Nigerian Research Journal of Engineering and Environmental Sciences 5(1) 2020 pp. 214-222

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Small Runoff Reservoir Water Quality Evaluation for Microirrigation and Tropical Fish Culture within an Afforested Area of Afaka, Kaduna, Nigeria

[1]Ameso, V.C., *[2]Onwuegbunam, D.O., [3]Onwuegbunam, N.E. and [1]Maxwell, D.

[1]Department of Water Resources and Environmental Management, National Water Resources Institute, PMB 2309, Mando Road, Kaduna, Nigeria.
[2]Department of Agricultural and Bio-Environmental Engineering, Forestry Research Institute of Nigeria, Federal College of Forestry Mechanization, Afaka, Kaduna, Nigeria.
[3]Department of Basic Sciences and General Studies, Forestry Research Institute of Nigeria, Federal College of Forestry Mechanization, Afaka, Kaduna, Nigeria.
*donancy2001@yahoo.com

ARTICLE INFORMATION

Article history:
Received 07 May, 2020
Revised 01 Jun, 2020
Accepted 02 Jun, 2020
Available online 30 June, 2020

Keywords:
Reservoir
Water quality
Microirrigation
Fish culture
Afforested area

ABSTRACT

The water quality status of a small runoff reservoir in an afforested area of Afaka, Kaduna, Nigeria was evaluated for suitability in microirrigation as well as fish culture. The parameters evaluated were pH, temperature, electrical conductivity, turbidity, total dissolved solids, chloride, salinity, magnesium, calcium, sodium, potassium, hardness and sodium adsorption ratio. These were analyzed following standard procedures. The mean values of the sampled parameters were not statistically significant over the sampled points on the reservoir. Except for the turbidity (47.2 NTU) and potassium (2.3 mg/l), the levels of the other parameters were found to be within normal or acceptable limits for microirrigation and tropical fish culture. Hence, the quality of runoff reservoir within the afforested catchment can be suitable for microirrigation and fish culture as a way of maximizing its potentials, provided the required microirrigation and fish culture best management practices as well as reservoir restriction practices are followed.

1. INTRODUCTION

Reservoirs or dams are structures built across a stream, a river, or an estuary to retain or conserve water. Reservoirs are built to provide water for domestic use, irrigating crops during dry spells, livestock watering, brick making, and recreational activities such as swimming, boating, and fishing or for use in industrial processes (Sugunan, 1997). Small reservoirs have vast range of uses and are developed to uplift people's living standards especially in communal areas where dry spells are experienced and livelihood centred on agricultural production (Zirebwa and Twomlow, 1999).

In view of the limitation in the quantity of water stored by the reservoir, the study focuses on the use of the water for microirrigation for better conservation of the water for irrigation. Microirrigation is the slow, frequent application of water directly to relatively small areas adjacent to individual plants through emitters placed along a water delivery line. The main advantage of microirrigation is the reduction of water loss associated with conventional irrigation systems such as the surface or sprinkler systems, by reducing evaporative losses and deep percolation beyond crop root zones (Michael, 2008). Generally, water must be of high quality to avoid clogging the small emitters. The main types of microirrigation systems are the surface and subsurface drip irrigation, and microspay irrigation systems (USDA-NIFA, 2020). In surface irrigation water is applied to the soil surface usually at or near the plant to be irrigated. In subsurface drip irrigation water is applied below the soil surface through drip line laterals that are installed at depths of 30-45 cm (USDA-NIFA, 2020). To conserve water for forest tree nursery operation microspray irrigation is required for wetting the seedlings.

In addition, more productive utilization of the reservoir through additional activity like fish culture within the project area can be considered for optimum use of the available reservoir water resource. This is a means of diversifying available natural resources for optimum productivity under agroforestry system. Considering the potential of the reservoir for microirrigation and fish culture, therefore, there is the need to evaluate some water quality parameters that are of basic significance for these activities.

Monitoring the quality of irrigation water is necessary for the protection of soil productivity, human health, plants growth and water bodies and for prevention of deterioration of irrigation water conveyance equipment (Ayers and Westcot, 1994). Water quality for fish culture is fundamentally important for high productivity in fish rearing as it affects the growth, health and survival of fish. Tropical fish, for instance, are generally sensitive to poor water quality and therefore require fish farmers to have a higher level of water quality management skills (Bhatnagar and Devi, 2013). Regardless of the kind of water available or the species chosen, all fish depend entirely on water to live, eat, grow and perform other bodily functions. Therefore, it is no surprise that the success of a fish farming establishment lies greatly on its water quality (Buttner *et al.*, 1993). Aquacultural water quality depends on management practices such as stocking density, feed administration and water circulation.

The present study is limited to the suitability of the reservoir water quality for initiating fish culture. Hence, the objective of the study is to evaluate the qualitative adequacy of water in the small reservoir for two agroforestry activities, namely microirrigation and fish culture.

2. MATERIALS AND METHODS

2.1. Description of Study Area

The small reservoir within Afaka Afforestation Project (10^o 33' N - 10^o 41' N and 07^o 26' E - 07^o 28' E) (Figure 1) was constructed in 1987 by the Japanese International Corporation Agency (JICA) in collaboration with the Trial Afforestation Project (TAP) of the Forestry Research Institute of Nigeria (FRIN) with a design capacity of 16,400 m^3, primarily for the purpose of nursery plantation seedling irrigation and forest fire fighting (JICA-FRIN, 1991). The reservoir catchment comprised *Eucalyptus camaldulensis* woodlot with about 70% canopy density and cultivated areas. Sheet and rill erosion have been predominant within the exposed parts of the catchment. The reservoir water source was surface and subsurface runoff which discharge into it during the rainy season. Onwuegbunam *et al.* (2008) determined the capacity of the reservoir to have reduced to 12,650 m^3 in a bathymetric survey carried out on the dam in 2004. The reduction in storage capacity was due to siltation of the reservoir occasioned by deposition of sediments transported from eroded portions of the reservoir catchment. The reservoir is 'small' on the basis of reservoir classification by CAESES (2019), the reservoir height and storage capacity being less than 7.5 m and 60,703 m^3, respectively.

Human activities such as recreation, fishing, swimming, bathing and laundry (Figure 2) take place from time to time at the reservoir. Also, herds of cattle come often to drink water in the reservoir and in many cases defecate and urinate in the water.

Figure 1: A view of the small reservoir within Afaka trial afforestation project

Figure 2: Human activities along the reservoir

2.2. Water Sampling

Water sampling was carried out within a week (28th March to 3rd April, 2019). On each day, two samples were purposively collected from each of five points which represent the downstream (DS), upstream (US), midstream (MS), point source (PS) and embankment downstream and upstream (EM) portions of the reservoir. Samples were collected just before noon (12:00 pm) into sterilized non-corrosive bottles, corked immediately and preserved for transfer to the laboratory. Samples at the non-peripheral points of the reservoir were collected by using floats to access these points.

2.3. Physical Water Quality Parameters

Measurements of the following physical water quality parameters: appearance, pH, electrical conductivity (EC), total dissolved solids (TDS) and turbidity were carried out on-site. The analytical methods adopted were based on international acceptable methods and analytical application principles. The procedure used for testing each of the parameters is given as follows:

pH was analyzed using Wagtech WE30200 pH meter. The pH test was conducted by dipping the electrode into the water sample at about 2 to 3 cm, stirring once and allowing reading to stabilize. Calibration of the pH meter was done using pH 4, 7 and 10 standard solutions.

Electrical conductivity (EC) and total dissolved solids (TDS) were determined using Wagtech WE30120 conductivity/TDS meter. The testing was conducted by submerging the probe into the water sample in a plastic beaker to minimize any electromagnetic interference, stirring and allowing the reading to stabilize. Calibration of the EC/TDS meter was conducted using compatible EC standard solution (12.88 µS/cm).

Temperature of the water samples was taken with the EC/TDS meter as the EC value automatically compensated for temperature. Turbidity was measured using Wagtech WE30140 Potalab Turbidimeter. The turbidity measurement was conducted by placing the meter on a flat surface, filling a clean sample vial to mark, placing in a sample well and covering the vial with light shield cap. The display reading was recorded as sample turbidity.

2.4. Chemical Water Quality Parameters

Chloride was measured by complexometric titration of 100 ml sample using 0.141 moldm^{-3} silver nitrate ($AgNO_3$) in the presence of 1 ml potassium chromate indicator (K_2CrO_4), at pH of 7- 8. At the endpoint titration colour changed from yellow to pinkish-yellow and the chloride concentration was computed by calculation as follows (Sastry *et al.*, 2013):

$$Chloride\ (mg/l) = \frac{(A-B)\times N\times 35450}{Volume\ of\ sample} \quad (1)$$

Where: A = Sample titre value, B = Blank titre value and N = 0.0141

Magnesium (Mg), Calcium (Ca), potassium (K) and Sodium (Na) were determined by direct aspiration into an air-acetylene flame using Atomic Absorption Spectrometer. The concentration of each metal in a sample was determined at specific determinant wavelength by using appropriate hollow cathode lamp and freshly prepared standards calibration solution.

Total water hardness (TWH) was computed from the calcium and magnessium concentrations as expressed by Lenntech (2017), as the sum of calcium hardness and magnesium hardness expressed as the concentration of calcium and magnesium ions expressed as equivalent of calcium carbonate ($CaCO_3$). The molar mass of $CaCO_3$, Ca and Mg are respectively 100.1 g/mol., 40.1 g/mol. and 24.3 g/mol.

The ratio of the masses are:

$$\frac{M_{CaCO_3}}{M_{Ca}} = \frac{100.1}{40.1} = 2.5$$

$$\frac{M_{CaCO_3}}{M_{Mg}} = \frac{100.1}{24.3} = 4.1$$

Where, M_{CaCO3} and M_{Ca} and M_{Mg} are the molar masses of calcium carbonate, calcium and magnesium, respectively.

Hence, the total permanent water hardness expressed in terms of $CaCO_3$ as given by Lenntech (2017) is:

$$[CaCO_3] = 25 * [Ca^{2+}] + 4.1 * [Mg^{2+}] \quad (2)$$

Sodium adsorption ratio (SAR) of the water samples was determined to evaluate the suitability of the water for agricultural irrigation with respect to its effect on soil structure stability and aggregation. SAR was expressed by Ayers and Westcot (1994) as:

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+}+Mg^{2+})}} \quad (3)$$

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Where, Na^+, Ca^{2+} and Mg^{2+} are in meq/l unit obtained by dividing each of the cation concentrations by the equivalent weight.

3. RESULTS AND DISCUSSION

The mean values of the physical water quality parameters are presented in Figure 3. The pH, temperature (T), electrical conductivity (EC), total dissolved solids (TDS) and turbidity (TUB), for all the sampled locations, were obtained as 7.6, 29.3°C, 71 µS/cm, 35.5 ppm and 47.2 NTU, respectively. Also, the mean values of the chemical parameters: Chloride (Cl), magnesium (Mg), calcium (Ca), sodium (Na), potassium (K), hardness and sodium adsorption ratio (SAR) for the same locations were 6.6 mg/l, 27.4 mg/l, 13.8 mg/l, 15.6 mg/l, 2.3 mg/l, 164.7 mg/l and 0.6 meq/l, respectively (Figure 4). The reservoir water quality test results were compared with acceptable standards for both microirrigation and fish culture (Table 1) to draw conclusion on the study objective.

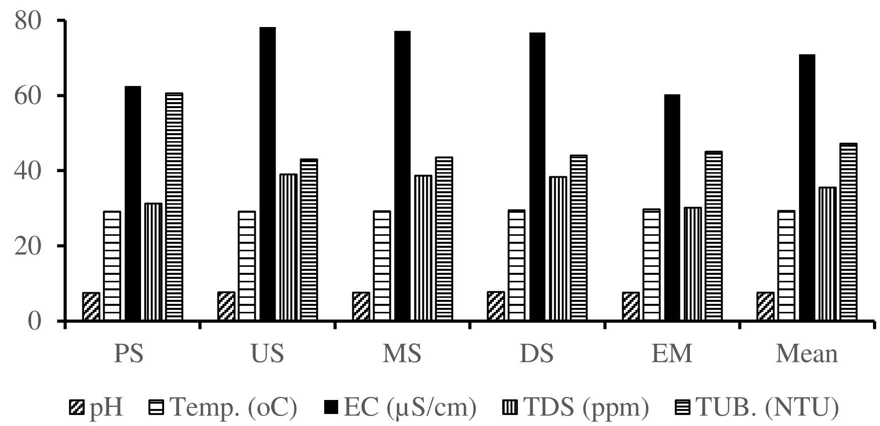

Figure 3: Mean values of physical water quality parameters

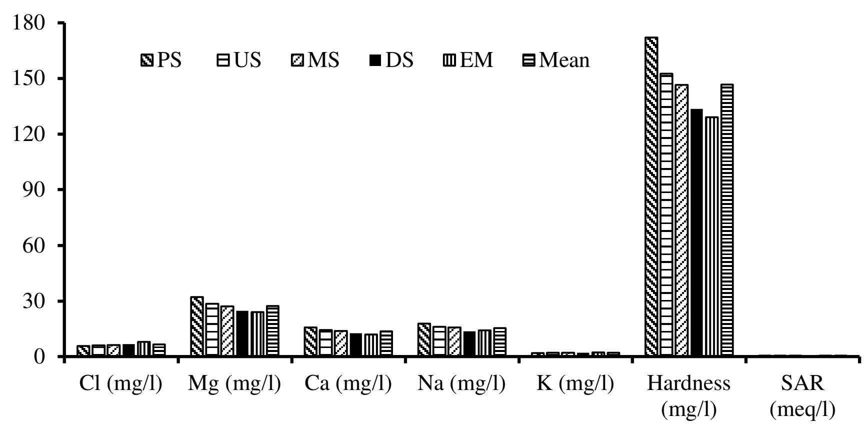

Figure 4: Mean values of chemical water quality parameters

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3.1. Physical Parameters

The reservoir water pH of 7.6 is within the FAO (2001) acceptable limit described as 'slight to moderate' (7.0 – 8.0) for microirrigation. PNW (2007) stated that pH values above 8 pose severe restriction on use of the water for microirrigation as it potentially clogs the device emitter. Towers (2007) presented the acceptable pH range for fish culture as 6.5 to 9.0. In very alkaline water (> pH 9), ammonium in water is converted to toxic ammonia, while acidic water (< pH 5) leaches metals from rocks and sediments. These lead to adverse effect on the fishes' metabolism rates and ability to take in water through their gills, and can be fatal (Swann, 1997). The mean temperature value of the sampled water for all sampled locations was 29 ^oC. This is within the optimum temperature for growth of tropical species like African catfish and tilapia (Wellborn, 1988; Boyd, 2018). In most types of aquaculture, temperature cannot be controlled and depends on the amount of solar radiation, air temperature, or the temperature of water passing through the culture unit. Hence, aquaculture operations must be timed such that fish culture should correspond to the periods of favourable water temperature. Water temperature is important for the growth and survival of fish because they are poikilothermic (coldblooded) meaning they cannot control body temperature, and they equilibrate with the temperature of the surrounding water (Boyd, 2018). Tropical species will die at water temperatures below 20 ^oC, and most do not grow at temperatures below 25 ^oC (Boyd, 2018). Optimum temperature for growth is 24-30 ^oC (Wellborn, 1988; Boyd, 2018). The mean EC value for all sampled locations (71 µS/cm) is normal for both microirrigation and fish culture, being less than the FAO limit of 7000 µS/cm and also within the lower limit for fish culture as stated by Wellborn (1988), Boyd (2018) and Stone *et al.* (2013). The total dissolved solids (TDS) of 35.5 ppm obtained in the analysis is normal as recommended by FAO (2001). TDS values are not readily available for fish culture. However, the EC value suffices since both are indicators of salt level in the water.

Table 1: Water quality standards for micro-irrigation and fish culture ([b]Wellborn 1988; [a]FAO 2001; Armstrong 2001; Stone *et al.* 2013; Muller and Cornel 2017; Boyd 2018)

Parameter	[a] Micro-irrigation			[b] Fish culture		
	Normal range	Acceptable range	Unit	Normal range	Acceptable range	Unit
pH	< 7.0	7.0 – 8.4	-	6.5 – 9.0	5.5 – 10.0	-
Temperature	variable	15.0 – 35.0	^oC	-	24 - 30	^oC
Electrical conductivity	< 7.0 < 70000	0.7 – 3.0 7000 - 30000	dS/m µS/cm	60 – 2000 0.06 – 2.0	30 – 5000 0.03 – 5.0	µS/cm dS/m
Total dissolved solids	< 450	450 -2000	g/ml	-	-	g/ml
Turbidity	< 21	21 - 43	NTU	-	-	NTU
Chloride	< 140	0 - 1065 0 - 30	mg/l me/l	> 100	10 x the nitrite level	mg/l
Magnesium		0 – 61 0 - 5	mg/l me/l	Non-limiting	Non-limiting	mg/l
Calcium		0 – 400	mg/l	> 20	> 5	mg/l
Sodium		0 – 920	mg/l	-	-	mg/l
Potassium		0 - 2	mg/l	-	-	mg/l
Total hardness		-	mg/l as	50 – 150	> 20	mg/l as
SAR	< 1	0 - 15	-	-	-	-

The water turbidity (47.2 NTU) is above the FAO (2001) limit for microirrigation. The high turbidity is attributed to clay formation within the reservoir and the occasional muddling of the reservoir by cattle which takes some time to settle. The water can be used for microirrigation following an appropriate filtration process during irrigation operation. This will require regular filter maintenance to avoid clogging of the system. No specific values are given in literature for turbidity level of water used for fish culture. However, Carballo *et al.* (2008) has indicated that high turbidity of water can decrease fish productivity by reducing light penetration into the water and thus oxygen production by the water plants. Fish filters can also be clogged and the gills injured. As a remediation for highly turbid water, Carballo *et al.* (2008) suggested the use of silt catchment basin in the form of a small reservoir at the inlet of the pond. The water flows into this reservoir and is kept there until the mud settles on the bottom so that the clear water is let into the fish pond. Also, addition of lime (CaO, alum ($Al_2(SO_4)_3.14H_2O$) at the rate of 20 mg/l and gypsum on the entire pond water at the rate of 200 kg/1000 m^3 of pond can reduce turbidity (Bhatnagar and Devi, 2013).

3.2. Chemical Parameters

The chloride level of 6.6 mg/l obtained in this test is normal for microirrigation, being less than the FAO (2001) recommended range of less than 140 mg/l (Figure 4). For commercial catfish production, the chloride level in the water is below standard as it should be at least 100 mg/l (Stone *et al.* 2013). Chloride helps the fish to maintain their osmotic balance. Chloride to nitrite ratio of 10:1 is required in water for fish culture to reduce the incidence of nitrite poisoning caused by excess nitrite in the water (Stone *et al.,* 2013). The calcium concentration in the reservoir water (13.8 mg/l) is within the FAO acceptable range (0 – 400 mg/l) for irrigation. In excess concentrations, calcium combines with carbonate to form calcium carbonate scale, which can plug microirrigation system emitters. The calcium is within the acceptable range for fish culture (> 5 mg/l) but less than the normal range (> 20 mg/l) (Wellborn, 1988; Stone *et al.*, 2013; Boyd, 2018) Magnesium behaves much like calcium, but precipitates at higher pH levels and is not typically a problem in microirrigation systems. The magnesium concentration in the reservoir water (27.4 mg/l) is within the FAO range for irrigation (0 – 61 mg/l) and is not limiting in tropical fish culture (Wellborn, 1988; Stone *et al.*, 2013; Boyd, 2018). Potassium is usually found in less amounts in natural waters but it is a major plant nutrient. Its recommended concentration is 0 – 2 mg/l in irrigation water (FAO, 2001). The sample test result of 2.3 mg/l is slightly above the recommended range. Sodium concentration in the sample water (15.6 mg/l) is within the FAO recommended range. High sodium in irrigation water can impact both the soil and the plant as soil with high sodium concentration associated with a clay fraction will develop poor physical properties for plant growth and water infiltration (FAO, 2001). FAO (2001) did not consider total water hardness for irrigation. It is known that total water hardness is a function of both calcium and magnesium concentrations with the carbonate. The reservoir water is hard, the total water hardness value (146 mg/l) being within the range 121 – 180 mg/l described by Boman *et al.* (2018) as hard water. The range is normal for fish culture (50 – 150 mg/l); the acceptable limit is 'greater than 20 mg/l (Stone *et al.*, 2013). Based on FAO (2001), sodium adsorption ratio (SAR) of 0 -15 me/l is acceptable for microirrigation but the normal range is < 1 me/l. SAR is however not considered in fish culture except if the water for the culture is intended to be used for irrigation. The SAR value of 0.6 meets the normal standard for irrigation water.

3.3. Parameter Homogeneity within Reservoir

An analysis of variance (ANOVA) of the mean values of all the water quality parameters over all sampled locations indicate that there is no significant variability in values of the parameters at 5% level of significance (Table 2). The relative uniformity of each parameter with respect to the sampling points can be attributed to rapid diffusion within the reservoir despite anthropogenic activities such as bathing, laundry and swimming.

The reservoir being small, there are shorter distances of solute path, and hence, a more rapid net movement of molecular particles from the points of high chemical potential to those of low potential so that equilibrium state is reached whereby there is similarity in concentration throughout the water body (Chaplin, 2019).

Table 2: Homogeneity of sampled reservoir test parameters

Test parameter	$F_{calc.}$	$F_{crit.}$	p-value	Conclusion
pH	0.6274	5.3177	0.4511	NS
Temperature	1.1755	5.3177	0.3099	NS
Electrical conductivity	1.3354	5.3177	0.2812	NS
Total dissolved solids	1.2898	5.3177	0.2890	NS
Turbidity	0.0071	5.3177	0.9348	NS
Chloride	0.7826	5.3177	0.4021	NS
Salinity	0.7817	5.3177	0.4024	NS
Magnesium	01400	5.3177	0.7180	NS
Calcium	0.2781	5.3177	0.6122	NS
Sodium	0.5423	5.3177	0.4813	NS
Potassium	0.7754	5.3177	0.4042	NS

$F_{calc.}$: Calculated F-value; $F_{crit.}$: Critical F-value; NS: Not significant

4. CONCLUSION

A small runoff reservoir in an afforested area of Afaka, Kaduna, Nigeria was evaluated for its qualitative suitability for microirrigation and fish culture as a way of maximizing its potential. Selected physical and chemical parameters related to microirrigation and fish culture were evaluated and found to be suitable for both microirrigation and fish culture, except for the turbidity which was found to be in excess of the microirrigation requirement, and potassium which slightly exceeded the limit for fish culture. With best management practices, appropriate reservoir catchment sanitation and restrictions, the reservoir can be used for microirrigation and fish culture within the agroforestry area, in addition to its present use for firefighting and conventional plantation seedling irrigation. This will put the scarce water resource in optimum use.

5. ACKNOWLEDGEMENT

The authors wish to acknowledge the Regional Water and Environmental Sanitation Centre, Kumasi (RWESCK) at the Kwame Nkrumah University of Science and Technology, Kumasi, which is funded by Ghana Government and the World Bank under the Africa Centre of Excellence Project, for initiating the internship programme under which this study was carried out. The authors also acknowledge the Federal College of Forestry Mechanization, Afaka, Kaduna / Forestry Research Institute of Nigeria (FRIN) for the training provided during the internship.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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