# EVALUATION OF THE EFFICACY OF ACTIVATED CARBON TREATMENT OF OLAIJA COAL MINE SURROUNDING WATER BODIES, BENUE STATE

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*Abstract*
*Coal mining is synonymous with water contamination and pollution. The efficient treatment of this water is crucial for environmental safety and sustenance. This study evaluates the effectiveness of activated carbon, derived from wood chippings, in the treatment of coal-contaminated water body in Olaija coal mine. The preparation involved heating sawdust to produce charcoal, followed by acid treatment and thorough cleaning. The treatment process showed significant efficiencies across various parameters: 6.40% for pH adjustment, 71.05% for conductivity, and 97.47% for turbidity removal. Substantial improvements were observed in reductions of bicarbonate (85.56%), cadmium (78.13%), nickel (76.72%), potassium (70.78%), and total dissolved solids (69.92%). Sulphate treatment efficiency was observed at 39.54%, indicating moderate success in removing sulphate ions from coal water samples. Conversely, dissolved oxygen (DO) showed a decrease of 3.55%, suggesting potential oxygen consumption or interference during the treatment. These results highlighted suggest that the activated carbon's varied effectiveness in removing different contaminants from coal water samples, underscoring its potential utility in comprehensive water treatment applications. The study shows that treatment can be tailored towards specific water quality parameters to optimize outcomes, particularly in environments affected by coal contamination.*

*Keywords: Coal mine water, activated carbon, treatment, environmental pollution, water quality*

## Introduction

During surface mining of coal, as water moves over or through the coal materials soluble components are dissolved and washed as contaminants into surrounding water bodies. Besides clean coal mine water, generally, coal mine water can be classified into four categories based on the harmful substances they contain (Gao *et al.,* 2020). The first is coal mine water with suspended solids which contains solid particles such as coal powder, rock powder, and clay resulting from groundwater physical, chemical, and biochemical reactions with coal and rock formations (Gao *et al.*, 2020). The second category is high salinity coal mine water, which contains high levels of inorganic ions like $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, $SO_4^{2-}$, $Cl^-$, and $HCO_3^-$, often exceeding 1,000 mg/L. This water is typically neutral or alkaline with a bitter taste and can be further classified into brackish water and saltwater, depending on the degree of mineralization. The third category is acidic coal mine water, which is classified into strong acid (pH < 3) and weak acid types (pH 3-6.5). The fourth category is coal mine water with trace elements, which may contain harmful substances such as trace radioactive elements, heavy metals, fluorine, and petroleum (Gao *et al*., 2020).

Dang and Dang, (2018) noted in their study that high concentrations of iron, manganese, and total suspended solids (TSS), along with low pH values, characterized mine drainage in the Hongai area where coal is mined in Vietnam. Several other studies have reiterated the serious influence of coal and its exploitation on water resources with varying degrees of impact on the local environment (Zhang *et al.*, 2014; Obiadi *et al.*, 2016; Qiao *et al.*, 2017; Kamble and Kumbhar, 2019). The presence of pollutants in coal mine water, makes it imperative to treat the mine water to prevent serious environmental hazards (Dang and Dang, 2018). Various treatment techniques have been employed to treat coal mine water notably, lime process, activated carbon filtration, reverse osmosis, forward osmosis, ion exchange, chemical precipitation (Gherairi *et al.*, 2013; Gao *et al*., 2020).

The lime treatment process uses an acid-base neutralization reaction where alkaline agents like lime are added into a regulation pool and mixed thoroughly using mechanical agitation to increase the pH of coal mine water (Dang and Dang, 2018). This causes metal ions to precipitate as low solubility hydroxides or carbonates, effectively purifying the water which is drained (Gao *et al*., 2020). Commonly used neutralizing agents include calcium oxide (CaO), hydrated lime ($Ca(OH)_2$), sodium carbonate ($Na_2CO_3$), caustic soda (NaOH)  and lime (limestone or calcium carbonate ($CaCO_3$). Activated carbon filtration makes

use of its large surface area and high adsorption capacity to remove organic compounds, chlorine, and volatile organic carbons (VOCs) from contaminated water. The process involves passing water through activated carbon, which adsorbs pollutants onto its surface, making it highly effective in improving water quality. Constructed wetlands, on the other hand, utilize natural processes involving wetland vegetation, soils, and microbes to treat mine water. This method is cost-effective and sustainable, reducing contaminants like heavy metals and acidity, thus promoting environmental health (Gherairi *et al.*, 2013; Changjia *et al.*, 2019).

Reverse osmosis (RO) technique utilizes membrane filtration to remove a wide range of contaminants, including dissolved solids and heavy metals, by forcing water through a semi-permeable membrane under pressure. Chemical precipitation, involving the addition of chemicals like lime or sodium hydroxide, precipitates dissolved metals as insoluble hydroxides, which are then removed via sedimentation and filtration. Ion exchange resins replace unwanted ions in mine water with more desirable ones, effectively removing specific contaminants such as heavy metals and radionuclides. These techniques collectively enhance the treatment of coal mine water, ensuring safer and cleaner water resource (Obiadi *et al.*, 2016; Qiao *et al.*, 2017; Dang and Dang, 2018). Other treatment employed with different levels of success have been explored by (Zhang *et al.*, 2014; Skousen *et al.*, 2016; Zakaria and Mohammad, 2017; Hamza *et al.*, 2022). Mining activities are relatively recent in the study area and extensive assessment of coal-water environmental effect and treatment have not been explored in this area, hence the basis of this study.

**Materials and Methods**
**Description of the Study Area**
The study area is Olaija coal mine, located within coordinates close to Benue, Benue State. The coal deposit is within the Benue Trough, a major geological formation in Nigeria, stretching over 1,000 kilometers in a northeast-southwest direction. It is a cretaceous rift basin formed during the break-up of the supercontinent Gondwana (Obaje *et al.*, 2004). The Benue Trough is geologically segmented into three depositional sub-basins: upper, middle, and lower. These sub-basins span from the Gombe area in the north to the Abakaliki area in the south, extending towards the Niger Delta. They consist of narrow sedimentary basin that extends from the Gulf of Guinea to the northeast (Sallau *et al.*, 2015). The trough is characterized by extensive sedimentary deposits, primarily consisting of sandstones, shales, and limestones. It hosts significant structural features, including faults and folds, resulting from tectonic activities. The region is also noted for its potential hydrocarbon reserves, making it a focus of economic interest (Obaje *et al.*, 2004).

**Sampling and Sample Handling**
Grab surface water samples were taken within the mine ponds and in the immediate surrounding stream traversing a section of the open pit mine using precleaned 1-liter sized plastic bottles. The designated sample locations are the mine flowing water and stream in the surrounding.

**Preparation of Activated Carbon using Saw Dust**
The activated carbon samples for water treatment were prepared in accordance with Açıkyıldız *et al.* (2014) and Chikri *et al.* (2023). Twenty grams of sawdust were heated for ten minutes at $35^{\circ}C$ in furnace to produce charcoal. After removing the charcoal (heated sawdust), it was submerged in water for 20 minutes. Following a thorough filtering process, it was dried for 24 hours at $105^{\circ}C$ in the oven. Half (0.5) mole of acid (HCl) was added and thereafter left for 24 hours. After treatment with the acid the charred material was extracted from the acid and properly cleaned to render it acid-free (neutralized) and then dried for a whole day in an oven. After oven dying, the prepared materials were ready as activated carbon for laboratory treatment of the water samples. Plates 1a and 1b show the pre-burnt saw dust and the burnt (charred) and treated saw dust.



Plate 1. Activated Carbon Material. (a) untreated saw dust (b) treated charred saw dust (activated carbon)

**Treatment of Water Samples with Activated Carbon**

Prior to the determination of the physicochemical properties of the water samples, the samples were batched into two groups of duplicates from each original water sample. First group was used as-obtained from the coal field as untreated samples while the second group was treated with activated carbon.

**Analytical Methods**

Determination of untreated water samples physico-chemical properties

In this study, selected physicochemical parameters were determined both on the untreated samples obtained from the coal field and the ones treated with laboratory prepared activated carbon .

The water quality tests carried out on the samples are broadly divided into four parameters:

i. Physical Parameters: This deals primarily with measurement of the physical properties of a sample including color, turbidity, conductivity, total solids;

ii. Metals: The effect of metals in water and wastewater range from essential or beneficial through troublesome to dangerously toxic.

iii. Inorganic Nonmetallic Constituents: Test carried out include acidity and alkalinity to chlorine, nitrogen and phosphorous, Dissolved oxygen, sulphates

iv. Organic Constituents: The analysis of organics or some fraction of the total.

Experimental analyses of the physicochemical properties of the water samples were carried using the standard methods for the examination of water and wastewater according to American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), APHA-AWWAWEF (2017). These include: Alkalinity: APHA 2320 B (Titration Method); Conductivity: APHA 2510 B; Conductivity (Electrometric Method); Acidity: APHA 2310 B (Titration Method); Dissolved Oxygen (DO) APHA 4500-O C Dissolved Oxygen (Winkler Method); Total Suspended Solids (TSS): APHA 2540 D gravimetric method; Total Dissolved Solids (TDS): APHA 2540 C. Total Dissolved Solids Dried at 180°C, Sodium (Na Method 3500-Na B); Calcium (Ca) 3500-Ca B: Calcium (Atomic Absorption Spectrometric Method), Magnesium (Mg Method 3500-Mg B), Bicarbonates ($HCO_3$), Carbonates ($CO_3$): 2320 B Method. Other properties determined using the United States

Environmental Protection Agency (USEPA) 1999 methods include: Metals in Water Method: USEPA 200.8 Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS); Turbidity Method: USEPA 180.1 Determination of Turbidity by Nephelometry and Sulphate ($SO_4$) Cations Method: USEPA 375.4 Determination of Sulphate by Automated Colorimetry.

**Determination of Treated Water Samples Physico-chemical Properties**

The treated water samples were analyzed for physicochemical properties, same as the methods used for the untreated samples.

**Determination of treatment efficiency**

The percentage treatment efficiency was determined using equation 1 as indicated in the following:

$$\% \text{ treatment efficiency} = \left(\frac{Wtu_i - Wtt_i}{Wtu_i}\right) \times 100 \qquad (1)$$

Where: $Wtu_i$ is the concentration of water property $i$ in an untreated water sample, $Wtt_i$ is the concentration of water property $i$ in a corresponding treated water sample.

**Results and Discussion**

**Results**

**Comparative analysis of metal concentrations in water samples**

According to Figure 1, untreated samples exhibit substantially higher concentrations of all measured parameters, highlighting the potential for environmental contamination in the absence of treatment as indicated in. The comparison between treated and untreated water samples reveals significant alterations in metal and ion concentrations following treatment with activated carbon. Activated carbon is known for its adsorptive capacity, particularly effective in removing metals like Ni, Cu, Zn, and Cd from aqueous solutions due to its large surface area and pore structure. In the treated samples, concentrations of Ni, Cu, Zn, and Cd are markedly lower compared to untreated samples, indicating successful adsorption processes. Additionally, the treated water (Figure 2) shows reduced levels of alkali and alkaline earth metals such as Na, Mg, Ca, and K. This reduction suggests that activated carbon treatment also influences the adsorption or precipitation of these ions, possibly through surface interactions or complexation processes. The variability in these concentrations across samples may reflect differences in initial water composition and the efficiency of the treatment process.
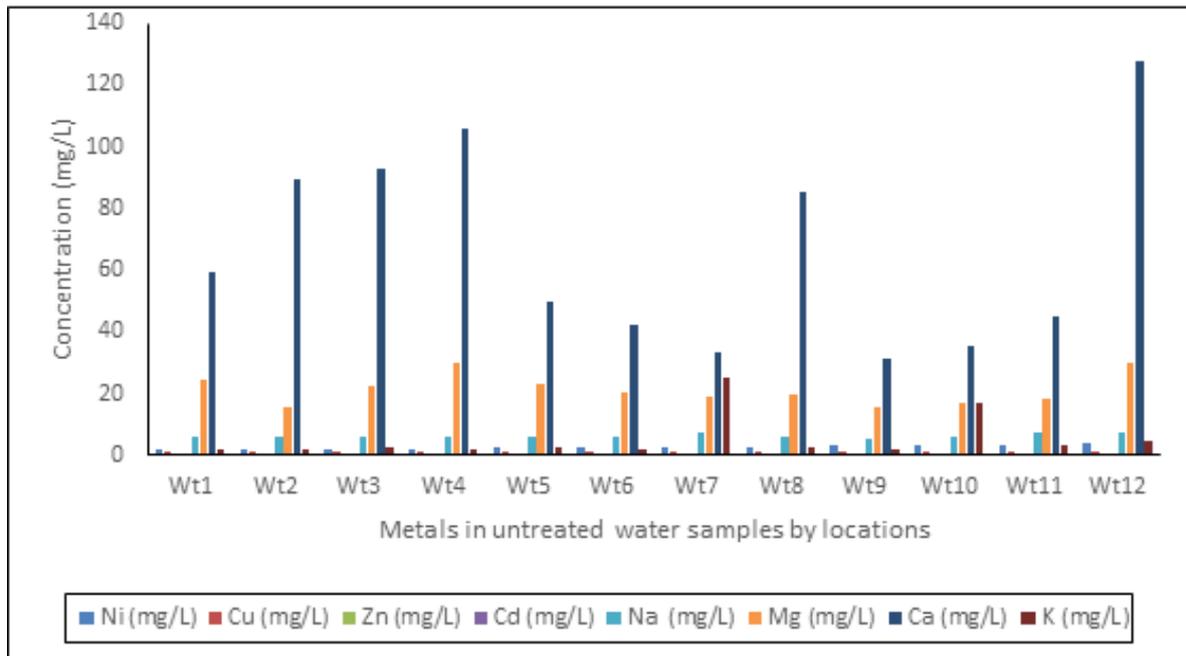
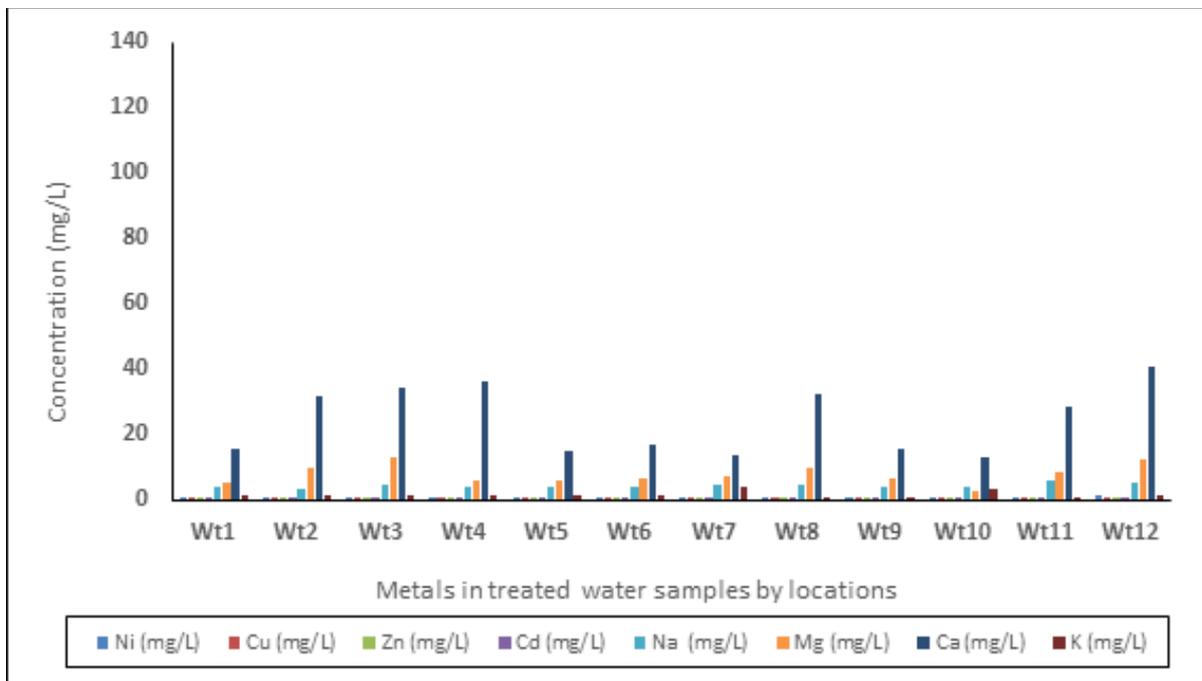Figure 1: Metal concentration of untreated coal mine water in study area



Figure 2: Metal concentration of treated coal mine water in study area

**Measure of central tendency and dispersion of untreated water Samples**

The descriptive statistics in Table 1 presents a summary analysis of various water quality parameters in the study area. The pH of the untreated surface water samples across the coal field and its immediate surroundings ranges from 4.93 to 7.63, with a mean value of 6.235 and a standard deviation of 0.845. This indicates that the water samples have slight acidity to neutral pH levels. Conductivity (cond_untreated) shows significant variability, with values ranging from 74.00 to 304.00 µS/cm, a mean of 117.167 µS/cm, and a high standard deviation of 62.244, suggesting diverse ionic concentrations in the samples. Turbidity (turbidity_untreated) also exhibits high variability, with a mean of 11.521 NTU and a standard deviation of 14.437, indicating that suspended particles varied significantly.

On the examination of the chemical properties, alkalinity and dissolved oxygen (DO_untreated) show distinct patterns. Alkalinity ranges from 60.00 to 204.00 mg/L, with a mean of 111.833 mg/L and a standard deviation of 47.722, indicating moderate variability in buffering capacity. DO values are relatively consistent, ranging from 4.51 to 5.30 mg/L, with a mean of 5.017 mg/L and a low standard deviation of 0.211, showing stable oxygen levels across samples. Chloride concentrations (chloride_untreated) range from 32.01 to 54.88 mg/L, with a mean of 42.453 mg/L and a standard deviation of 6.637, suggesting moderate variability. Bicarbonate ($HCO_3$_untreated) levels vary significantly, with values between 2.00 and 14.00 mg/L, indicating diverse contributions from carbonate species.

**Table 1 : Descriptive statistics of untreated water samples**

|  | N | Minimum | Maximum | Mean | Std. Deviation | Variance |
|---|---|---|---|---|---|---|
| pH_Untreated | 12 | 4.93 | 7.63 | 6.2350 | .84515 | .714 |
| Cond_Untreated | 12 | 74.00 | 304.00 | 117.1667 | 62.24414 | 3874.333 |
| Turbidity_Untreated | 12 | .25 | 39.40 | 11.5208 | 14.43741 | 208.439 |
| Alkalinity_Untreated | 12 | 60.00 | 204.00 | 111.8333 | 47.72237 | 2277.424 |
| DO_Untreated | 12 | 4.51 | 5.30 | 5.0167 | .21124 | .045 |
| Chloride_Untreated | 12 | 32.01 | 54.88 | 42.4525 | 6.63654 | 44.044 |
| HCO3_Untreated | 12 | 2.00 | 14.00 | 5.9167 | 3.55165 | 12.614 |
| Hardness_Untreated | 12 | 47.25 | 157.50 | 87.9375 | 35.89634 | 1288.547 |
| Acidity_Untreated | 12 | 40.00 | 240.00 | 84.3333 | 52.54839 | 2761.333 |
| Sulphate_Untreated | 12 | 53.33 | 14893.33 | 2141.1100 | 4133.63155 | 17086909.775 |
| TDS_Untreated | 12 | 35.00 | 145.85 | 56.3825 | 29.91561 | 894.943 |
| Ni_Untreated | 12 | 1.74 | 4.01 | 2.7708 | .67731 | .459 |
| Cu_Untreated | 12 | 1.21 | 1.57 | 1.4242 | .10449 | .011 |
| Zn_Untreated | 12 | .23 | .85 | .4583 | .16727 | .028 |
| Cd_Untreated | 12 | .02 | .16 | .0800 | .04862 | .002 |
| Na_Untreated | 12 | 5.65 | 7.48 | 6.3242 | .63556 | .404 |
| Mg_Untreated | 12 | 15.55 | 30.33 | 21.3608 | 4.94092 | 24.413 |
| Ca_Untreated | 12 | 31.36 | 127.73 | 66.5767 | 32.41959 | 1051.030 |
| K_Untreated | 12 | 2.12 | 25.15 | 5.7358 | 7.41452 | 54.975 |
| Valid N (listwise) | 12 |  |  |  |  |  |

Further analysis of the mineral content reveals substantial variability in untreated hardness (hardness_untreated) and acidity (acidity_untreated). The range of hardness from 47.25 to 157.50 mg/L, with a mean of 87.9378 mg/L and a standard deviation of 35.897, reflecting differences in calcium and magnesium content. Acidity values, ranging from 40.00 to 240.00 mg/L, with a mean of 84.333 mg/L and a high standard deviation of 52.549, show significant variability. The sulphate content of the untreated water has the highest variability, with values ranging from 53.33 to 14893.33 mg/L, a mean of 2141.110 mg/L, and a very high standard deviation of 4133.632, indicating occasional extreme concentrations. Total dissolved solids (TDS_untreated) show moderate variability, with values ranging from 35.00 to 145.85 mg/L. Untreated metal concentrations, including nickel (Ni)

copper (Cu), zinc (Zn), and cadmium (Cd) generally show low variability, with small standard deviations relative to their mean values, indicating consistent trace metal levels across the samples.

**Measure of central tendency and dispersion of treated water samples**

The descriptive statistics for the treated water samples in Table 2 reveals notable changes in water quality parameters compared to the untreated water samples. The pH of treated water ranges from 4.52 to 6.99, with a mean of 5.836 and a standard deviation of 0.727, indicating that the water is slightly more acidic on average than the untreated water. The conductivity (cond_treated) shows a substantial decrease, ranging from 17.00 to 86.00 µS/cm with a mean of 33.917 µS/cm and a standard deviation of 21.125, suggesting

that the treatment process significantly reduces the ionic concentration in the water. Turbidity (turbidity_treated) is greatly reduced, with a mean of 0.292 NTU and a standard deviation of 0.265, indicating a clearer water quality post-treatment.

The chemical properties of the treated water also exhibit changes. Alkalinity (alkalinity_treated) ranges from 20.00 to 80.00 mg/L, with a mean of 32.983 mg/L and a standard deviation of 18.777, reflecting a decrease in buffering capacity compared to untreated water.

Dissolved oxygen (DO_treated) remains relatively stable with values between 4.76 and 5.64 mg/L, and a mean of 5.195 mg/L with a low standard deviation of 0.215, indicating consistent oxygen levels post-treatment. Chloride (chloride_treated) levels are lower, ranging from 17.38 to 36.58 mg/L, with a mean of 26.905 mg/L and a standard deviation of 6.021, showing reduced salinity. Bicarbonate ($HCO_3$_Treated) is significantly lower, ranging from 0.00 to 6.15 mg/L, indicating the treatment process effectively removes bicarbonate ions.

**Table 2: Descriptive Statistics of treated samples**

|                      | N  | Minimum | Maximum | Mean_T    | Std. Deviation | Variance     |
|----------------------|----|---------|---------|-----------|----------------|--------------|
| pH_Treated           | 12 | 4.52    | 6.99    | 5.8358    | .72673         | .528         |
| Cond_Treated         | 12 | 17.00   | 86.00   | 33.9167   | 21.12499       | 446.265      |
| Turbidity_Treated    | 12 | .05     | .90     | .2917     | .26529         | .070         |
| Alkalinity_Treated   | 12 | 20.00   | 80.00   | 32.9833   | 18.77706       | 352.578      |
| DO_Treated           | 12 | 4.76    | 5.64    | 5.1950    | .21513         | .046         |
| Chloride_Treated     | 12 | 17.38   | 36.58   | 26.9050   | 6.02148        | 36.258       |
| $HCO_3$_Treated      | 12 | .00     | 6.15    | .8542     | 2.04222        | 4.171        |
| Hardness_Treated     | 12 | 15.75   | 53.55   | 32.2875   | 12.87637       | 165.801      |
| Acidity_Treated      | 12 | 20.00   | 100.00  | 41.0000   | 23.47145       | 550.909      |
| Sulphate_Treated     | 12 | 13.33   | 9080.00 | 1294.4450 | 2547.51635     | 6489839.565  |
| TDS_Treated          | 12 | 8.50    | 43.00   | 16.9583   | 10.56249       | 111.566      |
| Ni_Treated           | 12 | .07     | 1.50    | .6450     | .44429         | .197         |
| Cu_Treated           | 12 | .09     | .94     | .5400     | .29958         | .090         |
| Zn_Treated           | 12 | .10     | .25     | .1583     | .05408         | .003         |
| Cd_Treated           | 12 | .01     | .04     | .0175     | .00965         | .000         |
| Na_Treated           | 12 | 3.18    | 5.97    | 4.4483    | .70703         | .500         |
| Mg_Treated           | 12 | 2.96    | 12.94   | 7.8817    | 2.99116        | 8.947        |
| Ca_Treated           | 12 | 12.79   | 40.83   | 24.4058   | 10.42886       | 108.761      |
| K_Treated            | 12 | .65     | 4.17    | 1.6758    | 1.07624        | 1.158        |
| Valid N (listwise)   | 12 |         |         |           |                |              |

Regarding the mineral contents, hardness (hardness_treated) ranges from 15.75 to 53.55 mg/L, with a mean of 32.288 mg/L and a standard deviation of 12.876, indicating a reduction in calcium and magnesium levels post-treatment. Acidity (acidity_treated) varies from 20.00 to 100.00 mg/L, with a mean of 41.0000 mg/L and a standard deviation of 23.471, reflecting a decrease compared to untreated water. Sulphate (sulphate_treated) exhibits significant variability, with values between 13.33 and 9080.00 mg/L, a mean of 1294.445 mg/L, and a high standard deviation of 2547.516, indicating occasional extreme concentrations. Total dissolved solids (TDS_treated) range from 8.50 to 43.00 mg/L, with a mean of 16.958 mg/L, suggesting effective removal of dissolved substances.

**Pair-wise Comparison of Group Sample Means**
The paired samples test results Table 3 indicates significant differences between untreated and treated water quality parameters, with notable improvements in post-treatments. The pH, conductivity, turbidity, alkalinity, chloride, acidity, total dissolved solids (TDS), and trace metals (nickel, copper, zinc, cadmium) all show highly significant reductions ($p < .001$) in treated water compared to untreated water, as evidenced by the large t-values and low p-values. Dissolved oxygen (DO) slightly decreases post-treatment ($t = -6.270$, $p < .001$), indicating a minor but significant reduction. The most substantial reduction is seen in sulphate levels, although this change is not statistically significant ($p = .097$). These results highlight the effectiveness of the treatment process in improving overall water quality.

**Table 3: Paired Samples Test**

| | | Paired Differences | | | Sig. (2 - |
|---|---|---|---|---|---|
| | | 95% Confidence Interval of the Difference | t | df | tailed) |
| Pair 1 | pH_Untreated - pH_Treated | .55367 | 5.686 | 11 | .000 |
| Pair 2 | Cond_Untreated - Cond_Treated | 110.90418 | 6.626 | 11 | .000 |
| Pair 3 | Turbidity_Untreated - Turbidity_Treated | 20.26162 | 2.736 | 11 | .019 |
| Pair 4 | Alkalinity_Untreated - Alkalinity_Treated | 99.88072 | 8.252 | 11 | .000 |
| Pair 5 | DO_Untreated - DO_Treated | -.11574 | -6.270 | 11 | .000 |
| Pair 6 | Chloride_Untreated - Chloride_Treated | 19.88941 | 7.881 | 11 | .000 |
| Pair 7 | Acidity_Untreated - Acidity_Treated | 65.33874 | 4.334 | 11 | .001 |
| Pair 8 | Sulphate_Untreated - Sulphate_Treated | 1872.63116 | 1.816 | 11 | .097 |
| Pair 9 | TDS_Untreated - TDS_Treated | 52.46375 | 6.655 | 11 | .000 |
| Pair 10 | TSS_Untreated - TSS_Treated | .54452 | 5.011 | 11 | .000 |
| Pair 11 | Ni_Untreated - Ni_Treated | 2.30789 | 25.701 | 11 | .000 |
| Pair 12 | Cu_Untreated - Cu_Treated | 1.03346 | 13.035 | 11 | .000 |
| Pair 13 | Zn_Untreated - Zn_Treated | .37838 | 8.424 | 11 | .000 |
| Pair 14 | Cd_Untreated - Cd_Treated | .08864 | 5.262 | 11 | .000 |

**Treatment efficiency**

The overall mean of physicochemical properties of untreated and treated mine water in the study area is shown in Figure 3 where the variations in significance of the activated carbon treated is indicated. The efficiency of this activated carbon removal of excessive contaminants across various water quality parameters is indicated in Figure 4. pH improvement achieved 6.40%, and conductivity showed a significant 71.05% efficiency. Turbidity treatment was highly effective at 97.47%. Alkalinity, Total Dissolved Solids (TDS), and hardness treatments were also effective, showing efficiencies of 70.51%, 69.92%, and 63.28%, respectively. The process substantially removed bicarbonate (85.56%) and cadmium (78.13%). Other notable removal rates include nickel (76.72%), potassium (70.78%), and chloride (36.62%). However, dissolved oxygen (DO) showed a decrease of 3.55%. This comprehensive analysis underscores the variability in treatment effectiveness across different water quality metrics.
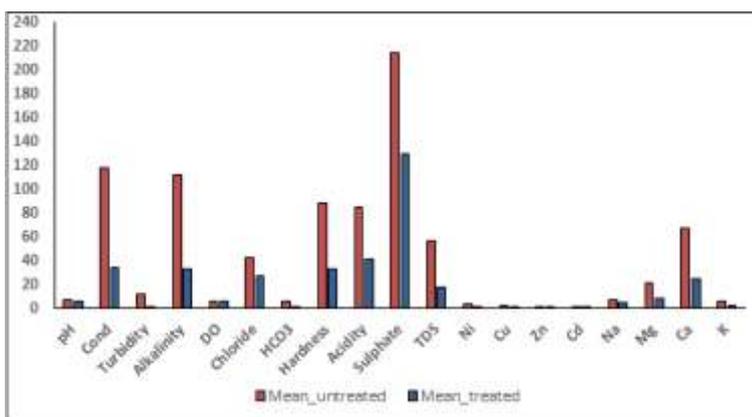


Figure 3: Overall samples mean of untreated and treated coal mine water in study area
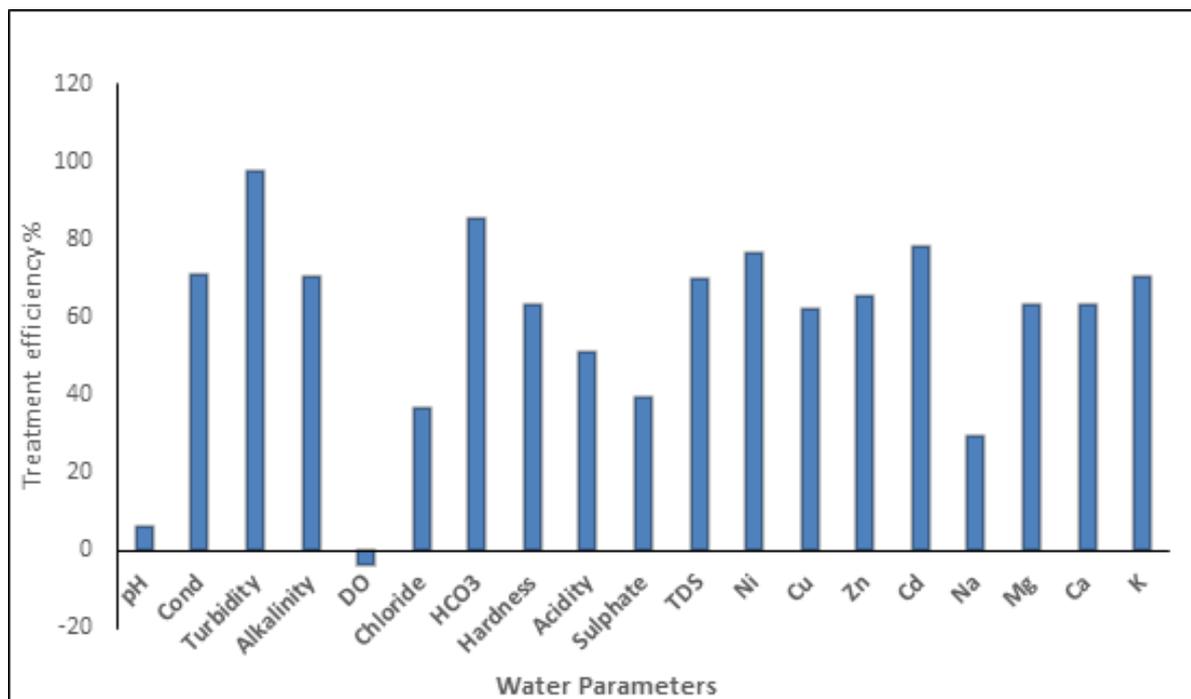
Figure 4: Efficiency of activated carbon treatment of coal mine water

**Conclusion**

The study concludes that treatment with activated carbon has demonstrated remarkable effectiveness in improving water quality across multiple parameters, as evident from the results comparing treated and untreated samples. The activated carbon treatment consistently led to significant reductions in heavy metals (Ni, Cu, Zn, Cd) and various ions (Na, Mg, Ca, K), with percentage decreases ranging from 29.66% to 78%. Moreover, there were substantial decreases in turbidity, conductivity, alkalinity, and total dissolved solids (TDS), highlighting the treatment's capability to remove suspended solids and dissolved contaminants. Changes in pH, dissolved oxygen (DO), chloride, bicarbonate, and sulfate further underscore the treatment's impact on water chemistry. Overall, these findings affirm activated carbon as a robust method for remediation, offering substantial improvements in water quality suitable for both environmental conservation and human consumption purposes. Future studies could explore optimizing treatment conditions to further enhance efficiency and address specific regional water quality challenges effectively. Based on the paired differences analysis, the untreated water consistently showed significantly higher sulfate levels compared to treated water across the samples, with a mean reduction of 1872.63 mg/L. Despite a p-value of 0.097 suggesting borderline statistical significance, this reduction underscores the effective sulfate removal capability of activated carbon treatment. Lower sulphate levels post-treatment are crucial in mitigating Acid Mine Drainage (AMD) risks associated with coal mine water, highlighting the treatment's importance in environmental management and water quality improvement for affected regions. Continued monitoring and optimization of treatment methods can further enhance these beneficial outcomes.

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