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RESEARCH ARTICLE

Visual Screening of Chloride (Cl^-) Ions Using a Colorimetric Sensor with Comparative Anion Study

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Abstract: The presence of inorganic anions, particularly chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{2-}), in aquatic environments and food products necessitates effective monitoring. Excessive concentrations of these anions may compromise fishery product quality and pose risks to human health. This study presents a visual screening approach for Cl^- ions that leverages comparative colorimetric responses of NO_3^- and SO_4^{2-} ions. The method employs a colorimetric indicator that generates distinct color changes upon interaction with target anions, allowing distinct visual differentiation between Cl^- ions and competing anions. Experimental results demonstrate a marked and concentration-dependent color change toward Cl^- ions in the 10–100 μM range, whereas NO_3^- and SO_4^{2-} elicit only weak or negligible visual responses, even at higher concentrations. The strong contrast in visual response underscores the selectivity of this screening strategy toward Cl^- ions. These findings suggest that the approach has potential as a rapid, practical, and cost-effective method for preliminary screening of inorganic anions in environmental and food monitoring applications.

Keywords: Visual, Screening, Colorimetric, Sensor, Anion

1. Introduction

Inorganic anions are pervasive in aquatic environments and fisheries products, where their concentrations directly influence water quality, product integrity, and food safety (Onyeaka et al., 2024). Although these anions are naturally present at moderate levels, excessive accumulation is closely associated with anthropogenic pollution and has been linked to ecological degradation as well as potential risks to human health (Yousefi & Karimi Douna, 2023). Consequently, the development of rapid and accessible monitoring strategies for these anions remains a critical analytical challenge in both environmental and food related contexts (Chiesa et al., 2019).

Established analytical techniques for anion determination, including ion chromatography and reagent based spectrophotometric methods, offer excellent sensitivity and quantitative accuracy (Hu et al., 2023). However, their reliance on sophisticated instrumentation, extensive sample preparation, and time-consuming analytical procedures limit their suitability for rapid screening and on-site monitoring (Mukherjee et al., 2021). These constraints underscore the need for alternative sensing strategies that combine simplicity, speed, and low operational cost.



Colorimetric sensors have attracted increasing attention as practical tools for chemical sensing due to their straightforward operation and visually observable signal output (Fudhail Majid & Irfandi, 2025). In such systems, analyte recognition is transduced into a color change arising from specific physicochemical interactions between a colorimetric indicator and the target species (Wu et al., 2023). Because rapid qualitative assessment is often prioritized over high precision quantification, naked eye detectability renders colorimetric sensors particularly well suited for visual screening applications (Algothary et al., 2021).

In this study, a visual screening strategy for chloride (Cl^-) ions is examined under conditions where competing inorganic anions, including nitrate (NO_3^-) and sulfate (SO_4^{2-}), are present. Rather than aiming for simultaneous multianalyte detection, the work introduces a chloride-focused screening approach based on comparative anion responses. This strategy enables effective discrimination of chloride-induced color changes, demonstrating its potential for rapid, practical, and selective visual screening applications.

2. Literature Review

2.1. Anion Contamination in the Environment

Inorganic anions are widely recognized as key indicators of water quality due to their influence on ecological balance and human health (Yousefi & Karimi Douna, 2023). Elevated Cl^- ions concentrations, typically originating from industrial effluents, agricultural activities, and groundwater salinization, have been reported to degrade aquatic habitats and compromise drinking water resources. Consequently, reliable and rapid monitoring of Cl^- ions has become a critical requirement in environmental management. Field studies by Breen et al. (2025) revealed substantial temporal fluctuations in chloride levels in urban water bodies, underscoring the need for detection methods that can respond effectively to changing environmental conditions.

In natural and wastewater systems, Cl^- ions rarely occur in isolation but coexists with other anions such as Br^- , I^- , NO_3^- , and SO_4^{2-} . The presence of these ions often leads to analytical interference, particularly in conventional detection methods, thereby complicating selective chloride determination. Chiesa et al. (2019) demonstrated that high concentrations of NO_3^- and sulfate SO_4^{2-} ions in agricultural runoff can significantly distort chloride measurements when method selectivity is insufficient. These findings highlight the importance of comparative anion studies as a fundamental component in the development of reliable detection strategies.

In addition to compositional complexity, anion contamination is inherently dynamic, influenced by seasonal variation, rainfall patterns, and anthropogenic activities. Changes in hydrological conditions can cause pronounced shifts in chloride distribution over time. Valencia-Castañeda et al., (2019) reported marked seasonal differences in groundwater chloride concentrations, indicating that analytical methods must be adaptable and suitable for repeated monitoring. Within this context, visual screening approaches offer a practical and cost-effective alternative for routine, field-based surveillance.

2.2. Colorimetric Sensors for Anion Detection

Colorimetric sensors have evolved as an analytical approach that enables direct anion detection through easily observable color changes. Unlike instrumental methods, this technique does not require complex laboratory equipment, making it highly suitable for field applications and rapid analysis (Hu et al., 2023). The visual response arises from specific interactions between chemical indicators and target anions, either through complex formation or ion-exchange mechanisms (Fudhail Majid & Irfandi, 2025). Picci et al. (2024) reported that polymer-film-based sensors incorporating metal complexes produced distinct color changes toward specific anions within a short response time and maintained stability over a wide pH range.



Selectivity is a key parameter governing the performance of colorimetric sensors, particularly when applied to samples with complex ionic compositions. Well-designed sensors must be capable of discriminating among anions with similar chemical characteristics to minimize interference. Picci et al., (2024) reported that integrating paper-based sensors with smartphone-assisted color analysis significantly enhanced the discrimination of Cl^- over Br^- and I^- , while also enabling semi-quantitative evaluation of color changes. This approach substantially improves the reliability of visual screening under practical conditions.

From an application perspective, colorimetric anion sensors have been developed in various formats, including indicator papers, polymer films, and portable liquid systems, supporting non-invasive use and high mobility. The combination of simple design, short response time, and potential for digital integration makes this method highly relevant for sustainable water quality monitoring. By bridging the gap between laboratory-level analytical accuracy and the practical demands of field monitoring, visual-screening-based colorimetric sensors offer a meaningful contribution to the development of efficient and applicable ion detection methods (Picci et al., 2024).

3. Research Method and Materials

3.1. Materials and Equipment

The materials used included a colorimetric indicator sensitive to anions, suitable solvents (distilled water or polar solvent mixtures), and standard solutions of chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{2-}) at low to moderate concentrations (e.g., 0–100 μM). The equipment comprised beakers, volumetric pipettes, test tubes or glass vials, and a smartphone or digital camera for documenting color changes. All experiments were conducted at room temperature under relatively constant lighting conditions.

3.2. Preparation of the Colorimetric Sensor

The colorimetric sensor was prepared by dissolving the indicator in the solvent to obtain a homogeneous and stable solution. The sensor solution was used directly without immobilization or further treatment, representing a simple and easily applicable sensor system for visual screening.

3.3. Visual Response Testing of Anions

The sensor solution was mixed with Cl^- solutions at various concentration levels. Color changes were visually observed after a certain interaction time and compared with a blank solution. The same procedure was applied to NO_3^- and SO_4^{2-} as comparison anions.

3.4. Selectivity Test

Selectivity was evaluated by comparing the color responses of the sensor toward Cl^- with those toward NO_3^- and SO_4^{2-} at identical concentrations. Differences in color intensity and visual clarity were used as indicators of visual selectivity.

3.5. Data Presentation

The results were presented as tables of visual responses and relative color intensity values, along with semi-quantitative schematic plots illustrating differences in response trends between Cl^- and the comparison anions. Schematic plots were used to emphasize response tendencies without relying on absolute numerical data.

4. Results and Discussion

The colorimetric sensor displayed clearly differentiated visual responses toward the examined anions. A pronounced color change was observed upon interaction with chloride ions (Cl^-), whereas nitrate (NO_3^-) and sulfate (SO_4^{2-}) produced only weak or negligible responses under identical conditions. This contrast highlights a preferential affinity of the sensor toward Cl^- relative to the other tested anions.



Table 1. Visual response of the colorimetric sensor toward chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{2-})

Anion	Concentration (μM)	Visual Color Response	Relative Color Intensity	Remarks
Blank	0	No change	0.05	Initial sensor condition
Cl^-	10	Weak	0.14	Minimal response
Cl^-	25	Visible	0.28	Visually observable
Cl^-	50	Clear	0.52	Positive screening
Cl^-	100	Very clear	0.81	Stable response
NO_3^-	10	Not visible	0.09	No response
NO_3^-	25	Not visible	0.10	No response
NO_3^-	50	Very weak	0.14	Minimal response
NO_3^-	100	Weak	0.17	Not significant
SO_4^{2-}	10	Not visible	0.07	No response
SO_4^{2-}	25	Not visible	0.08	No response
SO_4^{2-}	50	Very weak	0.11	Not significant
SO_4^{2-}	100	Very weak	0.13	Not significant

The colorimetric response toward Cl^- increased steadily with rising anion concentration, producing a color change that was readily distinguishable from the blank. A pronounced and well-defined response was observed for chloride, while comparable concentration increases of NO_3^- and SO_4^{2-} failed to induce meaningful color variation, even at higher levels. A visually detectable response to Cl^- became apparent at approximately 25 μM and intensified noticeably as the concentration increased further. These results indicate that the sensor is particularly well suited for visual screening of chloride, whereas its responses to nitrate and sulfate remain minimal.

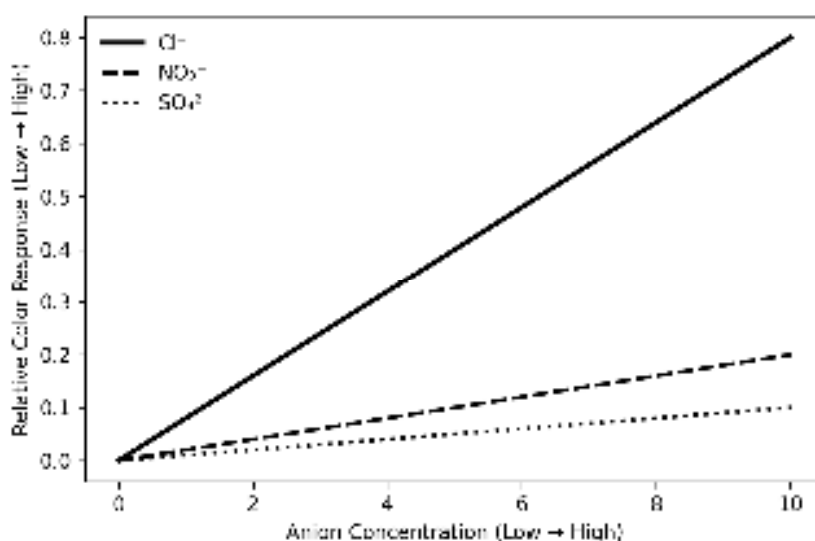


Figure 1. Schematic colorimetric response of the sensor toward different anions

The plot depicts the relationship between anion concentration (0–100 μM) and the relative color intensity of the colorimetric sensor. Chloride ions (Cl^-) show a clear and progressive increase in color intensity with increasing concentration, whereas nitrate (NO_3^-) and sulfate (SO_4^{2-}) elicit only marginal responses that remain close to the blank level. Differences in the slopes of the response curves further underscore the dominance of the chloride signal. The color intensity associated with Cl^- increases in a semi-linear manner across the tested concentration range, while the responses of NO_3^- and SO_4^{2-} remain essentially unchanged. Such behavior reflects a substantially higher sensitivity toward chloride and negligible interference from competing anions. This pronounced contrast highlights the strong preference of the sensor for chloride and supports its use as a selective visual screening tool.

Overall, the schematic plot captures the distinct colorimetric behavior of the sensor toward multiple anions under identical conditions. The concentration-dependent response observed for Cl^- indicates a stronger interaction between the sensor and chloride ions, in contrast to the weak and nearly constant signals produced by NO_3^- and SO_4^{2-} . This clear differentiation reinforces the visual selectivity of the sensor and confirms its suitability for preliminary chloride screening using nitrate and sulfate as reference anions.

5. Conclusion

Chloride (Cl^-) ions generate a pronounced, concentration-dependent visual response across 10–100 μM , whereas nitrate (NO_3^-) ions and sulfate (SO_4^{2-}) ions induce only weak or negligible changes. This stark contrast demonstrates the selectivity and practicality of the visual screening strategy for Cl^- detection. At the same time, the observed differences in anion-dependent behavior provide useful insight into response differentiation and may serve as a basis for future sensor optimization, particularly through the development of indicator systems with improved specificity toward NO_3^- and SO_4^{2-} .

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