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Reclaimed Air Conditioner Condensate as Alternative Source of Water in Hot Humid Region

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Abstract
Background: *As freshwater availability is running low due to pollution and climate change issues; consumption is likewise increasing due to population growth and the cumulative effect is causing depletion of available fresh water from natural sources. A potential approach for producing water to cater for the masses is extraction of water from atmospheric air through reclamation of condensate from air conditioning systems. This study investigated the quality and sufficiency of water generated from air conditioner condensate for non-potable uses in institutional buildings.*
Materials and Methods*: A case study approach was employed. Field studies involving; collection of condensate samples and measurement of relevant field data (including temperature, humidity, condensate discharge rate and reclaimable condensate quantities per unit time) and characterisation and analysis of the reclaimed AC condensate water samples were carried out.*
Results: *It was found that 7.4litres of condensate water is reclaimable from a single air-conditioning (AC) unit operated for eight hours per day at an average temperature of 24.9ºC and relative humidity of 60.1%. The reclaimed AC condensate water exhibits satisfactory physiochemical and biological characteristics for non-potable uses and equally attained good quality rating for domestic applications based on water quality index rating. The pH value of the reclaimed AC condensate water is acidic, indicating the need for pH corrective treatment during use as non-potable water. The measured 7.4litres daily reclaimable AC condensate water quantity is over 100% sufficient to meet the minimum per capital daily domestic water requirement recommended by the World Health Organisation (WHO) for survival of an individual.*
Conclusion: *The findings from this study indicates that reclaimed AC condensates could serve as an alternative source of water for non-potable domestic uses in hot humid regions. Future research will investigate the design of harvesting system and treatment processes to respectively harness and enhance the quality of the reclaimed condensate water for potable household uses through relevant treatments.*

Keywords: *Air conditioner, Condensate, Non-potable water uses, Discharge rate, Reclaimable quantity, Hot humid region*

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I. Introduction

Water is a very important basic amenity of life, though it seems abundant in supply, it is not a limitless resource. Particularly, fresh water available for human consumption is limited in supply compared to saline water. Conservation of water in terms of both the quantity and quality used is important for sustainable water usage and for prevention of depletion and over-consumption [1]. As freshwater availability is running low due to pollution and climate change issues, consumption is likewise increasing due to population growth and the cumulative effect is causing depletion of available fresh water from natural sources. Conservation of water resources refers to all the processes carried out to preserve the available sources of fresh water while exploring other means of producing water to cater for future generations.

Major landmass of the earth surface (about 14 billion km) is covered by water, however, 97.5% of this is saline water and only 2.5% is fresh water, yet two third of the 2.5% fresh water is trapped in ice and glacial leaving only 0.8% in easy to reach sources [2]. Thus, other innovative methods have been studied and adopted for reclaiming fresh water to balance the daily consumption and demands. Some of the most common methods are water extraction from air and desalination of sea water. Other approaches employed for reclaiming water for non-potable uses are harvested rainwater from roofs, grey water, and discharged water from water purification processes.

A potential approach for extracting water from atmospheric air is through reclamation of condensate from air conditioning systems. Air conditioning (AC) condensate is the liquid waste that is discharged from air conditioning units. An air conditioner (AC) is a machine that replaces warm air with a cooler and more humid air in an enclosed area through the process of refrigeration cycle. In hot humid regions (such as Nigeria) AC is often employed in homes, offices, vehicles to provide comfort by cooling the indoor air temperature. Condensation is the process in which water vapour in the air is changed to water [3]. When an air conditioning system is switched on, the indoor air temperature becomes cool, and humidity eventually develops thereby causing the water to be removed as condensates [4]. Thus, considering the prominent usage of AC system for cooling of hot indoor air in institutional and residential buildings in Nigeria particularly during the dry season and the coincidental water scarcity challenges during the same season, this study investigated the sufficiency and the quality of water generated from air conditioner condensate for non-potable uses in institutional buildings.

II. Materials and Methods

Field studies were conducted to achieve the aim of this study. The field study involved the collection of samples and measurement of relevant field data such as temperature, humidity and AC condensate discharge rate and reclaimable condensate quantities per unit time. Since this study is focused on assessing the quantity of AC condensate water obtainable from AC units in use at institutional buildings, an institutional building which has offices that opens daily for 8 hours working period (from Monday to Friday weekly) was selected as the location for collection of the AC condensate samples. The institutional building chosen as the case study for collection of samples is geographically located at GPS coordinates of latitude: 7.440120 and longitude: 3. 893566. The case study building is popularly known as the "Egbogar Centre for Petroleum Engineering" at the University of Ibadan, Nigeria, the building functions as office complex housing 25 offices and each of the offices are installed with individual functioning AC units.

Collection and Quantification of AC Condensate Water Reclaimable from the AC Units Per Day

The AC condensate samples were collected from three AC units (same model of AC units) over a period of three days. The atmospheric temperatures as well as the relative humidity which are factors of the moist air present in the indoor atmosphere were simultaneously measured and recorded at the time of collection of AC condensate samples. The quantity of AC condensate collected during 8hours daily operation of each of the chosen AC units (1, 2 and 3) were recorded in milliliters per minute (ml/minute). The 8 hours duration of operation being considered as daily usage duration. The expression in Equation 1 was used to determine the average quantity of condensate water reclaimable from a single AC unit per minute.

$$Q_{AC\ unit} = \sum \frac{Qd_1 + Qd_2 + Qd_3}{3} \quad \text{..... Eqn. 1}$$

Where: $Q_{AC\ unit}$ represents condensate discharge (ml/minute), and it is the average volume (ml) of condensate water discharged per unit time (minute) from a single AC unit. Qd_1, Qd_2, Qd_3 respectively represents the condensate quantity discharged on measurement day 1, day 2 and day 3 from a selected AC unit. The condensate discharge was calculated for each of AC unit 1, AC unit 2 and AC unit 3 and the overall average was recorded as the quantity of AC condensate reclaimable per minute from the operative indoor environmental condition in the case study building.

Also, the total quantity of AC condensate water obtainable based on the capacity (25 office capacity with 25 AC units) of the case study building on daily basis over 8 hourly working duration was estimated and recorded accordingly.

Estimation of the Sufficiency of the Reclaimable AC condensate water for Household Uses

The sufficiency of the reclaimable condensate for domestic uses at the case study building was estimated by considering the total occupant capacity of the building with respect to standard per capital water demand for domestic uses along with the AC condensate reclaimable capacity of the case study building. Certain relevant assumptions were made for simplicity of the estimation processes. It was assumed that; each of the 25 offices in the case study building were occupied by only one person each and that each of the offices have functioning AC units that operates for 8hours duration per day.

Testing, Characterisation and Analysis of the Reclaimed AC Condensate Water Samples

The collected AC condensate samples were taken to the laboratory and subjected to physical, chemical and biological characterisation in accordance with WHO recommended procedures. The rationale for the characterisation and analysis was to identify the various constituents and assess the quality of reclaimed AC condensate water samples. The tests carried out on the reclaimed AC condensate water samples are: physical

characterisation test [including; colour, hardness, Turbidity, Temperature], chemical characterisation test [including; pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Alkalinity, Iron, Lead, Chloride, Nitrate, Conductivity], and biological characterisation test [including; Coliform Count and Escherichia Coli].

Water Quality Index Calculation (WQI)

Water Quality Index Calculation (WQI) is a rating reflecting the composite influence of different water quality parameters [5][6] defined the water quality index (WQI) as a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level. Reference [7] equally refers to water quality index as a parameter that assigns weight to the sampling points based on the concentrations of the physio-chemical parameters and/or biological constituents of the water. In this study, the processes adopted for calculation of Water Quality Index involved: Selection of water quality index parameters, Conversion of each parameter into a unit less weight using the rating curve (q), Assignment of weighing (w) and Calculation of the final index score.

(1) Selection of water quality index parameters

Out of the nine parameters used in the calculation of water quality index, the required parameters were selected based on their importance.

(2) Conversion of each parameter into a unit less weight using the rating curve (q).

From the parameters chosen to be used in the Water Quality Index calculation, the q values are read from the graphs and the corresponding tables generated from the graphs. The rating curves convert the measurements which were in their various standard units (e.g., mg/L, µS/cm^3) into percentages.

(3) Assignment of weighing (w)

Under this stage, the parameters are judged based on the level of harm they can cause when present in a sample of water. This is where a scale of importance is in play.

Here, a factor is judged more important than the other based on the level of harm they can cause when present in a sample of water. Those ones with high hazards are assigned high value while those with less harm are assigned lower value.

(4) Calculation of the final index score

This is the water quality index. It is a mathematical equation which summed up all the products of the parameters weights and sub-index values. The rating is judged based on **Table 1** below. The calculations were executed using Equation 3.

$$Water\ Quality\ Index\ (WQI) = \sum(W_1 \times Q_1) \quad \text{..... Eqn. 3}$$

Where: W_1 represents weighting factor and Q_1 represents quality rating.

Table 1: Water Quality Index Rating [Source: Ott (1978) [8] cited in Vietnam (2017) [9]]

S/N	Range	Quality
1	90-100	Excellent
2	70-90	Good
3	50-70	Medium
4	25-50	Bad
5	0-25	Very Bad

III. Results and Discussion

Quantity and Sufficiency of the Reclaimed AC Condensate Water for Domestic Uses

The average quantity of AC condensate water reclaimable from the case study building during daily official hour of 8am to 5pm (8 hours duration) Nigerian time is presented in **Table 2**.

Table 2: Average Quantity of Reclaimed AC Condensate Water in Litre per day (at Ave. Temperature of 24.9ºC and Relative Humidity of 60.1%)

Study AC Units	Discharge rate (ml/minute)	AC condensate Quantity reclaimable over 8 hours duration (litre)
AC Unit 1	16.05	7.704
AC unit 2	18.00	8.64
AC unit 3	11.95	5.736
Ave. quantity of condensate water reclaimable per minute per AC unit in the case study building	**15.33**	7.40
Ave. quantity of condensate water reclaimable from the case study building capacity (i.e., 25 offices with 25 AC units) on daily basis over 8 hourly working duration = 185litres		

As presented in **Table 2** the average quantity of condensates reclaimable from one AC unit in a day is 7.4Litres. Using the capacity of the whole building which breaks down to 25 offices with installed functioning AC units, the total quantity of condensates obtainable from all functioning 25 AC units on daily basis (8hourly working duration) is 185 litres

The World Health Organisation (WHO) recommended that, minimum allocation of water for domestic water uses for survival of an individual should not be less than 7 litres per day [10]. Thus, using the WHO 7 litres per capital daily domestic water requirement as a reference, the assumed 25 people occupiers of the case study building will require 175 litres of water in a day for domestic uses thereby putting the daily domestic water demand at 175litres. This indicates that the estimated 185 litres daily reclaimable volume of condensate water in the 25 offices capacity case study building is over 100% sufficient to meet the water demand of the office occupiers of the building. Similarly, the measured 7.4 litres reclaimable AC condensate over 8 hours duration is maximally satisfactory to meet the minimum 7litres per capital daily water requirement for an individual. This means that reclaimed AC condensate water has potential to serve as alternative source of water for non-potable domestic uses in hot humid regions like Nigeria and its neighboring Sub-Sharan African developing countries which share similar indoor environmental conditions.

AC condensates could also be used to relieve pressure of potable water demand in developed and developing economies. Due to increasing quality of life and change in lifestyle patterns, water demand for non-potable uses in household and public environments such as offices and institutional buildings is high [11] and can benefit from supplementary supply from recycled and reclaimed water sources such as recycled grey water and reclaimed AC condensates. For example, the portion of household domestic water used for toilet flushing in developed and developing countries is high varying from 29% to 47% ([12]; [13]; [14]). A review study by [11] also reported that 48% to 63% of water demand in public environments or offices goes into toilet flushing. Hence, the findings of 7.4litres daily reclaimable AC condensate water per ac unit (at 24.9^{o}C temperature and 60.1% relative humidity) in this study indicates the potential for using AC condensates as alternative and sustainable source of non-potable water in households and public environments.

Physical, Chemical and Biological Characteristic of the Reclaimed AC Condensate Water Sample

The AC condensate samples reclaimed from the AC units were collected in a 75cL bottle and taken to the Environmental Health Laboratory at University College Hospital, Ibadan Nigeria for physical, chemical and biological analysis. The result of the analysis of the reclaimed AC condensate water samples were compared with the WHO standards as shown in **Table 3**.

As presented in **Table 3**, the reclaimed AC condensate water sample is moderately hard; not turbid; and has low conductivity; low Chloride content; as well as low Nitrate content which are all satisfactory based on the WHO recommended permissible levels. Also, the total dissolved solids and total suspended solids present in the condensate water sample is satisfactory as it appears very low compared to the WHO recommended permissible level.

However, the AC condensate water samples displayed alkalinity value of 12 (**Table 3**) which is quite low because high alkalinity helps to stabilize the pH value of water. Similarly, the average pH value of 5.82 exhibited by the reclaimed AC condensate water samples indicates high acidity. When the pH of water is less than 6.5 it is considered acidic. Hence, the 5.82 pH value exhibited by the reclaimed AC condensate water sample (Table 3) shows that it is highly acidic.

Table 3: Comparison of Physiochemical and Biological Characteristics of the AC Condensate Water Sample with WHO Standard Requirements.

Parameters	Parameters of Reclaimed AC Condensate water Sample	WHO Standards	Compliance of the Reclaimed AC Condensate water Sample
Colour	0.002	50 units	Permissible
Temperature	28 ºC	Nil	Ambient
pH	5.82	6.5 – 8.5	Too acidic
Total Hardness (mg/L)	84mg/L	500mg/L $CaCO_3$	Moderately hard
Turbidity (NTU)	0.00	25 units	Not turbid
Conductivity (µS/cm^3)	17.2	300 µS/cm^3	Permissible
Total Dissolved Solids (mg/L)	22.5	500mg/L	Permissible
Alkalinity (mg/L)	12	250mg/L	Low alkalinity
Chloride (mg/L)	11.00	600mg/L	Permissible
Total Suspended Solids (mg/L)	0.61	40mg/L	Permissible

Nitrate (mg/L)	0.23	50mg/L	Permissible
Iron (mg/L)	0.0003	0.3mg/L	Permissible
Lead (mg/L)	0.00	0.01mg/L	Not present
E.coli (MPN/100ml)	Less than 2	0/100mg/L	Present
Total Coliform count (MPN/100ml)	Less than 2	10	Permissible

Highly acidic water is not recommended for potable uses as it has potential to inhibit effectiveness of water treatment and cause indirect risk to human health. In addition to being toxic, acidic water is highly corrosive and can leach metals including lead, manganese, copper and iron from the reservoir or pipes supplying water.

Escherichia Coli was found present in the AC condensate water samples in low quantity although the total coliform count of the water sample appeared low and satisfies WHO requirements (**Table 3**). Escherichia coli is a major pathogen associated with waterborne diseases and its presence in water samples normally indicates recent faecal contamination or poor hygienic condition [15]. Escherichia coli can be present in ambient air and indoor air samples due to proximity to source of faecal pollution such as pet feaces or animal feaces ([16];[17]). Thus, the existence of E.coli in low quantity in the reclaimed AC condensate water sample investigated in this study may be attributed to possible presence of airborne E. coli in the humid indoor air that condensed into the condensate water reclaimed from the AC units.

However, the presence of E. coli in water sample may not necessarily mean the presence of disease-causing microbes but may signify the potential presence of faecal-borne microorganisms such as Salmonella and hepatitis A ([18];[19]) indicating non suitability for drinking purposes. In terms of standard quality requirements recommended by various existing legislations/guidelines for non-drinking water, quantities of E.coli and faecal coliform permissible in grey water/non-potable water use for toilet flushing and other urban uses includes; maximum of 1 CFU/100ml E.coli [13]; less than 10 CFU/100ml Ecoli [20]; and 14 CFU/100ml faecal coliform ([21];[13])

Hence, the presence of E.coli and coliform count in respective low quantities of less than 2 MPN/100ml E.coli and the less than 2 MPN/100ml coliform count in the reclaimed AC condensate water sample indicates that the quality is not suitable for drinking water purposes but permissible for non–potable uses such toilet flushing, clothe washing and irrigation purposes.

Based on these findings, the quality of the reclaimed AC condensate water sample is reckoned to be suitable for non-potable uses such as sanitation purposes, toilet flushing etc. However, corrective measures may be applied to raise the pH value to an acceptable level, the AC condensate water may be subjected to pH corrective action/treatment such as neutralizing filter containing calcite or ground limestone (calcium carbonate) or magnesia (magnesium oxide). Such treatment will prevent corrosion of metallic pipes and household utensils/basins during use of the reclaimed condensate water for non-potable purposes.

Quality of the Reclaimed AC Condensate Water Based on Water Quality Index Rating

As shown in Table 4, the WQI calculated for reclaimed AC condensate water sample is 74.72. With reference to the water quality classification in Table 1, Water Quality Index Rating that falls between 70 and 90 indicates good water quality. Hence, the quality of the reclaimed AC condensate water sample is regarded as 'Good'. This further ascertain the suitability of the reclaimed AC condensate water for non-potable uses.

Table 4: Estimated WQI for the Reclaimed AC Condensate Water Sample

Parameters	**Q_1 value**	**W_1 value**	**WQI**
Temperature	11	0.13	1.43
Ph	50	0.20	10
Nitrate	97	0.16	15.52
Turbidity	97	0.15	14.45
E. coli	98	0.22	21.56
Total solids	84	0.14	11.76
Total		$\Sigma = 1.00$	$\Sigma = 74.72$

Future Research

The scope of the present study covers investigation into the quantity and quality of water generated from condensates of air conditioner (AC) units operated over a period of 8 hours in an institutional building in Nigeria. However, since atmospheric temperature determines the ability of air to hold water vapour, more research is necessary to investigate the effect of temperature and humidity on the discharge rate of the condensates from the AC units at varying temperature and humidity. Also, having established the quality and

level of sufficiency of reclaimed AC condensate water for non–potable water demands, further investigation is needed to design potable harvesting/collection system for reclamation of AC condensate in institutional and residential buildings in Nigeria and neighboring hot humid regions experiencing water scarcity.

IV. Conclusion

This study investigated the sufficiency and quality of AC condensate water reclaimed from AC units in institutional building for non-potable household uses. Field studies were conducted to collect and measure relevant data. The field study entailed the collection of samples and measurement of relevant field data and analysis of measured data and collected water samples. The field data measured includes, temperature, humidity, AC condensate flow rate and reclaimable quantities of AC condensate per unit time. Physiochemical and biological characterisation and analysis of the reclaimed AC condensate water samples were also carried out. Based on the findings, it was concluded that, in terms of quantity, water generated from AC condensate has potential to serve as alternative source of water for non-potable domestic uses in hot humid region. An average of 7.4litres of condensate water was obtained from a single AC unit over 8 hours of operation at an average temperature of 24.9ºC and relative humidity of 60.1%. Operation of each of the selected AC units for eight hours generated more than the minimum domestic water requirement for each office occupier at the case study building. Also, the quality of the reclaimed AC condensate as water for domestic uses was rated 'Good' having satisfied the requirements in accordance with the Water Quality Index Rating. The physio-chemical and biological characterisation tests carried out equally shows that the reclaimed AC condensate water is suitable for non-potable household uses with recommended application of pH corrective actions to neutralise the acidic property exhibited by the AC condensate water sample.

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