Scientific Research Publishing

Journal of Materials Science and Chemical Engineering, 2026, 14(9), 60-75
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Treatment of Kandé and Lyndiane Well Water Using Activated Char from "Ditakh" Shells: Mechanisms and Performance

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How to cite this paper: Diedhiou, A., Manga, P.B.A., Traore, S. and Bensakhria, A. (2026) Treatment of Kandé and Lyndiane Well Water Using Activated Char from "Ditakh" Shells: Mechanisms and Performance. *Journal of Materials Science and Chemical Engineering*, **14**, 60-75.
https://doi.org/10.4236/msce.2026.149005

Received: August 12, 2026
Accepted: September 20, 2026
Published: September 23, 2026

Abstract

Groundwater quality decline is a major constraint on drinking-water supply in several localities of Casamance (Senegal), where well water often shows physico-chemical characteristics incompatible with World Health Organization (WHO) drinking-water standards. This study evaluates the effectiveness of activated char produced from "ditakh" (Detarium senegalense) shells, chemically activated with either lemon juice or phosphoric acid (H_3PO_4), for treating well water in the Kandé and Lyndiane neighbourhoods of Ziguinchor. Samples were collected over four months from four wells (two per neighbourhood) and characterised in situ (pH, electrical conductivity EC, TDS). The chars were then tested using two setups: direct char-water contact and multilayer bed filtration (sand, limestone, activated char). Results show high acidity and mineralisation in the raw waters, with occasional exceedances of the WHO conductivity guideline (1300 µS/cm). Activated-char treatment significantly improved pH and lowered conductivity, with an optimum obtained at 30 g of lemon-juice-activated char for Kandé water and 4 g of H_3PO_4-activated char for Lyndiane water. The H_3PO_4-activated char, being more porous, showed a higher adsorption capacity than the lemon-juice-activated char. Multilayer filtration incorporating two sand layers gave the best purification performance. These results confirm the potential of ditakh shells as a local, available and low-cost precursor for producing activated char for household water treatment.

Keywords

Activated Char, Ditakh Shells, Adsorption, Well Water, Casamance, Physico-Chemical Quality

1. Introduction

Water is an indispensable resource for human life, economic development and the preservation of ecosystems, particularly in areas where populations depend chiefly on groundwater for their daily needs. In the Ziguinchor region, the rate of drinking-water coverage remains below the national average, which increases households' reliance on traditional wells [1].

This reliance, however, becomes a public-health concern when groundwater quality deteriorates. Several studies conducted in West Africa on well and borehole water have documented recurrent exceedances of WHO potability standards for parameters such as pH, electrical conductivity, iron, manganese or nitrates [2]-[5]. In the specific context of Lower Casamance, saltwater intrusion and the decline in rainfall observed since the great Sahelian droughts have contributed to the mineralisation and acidification of coastal groundwater (Programme CEE-Casamance). The Kandé and Lyndiane neighbourhoods of Ziguinchor are no exception, and their well water sometimes shows worrying physico-chemical characteristics.

To address this type of problem, adsorption onto activated char is recognised as one of the most effective and widespread processes for water polishing treatment, owing to the microporous structure of the material, which gives it a high specific surface area and a strong capacity to retain organic and mineral pollutants [6] [7]. Numerous local plant precursors coconut shells, wood, bamboo have already been valorised for producing high-performance activated chars [8] [9]. Ditakh (Detarium senegalense), a tree widespread in West Africa whose fruit is commonly consumed, produces shells that have so far been regarded as a by-product with no added value, making them a local, low-cost and ecologically relevant precursor for manufacturing activated char.

It is in this context that the following question arises: to what extent can activated char produced from "ditakh" shells improve the physico-chemical quality of well water in the Kandé and Lyndiane neighbourhoods and provide a sustainable local solution for its treatment?

The overall aim of this work is to evaluate the effectiveness of activated char derived from "ditakh" shells in treating contaminated water in the Kandé and Lyndiane neighbourhoods. It comprises four specific objectives: i) to analyse the physico-chemical characteristics of well water in the two neighbourhoods; ii) to prepare an activated char from "ditakh" shells by chemical activation; iii) to study the influence of lemon juice and phosphoric acid on the performance of the activated char; and iv) to compare the results obtained with WHO potability standards.

2. Materials and Methods

2.1. Study Area and Sampling

The study was conducted in the Kandé and Lyndiane neighbourhoods (commune of Ziguinchor, Lower Casamance, Senegal). Samples were collected over a four-month period, covering both the rainy season and the dry season, from four wells: two per neighbourhood, one located in the centre and the other on the periphery. After each sampling, the physico-chemical parameters electrical conductivity (EC), pH, total dissolved solids (TDS), temperature (T) and a complementary measurement unit (U) were measured in situ using a multiparameter conductivity meter (**Figure 1**).

Figure 1. Multiparameter conductivity meter.

2.2. Preparation of the Activated Char

Ditakh shells (**Figure 2(a)**) were collected, crushed and carefully wrapped in aluminium foil before being placed in a muffle furnace (**Figure 2(b)**) for the carbonisation step. The carbon obtained from carbonisation then underwent chemical activation: one portion was treated with lemon juice (**Figure 2(c)**) and the other with phosphoric acid (H_3PO_4) (**Figure 2(d)**). The resulting carbons were washed repeatedly until the wash filtrate reached a neutral pH, then oven-dried at 105˚C for 24 h. All quantities of material used in the experiments were weighed using an electronic balance.

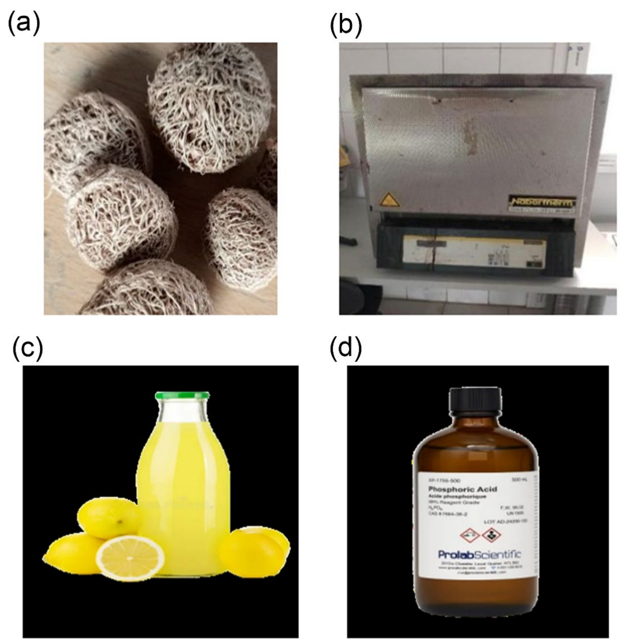

Figure 2. Equipment and chemical reagents used for sample conversion.

2.3. Water-Treatment Setups

Two complementary approaches were used to evaluate the performance of the activated carbon:

- Direct contact: the activated char was brought into contact with the water to be treated, with parameters (pH, EC, TDS, T, U) measured every 30 minutes, in order to determine the volume of water that a given mass of char could treat and to identify the optimal mass (25, 30 and 35 g for Kandé; 2, 3 and 4 g for Lyndiane), as well as the effect of the activating chemical (lemon juice vs. H_3PO_4);
- Multilayer filtration: water was percolated through a filter bed of superposed sand, limestone and activated char, under two configurations Entity 1 (2 layers of sand + 1 layer of char + 1 layer of limestone) and Entity 2 (2 layers of char + 1 layer of sand + 1 layer of limestone) with the outlet filtrate parameters measured (**Figure 3**).

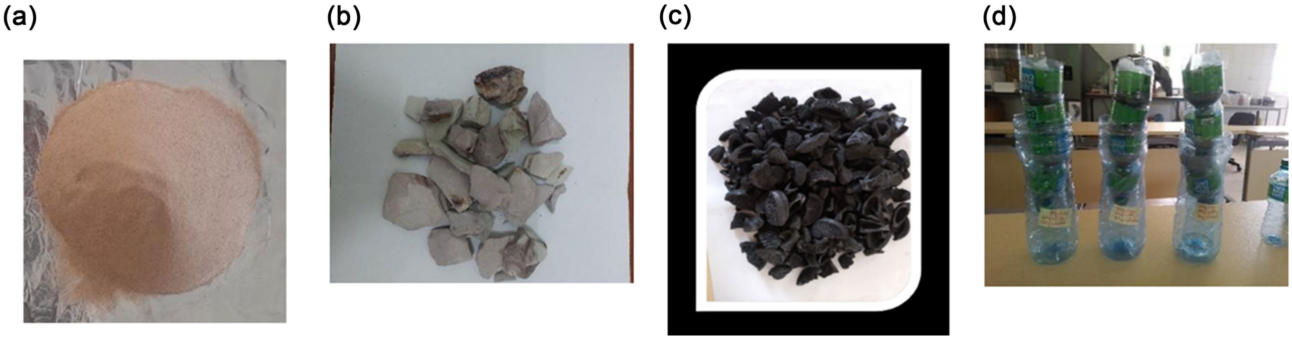

Figure 3. Filter components sand (a), limestone (b), activated char (c) and the superposed filter bed (d).

In this study, the results for pH and EC will be presented because TDS (mg/l) and U (electrical potential in millivolts, mV) are parameters related to ion variation (TDS is proportional to EC). However, the temperatures obtained range from 25˚C to 27.4˚C, so they remain within the WHO recommended range. To make the document less bulky, we focused on pH and EC, which provide more physicochemical insight into the samples.

All results were compared against WHO potability standards, in particular the electrical-conductivity limit of 1300 µS/cm.

3. Results and Discussion

3.1. Initial Characterisation of the Well Water

Monitoring of pH over four months shows that Kandé well water is generally acidic, with neutrality observed only in September and October, the rainy period (**Figure 4**). This transient neutralisation could be explained by rainwater intrusion into the well, diluting H_3O^+ ions or introducing cations. In Lyndiane, the same seasonal pattern is observed for pH, with neutrality during the rainy season (September-October) followed by a return to acidity in the dry season (**Figure 4(b)**).

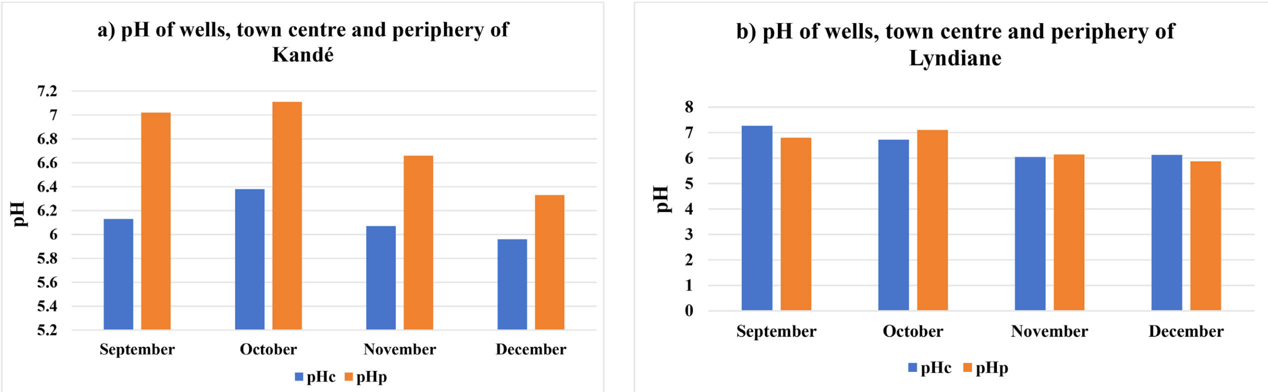

Figure 4. pH Variation of Kandé and Lyndiane well water, (a) and (b) respectively.

Monitoring of the electrical conductivity of Kandé water reveals values exceeding the WHO guideline (1300 µS/cm) (WHO, 2017), reflecting strong ineralized on of this water (**Figure 5(a)**).

The electrical conductivity of Lyndiane water generally complies with the WHO guideline, except for the peripheral well, whose water is strongly ineralized (**Figure 5(b)**).

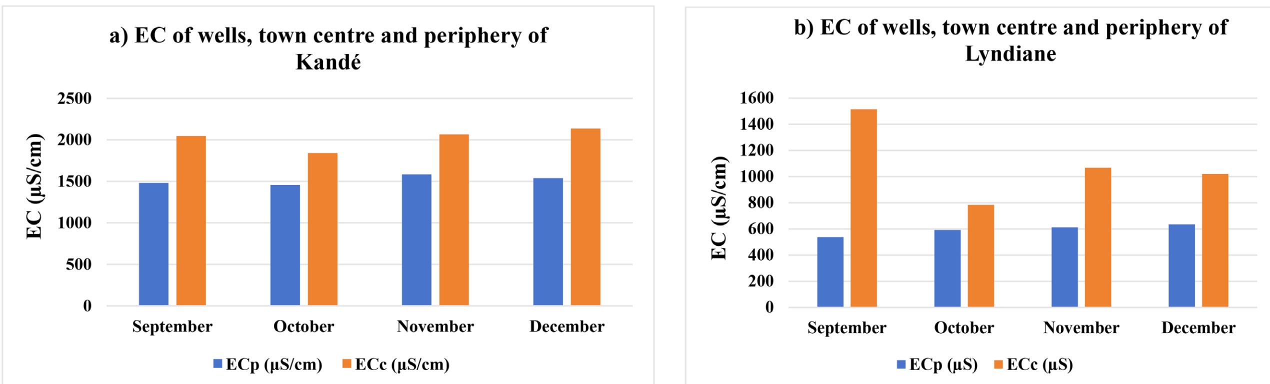

Figure 5. EC variation of Kandé and Lyndiane well water, (a) and (b) respectively.

These findings are consistent with those reported in other West African contexts, where the acidity and mineralisation of well water are frequently associated with the nature of the geological substrate and the seasonal dynamics of the water table [2] [4].

The spatio-temporal analysis of electrical conductivity (EC) in Kandé and Lyndiane shows that the town centre, characterised by higher population density, systematically displays higher conductivity values than the periphery (ECc > ECp) throughout the study period (September to December). In African urban and peri-urban hydrogeology, this spatial differentiation is explained by the interaction of anthropogenic and climatic factors. This anthropogenic-enrichment phenomenon drastically increases the overall ionic load of the water and hence its electrical conductivity. Conversely, although the dense urban centre is subject to strong anthropogenic pressure linked to on-site sanitation systems (soak-away latrines), the pollution there tends to be more localised and mainly composed of organic or bacteriological matter, together with an increase in total mineralisation.

Overall, in light of the interpretation criteria for physico-chemical water parameters ([9] [10]), these results confirm the need to treat Kandé and Lyndiane water before any consumption.

These observations are consistent with recent regional hydrogeochemical investigations, which attribute the mineralisation of shallow groundwater in Casamance to a combination of silicate weathering, carbonate dissolution and cation-exchange reactions, modulated by seasonal recharge and, in the most exposed coastal aquifers, by saltwater intrusion [11]. The transient neutralisation observed here during the rainy season is compatible with a dilution effect from meteoric recharge diluting acidic and saline end-members, a mechanism also documented for other mineralised aquifers of the Senegalese coastal zone [12]. It should be noted, however, that without major-ion or isotopic data the present study cannot formally distinguish between dilution by rainwater and a possible seasonal contribution of saline intrusion, and this remains a limitation of the physico-chemical monitoring performed here.

3.2. Performance of Direct-Contact Treatment

For Kandé water treated with 30 g of lemon-juice-activated char, the evolution of pH as a function of the volume of water treated shows two phases (**Figure 6(a)**): an initial increase, followed by a slight decrease beyond 290 mL. The increase would be related to the release, by the char, of internal basic ash (calcium, potassium and magnesium carbonates), which raises the basicity of the solution. The decrease observed beyond 290 mL would reflect the carbon reaching its adsorption limit, this volume thus representing the treatment capacity of 30 g of activated char for this water a saturation behaviour already reported for other plant-derived activated chars [8] [9]. At the same time, electrical conductivity decreases progressively with the volume treated (**Figure 6(b)**), consistent with effective adsorption of dissolved ionic species.

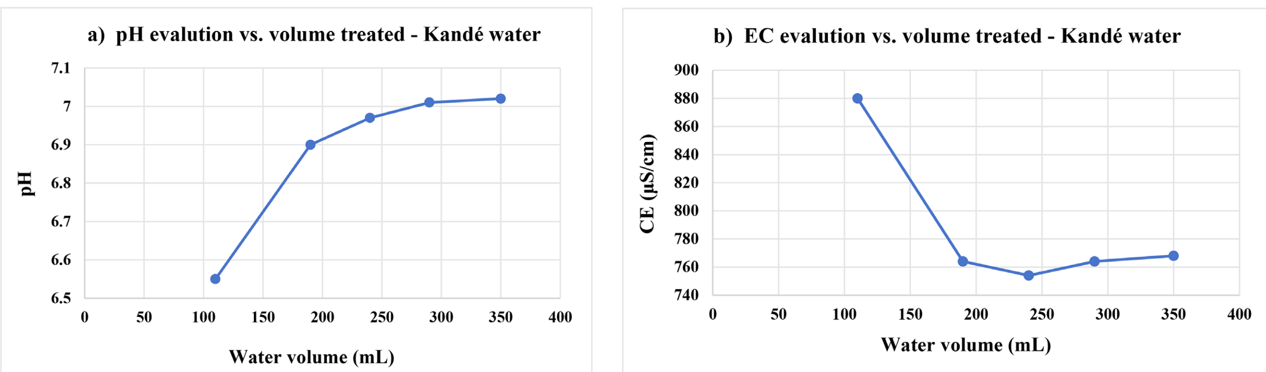

Figure 6. Variation of pH and EC of Kandé water after treatment with activated char (a and b respectively).

For Lyndiane water, electrical conductivity also decreases at first, before rising slightly beyond 290 mL (Figure 7(b)), which could be explained by partial release of previously adsorbed pollutants once the char becomes saturated a classic desorption phenomenon once the char's maximum capacity is reached. This volume of 290 mL therefore constitutes the treatable volume for 3 g of lemon-juice-activated char for this water (Figure 7(a)). These results confirm that knowledge of the water-volume/char-mass pairing is decisive in ensuring treatment effectiveness.

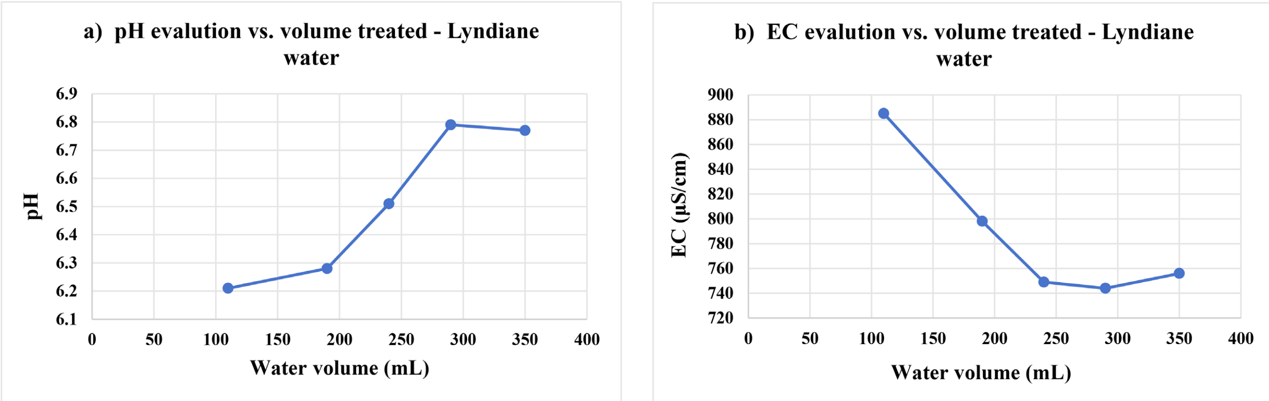

Figure 7. pH and EC of Lyndiane water after treatment with activated char (a and b respectively).

3.3. Effect of the Amount of Lemon-Juice-Activated Char for Kandé Water

Analysis of Figure 8 helps us to understand the impact of the mass of material (25 g, 30 g, 35 g) and the volume of treated Kandé water on two key physico-chemical parameters: pH and electrical conductivity (EC). The treatment causes the water to become progressively more alkaline. This effect is directly proportional to the quantity of material used.

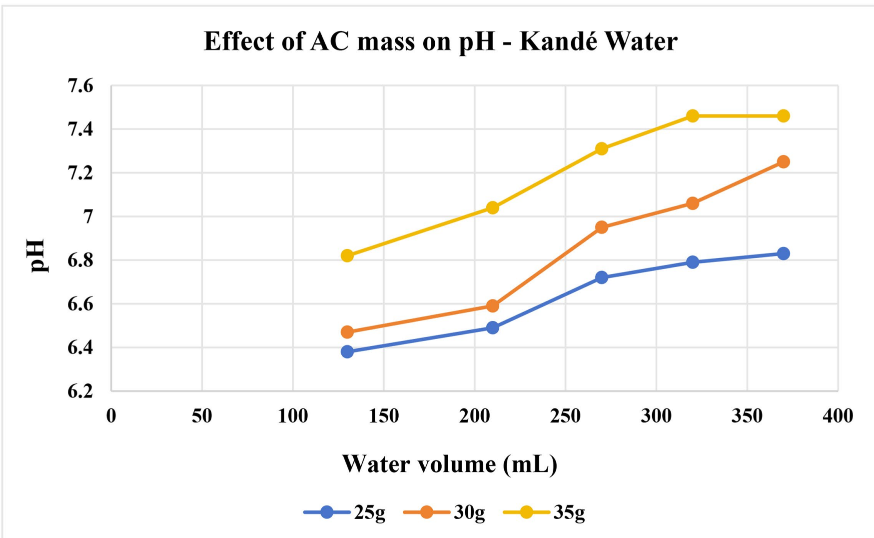

Figure 8. Effect of AC quantity on the pH of Kandé water.

The EC decreases markedly (**Figure 9**) for all masses (a drop of 58 to 108 µS/cm). This sharp decrease in the concentration of free ions in the water indicates a process of chemical precipitation or adsorption onto the material. The curve for 35 g consistently remains above that for 25 g. This shows that the increase in mass initially introduces more soluble ions into the medium, even though the downward trend remains the same. From 320 mL onwards, the EC stops decreasing and begins to rise slightly. This behaviour reflects the saturation of the binding sites on the activated char, or the depletion of the reagent limiting the precipitation.

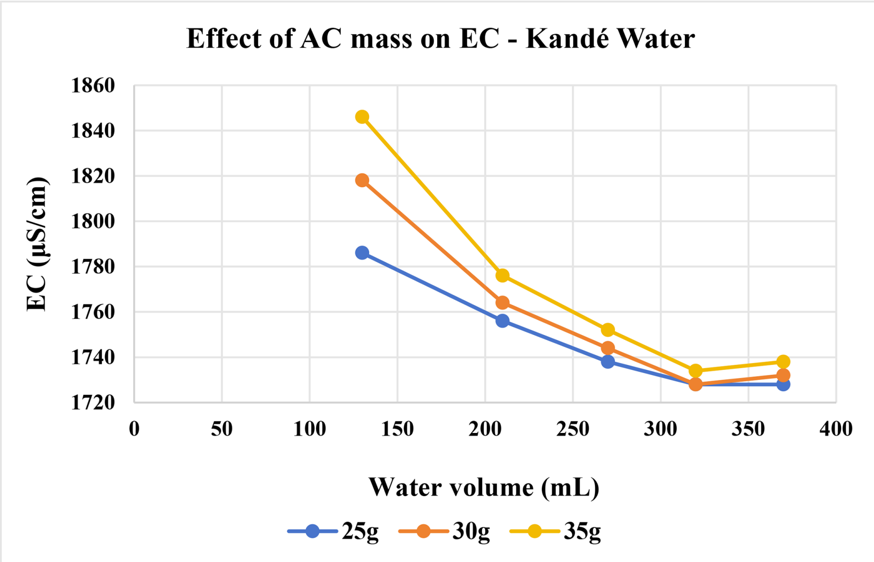

Figure 9. Effect of AC quantity on the EC of Kandé water.

For Lyndiane water treated with H_3PO_4-activated char, the mass of 4 g, among 2, 3, and 4 g, optimized both pH (**Figure 10**) and conductivity (**Figure 11**). Therefore, for each water type, there is an optimal mass of char beyond which treatment efficiency no longer improves significantly. This is a typical behavior of adsorption phenomena before saturation of active sites [8] [9]. As the treated water volume increased, pH increased (**Figure 10**), while electrical conductivity decreased (**Figure 11**). This inverse relationship suggests that chemical reactions release hydroxyl ions (OH^-) or consume hydrogen ions (H^+), while causing the precipitation or retention of certain dissolved salts, thereby reducing the overall EC of the water.

For the same water volume, a higher mass, 4 g, resulted in a higher pH and higher EC than a lower mass, 2 g. Increasing the mass provides a larger contact surface and more active sites. The increase in pH observed for both water samples is consistent with the general mechanism described for carbon-rich materials obtained by pyrolysis: their ash fraction contains carbonates and soluble oxides of calcium, potassium and magnesium, which neutralise H^+ ions and raise the pH of the solution with which they come into contact, an effect whose magnitude has been found to correlate more closely with the alkalinity of the carbonised material than with its own intrinsic pH ([13] [14]).

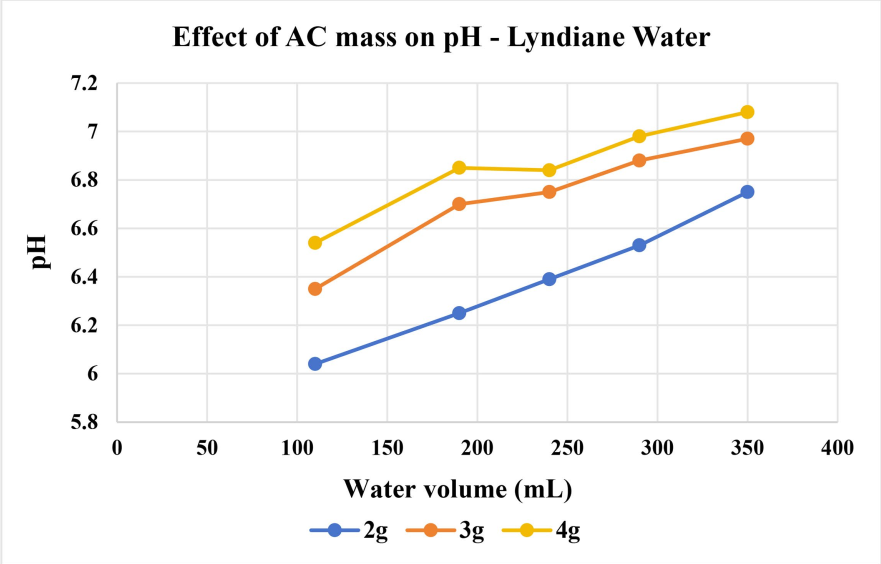

Figure 10. Effect of AC quantity on the pH of Lyndiane water.

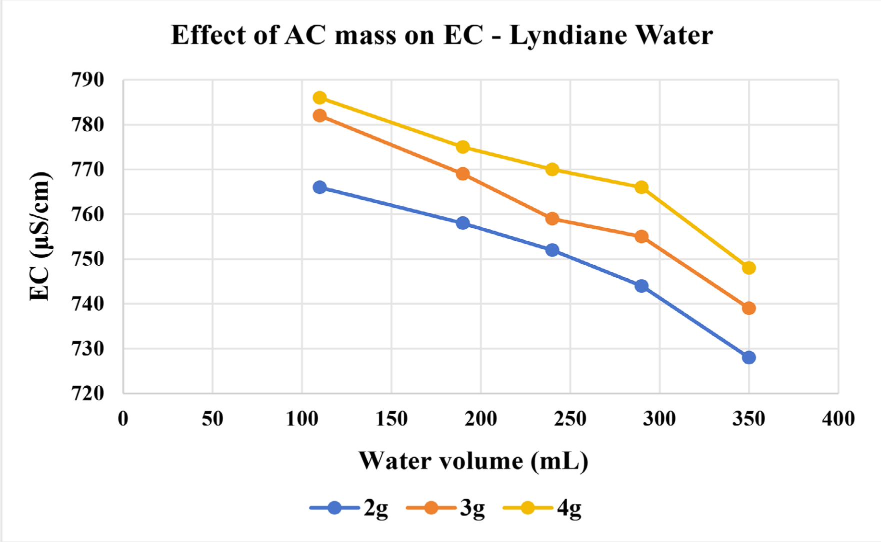

Figure 11. Effect of AC quantity on the EC of Lyndiane water.

This accelerates the release of alkaline compounds, increasing pH, and initially increases the quantity of ions released into the solution, increasing EC. The pH continued to rise and EC continued to decrease even at 350 mL, without reaching a perfect plateau, although the slope of the evolution varied depending on the mass. Evaluation of the saturation limit of the material may be conducted by testing much larger water volumes, for example greater than 500 mL, in order to identify the point at which treatment loses efficiency through stabilization of pH and EC.

3.4. Effect of the Type of Chemical Activation

Comparison of the two activation modes shows that H_3PO_4-activated char continues to treat the water beyond the point at which lemon-juice-activated char reaches saturation (around 370 mL for Kandé water), for both pH and electrical conductivity (Figure 12 and Figure 13).

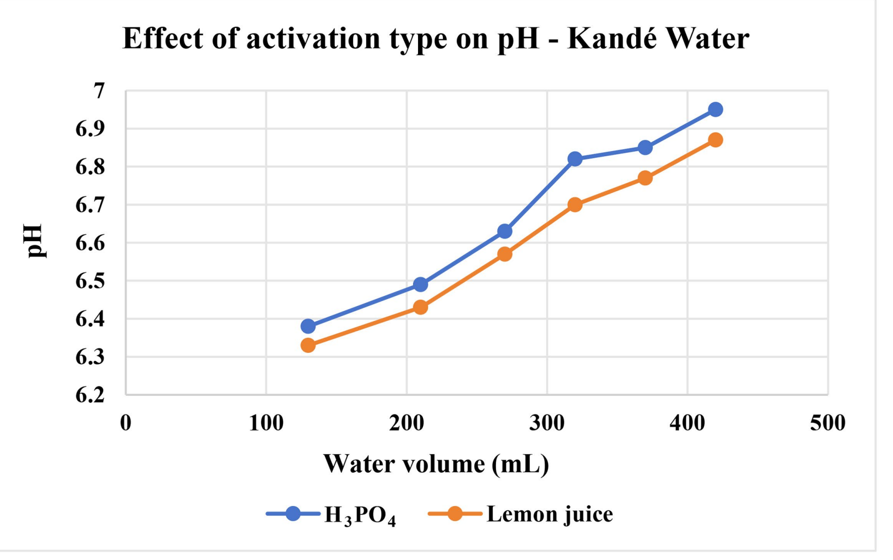

Figure 12. Effect of activation type on the pH of Kandé water.

This behaviour could be explained by a more developed porosity in the phosphoric-acid-activated char, giving it a higher adsorption capacity [6] [7].

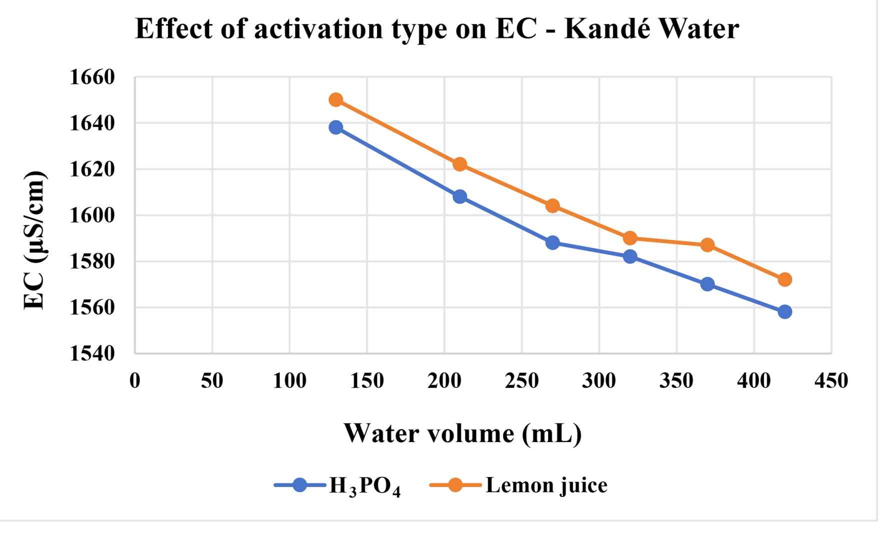

Figure 13. Effect of activation type on the EC of Kandé water.

The same observation applies to Lyndiane water, where H_3PO_4-activated char gives the pH values closest to neutrality (Figure 14) and the variation of the EC is shown in Figure 15. This result is consistent with the literature, which generally associates phosphoric-acid activation with the development of microporosity and a high specific surface area, favourable to the adsorption of organic and mineral pollutants [6] [7].

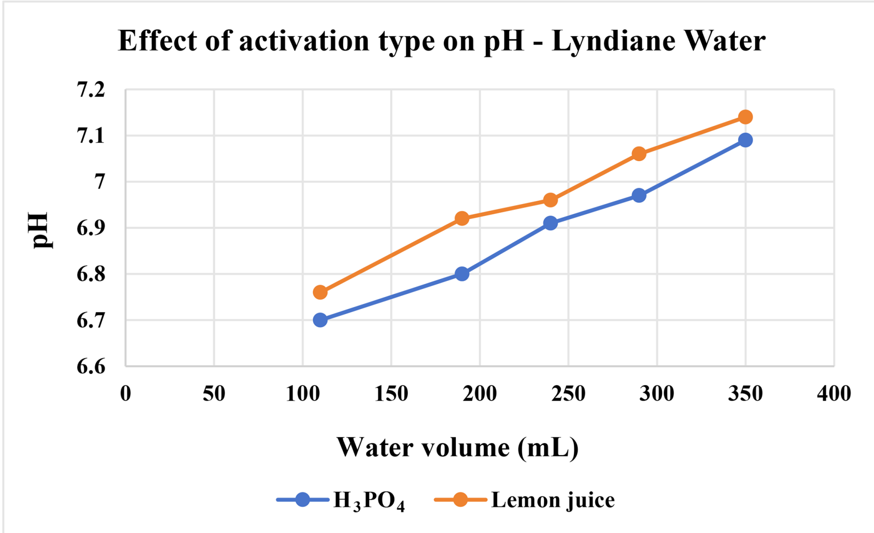

Figure 14. Effect of activation type on the pH of Lyndiane water.

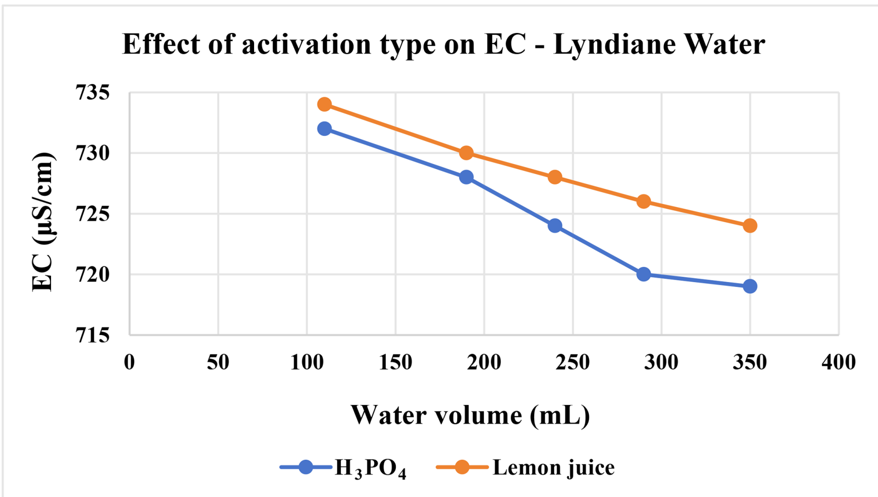

Figure 15. Effect of activation type on the EC of Lyndiane water.

This observation is in line with the broader literature on chemically activated char: phosphoric acid is widely regarded as one of the most effective agents for developing microporosity and mesoporosity in lignocellulosic precursors, with specific surface areas reported across a wide range of roughly 450 to 2800 m^2/g depending on the precursor and the acid-to-precursor impregnation ratio, generally exceeding what is achieved with weaker organic-acid activation [15]. Lemon juice, whose active agent is citric acid, is a much weaker acid than H_3PO_4 and predominantly promotes surface oxidation rather than the extensive pore-opening associated with phosphoric-acid impregnation, which is consistent with the more limited and more rapidly saturated performance of the lemon-juice-activated char observed in this study.

3.5. Effect of Multilayer Filtration

The multilayer filtration setup confirms the benefit of combining activated char with other filter media. For both neighbourhoods, the configuration with two layers of sand (Entity 1) gives pH values closest to neutrality (**Figure 16**), **Figure 17** illustrates the influence of the filter bed configuration (sand versus carbon) on the change in the pH of the Lyndiane water as a function of the volume filtered. The results show a gradual increase in pH for both systems as the volume of water increases from 110 to 350 mL. This continuous alkalisation of the effluent suggests a gradual release of basic species or an ion exchange process within the filter media as the water passes through. The configuration comprising two beds of activated carbon (Entity 2) consistently produces a higher pH than the sand-based system (Entity 1), with final values reaching 6.89 and 6.75 respectively. This superior performance of activated carbon can be explained by its naturally basic surface chemistry (the presence of surface functional groups such as hydroxyl or pyrone groups), which is capable of trapping H^+ ions or releasing OH^- ions. Although both configurations tend to neutralise the initial acidity of the Lyndiane water to bring it closer to drinking water standards (pH between 6.5 and 8.5), the carbon bed proves more effective from the very first volumes filtered, offering greater buffering and neutralising capacity than the sand. And the lowest electrical conductivities (**Figure 18**, **Figure 19**), compared with the configuration containing two layers of char (Entity 2).

From a comparative perspective, these results are consistent with the work in [16] and with studies on filtration using mixed granular media, which highlight that the addition or exclusive use of activated char alters the carbonate/bicarbonate equilibrium of the treated water more significantly than simple physical filtration using sand.

This superior performance of sand could be explained by its fine grain size and the low percolation rate it imposes, favouring a longer contact time and hence better pollutant retention [9] [10]. Conversely, the coarser grain size of the char in Entity 2 accelerates water passage, which reduces contact time and limits pollutant retention.

This finding is consistent with the mechanisms described for household slow sand filters, in which the fine grain size of sand and the correspondingly slow percolation rate promote extended contact time between water and the filter medium a condition favourable both to physicochemical retention and to the development of a biologically active surface layer capable of retaining dissolved and particulate contaminants [17]. Increasing the proportion of coarser-grained carbon, as in Entity 2, shortens the residence time of water within the bed and therefore curtails the diffusion-limited processes that adsorption efficiency depends on.

Taken together, the results show that activated char produced from ditakh shells, regardless of the activation mode, substantially improves the physico-chemical quality of Kandé and Lyndiane well water. Three factors determine treatment effectiveness: the mass of char used relative to the volume of water to be treated; the type of chemical activation, phosphoric acid conferring greater porosity and hence higher adsorption capacity than lemon juice; and the configuration of the filtration setup, with a sufficient quantity of sand improving pollutant retention, three levers already identified as decisive in optimising plant-derived activated chars [8] [9].

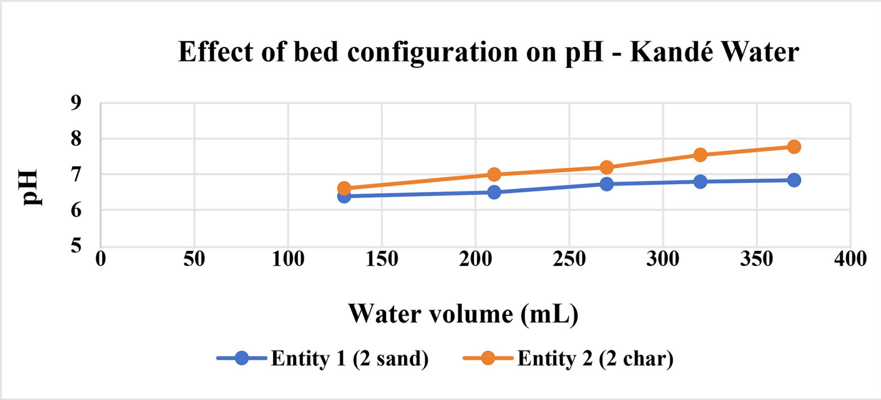

Figure 16. Effect of bed configuration on the pH of Kandé water.

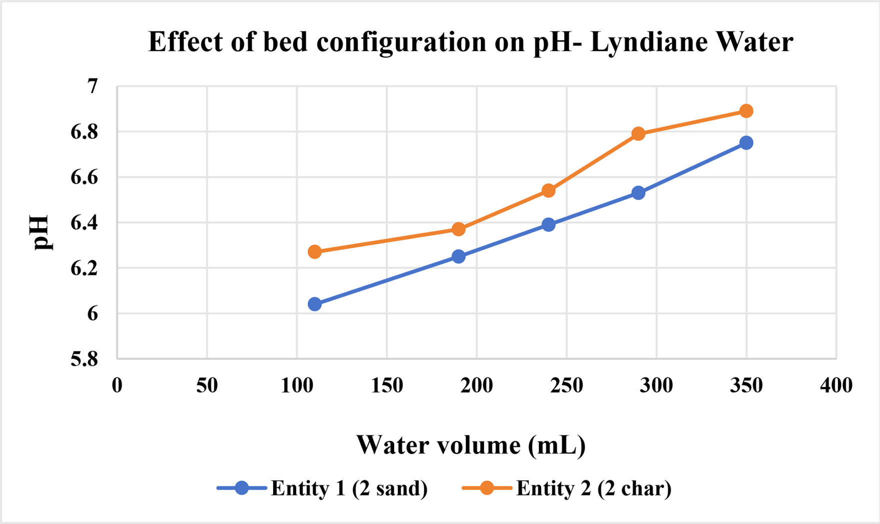

Figure 17. Effect of bed configuration on the pH of Lyndiane water.

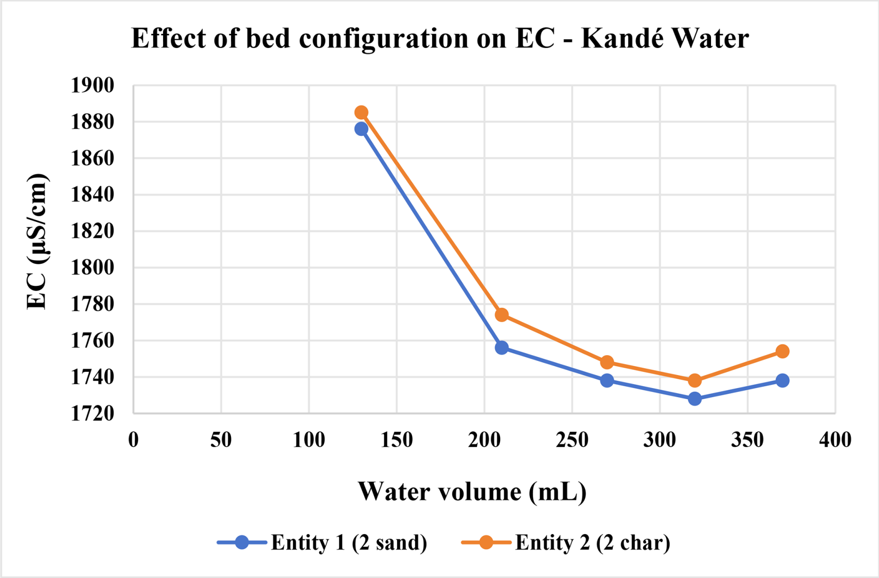

Figure 18. Effect of bed configuration on the EC of Kandé water.

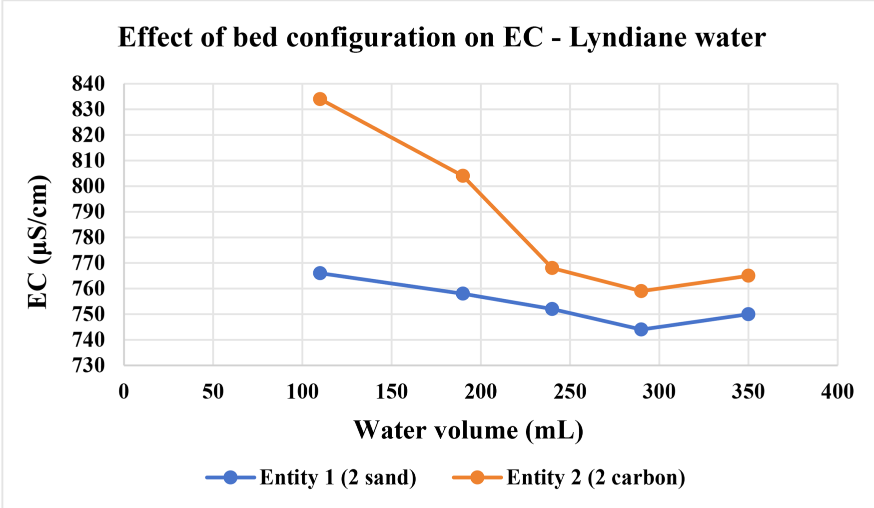

Figure 19. Effect of bed configuration on the EC of Lyndiane water.

4. Conclusions

This study evaluated the effectiveness of an activated char produced from "ditakh" shells for treating well water in the Kandé and Lyndiane neighbourhoods (Ziguinchor). The work shows that: Kandé and Lyndiane well water requires treatment before consumption owing to its acidity and/or high mineralisation; ditakh shells constitute an interesting local (unvalorised) raw material for activated-char production; char activated with either phosphoric acid or lemon juice significantly improves the physico-chemical quality of this water; and H_3PO_4-activated char, being more porous, shows a higher adsorption capacity than lemon-juice-activated char.

These results confirm the potential for valorising ditakh shells, a local, available and low-cost by-product, as a precursor for activated char intended for household water treatment in areas where access to safe drinking water remains limited.

Several avenues for future work emerge from this study:

- investigating the microbiological parameters and heavy-metal content of this water, which were not addressed in the present study;
- developing a low-cost household filter based on ditakh shells, transferable to other localities facing contaminated-water problems;
- evaluating the durability and regeneration of the activated char after several use cycles, in order to assess its long-term viability.

Acknowledgements

The authors would like to thank Assane Seck University in Ziguinchor, the UFR-ST and the Physics Department of the UASZ, as well as the Senegalese government, for their financial support for this work.

Author Contributions

Conceptualization, Ansoumane DIEDHIOU. and *Piere Benoit Aubia MANGA*;

methodology, Ansoumane DIEDHIOU; formal analysis, Ansoumane DIEDHIOU, and Sada TRAORE; investigation, Ansoumane DIEDHIOU. and *Piere Benoit Aubia MANGA*; resources, Ansoumane DIEDHIOU; writing—original draft preparation, Ansoumane DIEDHIOU; writing—review and editing, Ansoumane DIEDHIOU; visualization, Ansoumane DIEDHIOU. Sada TRAORE and *Piere Benoit Aubia MANGA*; supervision, Ammar BENSAKHRIA; project administration, Ansoumane DIEDHIOU and Ammar BENSAKHRIA.
All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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