formation of harmful trihalomethanes (THMs) [34–36]. Chlorine gas is the preferred disinfectant for municipal water systems which was used as early as 1850 by John Snow during an outbreak of cholera in London to disinfect water [35, 37]. Principally, chlorine is sold in three forms: as clear amber coloured compressed liquid or greenish-yellow elemental chlorine gas, a solid or calcium hypochlorite and in solution form, which is sodium hypochlorite (NaOCl or NaClO) [33, 35–38]. Among them, sodium hypochlorite is the easiest to handle, it increases pH, it provides good residual, is the lowest in terms of dosage for effective action, is more safe, convenient, fairly cost effective and there is no worry for any gas leakage – but is however less stable (becomes inactive during long time storage), forms THMs and is more expensive than the gaseous form of chlorine [33–35, 37]. On the other hand, calcium hypochlorite, as used in MWW is in dry powdered form or a white granular tablet, basically suited for small treatment plants. It is stable, it increases raw water pH, it poses no leakage problems, it produces good residual, is very convenient, it offers low installation cost and is highly efficient [34-35, 37-38]. As a demerit, it is toxic, more expensive than the other two forms of chlorine, has the ability to irritate the skin, also gives storage difficulty and may explode from heat or contamination [33, 34].

Chlorine dioxide with the ability to denature bacteria and viruses better than Cl_2 gas and all the other three forms of chlorine can be produced on site [33, 35]. ClO_2 is very soluble in water with associated disadvantages such as inability to store, non-reaction with NH-4, and the production of toxic chlorite and chlorate [33]. Ozone, a strong oxidant generated on site using significant amount of electricity, was first employed in 1886 by De Meritens [12, 33, 36].

Figure 6: Service water inlet to Alum Tank

Figure 7: (a) Overflow and (b) Drainage Outlet Pipe

Figure 8: Control Panel

Figure 9: The Clarifier

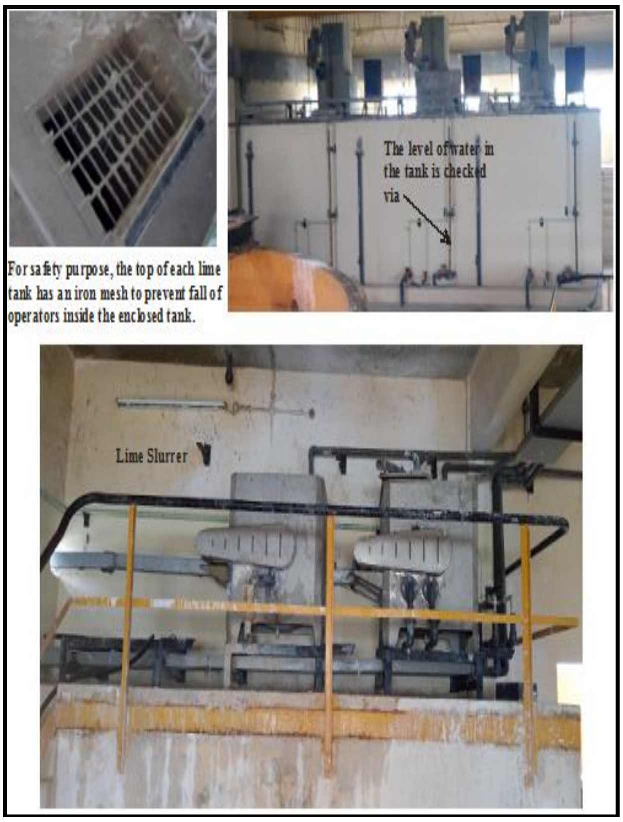

Figure 10: Lime Tanks and Lime Slurrer

Figure 11: Drained Clarifier Depicting Settled Mud

Figure 12: Filter Medium

Figure 13: Filter Nozzles

This raises its merits for effective replacement of the chlorination technique as it does not produce THM and organochlorine, is effective against protozoan cysts in water, has zero residual disinfectant and has no taste or ordor problems [12, 33]. Ozonation is majorly practiced in Europe, but its production requires high skill staff, in addition to being very expensive and difficult to monitor and control [33].

Calcium hypochlorite undergoing thorough mixing. The chemical chokes. Avoid too much inhalation. Hence it has a cover, unlike the alum tank

Water + $Ca(ClO)_2$ heading to the flash mixer

Figure 14: Chlorine Tanks

pH Adjustment: Lime is used for adjusting the pH of raw water which is between 6.5-8.0 based on laboratory records at MWW. Generally, raw waters are either acidic or basic whereas the pH of normal water is 7; hence the use of lime to make it as closer as possible to the neutral value. At the plant, 40-50kg bags of powdered lime is used for treating a single run of raw water intake. The lime tank is enclosed in a wall as depicted in Figure 10a, having an agitator machine consisting of two blades for effective lime-water mixing. The mixture in the lime tank goes to a cleaned lime slurrer (Figure 10b), because, it is always advisable to wash the lime slurrer before allowing flows into it. A slurry is chiefly a suspension of insoluble particles so much so that lime is generally dosed in this form due to its low solubility at 0℃ and ambient temperature [39]. It should be noted that lime does not completely dissolve into the solution before dosing in the raw water undergoing treatment. At MWW, hydrated lime is present as fine white-powdered substance of calcium hydroxide which is delivered as a slurry and pumped dosed into the flash mixer. In some facilities, they are delivered in dried powdered form and dosed through a dry feeder. Nevertheless, the timing as regards its use (in whatever dosing technique) in water treatment plants are either prior to coagulation to maintain an optimal pH levels for coagulation, to absorb carbon dioxide from ground water or as final pH or calcium ion level tuning to minimize corrosivity or plumbosolvency of the water before supplying to consumers [39]. To avoid suspended dust particles of lime and chlorine in air, two extractor fans (Figure 3d) which can be operated from the control panel is used to drive away these harmful chemical particles from the chemical building at MWW. Previously, New Zealand legislated on safety measures associated with hydrated lime utilization to protect the health of the surrounding communities and safe the environment from its hazard [39]. But in MWW, the extractor fan is the only obvious method put in place to reduce harmful chemical inhalation by the water treatment personnel.

V. FLASH MIXING

Lime, calcium hypochlorite and aluminium sulphate are all sent to the reaction area of the flash mixer to contact with raw water coming from the aerator. Formation of precipitate indicates an ongoing reaction at the reaction area. It is further mixed properly before discharging to various clarifiers. The mixer here, is called a flash mixer, having an agitator machine, which can also be operated from the control panel. The flash mixer is found at close proximity to the chemical building (Figure 3f). The chemical flow lines, reaction area, mixing section, mixers and discharge valves of the flash mixers are shown in Figure 15.

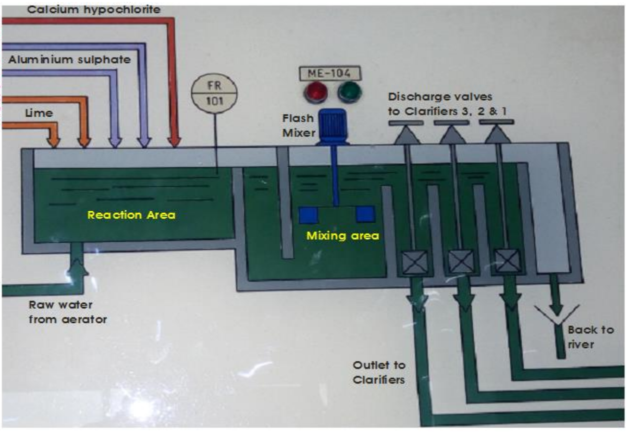

Figure 15: Schematic of the Flash Mixer

VI. CLARIFIER

Main purpose for having a clarifier (Figure 9) or sedimentation tank is to set it so that smaller solids called activated sludge moves by gravity to the bottom via method termed clarification. A clarifier that does that is called a secondary clarifier, which separates activated sludge/active bacteria or biological flocs from the treated water stream [9, 40]. This same function is divided into clarification and thickening at MWW and most plants [41–43]. Secondary clarifiers are the most widely used unit operations in water treatment plants, consisting of an effluent system, responsible for cleaning and decontamination and a sludge removal system for processing the wastewater [41, 44, 45]. On the other hand, primary clarifiers are not peculiar to MWW, whose main task is to sink heavy solids to the bottom, and so, invading foreign matter like leaves and leather are sometimes seen floating on the secondary clarifier surface [9, 43]. Again, primary clarifiers are customized for flows around 70 MGD, as too fast a flow, won't sink the solids while too slow a flow will impact the process upstream [9, 42]. Braginton-Smith et al. (2022) identifies problems including clarifier anaerobic condition causing hydrogen sulphide accumulation, high BOD concentrations, lack of oxygen transfer across the quiescent surface, efficient stripping of noxious volatiles in the discharge weirs, odor generation and longer detention periods responsible for its limited utilization in most treatment systems.

The sedimentation tank at MWW is made of the flocculator, scraper, dislodgement valves (Figure 18) and sludge pump all found on the travelling bridge (Figure 16) which is located top of the clarifier. There are two different types of clarifier design based on shape/structure [41, 43]. MWW uses the circular clarifier while at Maiduguri Water Treatment Plant, the rectangular clarifier design is used [11, 41, 43]. At the waterworks plant, the clarifier's main function is to improve the clarity of the incoming water from the flash mixer. The "flashed" raw water with chemicals comes directly to a central position in the circular clarifier for the flocculator machine to facilitate the formation of flocs which can easily settle. Flocculation is the process of bringing non-settleable particles together so that they finally settle. The settled mud is termed "sludge" as earlier explained. MWW utilizes three clarifiers in this case for this purpose, however, having different water quality output, identical with El-Asher Water Treatment Plant – as one clarifier could noticeably be better than the other [8]. During fluctuating weather conditions, the clarifier may risk an infestation or growth of algae and is accelerated during the summer heat [44, 47]. In the early 1990s, the sludge blanket clarifier technology known for effective algal removal was developed [47, 48]. Its operating principle enables both flocculation and clarification to be carried out within a single reactor, thereby minimizing the process cost [48]. According to Kelley (2016), cleaning the weir and launder with brushes or chlorine will help free them from algae. Other proven techniques mentioned by the same author are coating the launder with epoxy paint while cleaning, installing an opaque launder covers to prevent the entry of growth - promoting light, and attaching spring-loaded brushes to the rotating mechanism which clean the weir, launder walls and scum baffle.

Fig. 16: Features of the Clarifier

Fig. 17: Balancing or storage tank

Figure 18: Dislodgement Valves and Sludge Outlet

Scraper bridges are used for decantation, when there is a need to extract the sludge as it settles. A gear motor helps it revolves 360^0 for 45 minutes when in operation. The dislodgment valve is responsible for sending the effluent to the settling tank through a central column that distributes the flow and orients the liquid towards the bottom of the tank. As it crosses the tank, the sludge settles and scraping blades push it towards the collector located at the center of the tank. Under the effect of hydrostatic pressure, the sludge is then removed from the tank, while clarified water is drained off by overflowing. As the travelling bridge moves (Figure 16), the dislodgement valves are either opened or closed at different dislodgment point reached by the travelling bridge to allow sludge exit the clarifier. This sludge is sent back to the river. The main materials used are hot dip galvanized steel, aluminum and stainless steel. The scraper bridge has the following components: a reconstituted beam made of folded sheet metal, reinforced by a lattice to which the protective handrails, the bottom scrapers and, where applicable, the surface scraper are attached; a bridge mounted on a pivot; a slip ring for supplying power to the drive end; a beam supported by one or two rubber-tyred wheels; a gear motor; and a toothed outlet weir. Either central or peripheral drives are utilized by the sludge scrapers in all plants, which can last around 20 years depending on strict maintenance practices employed [49, 50]. Poor maintenance can lead to septic problems along the way as well as corrosion issues [44, 49]. For instance, strange noises ("snap, crackle and pop") originating from the drive unit, points to a broken ball in the main bearing [49]. Figure 11 shows a drained clarifier at MWW, being cleaned to avoid expensive replacement and modification of the structural components of the mechanism [44-45, 48-49].

VII. FILTRATION

Clear water from the clarifiers flows to the six filters at MWW to undergo the final treatment stage at the plant before it is declared pure (close to 99%) or safe for consumption. Water treatment scientist sees filtration as a method of passing water through a porous media for the elimination of suspended matter, also compared to a sieve or micro-strainer that holds suspended particles between the grains of the filter media [38, 51]. Such filters are termed 'sand filters' as water is passed through four different layers of sand (Figure 12) which is capable of trapping, clay, undissolved salts, organic fibres, metal oxides, silts, algae and harmful biotic particles (e.g. 0.01-0.1 μm virus particles, 5-20 μm algal microcolonies, 0.2-2 μm bacterial cells and 3-10 μm protozoan cysts) [51–53]. According to Reijnen (2020), only large salts can be filtered by sand filters and not salts that dissolve in water. The multi-media filter has different sands arranged from finer to coarser particles, keeping the finest at the top. Ncube et al. (2018) reported that, a design rule that stipulates between 1000-1200 L/dm ratio of the filter depth to media size has been recommended by engineers. Sand filters does two operations; filtration, where suspended materials are removed by the water through a sand media and backwash, where water flow is reversed to clean the sand [54]. This technique is further divided into two and dates back to 1804, where its first use in Scotland was documented [55]. As reported by Patil & Chougale (2020), slow sand filtration (SSF) is fundamentally a biological treatment method while rapid sand filtration (RSF) is a physical process.

SSF or filters is basically a heap of fine sand of about 1.2m deep, supported by 2 to 3 layers of gravel [57]. They are relatively labor intensive to maintain and operate, also requiring large expands of land if they are to serve large populations, because their percolation flow rate is slow [56]. SSF produces a microbiologically pure water, and requires only an addition of disinfectant to serve as residual for the distribution channels. Hence its surface is a thin layer (called *schmutzdecke*), concentrated mostly of variety of biologically active microbes [57]. However, RSF is a technique widely utilize in developed countries to treat large volume of water and so suits urban areas having a surface water source [57‑59]. That means, it requires 20% more land than slow sand filters, due to its high filtration rate and so is very difficult to implement in poorer communities – as the operation of an RSF requires energy for pumping, multiple filter units, elevated storage and highly trained personnel to carryout its basic function of filtration and backwashing [56, 57, 60]. Energy remains the biggest problems facing wastewater treatment plants, as an estimated 3-15% of United States' power is consumed annually by filtration alone [61]. Practical application of RSF is the Small Island Developing States (SIDS) like that on the main island of Mauritius and in Seychelles.

Previously, utilization of fine sand in RSF has been observed to cause, rapid surface clogging, excessive loss of sand through the strainer or underdrainage system, added cost on sand, shortening of the filter run, increased head loss and the percentage of wash water [62]. This has raise objections regarding its construction as its allowable depth is maximum of 10cm and not below [62, 63]. Sand diameter is normally 0.4-1.25 mm used for 24-30 inches deep RSF in most plants and deeper in newer ones [52, 63, 64]. Negative head, according to Biradar & Shete (2021), will cause air binding, formation of air bubbles in the filter sand and bumping of filter bed. Filtration in RSF entails the removal of suspended particles in turbid water by transport and attachment to the sand grain surfaces it is allowed to pass through [56]. Until turbidity removal reduces or the head loss through the filter rises to an excessive level, filtration continues. Most significantly, RSF can remove microplastics (MPs) and pathogenic cysts like *Cryptosporidium* [18, 56, 60]. Backwashing on the other hand, is the passage of water in the reverse direction to fluidized the media, thereby detaching the captured solids from the filter media and moving them out of the filter [56, 57, 60]. Backwashing time depends on the quality of water being filtered. RSF needs regular backwashing but however faces some backwashing hitches even though continuous backwashing filtration was a method developed in the 1970s to address such problems [55, 57, 65-66]. Because specific bio deposits accumulates to form larger mud balls after a few weeks, in addition to higher backwash water requirement, stratification of filter bed after backwashing as fine particles takes more time to settle as compared to coarser particles (Stoke's Law), bad overall performance and unsatisfactory operation and maintenance [58, 60, 65, 67]. Figure 19 clearly depicts the RSF at MWW and the backwashing system.

Figure 19: Rapid Sand Filter at Mada Water Works

Applying dual media, multimedia filters and extended terminal subfluidization wash (ETSW) can overcome the limitations associated with RSF [58, 67-68]. ETSW backwashing technique has been present for nearly 20 years, but the method is still less understood and practiced, despite the fact that it is capable of preventing filter ripening based on Amburgey et al. (2020)'s study. Fully, it is an acronym defined as: Extended (typically 5-10 min.), Terminal (last step of a backwash), Subfluidization (low flow rates with no media expansion or fluidization), Wash (washes out backwash remnant particles normally left in the filter after backwashing) [68]. RSF requires higher maintenance (e.g. filter repairs and equipment replacement) and operation cost than SSF, even as they produce different qualities of water [56, 57]. Dimitrova & Dabrowska (2019) reported that replacing of filter media and nozzles are the most expensive way to repair filters. Generally, overall repair of water treatment plants is costly. The United States needed around $180 billion to repair water treatment plants across the country while in 2014, the Government of Nasarawa state, Nigeria, through the Nasarawa State Water Board, awarded a contract sum of

₦600 million to repair the ailing MWW according to reports [7, 61].

Normally, the filter medium is kept beneath the nozzles (Figure 13). A filter nozzle is a component which retains the media (gravel) and also provide the means for good distribution of water and air (where used). It does that by sipping the clear water because they are perforated. Nozzles may be installed in lateral pipes or in suspended floors (viz., MWW). A nozzle has three main components, a strainer to exclude the media or packing gravel, a water control orifice and a tailpipe with an orifice(s) to control the air flow. Filter nozzle slot sizes vary considerably from about 0.2mm to around 10mm. Strainer slots can become partially blocked with media. When the nozzles are faulty, they would no longer filter water. As such, the media needs to be cleaned using the backwash flow. This loosens the filter media and frees the trapped contamination which is further removed in the backwash flow. Once the backwash process is complete, the bed is then allowed to sit before the filter is back to normal flow. Backwashing involves closing the inlet valve that takes water to the filter, closing the valve that carries treated water from the filter to the clear water tank, opening the drain and backwash valve, and opening the air-blowing valve. Filter backwash is the process in which about 5% of treated water is kept aside for backwashing. The duration required for backwashing with treated water is 7 to 10 minutes with additional flow of air [56]. The filtration unit and backwashing process are all operated from the Filter Control in Figure 23.

Figure 20: Pumping Station

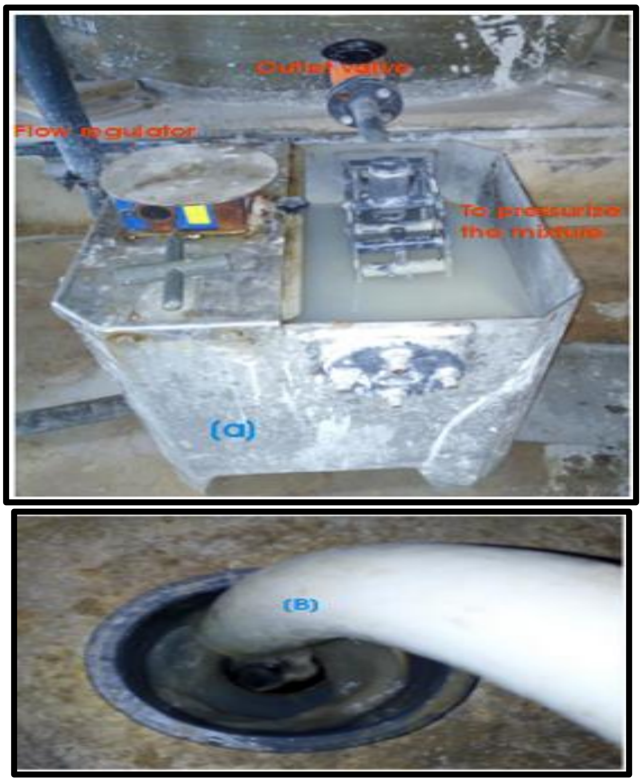

Figure 21: (a) Gravity Dosing Tank and (b) Flows to the Flash Mixer

Figure 22: Sample Water Taker

Figure 23: Filter Control

VIII. STORAGE & PUMPING STATION

Safe drinking water [69] from the filter beds at MWW are stored in two circular storage reservoirs (clear water tanks) or balancing tanks (Figure 17). Water chemists duly take samples of the treated water for quality test and possible post-chlorination to kill new organisms detected. The treated water is used by the plant and also pumped via a 450km total pipe length to other reservoirs in Keffi, Garaku and Akwanga to be supplied to consumers. Wash water tank in Figure 3b [64], as it is called holds water for plant's utilization, especially, during chemical mixing, general washing and laboratory water requirements. The supply of water to all these storage structures or reservoir units is through pumps and pressure tanks (Figure 20). Depending on distance and location, clean water from the balancing tanks is pumped by personnel at the pumping station to namely; a reservoir in Keffi of capacity 12500 m^3 via 600 mm pipe diameter, 4300 m^3 reservoir capacity in Garaku in Kokona Local Government and 650 m^3 and 1350 m^3 Akwanga old and new reservoirs respectively through pipes of 800mm diameter. In 2005, the Nasarawa State Water Board, Lafia, reported that MWW has the largest daily supply scheme of 45000 million cubic liters, followed by 13500 m^3/day by Lafia, 8100 m^3/day by Doma, 2250 m^3/day by Nasarawa, 2000 m^3/day by Nasarawa Eggon, 1125 m^3/day by Toto, 1000 m^3/day Obi, and 500 m^3/day by Keana [4]. Normally, pipe repair works experienced in 2019 has reduced or totally leads to stoppage of water treatment activities and supply to receiving communities depending on MWW for their supply leading to hardship and scarcity. Such cases are some that could prompt temporary suspension of works at the treatment plant in order not to overflow the storage reservoirs or send treated water which would end up lost due to leakages. Notwithstanding, application of technology had helped detect the water level in the clear water tank to help know when to halt operation.

IX. PROBLEMS, PRECAUTIONS AND SOLUTIONS

Risk of contamination along the treatment stages can be avoided if the surrounding environment is kept clean. Owing to the plant's location, rodents and snakes would likely use the plant's vicinity to hide and feed from plants and bushes around if not cleared. So, the need for personnel to wear safety boots and the recruitment of adequate cleaning personnel becomes necessary to prevent insects and snake bites as well as safe the water from further contamination. Notably, it is strange to find small live fishes on the surface of the sand filter during filter clean up, previously. Furthermore, visitors or officials must avoid throwing or mistakenly letting their belongings (e.g., pen, I.D. card, money, food etc.) to fall into any of the units. Though electricity supplied to MWW is almost described as constant, standby generators needs to be serviced, fueled and put to use whenever there is power disruption. Because accidents can be prevented if there is adequate lighting in and around the plant, especially for night treatment operations. In event of serious health emergency arising from the items described above, first aid treatment should be administered to victims first before transporting them to hospital using the plant's working vehicle. In that case, authorities must provide first aid tools and operational vehicles to ameliorate injuries from accidents and excessive chemical inhalation. The plant's vehicle can be used to survey supply pipelines and carryout preventive maintenance on them before they develop problems.

Chemical water treatment aids are known to be harmful to personnel, consumers and the plant's nearby surroundings. Currently, there is no special regards accorded to operators handling such chemicals at MWW. Inevitably, handlers get exposed to these substances (if not in large concentrations), in little amounts that would result in health consequences in the long run. There is apparent non-provision of safety gageites by government to protect oneself from potential health-impacting effects of these chemicals. In the same sense, consumers are not protected, the fact that, quality test is poorly carried out sometimes due to inadequate or non-availability of laboratory test equipment. There is also no prompt replacement of broken laboratory tools or obsolete ones by the relevant authorities. Consequently, it impacts speed, data reliability and accuracy and the time needed to complete certain water analysis task by the officials in charge. Also, creation of a research and development unit would facilitate the sharing of knowledge among experts working at different units in the plant. It would also help in keeping track of the current trends applied across the world.

All chlorine forms used at treatment plants can be produced on site. As a way of reducing transportation cost for these chemicals, small plants can be built closer to the treatment plant since they are needed in large quantities. As such, more jobs are created, in addition to ensuring security and transparency in their utilization; by not allowing government allocated chemical supply to the plant to be diverted or sold to potential buyers. This kind of check and balances has proven effective in other waterworks in the country and has ensure accountability in its use. There is need for training and re-training of staff handling important units at MWW to improve their efficiency and output so as to align them with current modern practices. Beside this, upgrade, re-design or modification should be carried out on outdated treatment methods and equipment, to existing technique. All these is necessary, as the current output volume is inadequate, given that, the targeted population has increased. According to literature, the usual one day supply interval to consumers has now been extended to three or more days [70]. So, the construction of additional clarifiers, filters, storage tanks or a phase II of the water treatment plant near MWW is required.

It is obvious that certain procedures carried out are manual and so is lengthy and tiring. Therefore, automation would put less stress on existing workers that are although few at the moment. Fundamentally, this is further traced to nonrepair of failed or broken-down machines and equipment at the plant, because of the availability of alternative ones. In that case, functional ones are over-burdened and made to perform repeated task, beyond what they were earlier designed to do at a time. If such practices continue, more and more machines would follow suite and forced a shutdown of the entire plant. Ultimately, this challenge is caused by non-supervision, lack of spare parts, little repair know-how and poor funding by the relevant authorities. This is why the mechanical workshop or unit must be adequately equipped and the technicians trained properly to face problems that may arise in the future.

Communication lines between MWW, reservoir stations and consumers must be open to allow feedback and complains reach the management at the right time. It will most likely help in tracking pipe leakages and enable the consumers voice their concern from time to time. In 2013, a cut in water supply leads to a morning protest by thousands of students affected [7]. To forestall future occurrences, notification on plant shutdown for repair and maintenance or any other issue will be properly communicated to users beforehand. Such action will also enhance the general security of the facility, whenever it is threatened. It is foreseen that addressing most of the problems at MWW would mean, adequate water supply, optimal production, high purity water, personnel motivation, ease of operation, cost reduction and consumer satisfaction. Because estimates of budgetary allocation on chemicals and diesel to all water treatment plants in Nasarawa state recently amounts to ₦120 million and ₦150 million respectively [71].

X. CONCLUSION

Functionality, challenges encountered and successes achieved presently, during quality water production at MWW has been explained. Studies shows that MWW relies heavily on fix methodology, old experience and improvised technique in the course of treating the surface water from Mada River, which sometimes has proven effective. Satisfactory water analysis results, in most cases, that includes pH, temperature and color examination of sample raw water, clarified and purified water has been obtained at the laboratory. The three water categories from the plant unit operations can be directly collected using the Sample Water Taker (Figure 22) inside the laboratory for quality test. There is less likelihood of including additional quality parameters in the test carried out due to shortage of laboratory equipment and staffing. MWW therefore, needs to work on manpower development, energy supply, water quality analysis, personnel safety, unit maintenance and supervision. Additional studies should be conducted on individual units and water quality analysis to address the problems highlighted and suggest areas for improvement.

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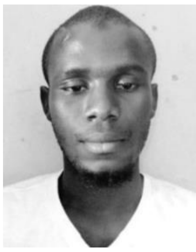

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