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Activated Carbon Adsorbent Porosity and Loading Factor Effects on the Adsorption Efficiency of Groundwater Treatment System for Crude Oil Hydrocarbons and Solid Metals Impurities Recovery in Niger Delta Region

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Abstract: *Despite how large hydrosphere tends to occupy the earth (70%), unavailability of useful industrial and domestic water (especially within oil producing countries) happens to be increasing daily, proportional to increase in population density, industrialization, poor wastes management and fossil fuel processing, which promotes hydrocarbons and solid metals contaminants deposition within human environments, with high potency of altering surface and groundwater quality, making water treatment using adsorbent such as activated carbon (AC), a most recommended measure. This work focus on assessment of AC porosity and loading factor effects on crude oil hydrocarbons and solid metals recovery efficiency of an adsorption system using Niger Delta regions groundwater as adsorbate medium. Coconut shells activated carbon (CSAC) were produced at different carbonated temperatures of 500°C, 700°C and 900°C, and their porosities as function of the monolayer capacity (V_m) were equally determined using the LBET analytical tool. After which the CSACs were used in treatment of hydrocarbon based contaminated groundwater of Okrika LGA (Niger Delta region of Nigeria), at different packed bed adsorbent loading factor (ALF): 100% CSAC-500°C, 100% CSAC-700°C, 100% CSAC-900°C, 50:50% CSAC-500°C:700°C and 50:50% CSAC-500°C:900°C. The LBET analytic results identifies CSAC-500°C adsorbent to be of 0.0485 intercept and 751.8797 Kpag/cm^3 monolayer capacity (V_m), while CSAC-700°C shows intercept of 0.0485 with 1086.9565 Kpag/cm^3 V_m, then CSAC-900°C. shows intercept of 0.0225 and V_m of 1250 Kpag/cm^3 which depicts a higher porosity. The LBET result was able depicts that increase in carbonation temperature of an AC promotes the increase in the adsorbent porosity. Also, the treatment result using hydrocarbon contaminated ground water identifies the 900°C carbonated AC to be of higher recovery efficiency (86.85%) on solid metals and BTX recovery from Okrika groundwater, such that groundwater consisting Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene aromatic compounds at 29.63721 ppm, 36.48904 ppm 19.32716 ppm, 15.56647 ppm, 12.29102 ppm, and 27.81541 ppm contaminant level respective, was treated to 6.26581 ppm, 7.90743 ppm, 1.25129 ppm, 0.0000 ppm, 0.0000 ppm, and 0.61832 ppm using the 900°C produced CSAC, while that of the 700°C reduced the aromatics to 10.78562 ppm, 12.90318 ppm, 5.32647 ppm, 1.28593 ppm, 0.000 ppm, and 4.93820 ppm, and that of 500°C reduced them to 13.85162 ppm, 17.90648 ppm, 8.61773 ppm, 4.37570 ppm, 1.54382 ppm and 11.91048 ppm, which are (700°C and 500°C CSAC) both less efficient compared to that achieved by the used of CSAC-900°C. Also, the reactor adsorption performance proves to be more effective in using a combined ALF approach with 50:50 loading factor of 500°C – 900°C-CSAC most efficient in treatment of the hydrocarbon contaminated water, such that the untreated groundwater Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene levels depleted to 2.51623 ppm, 3.40394 ppm, 0.0000ppm, 0.0000 ppm, and 0.0000ppm, 0.0000 ppm respectively when assessed. It's concluded that high carbonation temperature of adsorbent increase adsorbent porosity, which proportionally increases the adsorbent efficiency over reactor resident time of the studied system. Also, a combined ALF approach is most appropriate for effective water treatment.*

Keywords: *contaminates recovery factor, Oil spillage, langmuir adsorption model, water pollution, groundwater treatment, adsorbent loading factor (ALF), carbonation temperature*

INTRODUCTION

Human existence and their effective performance on daily activities depends fully on the presence and management of natural resources, which takes different forms and values (Giacomo *et al.*, 2021; Theophilus *et al.* 2025; Ahmad *et al.* 2023). These resources such as crude oil, natural gas, coal, air, water, etc. are been utilized by man for energy, food, electricity, medium for transportation and means of capital generation of which countries opportune of having a marketable natural resource (such as crude oil) utilizes the resource benefits for enhancement of national wellbeing, creating standard and easier mood of living.

Natural and mineral resources promote industrialization, technological advancement, economic development, etc., hence they are always explored on large quantities using different techniques and utilities, then transformed into consumable states for satisfaction of man needs (Liu *et al.*, 2021; Syed *et al.*, 2021; Ugi *et al.*, 2023; Erdoğan *et al.*, 2021; Cai *et al.*, 2018). Water is one of the most essential life sustainable natural resources (same as air) that is utilized on daily basis by man for domestic, industrial and locomotive measures, cooking, washing, drinking, bathing, inclusive. It occupies about 70% of the earth, and serves as home (aquatic habitat) for large groups of animals such as fishes, as well stands as medium for carbon capturing either via natural processes, such as the ocean absorption, or via engineered technologies designed to reduce CO_2 in our atmospheres (Lorenzo *et al.*, 2021; Almamari *et al.*, 2025; Newmark et al., 2010). Though CO_2 has relatively low solubility in pure water, it can be captured through both physical dissolution and chemical reactions, especially when enhanced by additives or specific pressure/temperature conditions. Water is a universal polar covalent solvent, with an unsymmetrical shape is a colorless liquid with an unknown but identifiable unique. The liquid form substance is made up of hydrogen – oxygen bonded atoms, with a molecular formula of H_2O, with the hydrogen atoms bonded to the oxygen atom at a about 104.5^o polar angle. (Perry and Green, 2007) The O—H distance (bond length) is 95.7 picometres (9.57×10^{-11} meters, or 3.77×10^{-9} inches). Because an oxygen atom has a greater electronegativity than a hydrogen atom, the O—H bonds in the water molecule are polar, with the oxygen bearing a partial negative charge (δ−) and the hydrogens having a partial positive charge (δ+). Water at its purer state boils at 100^oC (212 °F) and freezes at 0^oC (32 °F), as well doesn't conduct electrical charges. At the pure state water exist with $[H^+] = 1.0 \times 10^{-7}$ M and a pH value of 7.0, which makes it regarded as neutral pH substance.

Water could be surface or ground water based on its location on the geological formations of the earth. Just as their names employed surface water is located on the surfaces of earth crust while the ground water lies beneath where man needs to drill a well to achieve the water via pressure, but despite surface or groundwater they are essential to man and industrial acts (Perry's and Green, 2007; Gracia-de-Rentería et al., 2020). Surface water (rivers, lakes, streams) and groundwater (water in underground aquifers) are interconnected components of the hydrologic cycle, not separate entities. While surface water is directly accessible, groundwater is stored in soil/rock pores and provides crucial drinking water. They constantly interact, with groundwater feeding streams and surface water recharging aquifer Water is in constant circulation, powered by the energy from sunlight and gravity in a natural process called the hydrologic cycle. Water evaporates from the ocean and land surfaces, is held temporarily as vapour in the atmosphere, and falls back to Earth's surface as precipitation. Surface water is the residue of precipitation and melted snow, called runoff. Where the average rate of precipitation exceeds the rate at which runoff seeps into the soil, evaporates, or is absorbed by vegetation, bodies of surface water such as streams, rivers, and lakes are formed. Water that infiltrates Earth's surface becomes groundwater, slowly seeping downward into extensive layers of porous soil and rock called aquifers. Under the pull of gravity, groundwater flows slowly and steadily through the aquifer. In low areas it emerges in springs and streams. Both surface water and groundwater eventually return to the ocean, where evaporation replenishes the supply of atmospheric water vapour. Winds carry the moist air over land, precipitation occurs, and the hydrologic cycle continues.

Ground water serves very important roles in plants growth, aiding efficient and functional practices of agricultural cultivations as it provides substantiable water for plants growth, microbial performance as well as creating conducive environment for microorganism. Ground water helps in regulating soil temperature, facilitating nutrients fixation to plants through their roots (Horel, 2024; Ma *et al.,* 2024; Calleja-Cabrera *et al.,* 2020; Mehmet *et al.,* 2024). Groundwater promotes the digestion of organic matters that are buried beneath the earth crust leading to formation of essential minerals and fossils (Ugi *et al.*, 2023; Aranguren-Díaz *et al.*, 2024; Lachassagne, 2020).

Figure 1: Surface and ground water as elements of the hydrological cycle

Most cases groundwater is stored in an aquifer which lies between geological folds and rocks and such will require advance techniques to make the water available for human usage. The value of an aquifer as a source of groundwater is a function of the porosity of the geologic stratum, or layer, of which it is formed. Water is withdrawn from an aquifer by pumping it out of a well or infiltration gallery. An infiltration gallery typically includes several horizontal perforated pipes radiating outward from the bottom of a large-diameter vertical shaft. A submersible pump driven by an electric motor can be used to raise the water to the surface, but locally robes tired to a container is ben used in dragging out the water for domestic usage. Sometimes a deep well may penetrate a confined artesian aquifer, in which case natural hydrostatic pressure can raise the water to the surface and such is experienced during deep water drilling or borehole water drilling.

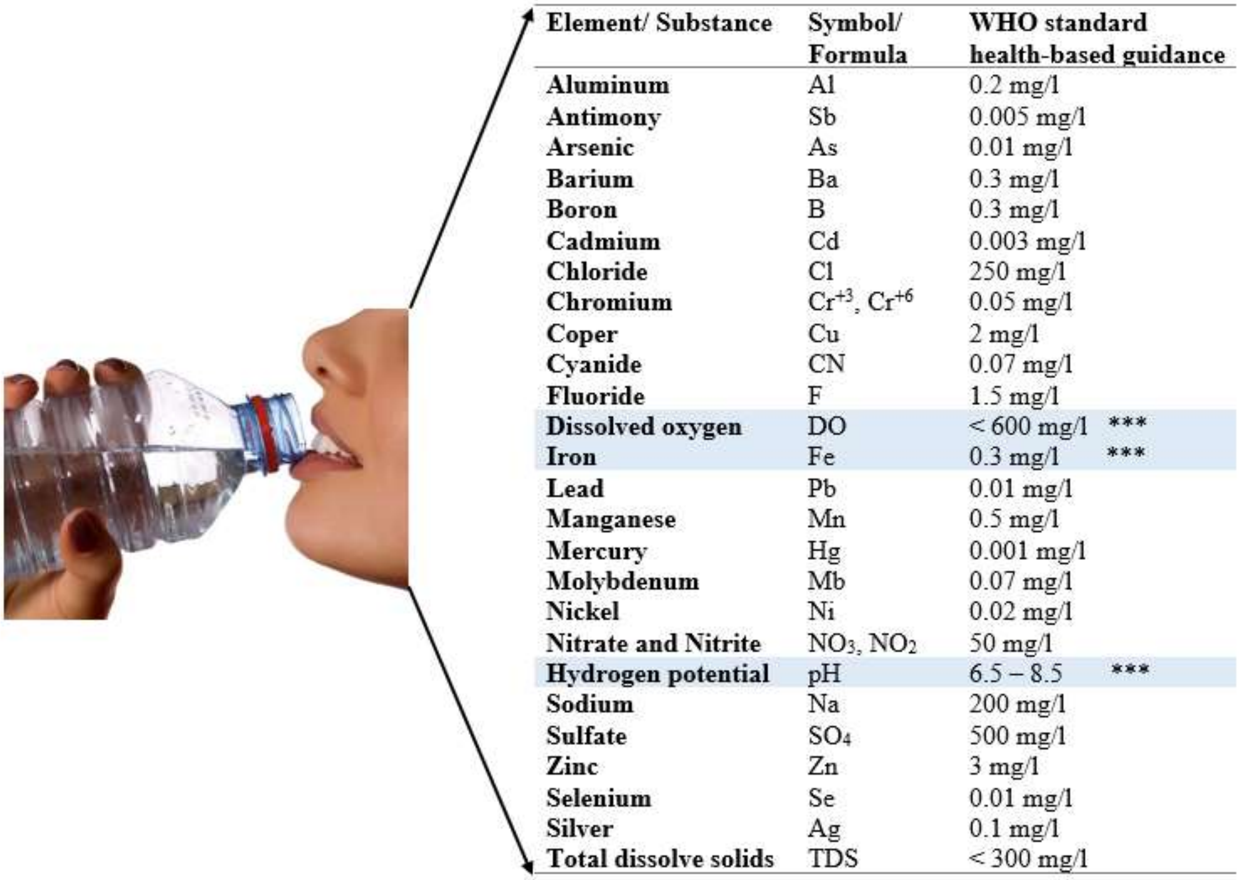
Groundwater commonly dissolves and adsorbs a variety of metals from the rocks and sediments of the Earth's crust through natural **geogenic** processes like **weathering** and **mineral dissolution,** farther than surface water does. Minerals such as Calcium (Ca)**,** Magnesium (Mg)**,** Sodium (Na)**,** and Potassium (K)**.** Barium (Ba) and Strontium (Sr), etc. are among those adsorbed from sediments of the earth where it dwells (Abdullah *et al.*, 2021; Ofosu *et al.*, 2024), making most preferred for drinking. It is also known to be free from environmental contaminants such as the greenhouse gases (GHGs) as well as surface microorganisms such as *guinea worm* (Dracunculus medinensis) which can’t travel too far beneath the earth surface due to the fact they are surface-level parasites that rely on specific, shallow water conditions to survive (Cairncross *et al.,* 2002; Pellegrino *et al.,* 2022).

Both groundwater and surface water type as categorized in this work are very important are important to man, with both having the ability of existing in three forms; solid, vapor and liquid, each is of great relevancies, which has made water to be rated among the most essential natural resources identified by man. (Osibanjio *et al.*, 2011; Tilley *et al.*, 2014; Horel, 2024; Ma *et al.*, 2024; Calleja-Cabrera *et al.*, 2020; Mehmet *et al.*, 2024). It's obtainable from different routes or sources, consisting different metallic composites, minerals and physiochemical properties relative to the source, of which some of the sources are not suitable for domestic use or activities but can be industrially applicable for activities such as oil recovery, coolant for heat equipment's or system, for hydrolysis reactions, electroless, and as solvent, etc. In summary, water is achievable from the following sources:

a. Sea / Oceans
b. Rivers
c. Streams
d. Springs
e. Rain
f. Lakes
g. Wells

All sources of water are opened for man's application, but the purity of the water (which defines its quality) as determined by the world health organization (WHO) standard is a function of the water source, and it stands as a deterministic factor of man usability value of water. Clean water suitable for domestic use is identified by the WHO to be of health safety physiochemical properties as stated at Table 1 (based on the WHO drinking water standard 1993), and when deviated, the water becomes harmful to man for domestic consumption such as for drinking, cooking as well a for bathing. Cleaner water is not pure but consist of essential ions which are beneficial to human system, when extracted leaving just hydrogen and oxygen as composites of the water, it will be regarded as pure water but at such stage the water is no better to be taken as drinking water. These ions that plays beneficial role in water consist calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{2+}), and sodium (Na^{+}), which contribute to mineral balance, bone health, and cardiovascular function, Bicarbonate (HCO^{-3}) aids digestion, while trace amounts of fluoride (F^{-}) strengthen teeth. These, alongside sulfate (SO_4^{2-}) and chloride (Cl^{-}), typically define a healthy TDS level of 300–600 mg/l

Table 1: Water physiochemical parametric with their respective WHO standard



Element/ Substance	Symbol/ Formula	WHO standard health-based guidance
Aluminum	Al	0.2 mg/l
Antimony	Sb	0.005 mg/l
Arsenic	As	0.01 mg/l
Barium	Ba	0.3 mg/l
Boron	B	0.3 mg/l
Cadmium	Cd	0.003 mg/l
Chloride	Cl	250 mg/l
Chromium	Cr^{+3}, Cr^{+6}	0.05 mg/l
Coper	Cu	2 mg/l
Cyanide	CN	0.07 mg/l
Fluoride	F	1.5 mg/l
Dissolved oxygen	DO	< 600 mg/l ***
Iron	Fe	0.3 mg/l ***
Lead	Pb	0.01 mg/l
Manganese	Mn	0.5 mg/l
Mercury	Hg	0.001 mg/l
Molybdenum	Mb	0.07 mg/l
Nickel	Ni	0.02 mg/l
Nitrate and Nitrite	NO_3, NO_2	50 mg/l
Hydrogen potential	pH	6.5 – 8.5 ***
Sodium	Na	200 mg/l
Sulfate	SO_4	500 mg/l
Zinc	Zn	3 mg/l
Selenium	Se	0.01 mg/l
Silver	Ag	0.1 mg/l
Total dissolve solids	TDS	< 300 mg/l

N/B: *** Not specify by WHO

The absence of these essential ions in water makes the water soft, which is beneficial for washing of cloths and properties as the water easily forms soap lather. But soft water is pure and not healthy to be consumed as drinking water, and it's not subjected to WHO standard (Perry's and Green, 2007; Latif *et al.,* 2024; Yujia et al., 2025), though few researchers such as Zhao *et al.,* (2024) recommend soft water for kidney stone treatment (yet not medically validated). The quality of water is affectable via natural and anthropogenic factors, but above all. the man causal factors (anthropogenic) tends to be greater when compared to those naturally influenced. The quality of water is classified based on water application (Figure 1), but that used domestically for drinking needs to meat up the WHO standard so as to ensure it attends toxic, temperature, test and order clearance. Water used for wildlife only needs to overcome the toxic standard clearance while that for recreation needs nothing concerning the taste and temperature clearance

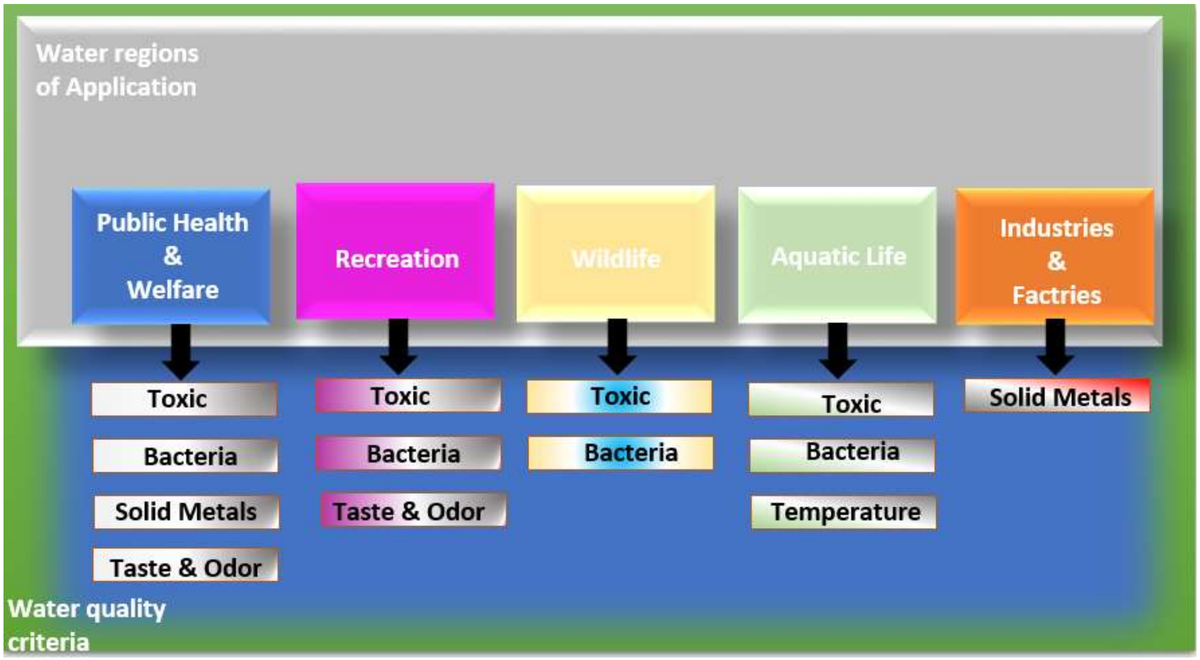


Figure 2: Water quality criteria for water application / usage

These water quality criteria are necessary to be attended for every system which water is required to play a part so as to enhance the performance of the system as well as to reduce mortality caused by contaminants. Water that couldn't meets the criteria requirements should be treated efficiently before been used in any of the sectors.

Water Contamination and Its Treatment Measures

Causalities of Water Contamination

Despite how dominating water occupies the earth, it exists with less recognition value by man, such that most times humans rarely remember that water is an essential resource that sustains life, and this is due to the fact that water as an entity can't fit in as a valuable commodity for international trading, despite how dependent man rely on its availability and quality for survival, as well as for plants growth. Water is the most utilized natural resource on earth (after environmental air) that enables the operations of various activities and phenomenon in the ecosystem. The uses of water are too numerous and can't be completely numerated in just a single article, but it's wise to always remember that life is a dependent function of water, hence man is highly worried over water contamination (Perry's and Green, 2007; Osibanjio *et al.*, 2011; Tilley *et al.*, 2014; Horel, 2024; Ma *et al.*, 2024; Calleja-Cabrera *et al.*, 2020; Mehmet *et al.*, 2024; Al-Hashimi et al., 2021). The value of water in general terms is mostly recognized in domestic sector of life, and these values tends to keep increasing as the ratio of available water decreases with increase in natural and anthropogenic generative contaminants nature and quantity which are the fundamental causalities of water contamination. Contaminants reduces the availability of consumable water useful for domestic activities, and these contaminants varies in class and form with respect to their source. Man contributive contaminants are subject to man activities and their effects are proportional to increase in population, industrialization and technology. The fundamental anthropogenic causalities or causalities of water contamination are as follows:

i. Fossil fuel production, processing and distribution
ii. Municipal wastes generation and poor management
iii. Industrial effluent discharge

Amongst these sources of surface and ground water contaminants, fossil fuel tends to be most supportive or contributary as it distributes hydrocarbon contaminants in an environment. Fossil fuel consist crude oil, natural gas and coal are the fundamental baseline of energy generation, essential to all countries in the world for production of energy base fuels, petrochemicals as well as lube base oils (Ugi *et al.*, 2023; Igwe *et al.*, 2026; Sammy *et al.*, 2023; Chikwe and Igwe, 2023; Chikwe, & Igwe, 2024). They are very important to man as the facilitates economic development with massive improve in development. Crude oil among all other fossil fuel is most produced and utilized all over the globe (Igwe *et al.*, 2026; Sammy *et al.*, 2023; Chikwe and Igwe, 2023; Chikwe, & Igwe, 2024), and during the production, processing and transportation of the crude oil, the material (oil) likely gets spilled on soil and water surfaces, releasing large quantity of environmental unfriendly coonhounds (Ugi *et al.*, 2023; NeeBee *et al.*, 2024; Wordu *et al.*, 2023) of which some of they contaminants are corrosive promoting (Ugi *et al.*, 2023; Ugi *et al.*, 2025; Benedict and Fredrick, 2023, Benedict *et al.*, 2022; Ugi *et al.*, 2023; Ugi *et al.*, 2026; Ugi *et al.*, 2021; Igwe *et al.*, 2026) and others affects humans health in a tremendous manner as well as affecting the feeding nature of humans as it attacks agricultural yielding (NeeBee *et al.*, 2024; Ugi *et al.*, 2023, Modestus *et al.*, 2025)

Crude oil and other fossil fuels are mixtures of organic hydrocarbons, formed from the decomposition and biological intervention of microorganisms on organic matters beneath earth surface, at high pressure and low temperature (Perry's and Green, 2007; Igwe *et al.*, 2026; Sammy *et al.*, 2023; Chikwe and Igwe, 2023; Chikwe, & Igwe, 2024). It's an essential mineral resource that is of a great financial value to countries that are blessed with it reserves such as Nigeria, boosting the country's national wellbeing as well as creating massive job opportunities, rooms for industrialization, promotes improvement in the nation's social amenities, etc. As aforementioned, crude oil is the most produced and utilized fossil fuel in the world and it consist mainly of a mixture paraffins, naphthene, and aromatics hydrocarbons, as well as impurities of inorganic salts, nitrogen, oxygen, mercaptans, etc. of which some act as catalytic poison, corrosion agents, etc.

Crude oil is of different colors and quality (though mostly the well-known color is black) and its quality depends on the soil type and properties where the oil is been, though all are rich in hydrocarbon compounds. After been recovered from the reservoir (conventional or nonconventional) the oil is first treated to remove possible impurities, before been conveyed to the refinery to be distilled into distillates using different distillation units and methods of mixture separation. They distillates achieved from the refinery distillation of crude oil are serves to other industrial units' precursor to be used for the production of other market demanding products, as well provide materials (such as asphalt / bitumen) that are used by civil engineers in road construction (Ugi *et al.*, 2023; Igwe *et al.*, 2026; Sammy *et al.*, 2023; Chikwe and Igwe, 2023; Chikwe, & Igwe, 2024). Despite how extensive crude oil benefits tends to be, which is actually pulling up its annually production line above the statistical grid demand points as it aids also the increase in the gross domestic products (GDP) of a country, crude oil production, processing and distribution still have its cons, of which crude oil water and land contamination is one of the most destructive and well known contributions effects of crude oil production in a country.

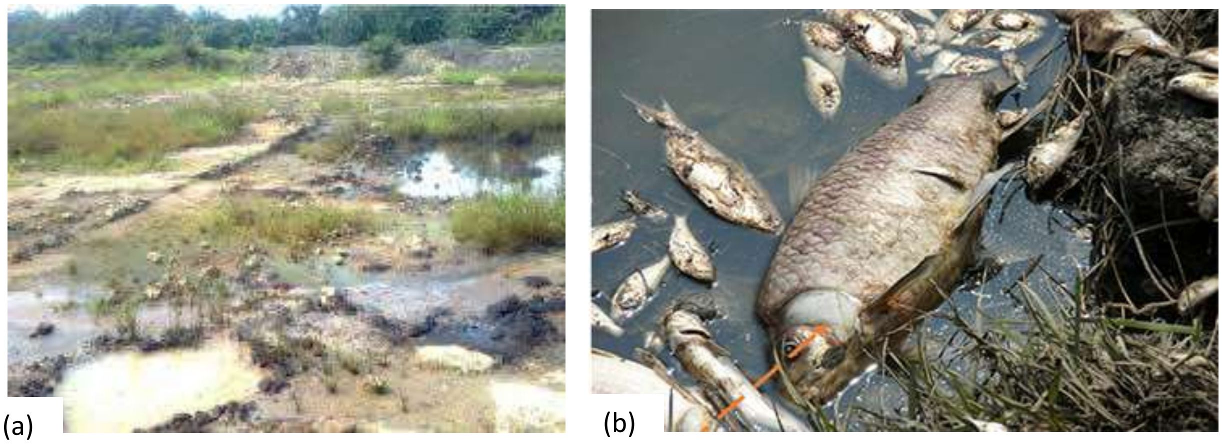

(a) (b)

Figure 3: Soil contamination and aquatic mortality rate causalities of crude oil processing

Crude oil spillage exposes the soil to series of giant hydrocarbon compounds which act as pollutants to agricultural soils, reducing the soil value over time, so as well for water bodies that could have been of domestic and industrial use (NeeBee *et al.*, 2024; Ugi *et al.*, 2023; Igwe *et al.*, 2026). Hydrocarbon contaminants in the atmosphere reduces the air value as well, and promote serous health issues such as lungs disease, heart failure, skin cancer, etc. (Ugi *et al.*, 2023; Perry's and Green, 2007), but in most times their effects on water and soil grasp more attention for remediation. Apart from reducing the value of the water, it also makes the water unsuitable for life to exist it, hence facilitating the motility of animals such as fishes that deals in the water (Figure 3b) as the hydrocarbon compounds in the oil competes with environmental air and increases the water dissolve oxygen (DO). It also the presence of hydrocarbons reduces the water chemistry and increase in water hardness / surface tension.

Hydrocarbons of crude oil spilled on soils and water surface also travels beneath the earth crust to contaminate the groundwater used for drinking and washing within regions were oil and gas are produced and processed such as the Okrika local government areas of Port Harcourt, Nigeria. The Niger Delta region historically consist three states in Nigeria, which are the Bayelsa, Delta, and Rivers States, but at 2000, Obasanjo's regime included Abia, Akwa-Ibom, Cross River State, Edo, Imo and Ondo States, making nine states currently regarded till date as the Niger Delter regions. The region covers about 40,000 square miles, and it is iNigeria's primary oil hub, contributing over 90% of the country's foreign exchange since 1956 when crude oil and natural gas was discovered at Oloibiri region in Ogbia LGA, Bayelsa State, over 600 oil fields and 3,000 km of pipelines have been established, split between onshore (360) and offshore (246) locations (Olukaejire *et al.*, 2024; Ordinioha *et al.*, 2013; Oluwadayo *et al.*, 2008).

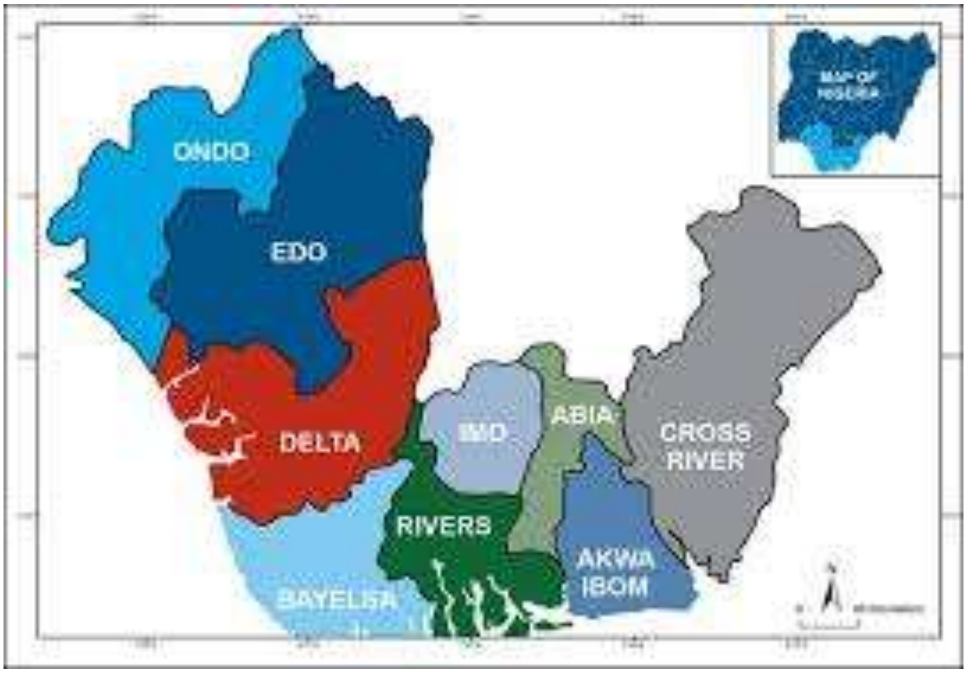


Figure 4: Map of the Niger Delta oil producing regions and states in Nigeria

Most Niger Delta regions surface waters are highly contaminated with crude oil which often gets into the water body via oil spillage from tankers or pipelines leakage, explosion, vandalization, etc. (Mogborukor et al., 2024; Oteh and Eze, 2012; Hamman Muhammad and Meztler, 2023), making it hard for the residents of Niger Delta regions to having clean and standard water for use, except when drilled beneath the earth surface to achieve groundwater, which is now pumped for usage (Figure 4), still the groundwater in most of the regions is known to consist some hydrocarbons contaminates such as the BTX whose presence in humans health promotes cancer and destruction of internal body organs, as well consist properties which exceeds the WHO standard, making the both surface and groundwater dangerous for consumption.

Contaminated water when been consumed promotes great health hazards and hence different researchers have implemented diverse strategies on how to treat the ground water before been used, using adsorbents that are affordable such as activated carbon (AC). Adsorbents for treatment of contaminated water are of different properties of which some properties variation are connected to the ACs mode of production. Adsorbent properties have great deal on the degree of treatment efficiency when used in water treatment, and the use of adsorbent in treatment of contaminated water is a resourceful technique for the rural regions where oil and gas are produced, as it stands as a support to the residents in obtaining health standard water for drinking, but some of the adsorbents such as zeolite are expensive for the poor to afford, hence researchers such as Xinle *et al.* (2025); Ayotamuno *et al.* (2006); Alves *et al.* (2021) and many others investigated the use of AC in treatment of contaminated groundwater and discovered that AC of wood, palm shells, coconut shells, etc. are effective in treatment of contaminated water effluent for domestic use. According to Ayotamuno *et al.* (2006), ground-water contamination resulting from the leakage and usage crude oil and refined petroleum products is a serious and a growing environmental problem in Nigeria. Consequently, a study of the use of activated carbon (AC) in the cleanup was undertaken with the aim of reducing the water contamination to a more acceptable level. In the experiments described, crude-oil contamination of ground water was simulated under laboratory conditions using ground-water samples collected from existing hand-dug wells at Eagle Island, Port Harcourt, Nigeria. Results showed that AC is an excellent means for stripping-off contaminant; as the assessed contaminant concentration from 9304.70 mg/l to 361.00 and 12.37 mg/l.

María *et al*. (2025), produce AC from desilicated rice husks using various carbonization and activation methods. Advanced characterization techniques were employed, such as scanning electron microscopy (SEM), which revealed a highly porous and irregular surface structure, and energy dispersive X-ray spectroscopy (EDS), confirming the effective removal of impurities and optimization of the elemental composition. Atomic force microscopy (AFM) demonstrated favorable surface roughness for adsorption processes. The activation treatments with phosphoric acid and calcium carbonate significantly improved the porous structure, further enhancing the material’s adsorptive properties.

Figure 5: Groundwater for domedstic usage at Okoshiri in Okrika LGA, River state, Nigeria

Despite how efficient, cost conservative and available the use of AC is to rural and urban residents in oil producing regions, the residents still suffers from contaminates of ground water which are mostly hydrocarbon – metallic base, but despite how bad their ground water has become, the residents of oil processing and producing regions such as those in River State such as the (Okrika regions) still depend on it for their domestic use (Figure 4), hence they are prompt to illnesses caused by such contaminates.

Contaminated Water Treatment for Domestic Usage

Treatment of contaminnated water is the only way out when one desires to make use of contaminated water for domestic purposes, as well as for safe disposal of industrial effluent (Igwe *et al.,* 2026). Water treatmen techniques are essential designed to limit contaminants effects to human and the environmnet, and this techniques takes different approach, which amongst are they adsorbtion and absorbtion technique, that relies on the use of solid adsorbent or liqiod absorbent to trap or recover impurities from water of gas stream (Ugi *et al.,* 2023; Kidnay and Parrish, 2006). Both processes use the principle of packed bed reactors to remove impurities from stream of fluids, and depending on the mechanism binding the compounds in solvent, one can distinguish the process as either physical and chemical (or reactive) adsorption (An *et al.,* 1999), which are commonly regarded as the physisorption and chemisorption processes respectively. Physical adsorption of gas or gas mixture components in a liquid solvent comprises mass transfer at the gas–liquid interface and mass transport within the phases. In physisorption, a molecule becomes attracted to the surface atoms via van der Waals forces. These include dipole-dipole interactions, induced dipole interactions, and London dispersion forces. In a common term, adsorption is applied to industrial practice which involves the transport phenomena of substances from present state into liquid or solid substance (absorbent). It is a mass transfer between two phases of matter, in which the adsorbent can either be a liquid, solid or even gas. The adsorbent absorbs the gas or liquid as an act of removing or extracting the liquid or gas from a mixture. There are four basic phases of process absorption, and these are;

i. Gas – Liquid Adsorption (GLA)
ii. Gas – Solid Adsorption (GSA)
iii. Liquid– Gas Adsorption (LGA)
iv. Liquid– Solid Adsorption (LSA)

Activated carbon (AC) and zeolites are wellknown substances used as adsorbent in treatment of contaminated fluids. These two have proved to be very effective in recovering impurities from liquid and gas streams under standard reactor condions. AC among the two is the most affordable and steabled adsorbent used in treatment of contamianted water for domestic usage, and has been used in the recovering of both organic inorganic contaminants (Xinle *et al.*, 2025; Ayotamuno *et al.*, 2006; Alves *et al.*, 2021), and due its potency, it has been used by different domemstic water producing factorories as a medium for impurities removal from water before been chlorinated and used forether. Activated carbon is produccable from fibre plants, trees (wood) and fruits shells ssuch as palm nuts, cocnuts shells, etc., also animal bones and calcereous shells of mollusce have proves effective when used as adsorbents.

Coconuts are most affordabble plants found within oil and gas prodcing regions such as the Niger Delta zones, to extent that alsmost every coumpound will have at least a tree of coconut in their compound (as seen st Figure 5), making easier to be used for the production of ACs for treatment of domestic water as a cost conservative measure, and a means of attaining good and standard health status in oil prodiucing regions such as Okrika expetially when the cocnut shells ACs are produced at suitable and quailaty means, such that will inprove their efficiency when applied.

MATERIALS AND METHODS

Materials used for the Study

Materials used in the study include distilled water, groundwater from oil producing regions, coconuts, activated carbon, sieve, crusher, HCl, chromatography glass, restart strand, beaker, oven pyrolysis reactor, spatula. CSTR, Packed bed reactor

Preparation Process of Thermally Differential Activated Carbon (AC)

Tropical coconut obtained from the local markets of River State where rinsed with distilled water and shells achieved after pilling of the coconut husk (which are the fibrous outer layer of a coconut), the shells where then allow to dried under UV for a period of 7 days to reduce moisture content (MC), after which the shells were carbonated at thermally differential levels of 500°C, 700°C and 900°C in a high temperature pyrolysis reactor based on destructive distillation concept till it char within 1.25 hours, then the charred shells were allowed to cool at room temperature, then later crushed using a jaw crusher and sieved into a sieve meshed size of 80µm micro-size particulate. Then the carbonated particulates were washed using 250m distilled water in separate washing containers sectioned for the 500°C, 700°C and 900°C produced carbons, after which the then filtered out and dried at 120°C for 2hrs. Then, 500g of the crushed carbonated dried samples were measured separately into different continues stair tank reactors (CSTRs) and 250ml of 1mol concentrated hydrochloric acid (HCl) was added to the reactors for activation, each were stirred vigorously for homogeneity for 2minutes before been covered and allowed for 24hrs for activation, before been rinsed and oven dried for 10 hours at 100°C yielding quality ACs of 500°C, 700°C and 900°C production temperatures. The produced ACs porosity structure were determined using the Langmuir Brunauer-Emmett-Teller (LBET) analytical tool, before been used in treatment of ground water. After analyzing the ACs using LBET, 200g of each ACs were loaded into five (5) separate packed bed reactor in a bed loaded rate (BLR) of 100% CSAC -500°C, 100% AC-700°C, 100% AC-900°C, 50:50% CSAC -500°C : CSAC -700°C and 50:50% CSAC-500°C : CSAC -900°C, suspended on a rector stand of which after, 400ml of oil based groundwater was added into the reactors and allowed for effective adsorption. Then the treated water samples and that of the ground water was evaluated, determining the BTX-aromatics level and response to the coconut shells activate carbons (CSACs) as well as the nature of their physiochemical status of the water through each loaded packed bed reactor ACs stage, were recorded and used to assess the efficiency of the coconut based thermal differentiated CSACs in treatment of hydrocarbons based contaminated groundwater.

Results and Discussion on Groundwater Treatment Using CSACs

Coconut Shell Activated Carbon (CSAC) Porosity Assessment

In assessment of the porosity difference between coconut shell activated carbons (CSACs) which where produced at differential thermodynamic states of 500°C, 700°C and 900°C labeled as (a), (b) and (c) at Figure 5, using the Langmuir Brunauer-Emmett-Teller (LBET) analytical approach, it was depicted that he porosity of activated carbon is subject to the production thermodynamics which involves the carbonation temperature, oxygenation level during production.

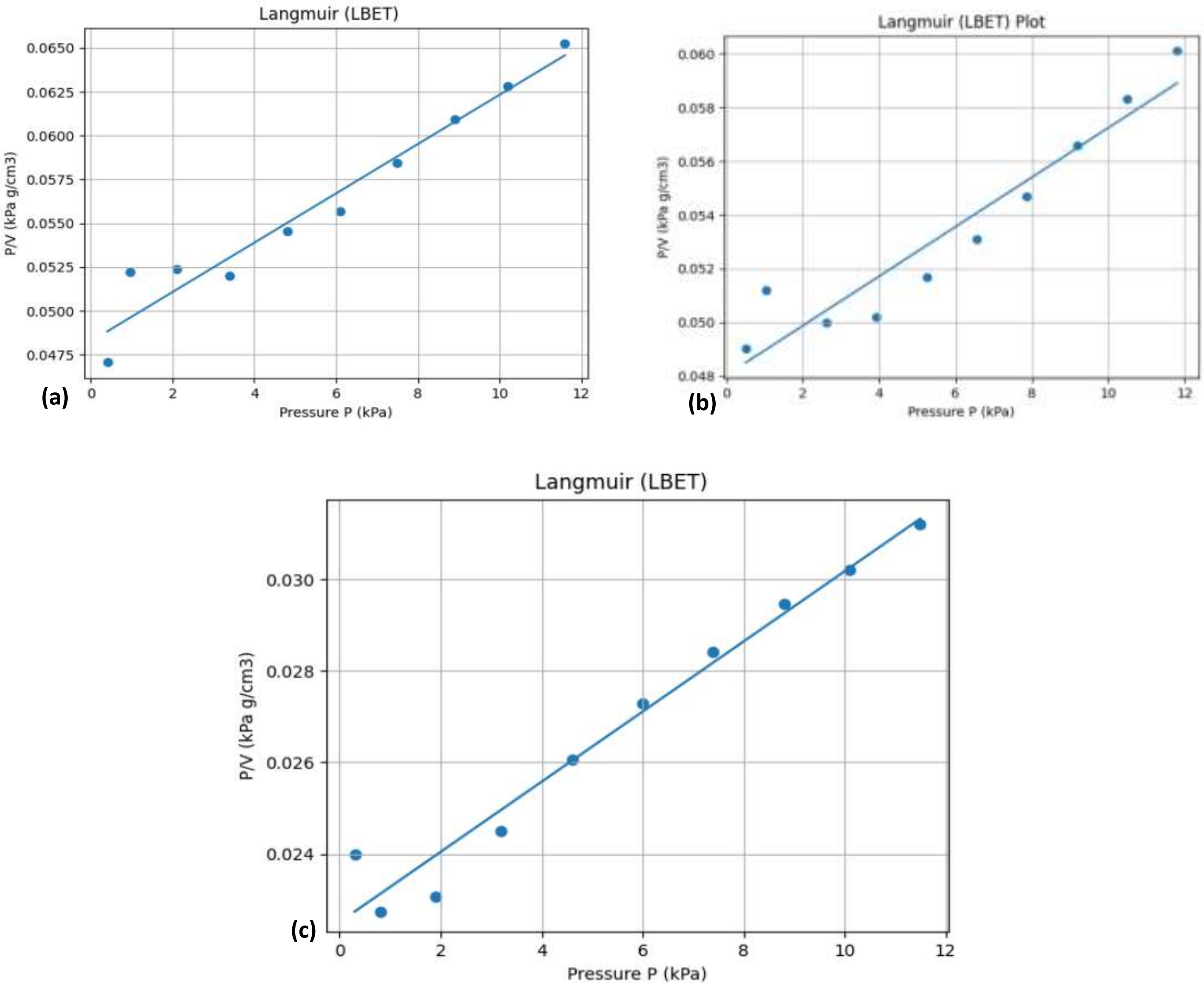


Figure 6: Coconut shells activated carbon (CSAC) porosity behavior at different thermal carbonated temperatures

The results at Figure 6 shows that porosity of coconut shell activated carbon (CSAC) increases with increase in carbonation temperatures, subject to the linearized Langmuir adsorbent adsorption isotherm which is defined by the Langmuir equation

$$\frac{P}{V} = \frac{1}{V_m K} + \frac{P}{V_m} \qquad (1)$$

Where

$$V_m = \frac{1}{slope} = \frac{1}{\Delta X/_{\Delta Y}} = \frac{\Delta Y}{\Delta X} \tag{2}$$

$$K = \frac{1}{V_m \times intercept} \tag{3}$$

Where

P =Equilibrium pressure of the fluid on the adsorbent
V = volume of fluid
V_m = Monolayer adsorption capacity
K = Langmuir adsorption constant.

Figure 5 (a) which is the LBET analytic outcome of CSAC-500^{o}C depicts an intercept of 0.0485 with slope of 0.000133 was detected (1/slope) which defines the monolayer capacity (V_m) of 751.8797 Kpag/cm^3 which depicts a higher adsorbent capacity. While that for CSAC-700^{o}C (Figure 5 (b)), shows an intercept of 0.0485 with the slope of 0.00092 and monolayer capacity (V_m) of 1086.9565 Kpag/cm^3. Also, the Figure 5 (c) which is the LBET analytic outcome of CSAC-900^{o}C shows an intercept of 0.0225 with slope of 0.0008 and monolayer capacity (V_m) of 1250 Kpag/cm^3 which depicts a higher adsorbent capacity among the three assessed adsorbents.

The result also shows a clear linear trend, especially at higher pressures (above 4 kPa) for CSAC-500^{o}C and CSAC-700^{o}C, while above 1kpa for the CSAC-900^{o}C, though there is a slight deviation at the lower pressure range (around 1-2 kPa), which is common in experimental adsorption data as the surface begins to fill. Based on data fit, the blue dots which represents the experimental data points displayed along a solid blue line which defines a best fit linear regression of the Langmuir assessment of the adsorbents porosity in the system, and a higher porosity indicates more microporous channels inside the material, thus more favorable to the storage, transport, and diffusion of fluid through the CSAC, depicting that increase in carbo nation temperature increases the adsorbent pours, defining CSAC-900^{o}C to be of high porosity

Coconut Shell ACs Treatment Efficiency of Aromatics in Niger Delta Groundwater

Aromatics in Assessed Niger Delta Groundwater

In assessing the aromatic composites of Okrika oil regions groundwater in Niger Delta zone of Nigeria, it was identified that their water consist more of Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene aromatic compounds at the value of 29.63721 ppm, 36.48904 ppm 19.32716 ppm, 15.56647 ppm, 12.29102 ppm, and 27.81541 ppm respective as seen at Table 3 (Appendix C), which is above the WHO standard.

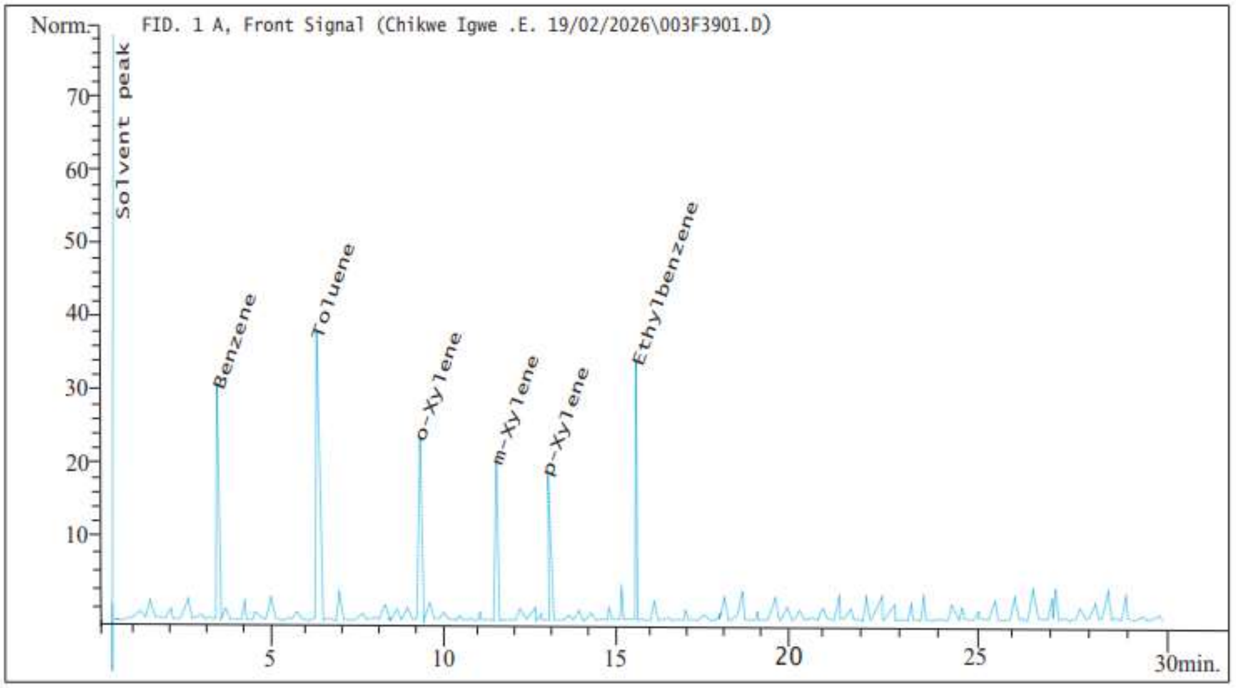


Figure 7: BTX concentration in untreated Okrika groundwater, Niger Delta Region of Nigeria

The result identifies Toluene to be of the highest concentration (36.48904 ppm), and consuming aromatic contaminated water consisting BTX which are known o likely facilitates the formation of Polycyclic Aromatic Hydrocarbons (PAHs) has great health effects as it promotes cancerous cells formation, organ damage, brain damage and many more (Abdulai *et al.*, 2025; Ali *et al.*, 2025; Kponee *et al.*, 2015; Igwe *et al.*, 2026; Perry's and green, 2007), hence treatment is indeed highly recommended, which facilitates this current research into assessment of coconut shells activated carbons (CSAC)

Effects of Thermally Variated Produced CSAC Adsorbent on Ground water Aromatic

Treating the assessed groundwater achieved from the Okrika local government area (LGA) region of River State, which is among the Niger Delta zones, using the $500^{o}C$, $700^{o}C$ and $900^{o}C$ thermally variated produced CSAC it was noticed that the concentration of the Aromatics depleted with increase in the CSAC produced or carbonated temperature, such that at $500^{o}C$ the concentration of the aromatics (Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene) decreased respectively from 29.63721 ppm, 36.48904 ppm 19.32716 ppm, 15.56647 ppm, 12.29102 ppm, and 27.81541 ppm to 18.50134 ppm, 24.94083 ppm, 11.41716 ppm, 6.09352 ppm, 4.14084 ppm, and 15.27162 ppm as seen at Figure 8

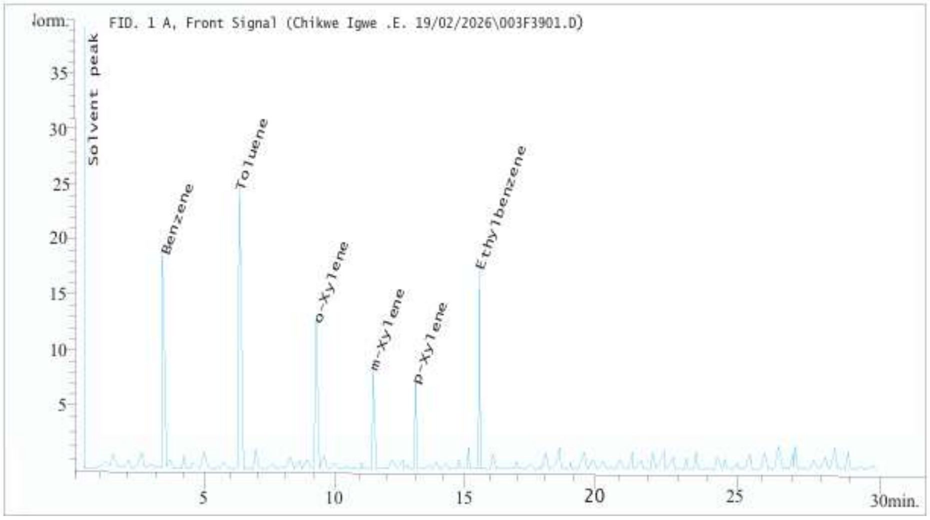


Figure 8: BTX concentration in 500ºC-CSAC treated Okrika groundwater, Niger Delta Region of Nigeria

While by using the 700ºC produced CSAC the Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene composites in the groundwater of Okrika reduces to 13.85162 ppm, 17.90648 ppm, 8.61773 ppm, 4.37570 ppm, 1.54382 ppm and 11.91048 ppm by the Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene respective as seen at Figure 9, which is far lesser than that of the untreated groundwater, as well as more efficient in adsorbent recovery than that attained by the use of the 500ºC CSAC adsorbent

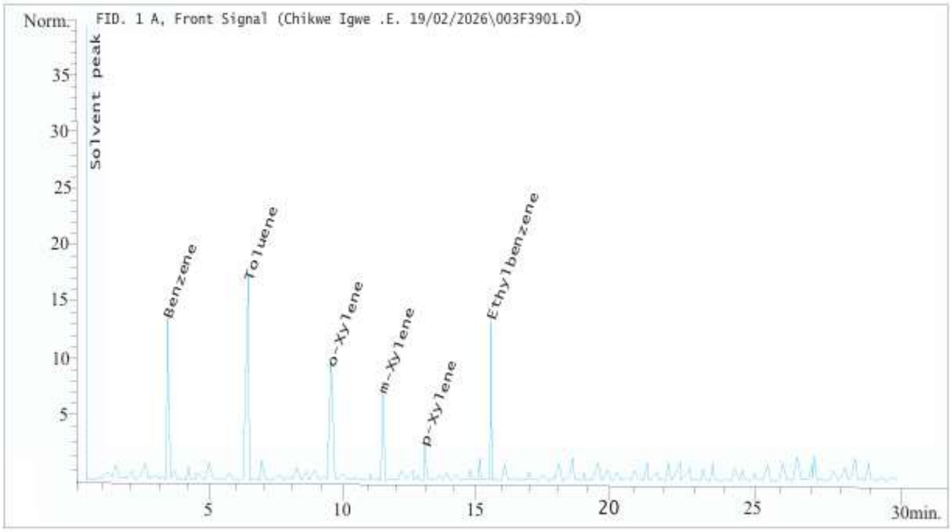


Figure 9: BTX concentration in 700ºC-CSAC treated Okrika groundwater, Niger Delta Region of Nigeria

It was experienced that more of the BTX reduced from the treatment of the Okrika groundwater when CSAC-900ºC was used as the adsorbent, such that the Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene amounts in the water reduced to 10.78562 ppm, 12.90318 ppm, 5.32647 ppm, 1.28593 ppm, 0.000 ppm, and 4.93820 ppm, respectively, which is more appreciative as seen at Figure 10, with the p-xylene totally adsorbed by the 900ºC-CSAC

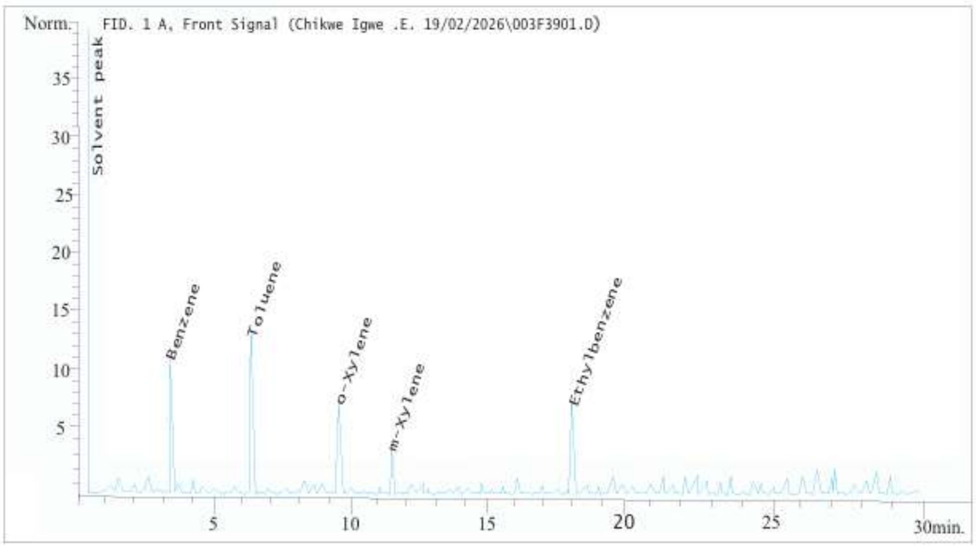


Figure 10: BTX concentration in 900ºC-CSAC treated Okrika groundwater, Niger Delta Region of Nigeria

The combination of the adsorbents with the CSAC-500ºC shows a better aromatic reduction efficiency as it was able to reduce the aromatics compositions (Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene) from 29.63721 ppm, 36.48904 ppm 19.32716 ppm, 15.56647 ppm, 12.29102 ppm, and 27.81541 ppm to 6.26581 ppm, 7.90743 ppm, 1.25129 ppm, 0.0000 ppm, 0.0000 ppm, and 0.61832 ppm respectively, over the used of 50:50% 500ºC-CSAC - 700ºC-CSAC as seen at Figure 11, which is far lesser than using 100% CSAC produced at thermal differentiated temperatures 500ºC, 700ºC and 900ºC. At this stage, the result also depicts the total depletion or adsorption of the m – and p – xylene which is more advantageous to human health of residents living with oil and gas producing regions.

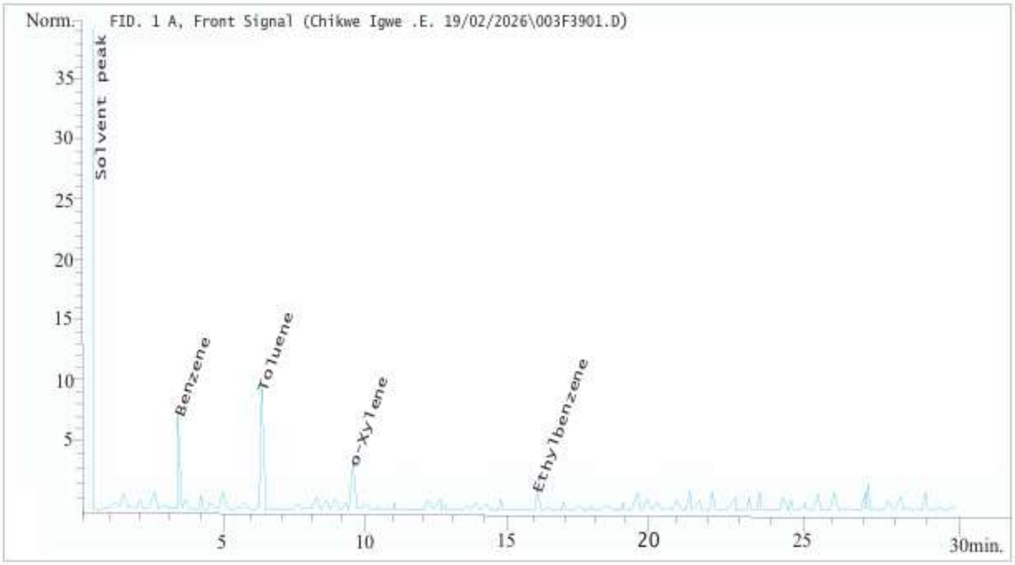


Figure 11: BTX concentration in 50:50% 500^{o}C – 700^{o}C-CSAC treated Okrika groundwater, Niger Delta Region of Nigeria

Finally, using the combined adsorbent type of 50:50% 500^{o}C-CSAC - 900^{o}C-CSAC reduces heavily the BTX aromatics (Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Ethylbenzene) from 29.63721 ppm, 36.48904 ppm 19.32716 ppm, 15.56647 ppm, 12.29102 ppm, and 27.81541 ppm to 2.51623 ppm, 3.40394 ppm0.0000ppm, 0.0000 ppm, and 0.0000ppm, 0.0000 ppm respectively as seen at Figure 12

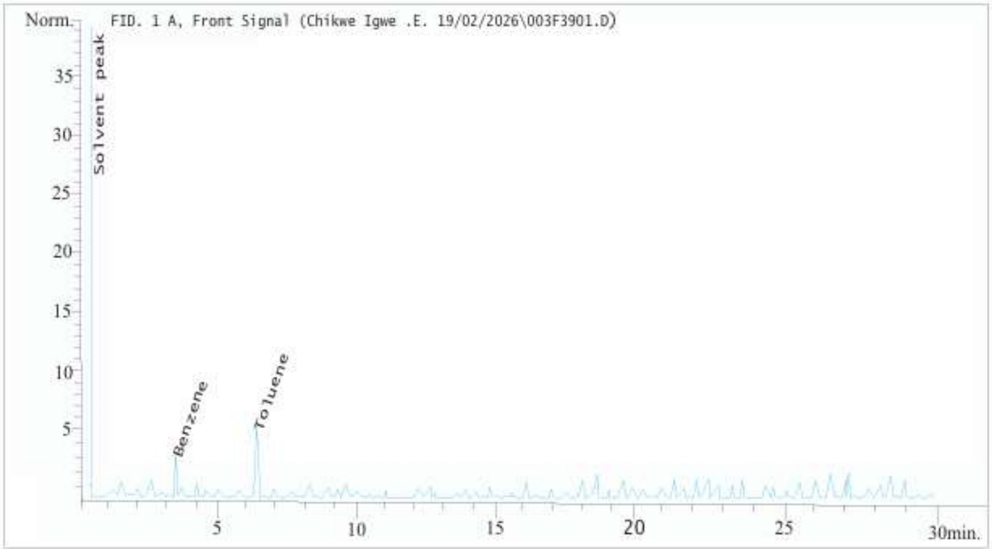


Figure 12: BTX concentration in 50:50% 500^{o}C – 900^{o}C-CSAC treated Okrika groundwater, Niger Delta Region of Nigeria

Comprehensively, the performance of using 100% loading and 50 by 50% loaded CSACs depicts the use of combined adsorbent of 50:50% 500^{o}C – 900^{o}C-CSAC bets for remediation of groundwater from aromatic compounds as presented at Figure 13

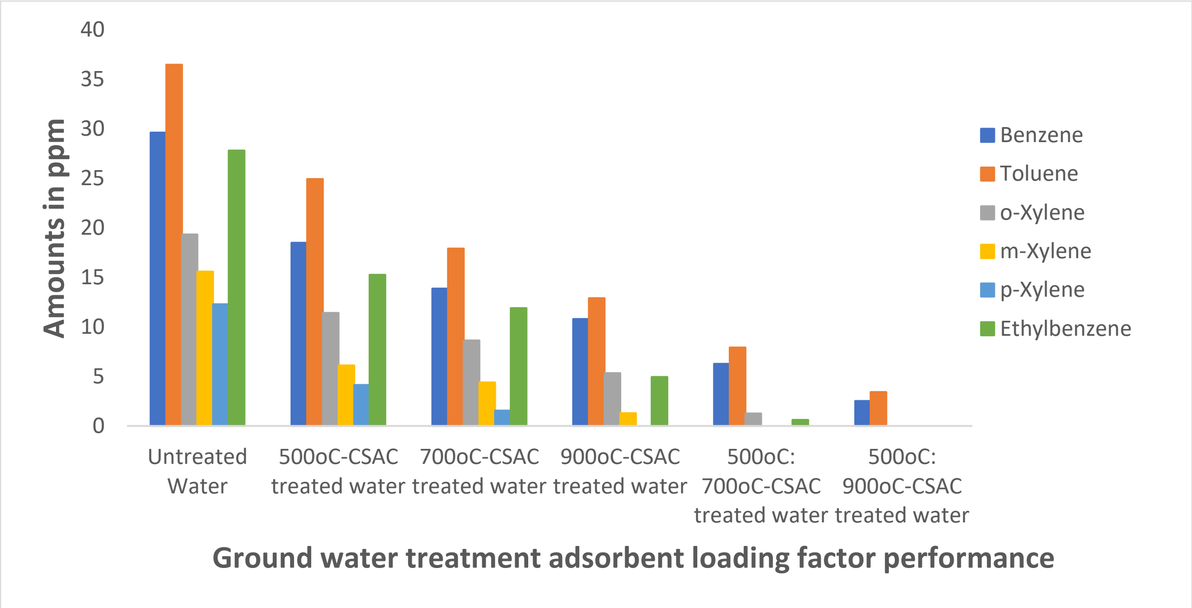


Figure 13: Comprehensive thermally differentially produced CSAC BTX treatment efficiencies in groundwater

Assessed Physiochemical Properties Behavior of Niger Delta Grounder Water within CSAC Adsorbent Environment

In assessment of the treatment performance of thermally differentially produced CSAC on groundwater physiochemical properties, it was identified that conductivity (EC), total dissolve solids (TDS), chemical oxygen demand (COD) and the groundwater chlorine content, reduced in milligram per liter (mg/l) from 8750.14 ppm, 5250.08 ppm, 157.42 ppm, 4260.17 ppm respectively as well as the amounts of solid metals such as Cu, Mn, and Al with increase in the loading factor and increase in thermally differentially produced CSAC

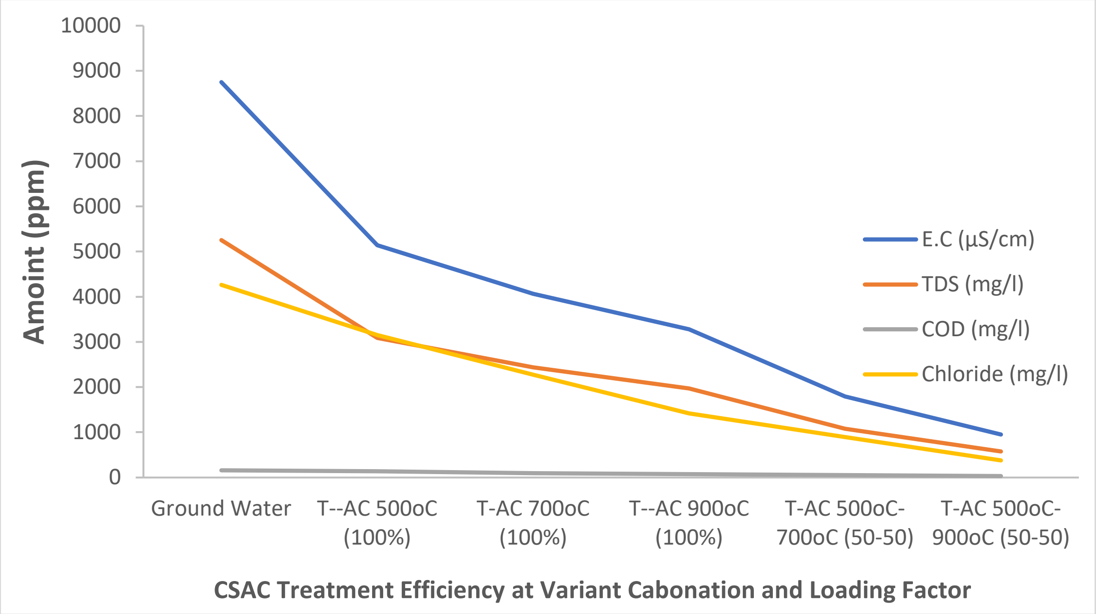


Figure 14: Behavior of physiochemical properties of groundwater with respect to thermally differentiated CSAC and loading factor

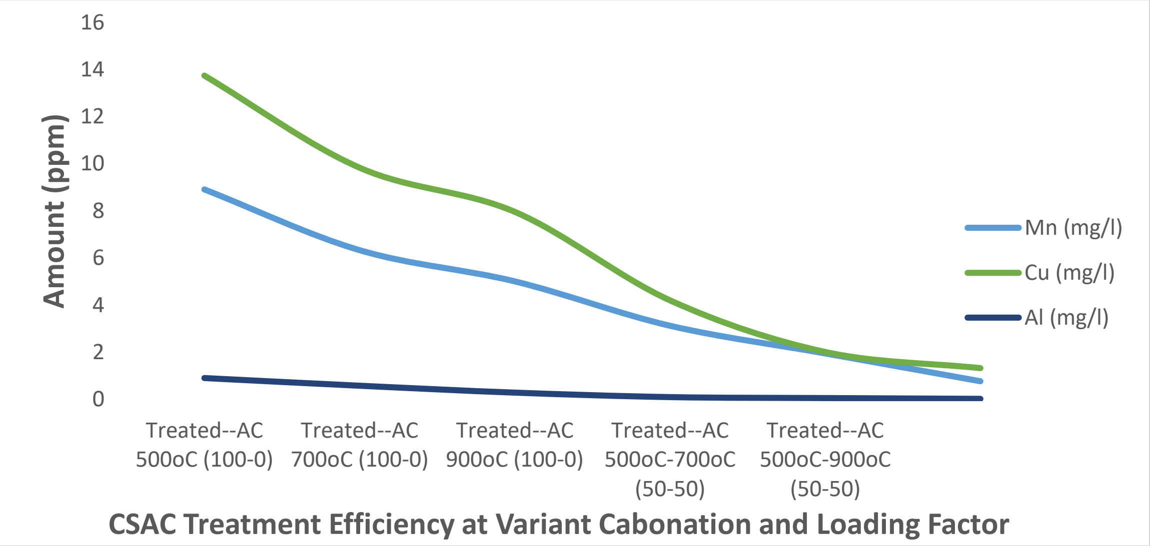


Figure 15: Behavior of solid metals in groundwater with respect to thermally differentiated CSAC and loading factor

CONCLUSION

Coconut shells activated carbons (CSACs) are good adsorbent and treatment medium for solid metals extraction, aromatics / total hydrocarbon compounds depletion, and reduction of BOD, COD with other water properties while increasing the water pH level, efficient for hydrocarbon contaminated water treatment desired for domestic and industrial use. Also, the production nature and the carbonation temperature of activated carbon defines its porosity structure, performance as well as its metal adsorption efficiency over time, such that increase in the carbonation temperature increases the ACs porosity and proportionally increases ins performance when used as an adsorbent. Finally, combined loading factor of ACs produced at different and higher carbonation temperatures above 700^{o}C promotes the treatment reactor performance. Hence, a 50:50 loading factor of two or more thermally differentially produced ACs should be used as a loading factor of a packed bed reactor for effective treatment of surface and ground water for domestic and industrial usage

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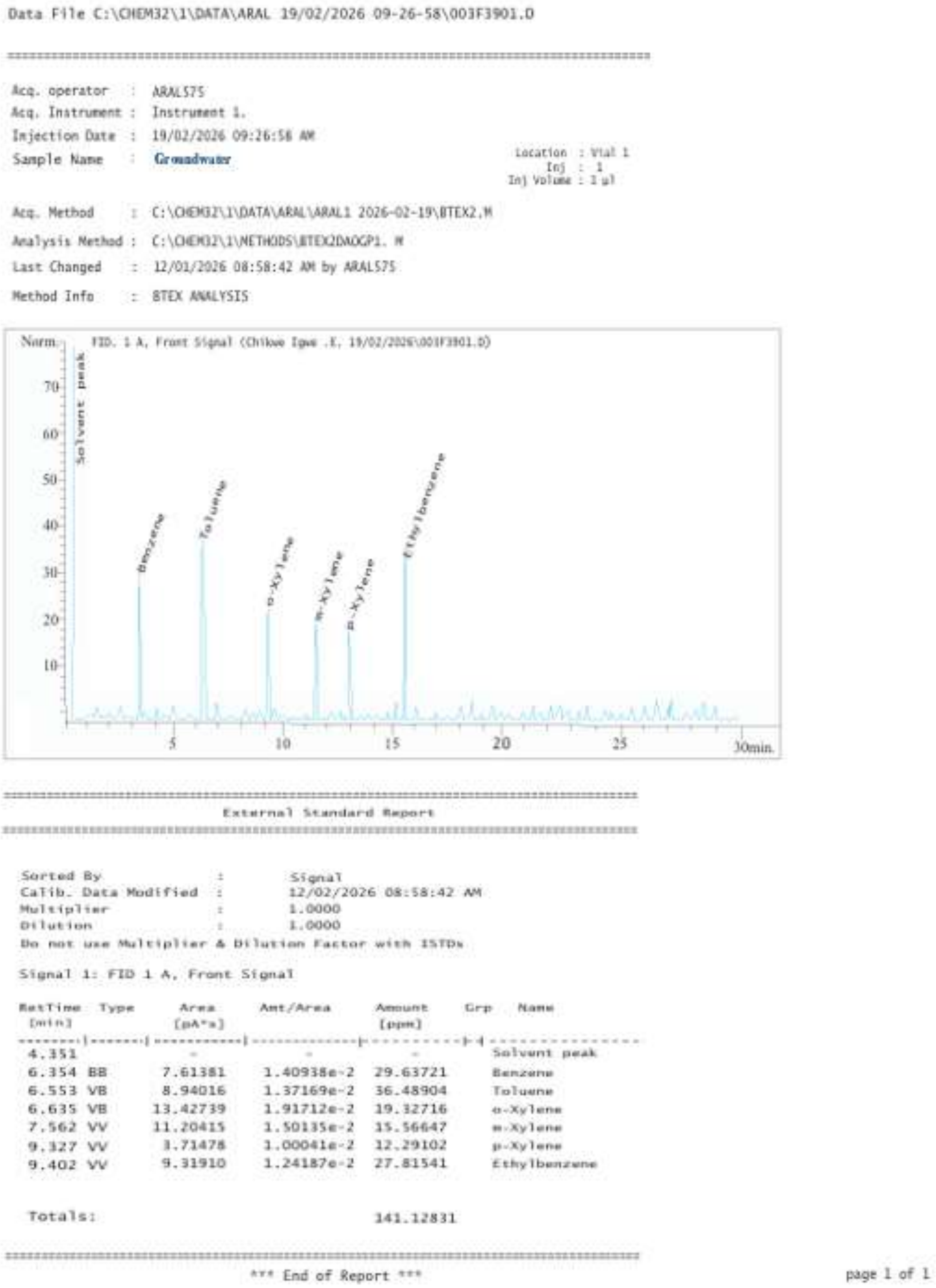
Appendix A

a. BTX Analytical result for the untreated groundwater aromatic contamination



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Data File C:\CHEM32\1\DATA\ARAL 19/02/2026 09-26-58\003F3901.D

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Acq. operator   :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date  :  19/02/2026 09:26:58 AM
Sample Name     :  Groundwater                              Location  : Vial 1
                                                                 Inj  :  1
                                                           Inj Volume : 1 µl

Acq. Method     :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M

Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DAOGP1. M

Last Changed    :  12/01/2026 08:58:42 AM by ARAL575

Method Info     :  BTEX ANALYSIS

=====================================================================================
                         External Standard Report
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Sorted By              :       Signal
Calib. Data Modified   :       12/02/2026 08:58:42 AM
Multiplier             :       1.0000
Dilution               :       1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: FID 1 A, Front Signal

RetTime  Type     Area      Amt/Area       Amount     Grp   Name
 [min]           [pA*s]                    [ppm]
-------|------|----------|-------------|----------|-|----------------
 4.351              -           -           -           Solvent peak
 6.354 BB      7.61381   1.40938e-2  29.63721         Benzene
 6.553 VB      8.94016   1.37169e-2  36.48904         Toluene
 6.635 VB     13.42739   1.91712e-2  19.32716         o-Xylene
 7.562 VV     11.20415   1.50135e-2  15.56647         m-Xylene
 9.327 VV      3.71478   1.00041e-2  12.29102         p-Xylene
 9.402 VV      9.31910   1.24187e-2  27.81541         Ethylbenzene

 Totals:                             141.12831

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                           *** End of Report ***                                       page 1 of 1
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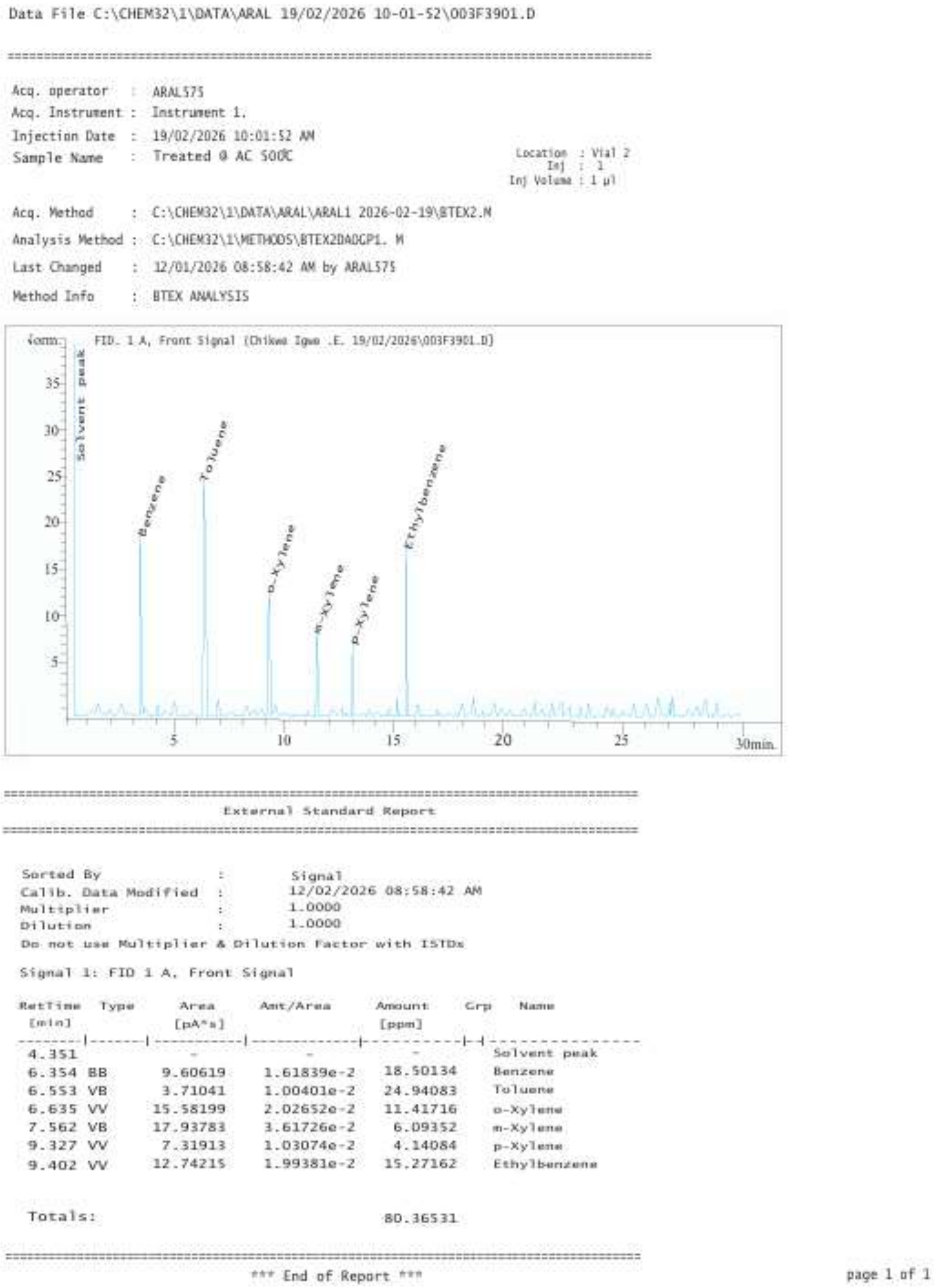
b. BTX Analytic result on the use of 500°C – CSAC adsorbent in treating groundwater contaminates



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Acq. operator   :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date  :  19/02/2026 10:01:52 AM
Sample Name     :  Treated @ AC 500C                        Location  : Vial 2
                                                                 Inj  :  1
                                                           Inj Volume : 1 µl

Acq. Method     :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M
Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DADGP1. M
Last Changed    :  12/01/2026 08:58:42 AM by ARAL575
Method Info     :  BTEX ANALYSIS
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                          External Standard Report
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Sorted By                  :        Signal
Calib. Data Modified       :        12/02/2026 08:58:42 AM
Multiplier                 :        1.0000
Dilution                   :        1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: FID 1 A, Front Signal

RetTime  Type    Area      Amt/Area      Amount    Grp   Name
 [min]          [pA*s]                    [ppm]
--------|-------|----------|-------------|----------|--|----------------
 4.351             -           -            -          Solvent peak
 6.354 BB       9.60619   1.61839e-2   18.50134      Benzene
 6.553 VB       3.71041   1.00401e-2   24.94083      Toluene
 6.635 VV      15.58199   2.02652e-2   11.41716      o-Xylene
 7.562 VB      17.93783   3.61726e-2    6.09352      m-Xylene
 9.327 VV       7.31913   1.03074e-2    4.14084      p-Xylene
 9.402 VV      12.74215   1.99381e-2   15.27162      Ethylbenzene

 Totals:                               80.36531

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                           *** End of Report ***                              page 1 of 1
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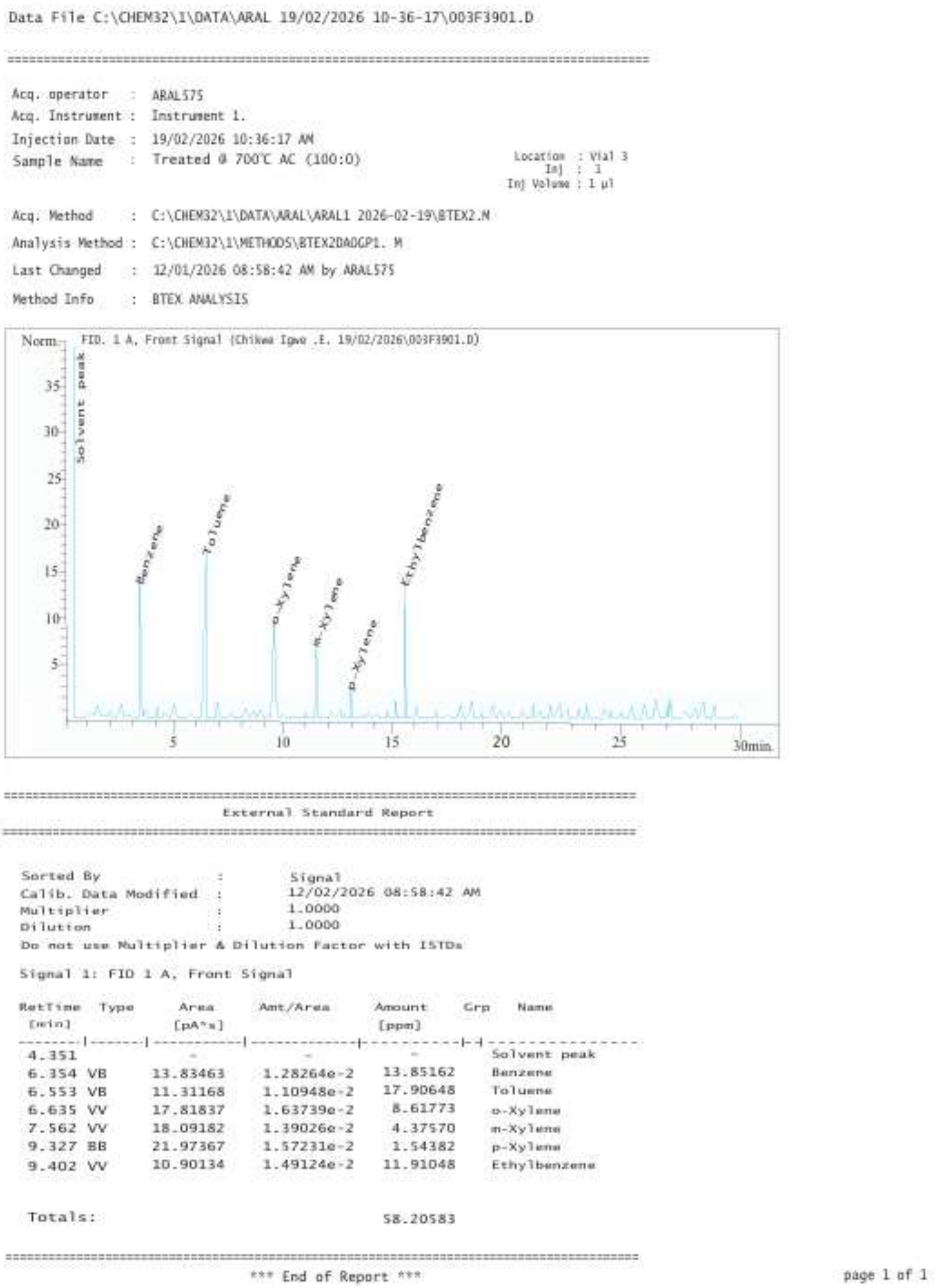
c. BTX Analytic result on the use of 700ºC – CSAC adsorbent in treating groundwater contaminates



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Acq. operator   :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date  :  19/02/2026 10:36:17 AM
Sample Name     :  Treated @ 700'C AC (100:0)            Location  : Vial 3
                                                              Inj  :  1
                                                       Inj Volume  : 1 µl

Acq. Method     :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M
Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DADGP1. M
Last Changed    :  12/01/2026 08:58:42 AM by ARAL575
Method Info     :  BTEX ANALYSIS

=====================================================================================
                          External Standard Report
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Sorted By               :       Signal
Calib. Data Modified    :       12/02/2026 08:58:42 AM
Multiplier              :       1.0000
Dilution                :       1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: FID 1 A, Front Signal

RetTime  Type     Area        Amt/Area       Amount     Grp   Name
 [min]           [pA*s]                      [ppm]
--------|-------|-----------|-------------|-----------|--|-----------------
 4.351              -            -            -           Solvent peak
 6.354 VB      13.83463     1.28264e-2    13.85162        Benzene
 6.553 VB      11.31168     1.10948e-2    17.90648        Toluene
 6.635 VV      17.81837     1.63739e-2     8.61773        o-Xylene
 7.562 VV      18.09182     1.39026e-2     4.37570        m-Xylene
 9.327 BB      21.97367     1.57231e-2     1.54382        p-Xylene
 9.402 VV      10.90134     1.49124e-2    11.91048        Ethylbenzene

 Totals:                                  58.20583

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                           *** End of Report ***                          page 1 of 1
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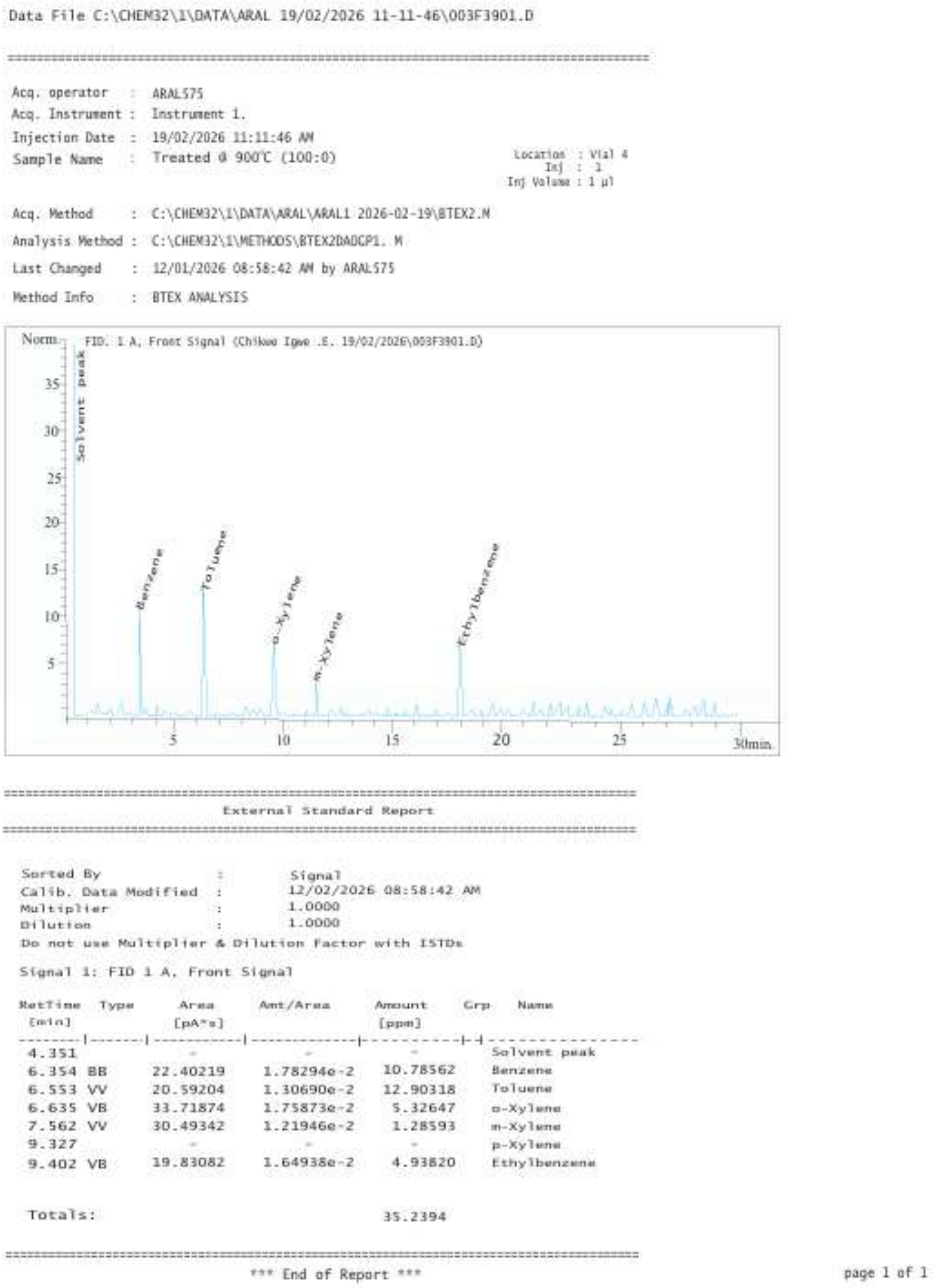
d. BTX Analytic result on the use of 900^{o}C – CSAC adsorbent in treating groundwater contaminates



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Acq. operator   :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date  :  19/02/2026 11:11:46 AM
Sample Name     :  Treated @ 900'C (100:0)                    Location  : Vial 4
                                                                   Inj  :  1
                                                            Inj Volume : 1 µl

Acq. Method     :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M

Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DADCP1. M

Last Changed    :  12/01/2026 08:58:42 AM by ARAL575

Method Info     :  BTEX ANALYSIS
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                         External Standard Report
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Sorted By             :      Signal
Calib. Data Modified  :      12/02/2026 08:58:42 AM
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: FID 1 A, Front Signal

RetTime  Type    Area      Amt/Area      Amount    Grp   Name
 [min]          [pA*s]                   [ppm]
-------|------|----------|------------|----------|--|---------------
 4.351            -           -           -           Solvent peak
 6.354 BB     22.40219   1.78294e-2   10.78562        Benzene
 6.553 VV     20.59204   1.30690e-2   12.90318        Toluene
 6.635 VB     33.71874   1.75873e-2    5.32647        o-Xylene
 7.562 VV     30.49342   1.21946e-2    1.28593        m-Xylene
 9.327            -           -           -           p-Xylene
 9.402 VB     19.83082   1.64938e-2    4.93820        Ethylbenzene

 Totals:                              35.2394

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                        *** End of Report ***                         page 1 of 1
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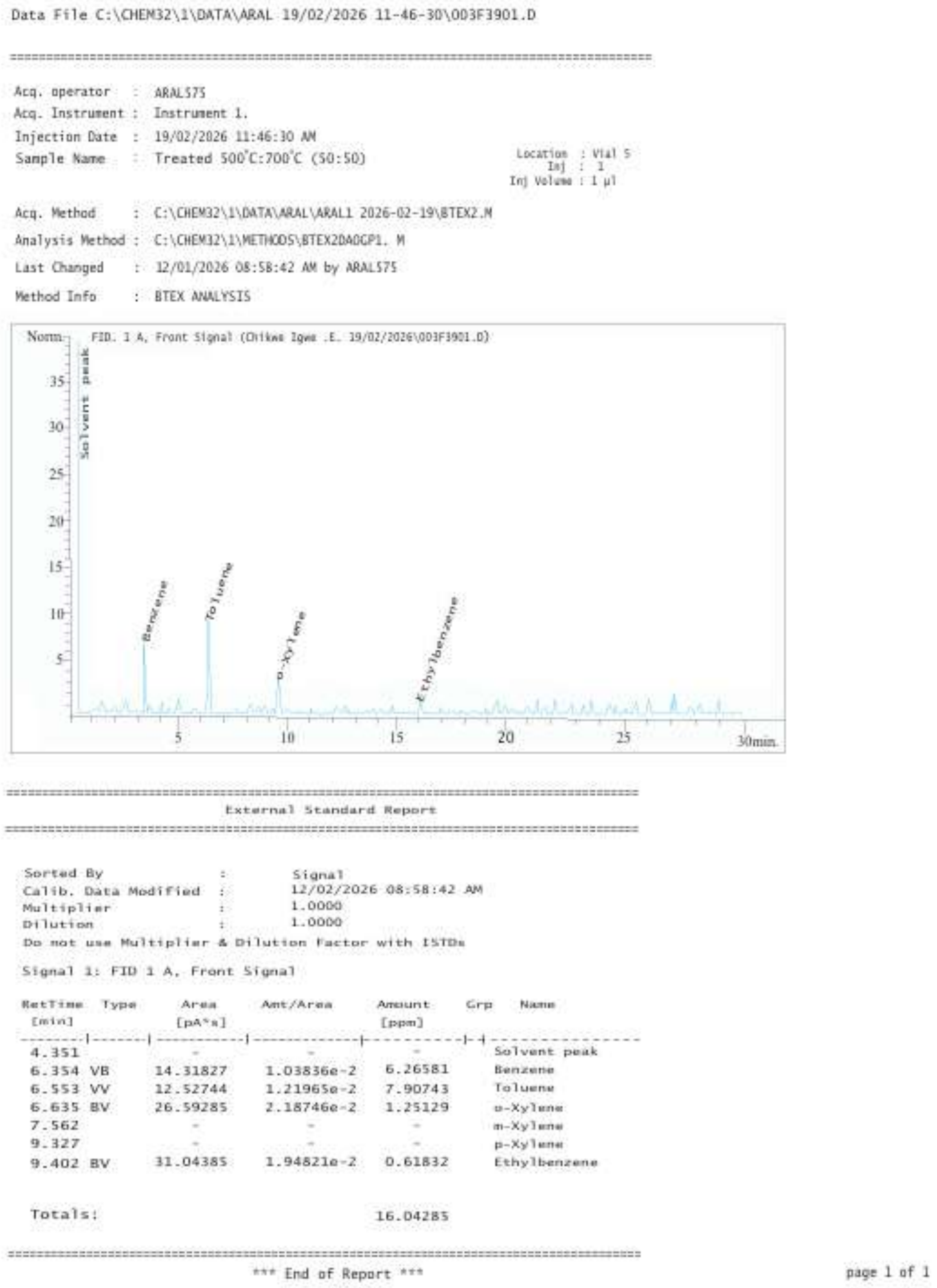
e. BTX Analytic result on the use of 50:50% 500^{o}C – 700^{o}C-CSAC adsorbent in treating groundwater contaminates



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Data File C:\CHEM32\1\DATA\ARAL 19/02/2026 11-46-30\003F3901.D

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Acq. operator   :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date  :  19/02/2026 11:46:30 AM
Sample Name     :  Treated 500°C:700°C (50:50)              Location  : Vial 5
                                                                 Inj  :  1
                                                           Inj Volume : 1 µl

Acq. Method     :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M
Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DA0GP1. M
Last Changed    :  12/01/2026 08:58:42 AM by ARAL575
Method Info     :  BTEX ANALYSIS
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                              External Standard Report
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Sorted By                 :         Signal
Calib. Data Modified      :         12/02/2026 08:58:42 AM
Multiplier                :         1.0000
Dilution                  :         1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: FID 1 A, Front Signal

RetTime  Type     Area      Amt/Area      Amount    Grp   Name
 [min]           [pA*s]                   [ppm]
--------|-------|----------|-------------|----------|-|----------------
  4.351             -           -            -          Solvent peak
  6.354 VB     14.31827   1.03836e-2    6.26581         Benzene
  6.553 VV     12.52744   1.21965e-2    7.90743         Toluene
  6.635 BV     26.59285   2.18746e-2    1.25129         o-Xylene
  7.562             -           -            -          m-Xylene
  9.327             -           -            -          p-Xylene
  9.402 BV     31.04385   1.94821e-2    0.61832         Ethylbenzene

  Totals:                               16.04285

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                              *** End of Report ***                              page 1 of 1
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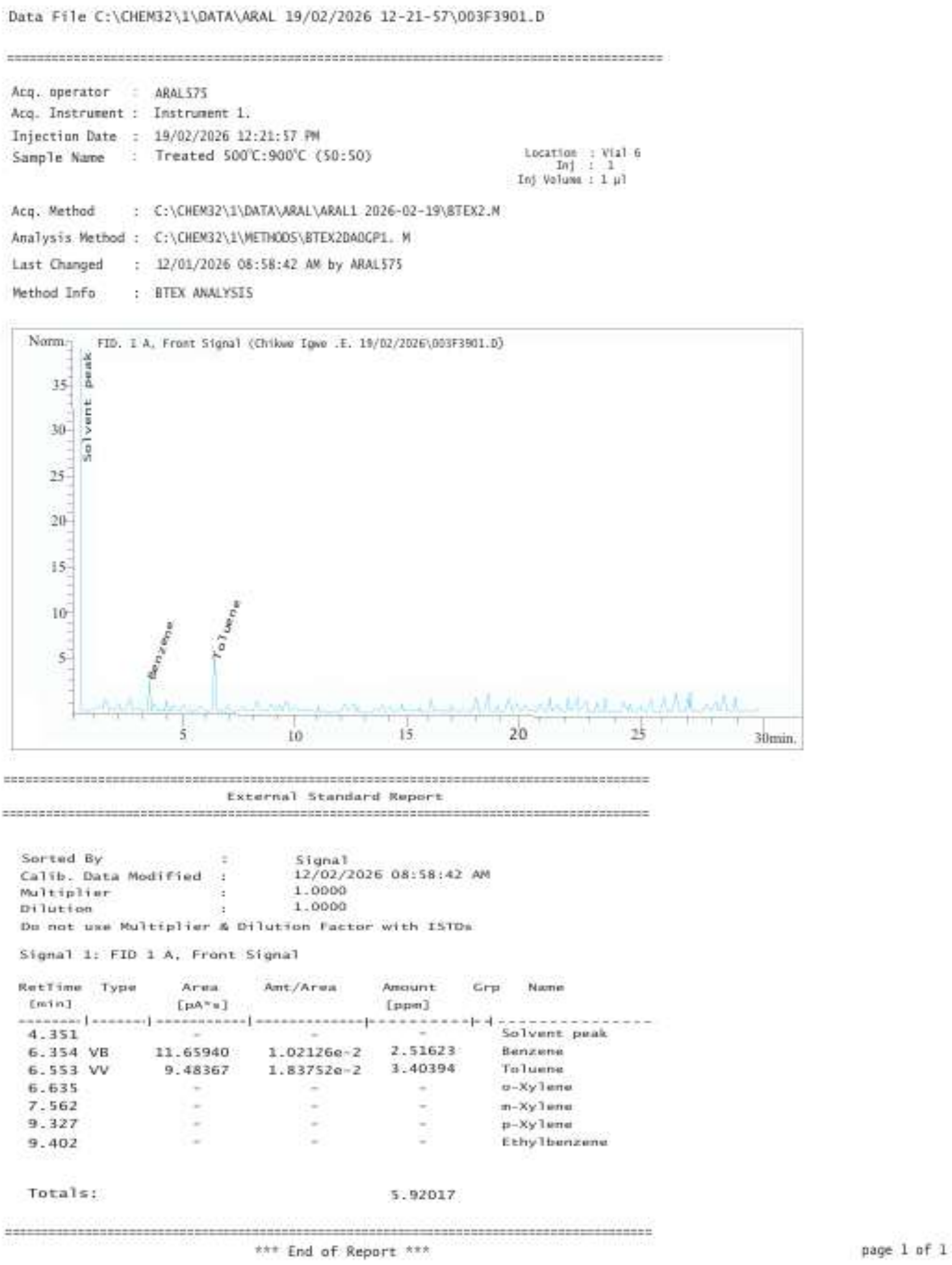
f. BTX Analytic result on the use of 50:50% 500ºC – 900ºC-CSAC adsorbent in treating groundwater contaminates



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Acq. operator     :  ARAL575
Acq. Instrument :  Instrument 1.
Injection Date   :  19/02/2026 12:21:57 PM
Sample Name      :  Treated 500°C:900°C (50:50)                    Location  : Vial 6
                                                                         Inj  :  1
                                                                   Inj Volume : 1 µl

Acq. Method      :  C:\CHEM32\1\DATA\ARAL\ARAL1 2026-02-19\BTEX2.M
Analysis Method :  C:\CHEM32\1\METHODS\BTEX2DA0GP1. M
Last Changed     :  12/01/2026 08:58:42 AM by ARAL575
Method Info      :  BTEX ANALYSIS
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                                 External Standard Report
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  Sorted By              :        Signal
  Calib. Data Modified   :        12/02/2026 08:58:42 AM
  Multiplier             :        1.0000
  Dilution               :        1.0000
  Do not use Multiplier & Dilution Factor with ISTDs

  Signal 1: FID 1 A, Front Signal

  RetTime  Type    Area       Amt/Area      Amount    Grp   Name
   [min]          [pA*s]                    [ppm]
  -------|------|----------|-------------|----------|-|---------------
   4.351            -            -            -           Solvent peak
   6.354 VB     11.65940    1.02126e-2    2.51623         Benzene
   6.553 VV      9.48367    1.83752e-2    3.40394         Toluene
   6.635            -            -            -           o-Xylene
   7.562            -            -            -           m-Xylene
   9.327            -            -            -           p-Xylene
   9.402            -            -            -           Ethylbenzene

   Totals:                                5.92017

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                               *** End of Report ***                              page 1 of 1
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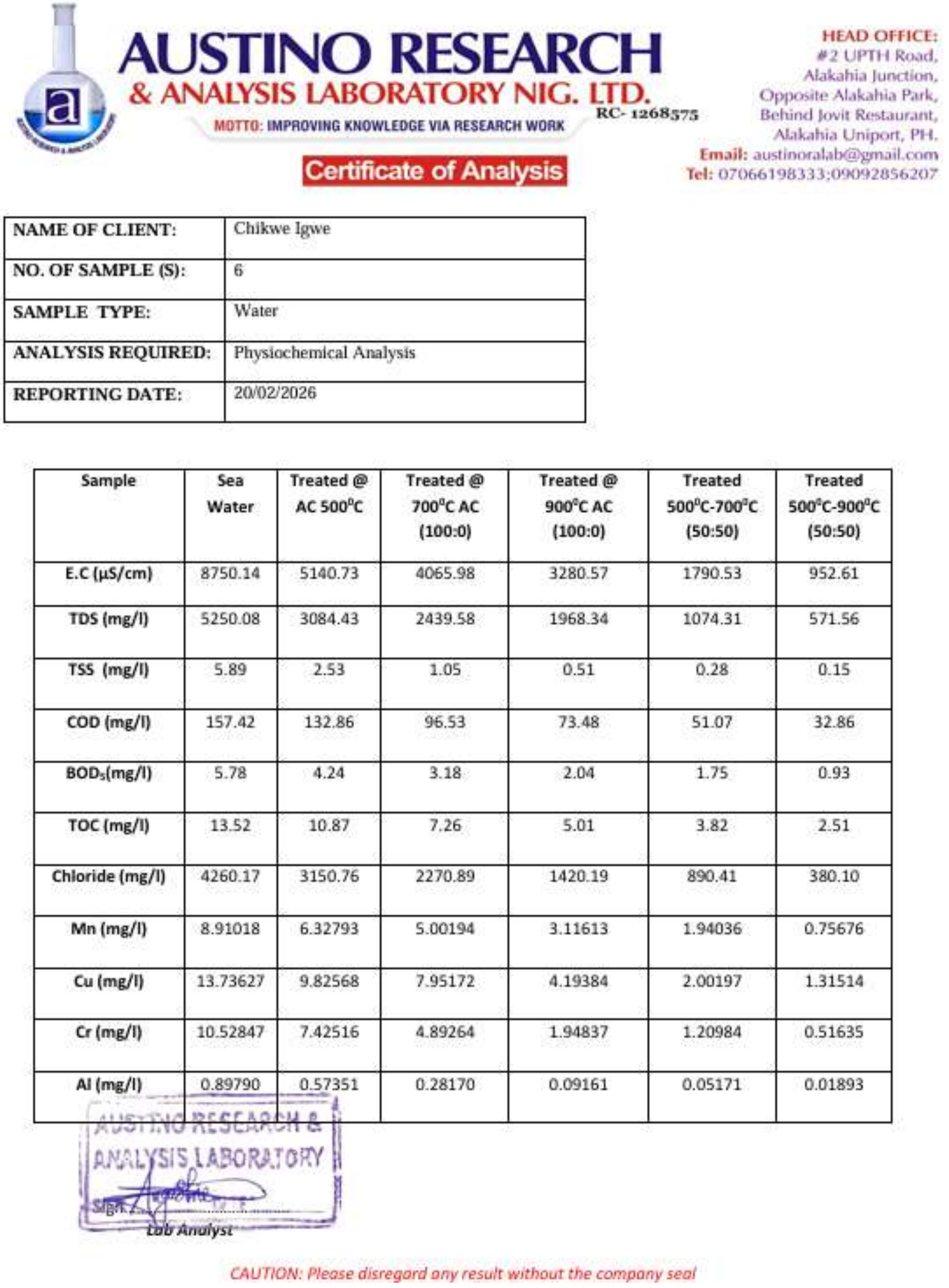
Appendix B

Table 2: Physiochemical properties of treated and untreated groundwater



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Behind Jovit Restaurant,
Alakahia Uniport, PH.
Email: austinoralab@gmail.com
Tel: 07066198333;09092856207

Certificate of Analysis

NAME OF CLIENT:	Chikwe Igwe
NO. OF SAMPLE (S):	6
SAMPLE TYPE:	Water
ANALYSIS REQUIRED:	Physiochemical Analysis
REPORTING DATE:	20/02/2026

Sample	Sea Water	Treated @ AC 500°C	Treated @ 700°C AC (100:0)	Treated @ 900°C AC (100:0)	Treated 500°C-700°C (50:50)	Treated 500°C-900°C (50:50)
E.C (µS/cm)	8750.14	5140.73	4065.98	3280.57	1790.53	952.61
TDS (mg/l)	5250.08	3084.43	2439.58	1968.34	1074.31	571.56
TSS (mg/l)	5.89	2.53	1.05	0.51	0.28	0.15
COD (mg/l)	157.42	132.86	96.53	73.48	51.07	32.86
BOD_5(mg/l)	5.78	4.24	3.18	2.04	1.75	0.93
TOC (mg/l)	13.52	10.87	7.26	5.01	3.82	2.51
Chloride (mg/l)	4260.17	3150.76	2270.89	1420.19	890.41	380.10
Mn (mg/l)	8.91018	6.32793	5.00194	3.11613	1.94036	0.75676
Cu (mg/l)	13.73627	9.82568	7.95172	4.19384	2.00197	1.31514
Cr (mg/l)	10.52847	7.42516	4.89264	1.94837	1.20984	0.51635
Al (mg/l)	0.89790	0.57351	0.28170	0.09161	0.05171	0.01893

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Lab Analyst

CAUTION: Please disregard any result without the company seal

Appendix C

Table 3: Comprehensive thermally differentially produced CSAC BTX treatment efficiencies in groundwater

BTX in Okrica groundwater	**Untreated Water**	**500°C-CSAC treated water**	**700°C-CSAC treated water**	**900°C-CSAC treated water**	**500°C: 700°C-CSAC treated water**	**500°C: 900°C-CSAC treated water**
Benzene	29.63721	18.50134	13.85162	10.78562	6.26581	2.51623
Toluene	36.48904	24.94083	17.90648	12.90318	7.90743	3.40394
o-Xylene	19.32716	11.41716	8.61773	5.32647	1.25129	0.0000
m-Xylene	15.56647	6.09352	4.37570	1.28593	0.0000	0.0000
p-Xylene	12.29102	4.14084	1.54382	0.0000	0.0000	0.0000
Ethylbenzene	27.81541	15.27162	11.91048	4.93820	0.61832	0.0000